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Reducing Greenhouse Gas Emissions with Hybrid-Electric Vehicles: An Environmental and Economic Analysis

A Group Project submitted in partial satisfaction of the requirements for the degree of Master's of Environmental Science and Management
for the
Donald Bren School of Environmental Science and Management

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May 2005

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a four-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Table of Contents

List of Tables

List of Figures

Common Acronyms

CARB	California Environmental Protection Agency, Air Resources Board
CO_2e	Carbon Dioxide equivalent
CVT	Continuously Variable Transmission
EPA	U.S. Environmental Protection Agency
GHG	Greenhouse Gas
GWP	Global Warming Potential
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
LCA	Life Cycle Assessment
MPG	Miles per Gallon
MY	Model Year
NiMH	Nickel Metal Hydride
NESCCAF	Northeast States Center for a Clean Air Future
NPV	Net Present Value
OTA	Office of Technology Assessment
SUV	Sport Utility Vehicle

Abstract

Hybrid-electric vehicles (HEVs), first introduced in the United States in 1999, allow for increased fuel efficiency by combining the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle. Although the HEV market share continues to grow, uncertainties remain concerning the environmental impacts and economic costs associated with purchasing an HEV instead of a conventional internal combustion engine vehicle (ICEV). This study compared the lifecycle greenhouse gas (GHG) emissions and lifetime consumer costs of HEVs with those of comparable ICEVs. The potential impact that new HEV sales can have on GHG emissions and consumer expenditures in the State of California through 2025 was also examined. Finally, a model was developed to allow consumers to estimate the lifecycle GHG emissions and the lifetime costs of a given vehicle and to rate its environmental and economic performance against other vehicles.

The major findings of this study include:

(1) GHG emissions are significantly lower for HEVs than for comparable ICEVs, both during vehicle operation and over the entire vehicle lifecycle. For the operation phase, reductions range from 10-40%, and overall lifecycle reductions range from 8-35%.

(2) Although the breakeven point for a Honda Civic Hybrid will not occur within the vehicle's lifetime unless fuel prices are close to $4.00 per gallon of gasoline, the breakeven point for a Ford Escape Hybrid will occur within the vehicle's lifetime at a fuel price of $2.50 per gallon ($1.79 for the 4WD and $2.40 for the FWD).

(3) Because larger vehicles generally consume more gasoline and emit more GHGs than smaller ones, replacing large ICEVs with HEVs offers a more cost-effective emissions reduction strategy than replacing small ICEVs with HEVs.

4) The projected HEV diffusion into the California new automobile market would result in a 156.7 million tonne (2.54%) reduction in the State's cumulative lifecycle GHG emissions from light duty vehicles through 2025, compared to a scenario with no HEVs.

Executive Summary

Introduction

According to the Intergovernmental Panel on Climate Change, the Earth's surface temperature has risen by about 0.6 degrees Celsius (1° F) in the past century, with accelerated warming during the past two decades. Evidence suggests that this warming is a result of human activities that produce greenhouse gas emissions, particularly the burning of fossil fuels (IPCC, 2001). In the United States, the transportation sector is the second largest emitter of greenhouse gases, producing about 27% of national greenhouse gas (GHG) emissions annually (EPA, 2005). Transportation has an even greater contribution in California, emitting 58% of the State's total greenhouse gases (CEC, 2002).

Hybrid-electric vehicles (HEVs) employ efficiency-improving technologies that help reduce emissions from the transportation sector. Combining the internal combustion engine of a conventional vehicle with the electric motor and battery of an electric vehicle, HEVs generally achieve greater fuel efficiency than similarly equipped conventional internal combustion engine vehicles (ICEVs). The infrastructure, performance, and price barriers that have discouraged market penetration of other emission-reducing technologies and fuel types have generally not been as prohibitive for HEVs.

Whether HEVs are an appropriate tool for reducing GHG emissions has yet to be conclusively determined. The sale of HEVs has been hindered by a higher sticker price compared to similarly equipped ICEVs, although this price premium can potentially be offset by lower fuel expenditures. Additional uncertainty stems from the fact that HEVs use additional materials for their electrical systems, which could potentially offset the emissions reductions associated with increased fuel efficiency.

Objectives

This project set out to find answers to the questions surrounding HEVs, including the emission and cost implications of purchasing HEVs rather than similarly equipped ICEVs. This was accomplished by conducting a thorough and objective evaluation of emissions and costs from the entire life of the vehicles. The differences in lifecycle emissions and lifetime costs for comparable HEVs and ICEVs were then applied to the California vehicle fleet to determine the environmental and economic impacts associated with using HEVs to reduce greenhouse gas emissions. This project also created an interactive online tool to aid consumer purchasing decisions by comparing vehicles' lifecycle greenhouse gas emissions and lifetime costs to those of 180 vehicles in a database.

Project Approach
A lifecycle approach was used to analyze the environmental and economic impacts of vehicles. The lifecycle of a vehicle includes all of the processes from the extraction of raw materials used in the vehicle through the disposal of these materials at the end of the vehicle's life. Consumer costs of a vehicle were calculated over its lifetime, including the purchase price and lifetime gas and maintenance costs. Costs were discounted over time to account for the time value of money.

Three models were developed to compare the lifecycle GHG emissions and lifetime consumer costs of HEVs and ICEVs, and to analyze the impacts of increasing the percentage of HEVs in California new vehicle sales.

The Carbon dioxide-equivalent Lifecycle Emissions Model (CLEM) used lifecycle assessment (LCA) methodology to determine the greenhouse gas emissions of a Honda Civic Hybrid and a Honda Civic LX over their lifecycles. The HEV-ICEV Lifetime Cost (HILC) Model calculated the present value of the lifetime costs of a Civic Hybrid and a Civic LX, as well as those of a Ford Escape Hybrid and Escape XLT with four cylinders. These analyses were then extended to compare any HEV to a similar ICEV.

The Fleet Composition Model (FCM) measured the effects of increasing the portion of HEVs in California's new vehicle sales through 2025. Diffusion scenarios were analyzed to determine the resulting change in GHG emissions and consumer expenditures. This model assumed that the total number of cars on the road would increase and HEV price premiums would decrease over time (Lipman & Delucchi, 2003).

Several assumptions were consistent throughout this study, including a vehicle lifetime of 241,000 kilometers (150,000 miles), an annual driving distance of 19,000 kilometers (12,000 miles), a discount rate of 3%, and a $2.50 per gallon gasoline price. Based on currently available HEVs, the large truck class was assumed to have a less advanced type of hybrid-electric technology than the other classes of vehicles

Results
The CLEM found that an average Honda Civic Hybrid generates 47.1 tonnes of carbon dioxide-equivalent (CO_2e) over the entire vehicle lifecycle, compared to 62.5 tonnes for a Honda Civic LX – a 15.4 tonne (25%) reduction.

Fuel economy has a direct impact on emissions from the use and upstream fuel production stages of the vehicle lifecycle, which account for over 80% of the total GHG emissions of each vehicle. Although emissions from vehicle use are the most significant, the relative contribution of the other lifecycle stages increases as fuel economy improves. The materials, assembly, and transport lifecycle stages are responsible for a minority of lifecycle emissions, but can still have significant impacts on the total environmental impact of a vehicle. For instance, the 29% difference in fuel economy between a Civic Hybrid and Civic LX results in a 25% difference in total lifecycle emissions. The four percent difference is due to the impacts of additional materials used in the Civic Hybrid.

The results of the HILC model showed that the present value of lifetime costs to a consumer is $1,585 higher for an average Civic Hybrid than for an average Civic LX, but the present value of lifetime costs of an average Ford Escape Hybrid is $783 lower than that of an average Ford Escape XLT. As Civics are more efficient ICEVs than Escapes, the reduction in fuel consumption is greater for Escapes, and therefore more money is saved by reduced fuel expenditures over the lifetime.

The breakeven point occurs when the savings in fuel expenditures completely offset the initial price premium of an HEV. At $2.50 per gallon of gasoline, it will take 23.6 years for a Civic Hybrid to reach its breakeven point, while the Escape Hybrid will take 10.3 years to break even. The breakeven point occurs sooner with higher gasoline prices, increased driving distances, or lower discounts rates.

As determined by the FCM, GHG emissions from California's vehicle fleet would be lower if HEVs were diffused into the fleet. For the 2025 model year, a predicted 20% HEV market share would result in a savings of 13.9 million tonnes of CO_2e, compared to a no-HEV scenario for the same year. The cumulative emission savings due to the projected HEV market share through the model year 2025 time period would equal 156.7 million tonnes of CO_2e. Despite these annual emission savings, total yearly emissions from new vehicles are still projected to grow during the period analyzed due to growth in the total number of new vehicles on the road in California. Even with HEVs comprising 20% of all new vehicles in model year 2025, lifecycle GHG emissions for that model year would still be 95.6 million tonnes of CO_2e higher (47%) than the emissions from the 2002 baseline model year, due to the projected 54% increase in vehicle sales over the time span.

Across all vehicle classes, discounted lifetime consumer costs were projected to be lower for most HEVs than for their ICEV counterparts as the savings in gasoline expenditures make up for the higher purchase price. For the 2025 model year, discounted savings of $350 million across the vehicle fleet would be achieved with 20% HEV market share. The cumulative discounted lifetime savings through the model year 2025 would be approximately $4.1 billion.

Hybrid-electric technology tends to produce a greater relative savings in GHG emissions and fuel costs for vehicles that start out with lower fuel efficiencies. On average, a small car HEV would emit fewer GHGs over its lifecycle than a small truck HEV. However, because an average conventional small truck is less efficient than an average conventional small car, switching from an ICEV to an HEV would achieve a greater emission reduction for a small truck than for a small car.

The effect of baseline efficiency is also reflected in monthly fuel savings. Although fuel expenses for an average small car HEV would be lower than those of an average small truck HEV, switching from an ICEV to an HEV would result in a greater reduction in fuel costs for the small truck. This allows the breakeven point to occur sooner for small trucks than for small cars. Across a range of different vehicle types, switching from an ICEV to a comparable HEV will produce a greater reduction in lifetime costs per tonne of CO_2e reduced for vehicles that start out with worse fuel economies.

The final step in our project was to create a way for consumers to compare the environmental and economic characteristics of different vehicles they may purchase. The Lifecycle Environmental and Economic Vehicle (LEEV) system estimates the lifecycle GHG emissions and lifetime consumer costs based on vehicle characteristics (fuel economy, price, vehicle class, HEV or ICEV) input by a user. GHG emissions and economic impacts are also ranked based on percentiles relative to a vehicle database, ranging from one (low impacts) to one hundred (highest level of impacts).

Conclusions

These findings show that LCA is an important tool for measuring GHG emissions in the transportation sector. As alternative fuels and advanced technologies are used to minimize tailpipe emissions, consideration must be given to the upstream GHG emissions as well as those associated with the disposal of the vehicles and fuels.

The Honda Civic Hybrid emits about 25% fewer GHG emissions than a similar ICEV over its entire lifecycle. If future HEVs are able to achieve similar emission reductions, significant reductions in GHG emissions from California's transportation sector are possible.

With the assumptions used, the Honda Civic Hybrid does not reach its breakeven point within its lifetime, but the Ford Escape Hybrid does. As HEV market share increases, economies of scale are expected to reduce price premiums, allowing almost all HEVs to reach their breakeven points during their lifetimes.

A consumer deciding between a comparable HEV and ICEV must have a willingness to pay for GHG emission reductions for HEVs that do not break even. HEVs that do break even represent a win-win situation, where total consumer expenses are lower and emissions are reduced. The growing popularity of HEVs shows that there is a willingness to pay for the environmental benefits they provide and that HEVs are potentially an appropriate tool for reducing GHG emissions in California.

On an individual basis, GHG emissions are lower for HEVs than similar ICEVs, but the potential reduction depends on the fuel efficiency of the baseline ICEV. Across California, the potential emission reduction depends greatly on the purchasing behavior of consumers. Educating consumers about potential savings both in emissions and in dollar amounts can help drive the demand for HEVs.

1. Introduction

Since the United Nations Framework Convention on Climate Change (UNFCCC) entered into force in 1992, global warming has become an important issue at the local, national and international levels. According to the National Academy of Sciences, the Earth's average surface temperature has risen by about 0.56 degrees Celsius (1° F) in the past century, with accelerated warming during the past two decades. Recent research has hypothesized that this warming trend could cause rising sea levels, species extinction, and extreme weather events such as flooding and heat spells. The cause of global warming has been linked to elevated emissions of greenhouse gases (GHGs) (US EPA, 2005). GHGs in the atmosphere such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone occur both naturally and as a result of human activities. Evidence suggests that the majority of the warming over the last fifty years is attributable to human activities in general, and to the burning of fossil fuels in particular (EPA, January 2000). In fact, the consumption of energy in the form of fossil fuel combustion has been identified as the largest single contributor to GHG emissions in California, the United States, and the world (US DOE, 2004).

Over the past decade, annual net GHG emissions from the State of California have increased by about 5.5%, from 377.5 to 398.2 million metric tons of carbon dioxide-equivalent (CO_2e) (see Figure 1-1). As shown in Figure 1-2 almost 60 percent of the State's GHG emissions in 1999 came from the transportation sector (CEC, 2002). Nationally, the contribution to total GHG emissions from the transportation sector is much lower, at 27 percent (Greene & Schafer, 2003). California has recognized the transportation industry's significant contribution to the problem and has targeted the sector for GHG reductions.

Figure 1-1: Distribution of California Greenhouse Gas Emissions by Gas in 1999 (source: CEC, 2002)

	1990	1999	% change
Carbon Dioxide	363.8	362.8	
Fossil Fuel Combustion Other	358.2 5.6	356.3 6.5	
Methane	34.6	31.6	
Nitrous Oxide	24.6	23.5	
HFCs, PFCs, SF_6	2.1	9.7	
Gross Emissions	**425.1**	**427.7**	**0.6%**
Soils and Forest (Sink)	-25.6	-18.8	
Net Emissions	**399.5**	**408.9**	**2.4%**
Marine Bunker Fuels	22.0	10.7	
Gross Emissions Minus Marine Bunkers	**403.1**	**417.0**	**3.5%**
Net Emissions Minus Marine Bunkers	**377.5**	**398.2**	**5.5%**

Figure 1-2. Carbon Dioxide Emissions from the Combustion of Fossil Fuels by Sector for 1999 (source: CEC, 2002)

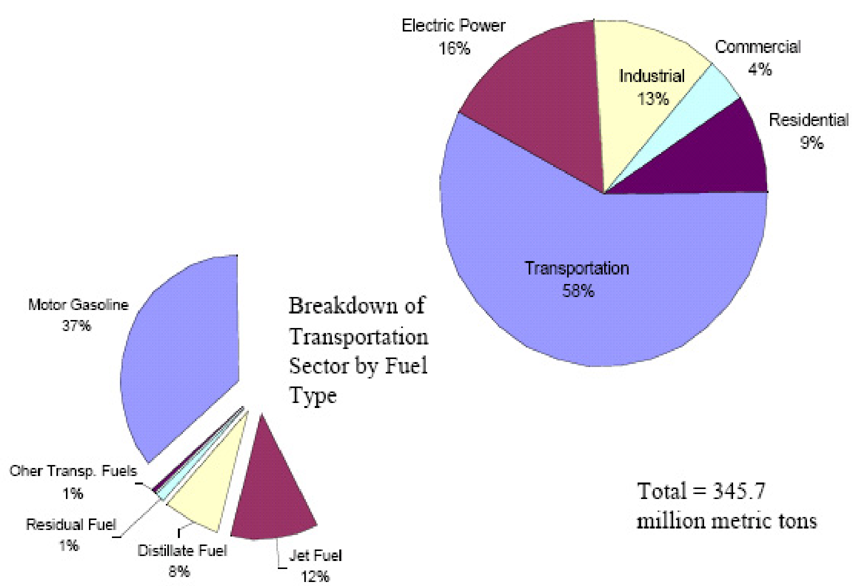

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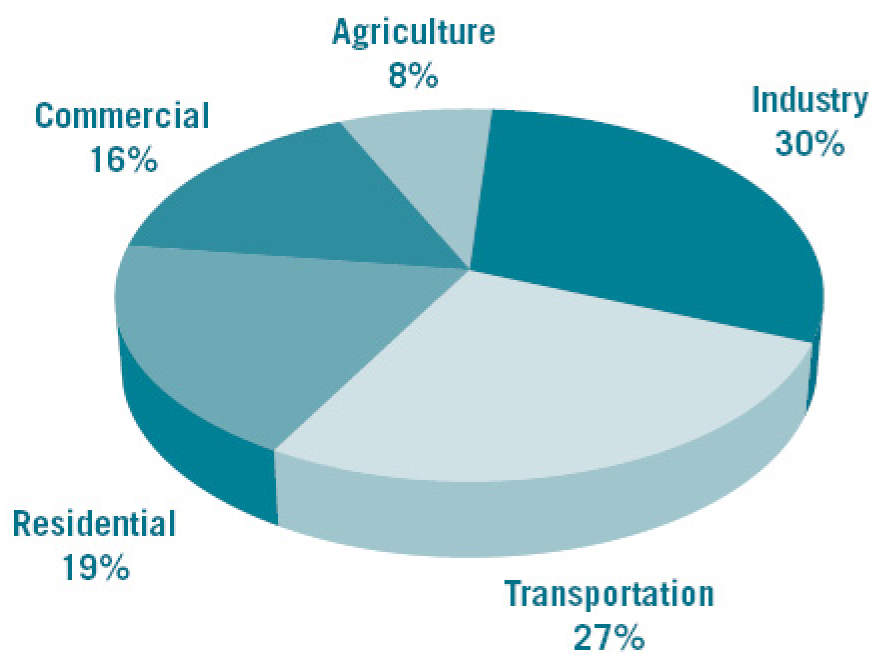
Figure 1-3. Sources of U.S. Greenhouse Gas Emissions, 2000.



Source: U.S. EPA, 2002, ES-5.

In July of 2002, California became the first state to adopt GHG emission reduction legislation. Assembly Bill 1493 directed the California Air Resources Board (CARB) to create standards to achieve the maximum feasible cost-effective reduction of greenhouse gas emissions from passenger cars and light duty trucks—starting with the 2009 model year— by 2005 (CalEPA, 2004). In the *Initial Statement of Reasons* for the standards, several technologies were suggested to reduce GHG emissions from automobiles in a cost-effective way (CARB ISOR, 2004). Hybrid Electric Vehicles (HEVs) were identified as one potential long-term solution in the report.

Given the transportation sector's large contribution to the State's GHG emissions, this standard has the potential over time to achieve significant emission reductions. If the current proposal is enacted, it is estimated that the regulation will reduce GHG emissions by 85,900 tons of CO_2e per day in 2020 and by 143,300 tons of CO_2e per day in 2030. This translates into a 17 percent overall reduction from projected levels in GHG emissions from the light duty fleet in 2020 and a 25 percent overall reduction in 2030. However, questions about the legality of this regulation have been brought up by automobile manufacturers.

There are several alternative fuels that could reduce GHG emissions from the transportation sector, including hydrogen, biodiesel, electricity, and natural gas. To date none of these alternative fuels has proven to be a successful substitute for petroleum in mainstream use. Hydrogen fuel cell vehicles and hydrogen fuel are expensive to produce and are not expected to reach mass market before 2010 (US DOE, 2005). Converting to a fuel cell fleet would also require service stations to undergo a complete infrastructure change in order to handle the new fuel. Natural gas vehicles have the cleanest emissions of any vehicle running on fossil fuel, but have added costs and operational limitations. In addition, widespread adoption would require expensive infrastructure changes (UNDP, 2001). Biodiesel is currently more expensive than gasoline and conventional diesel and has operational limitations (US EPA, 2002). Electric vehicles have long been regarded as the most environmentally friendly means of transportation because they have no tailpipe emissions. There are, however, emissions related to the production of electricity on which the vehicles run. Current battery technology limits the distance driven between battery charging to 80 to 160 kilometers (50 to 100 miles), making electric vehicles suitable only for select purposes (Wilkinson, 1997).

In contrast to the obstacles faced by alternative fuel vehicles, HEVs perform similarly to conventional vehicles and do not require changes to the fuel infrastructure. HEVs combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle. This combination has the potential to increase fuel economy and lower emissions compared to conventional internal combustion engine vehicles (ICEVs). HEVs usually have longer driving ranges than ICEVs, can be used in everyday applications, and can use existing refueling infrastructure.

Several different configurations of hybrid technologies are used in commercially available HEVs. Each configuration differs in the way the battery and electric motor are used to move the vehicle or provide extra power to the internal combustion engine. A storage battery, generally a nickel-metal hydride (NiMH) battery, is used to provide power to the electric motor. Some HEVs can run completely off of the electric motor at low speeds, while others use the electric motor to provide extra power to the internal combustion engine during acceleration. Compared to a similar ICEV, these characteristics can allow HEVs to operate with only partial use of the engine, or to meet peak power demands with a smaller engine, improving fuel efficiency.

Other fuel economy improving technologies or techniques employed by the vehicle include regenerative braking, an idle-off system, and running electric accessories off of the electric motor instead of the engine. Regenerative braking captures potential energy, which would otherwise be lost to friction when the vehicle is slowing down, and stores it in the battery for future use. An idle-off system turns the engine off when the car is stopped and uses the electric motor to restart the engine. Finally, engine efficiency can be increased by running electrical accessories such as the air conditioner, power steering and water pumps off of the electric motor rather than the engine (German, n.d.).

The first commercially available HEV was the Toyota Prius, which was introduced in Japan in 1997. The first HEVs available in the United States were the Honda Insight, introduced in 1999, and the Prius, which followed in 2000. Since then, many companies including Ford, Lexus, GM, and DaimlerChrysler have made efforts to join the market for lower-emission, higher gas mileage vehicles (US DOE, 2003). The four best known HEVs currently being offered to American consumers are the Honda Insight, the Honda Civic, the Toyota Prius and the Ford Escape. Over the past two model years, the HEV market has been expanded to include trucks, sport utility vehicles (SUVs), and larger midsize cars.

Since their introduction in the U.S. in 1999, HEVs have rapidly increased in popularity. New HEV sales were 85,699 vehicles in 2004, compared to 43,435 in 2003, an increase of 97.3 percent. U.S. hybrid sales have been predicted to reach 222,000 in 2005 and 500,000 by 2009, which would be about 3 percent of estimated 2009 new car and truck sales (Mercury News, 2005). John German, of American Honda Motor Co., hypothesized that the HEV market share could be as high as 70% in that time (Asia Times, 4/6/05). HEV sales in 2004 represented about 0.5 percent of the 16.9 million vehicles sold, with 42 percent of all HEVs bought in California (Mercury News, 1/22/05). One of the barriers to more rapid HEV market diffusion is the cost of the vehicle, which is typically about $4,000 more than a comparable conventional vehicle (Lipman & Delucchi, 2003). As HEV technology matures, the price premium is expected to decrease, which should help increase HEV sales. In addition, rising gasoline prices have been driving the demand for more efficient vehicles, including HEVs.

Since an HEV burns less gasoline than a comparable ICEV over a given driving distance, it emits fewer GHGs during use. If HEVs replace ICEVs in a given fleet of vehicles, overall GHG emissions would be lower, assuming emissions from other lifecycle stages don't offset the reductions from the use phase. Similarly, the comparison of costs of HEVs and ICEVs could be greatly affected by costs other than the purchase price. Therefore, the difference in lifetime cost to consumers between HEVs and ICEVs needs to be examined as well. This study examines both of these issues and then applies the results to the California fleet of new vehicles. It also includes a tool for consumers to compare the lifecycle GHG emissions and lifetime costs of vehicles that they may potentially purchase.

The results of this study are intended to provide information for three stakeholder groups: auto manufacturers, state regulatory agencies, and automobile consumers. Auto manufacturers can use the results to assess the best classes of vehicles to convert to HEVs in order to maximize GHG emission reductions while attracting the cost-conscious consumer. State regulatory agencies can use the results to guide their policy decisions regarding GHG emissions reductions from automobiles. Finally, automobile consumers can use the analyses of this project and the lifecycle environmental and economic vehicle rating tool to make better purchasing decisions when deciding between vehicles that have differing lifecycle GHG emissions and lifetime costs.

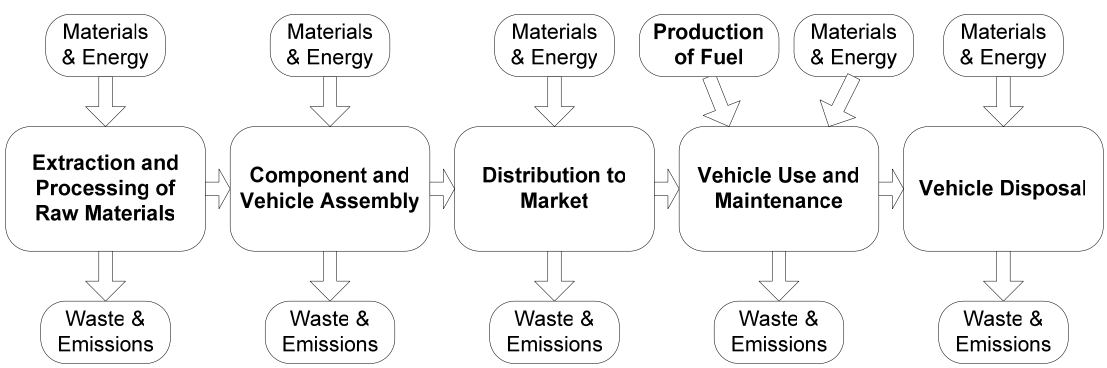
If the CARB regulation comes into effect, manufacturers will be forced to reduce GHG emissions from their vehicles and HEVs may or may not be the most efficient technology option. Even if this regulation fails, California may try another avenue to reduce GHG emissions from its transportation sector. The influence of any GHG emission standard on automobiles in California may extend beyond state borders. The Clean Air Act gave California the right to enact its own air pollution regulations as long as they are more stringent than the Federal Government's, and any state has the right to adopt an identical regulation as California. Since 1970, seven states have elected to adopt California's standards for air pollution. It is likely that support for stricter standards will continue as other states, such as those in the Northeast, have pledged their support for the regulation. Because other states may follow in California's footsteps, it becomes essential that California's policy choice for GHG emissions reductions from light-duty vehicles be robust and efficient.

2. Project Background

2.1 Life Cycle Assessment

One of the basic premises for the environmental analyses in this study is that GHG emissions should be evaluated over the entire vehicle lifecycle. This "cradle to grave" approach includes emissions that occur due to resource extraction and processing, component and product assembly, distribution, use, and end of life processing of a vehicle (see Figure 2-1). Lifecycle assessment (LCA) is an objective process that evaluates the overall impacts that a product or process has on the environment through all of these lifecycle stages. This type of assessment provides a more complete picture of the environmental impacts caused by a given product than the typical method of evaluating only the impacts that occur during the use phase.

Figure 2-1: Lifecycle of an automobile



The comprehensive cradle to grave approach has made LCA a popular tool in research for analyzing the environmental impacts of a product, process, or service. It has also been adopted by businesses to minimize environmental impacts and the use of resources, or to compare the impacts of alternative products, processes, or services. For example, Patagonia, Inc. used LCA to determine whether organic cotton caused fewer environmental damages than the regular cotton used in its T-shirts (Reinhardt et. al, 2004).

The LCA process is a systematic, phased approach to environmental impact analysis that consists of four stages: goal definition, scoping, inventory analysis, and impact assessment. The goal definition stage includes defining and describing the product, process, or activity to be analyzed. The scoping stage identifies boundaries of the assessment and the environmental impact categories to be analyzed. Impact categories may include global climate change, stratospheric ozone depletion, water and air degradation, human toxicity, and several others. During inventory analysis, resource and energy usage, as well as environmental releases (i.e., air emissions, solid waste disposal, and wastewater discharge) are identified and quantified. The impact assessment stage analyzes the inventory results in terms of the impact categories identified for the analysis (US EPA, 2001).

This study used LCA to compare the lifecycle GHG emissions of HEVs and ICEVs. GHG emissions were used to compare the impacts to climate change, as climate change was the only impact category examined.

2.2 Present Value and Discounting

Discounting is an economic tool that accounts for the time value of money and allows for the comparison of costs and benefits over time. In present value discounting, a stream of future debits or credits is discounted in order to find the present value of that stream of payments. The rate by which future values are discounted is known as the discount rate. Future values are discounted due to the greater value that is placed on current costs and savings, as compared to future costs and payments. This methodology accounts for the opportunity cost associated with waiting until a future time to receive a given amount of money rather than receiving it today. Cash flows can be discounted over many different time periods, annually, monthly, daily, or continuously, as shown in Table 2-1. This study used continuous discounting in all economic analyses.

Table 2-1: Discounting formulas

Type of Discounting	Formula
Periodic	Present Value = Future Value / $(1+ r / m)^{mt}$
Continuous	Present Value = Future Value * e^{-rt}

Where: r = the annual discount rate;
t = the number of years in the future that the cash flow occurs;
m = the number of annual payments.

2.3 Past Studies

2.3.1 Lifecycle Emissions Model (LEM)

In December of 2003, Mark Delucchi of the Institute of Transportation Studies at the University of California, Davis, published *A Lifecycle Emissions Model (LEM): Lifecycle emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity use, Heating and Cooking Fuels and Materials*. The report documented changes to an earlier emissions model, and presented a methodology for calculating the emissions of air-pollutants and greenhouse gases from the energy and transportation industries. The model calculated emissions of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, nitrogen oxides, carbon monoxide, non-methane organic compounds, sulfur oxides, hydrogen and particulate matter from the lifecycle of fuels and materials for various transportation modes, vehicles and fuel.

Emissions from passenger transportation, including passenger cars, buses, motor scooters, and rail transit were calculated for several fuel types. The model estimated the energy consumption and emissions of air pollutants and greenhouse gases from the fuels, materials, vehicles and necessary infrastructure for each transportation mode. The sources of emissions included combustion of fuels for energy needed throughout the vehicle lifecycle, evaporative losses from energy feedstocks and finished fuel, venting, leaking or flaring of gases, non-combustion chemical changes, and land-use changes.

To calculate the full lifecycle impacts, emission factors were determined for various materials that are used in vehicles, infrastructure including highways railways and other roads, as well as refueling stations. The LEM calculated the lifecycle emissions from material processing of various grades and types of steel, iron, plastics, fluids and lubricants, rubber, aluminum, glass, copper, and several other materials. The material emission factors include the recovery and transport of crude ores, manufacturing of these ores into finished materials, transportation of these materials to a final user, and end of life treatment of these materials.

In general, the LEM was used as a framework for an environmental LCA of automobiles. Although the LEM is much more in depth than this study has the capacity to be, much of the LCA methodology and emissions data of the LEM are incorporated here. In the case of missing data, assumptions were often made based on the Delucchi's assumptions in the LEM.

2.3.2 HEV Design Retail and Lifecycle Cost Analysis

In April of 2003, Mark Delucchi of the Institute of Transportation Studies at the University of California, Davis and Timothy Lipman of the Energy and Resources Group at the University of California, Berkeley published *Hybrid-Electric Vehicle Design Retail and Lifecycle Cost Analysis*. This paper, written for The Energy Foundation, analyzed HEV technology options, and estimated the retail price and lifetime cost of applying these technologies to five different vehicles. The vehicles were representative of different vehicle classes, and included a compact passenger car, a midsize passenger car, a large pickup truck, a minivan, and a sport utility vehicle. The analysis assumed that HEVs would be in high-volume production by 2010.

The paper examined five different potential ways of utilizing hybrid technology combined with other fuel saving modifications. The hybrid technologies adopted could either be mild (M) or full (F1, F2), and the modifications considered were designated as either modest (M) or advanced (A). Mild hybridization includes regenerative braking and idle-off technology, while full hybridization also incorporates the ability of the car to run solely on the electric motor. Moderate vehicle modifications include a small reduction in the vehicle weight and drag while advanced improvements include more dramatic weight reductions. Two separate full hybrid advance technology cases were examined, AF1 where the electric motor supplies 40% of the drive train power, and AF2 where the electric motor supplies 25% of the power.

Retail prices in this study were estimated based on 2000 manufacturer suggested retail price (MSRP). MSRPs include vehicle manufacturing costs, division costs, corporate costs, and dealer costs, but do not include shipping or taxes. The costs of electric motors were estimated as a function of the power of the motor, and as a function of production volume, which was expected to increase over time.

The analysis estimated retail price premiums for HEVs ranging from $2,500 to $6,700 over the similar ICEVs. Table 2-2 presents the results of the study.

Table 2-2: Results from Lipman, Timothy E., Mark A. Delucchi, "Hybrid Electric Vehicle Design Retail and Lifecycle Cost Analysis"

Vehicle Type	HEV Price Effect (Year 2000 $)				
	MM	MF	AM	AF1	AF2
Compact	$2,697	$4,251	$2,543	$3,726	$3,385
Midsize	$2,756	$4,382	$2,578	$4,240	$3,795
Pickup	$3,778	$6,694	$3,390	$5,287	$4,823
Minivan	$3,162	$4,827	$2,766	$4,388	$3,930
Sport utility	$3,461	$5,719	$3,534	$5,209	$4,726

These price premiums were calculated for the year 2010, when it was assumed that volume of new HEVs sold would be approximately 200,000. Most HEVs currently on the market would fall into the mild hybridization, modest package of improvements category. Therefore, for this study, the price premiums for HEV type MM were used.

2.3.3 Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles

In September 2004, the Northeast States Center for a Clean Air Future (NESCCAF) prepared a report which investigated emerging technologies and the potential for GHG emissions reductions from passenger cars and light-duty trucks. The main goal of the NESCCAF study was to determine the most feasible and cost-effective technology options to reduce the overall emissions of California's vehicle fleet in support of California Assembly Bill 1493. The study used AVL Powertrain, Inc. CRUISE software to select a representative vehicle for each of five vehicle classes, and to analyze the combinations of possible technologies (NESCCAF, 2004). NESCCAF's method of vehicle class designation was adopted for the current study to simulate the change in GHG emissions due to HEV infusion into the market.

The NESCCAF study categorized MY (model year) 2002 vehicles by size, technology characteristics, and sales. The five vehicle classes used were small car, large car, small truck, large truck, and minivan. The general characteristics of each vehicle class, including the EPA classifications included in each class, are shown in Table 2-3 below (NESCCAF, 2004**).**

Table 2-3: Vehicle Class Characteristics

Vehicle Class	Fraction of Sales in 2002	USEPA Classifications Included	Dominant Technology Characteristics
Small cars	22%	Subcompact, Compact Cars	4-cylinder, naturally aspirated, dual overhead cam (DOHC, four-speed automatic transmission, front wheel drive vehicles
Large cars	25%	Midsize, Full Size Cars	6-cylinder, naturally aspirated, DOHC, four-speed automatic transmission vehicles
Small trucks	23%	Pickups, SUVs <6,000 lbs	6-cylinder, naturally aspirated, DOHC, four-speed automatic transmission vehicles, with a nearly 50/50 split between two and four wheel drive
Large Trucks	21%	Pickups, SUVs >6,000 lbs	8-cylinder, naturally aspirated, OHV, four-speed automatic transmission vehicles, also with a nearly 50/50 split between two and four wheel drive
Minivans	7%	Minivans	6-cylinder, naturally aspirated, OHV, four-speed automatic transmission, front wheel drive vehicles

CARB Extension of NESCCAF Methodology

The California Air Resources Board (CARB) compiled a database of US vehicle sales for major auto manufacturers following the above criteria. The six largest auto manufacturers and their subsidiaries, as well the other manufacturers included in the database are shown in Table 2-4. The database included information on US nameplate sales, vehicle technology, fuel economy, engine size, and curb weight. CARB used this information to analyze fleet emissions from the six major manufacturers and to propose a standard for GHG emission reductions based on NESCCAF's modeling and technology assessments. The CARB database was used in this study to analyze the potential GHG emission reductions and costs of increasing HEV diffusion into the California vehicle fleet. Appendix C shows the vehicles from each manufacturer included in each vehicle class.

Table 2-4: Manufacturers and their Subsidiaries

Daimler-Chrysler	Ford	General Motors	Honda	Nissan	Toyota	Other
Plymouth	Ford	Oldsmobile	Honda	Nissan	Toyota	Audi
Chrysler	Jaguar	Chevrolet	Acura	Infinity	Lexus	BMW
Dodge	Mazda	Pontiac				Daewoo
Mercedes Benz	Lincoln	Subaru				Hyundai
Mitsubishi	Mercury	Suzuki				Kia
Jeep	Land Rover	Saturn				Volkswagen
		Buick				
		Cadillac				
		Saab				
		Isuzu				

2.4 Project Objectives

Although several studies have been done on the environmental performance and economic costs of HEVs, there are no comprehensive studies looking at both from a lifecycle perspective. The potential for HEVs to reduce GHG emissions in California has also not been investigated in depth.

Therefore, this study attempted to fill these information gaps by determining if HEVs are actually lower GHG emitters than pure internal combustion engine vehicles (ICEVs), when viewed from a lifecycle perspective. It also examined the degree to which a consumer could recover the HEV price premium through savings in gasoline expenditures. These findings were then synthesized to determine the extent of GHG emission reductions and the financial implications of increasing the HEV market share in the State.

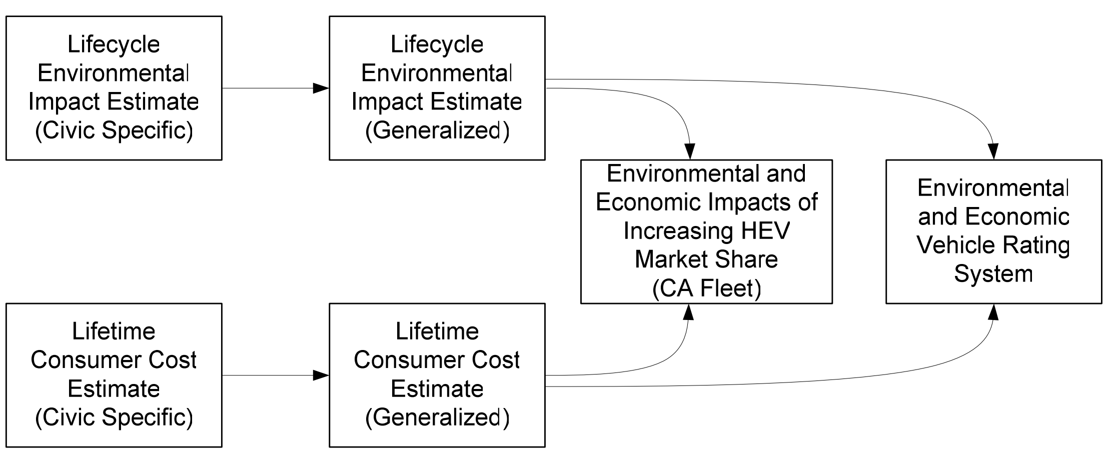
Finally, a system to rate vehicles based on their lifecycle GHG emissions and lifetime consumer expenses was developed.

The specific objectives of this study were to:

- Determine lifecycle GHG emissions for the Honda Civic HEV and ICEV
- Determine the differences between lifecycle and use phase GHG emissions for both vehicles
- Estimate lifecycle GHG emissions for average HEVs and ICEVs in California's vehicle fleet
- Determine and compare lifetime costs to consumers for the Honda Civic HEV and ICEV and the Ford Escape HEV and ICEV
- Estimate lifetime costs for average HEVs and ICEVs in the vehicle fleet of California
- Determine the change in expected lifecycle GHG emissions through 2025 due to increased diffusion of HEVs into California's vehicle fleet
- Determine the expected costs to consumers through 2025 due to this diffusion
- Develop a system to rate vehicles based on their lifecycle GHG emissions and lifetime costs to consumers

A conceptual model of the objectives of this study and their relationships to one another is presented in Figure 2-2.

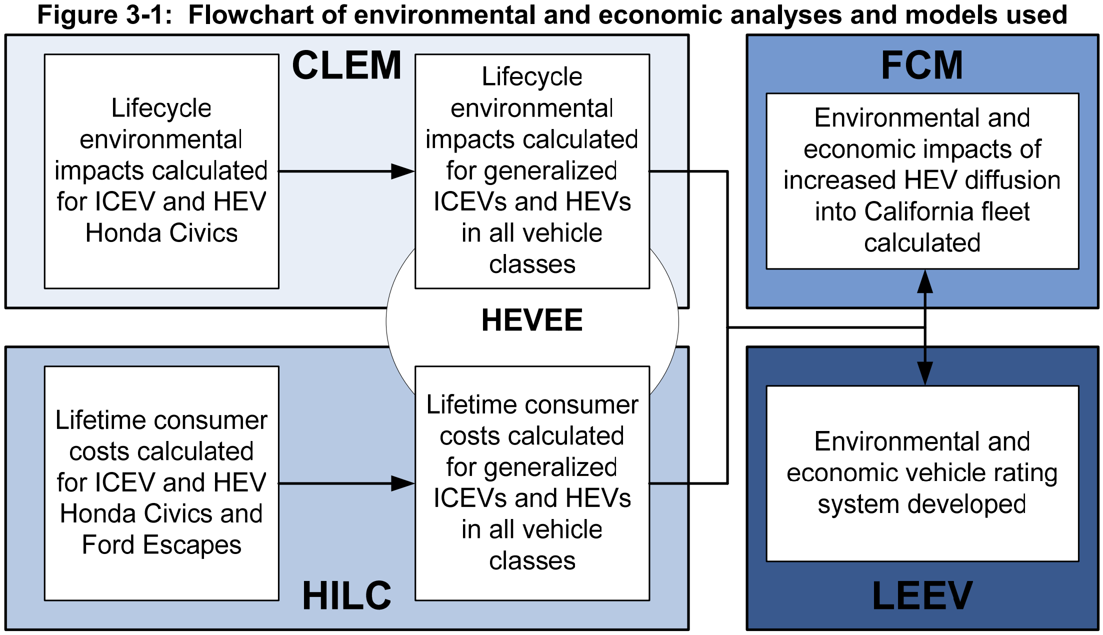
Figure 2-2: Project objectives and interdependence



3. Methodology

Several models were developed to analyze the potential environmental and economic impacts of increasing the HEV market share in California. The Carbon-equivalent Lifecycle Emissions Model (CLEM) was used to analyze the lifecycle GHG emissions of an HEV and ICEV Honda Civic. The HEV-ICEV Lifetime Comparison model (HILC) calculated the lifetime consumer costs of HEV and ICEV versions of the Honda Civic and Ford Escape. It was also used to calculate the breakeven point and breakeven gasoline price for these vehicles. The Hybrid Electric Vehicle Emissions Estimator (HEVEE) approximated vehicle characteristics for HEV versions of currently available ICEVs, based on current technology. These theoretical HEVs and their conventional counterparts were analyzed using the CLEM and HILC to determine their respective environmental and economic impacts. This information was then used in the Fleet Composition Model (FCM) to estimate the impacts of increasing the portion of HEVs in the California vehicle fleet. Outputs from the CLEM and HILC were also used to develop the Lifetime Environmental and Economic Vehicle (LEEV) estimator system to compare the lifecycle GHG emissions and lifetime cost impacts of vehicles across vehicles classes and vehicle types.

Figure 3-1: Flowchart of environmental and economic analyses and models used



3.1 Carbon-Equivalent Lifecycle Emissions Model (CLEM) [1]

3.1.1 Motivation

Although consumers and regulators generally only consider vehicle emissions that occur during the use phase, emissions from other phases of the product lifecycle can also be significant. For example, making a car lighter by substituting aluminum parts for steel parts can increase the fuel efficiency of the vehicle, reducing most tailpipe emissions. However, the processing of virgin aluminum is much more energy intensive than the processing of virgin steel, making emissions during the manufacturing phase of the product's lifecycle higher as a result of the substitution of aluminum for steel (Birat et al, 2004). Looking only at the use phase overestimates the benefit of increasing fuel efficiency with this material substitution. As a result of situations like this, life cycle assessment (LCA) has become a popular tool for evaluating the total environmental impacts of automobiles.

HEVs are generally considered to be better environmental performers than ICEVs because their increased fuel efficiency allows them to consume less gasoline and produce fewer air emissions. However, emissions from other parts of the HEV lifecycle may offset some of the emissions reductions associated with better fuel efficiency. Using a lifecycle perspective allows for the measurement of emissions throughout the lifecycle.

The CLEM was created with the intention of comparatively evaluating the lifecycle environmental impacts of an ICEV Civic with an HEV Civic. The CLEM is a spreadsheet-based model that is capable of calculating the total GHG emissions of a vehicle over its lifecycle and converting these emissions to units of CO_2-equivalent emissions.

3.1.2 Conceptual Framework

The CLEM used LCA methodology to calculate lifecycle GHG emissions for any given vehicle. The model divided the vehicle lifecycle into five distinct sections: *Materials, Assembly, Transport, Upstream Fuel, and Use*. Data used in the CLEM was obtained from many sources, including vehicle manufacturers, government agencies and reports, peer-reviewed journal articles, and LCA databases. Using this data, the model estimated the quantity of carbon dioxide equivalent (CO_2e) emissions that are produced during each stage of a vehicle's lifecycle.

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[1] A more detailed description of the data sources and impact calculations in the CLEM is provided in Appendix A.

3.1.3 Impact Categories

The CLEM calculated lifecycle emissions for gases that affect global climate change. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons 134a and 152a (HFC 134a, HFC 152a) were identified by the California Air Resources Board (2004 [2]) as the primary GHGs associated with the use of motor vehicles.

The CLEM aggregated emissions of these gases over the lifecycle of a vehicle and converted them to CO_2e emissions using the global warming potential factors in Table 3-1. Global warming potential (GWP) is a measure of the heat-trapping properties (radiative force) of a gas in the atmosphere, compared to carbon dioxide. For example, one kilogram of a gas with a GWP of two would have two times the warming effect as one kilogram of CO_2.

Table 3-1: Global Warming Potential of Gases analyzed in the CLEM

CO_2	CH_4	N_2O	HFC 134a	HFC 152a
1	23	296	1,300	120

Source: IPCC, Third Assessment Report, 2003. 100 year potentials.

A summary of the lifecycle CO_2e emissions calculation is given by the following equation:

Equation 3-1:

$$LifecycleGHGemissions = \sum_{GHG}\left(\sum_{LS} Emission_{GHG,LS}\right) \times GWP_{GHG}$$

Where:

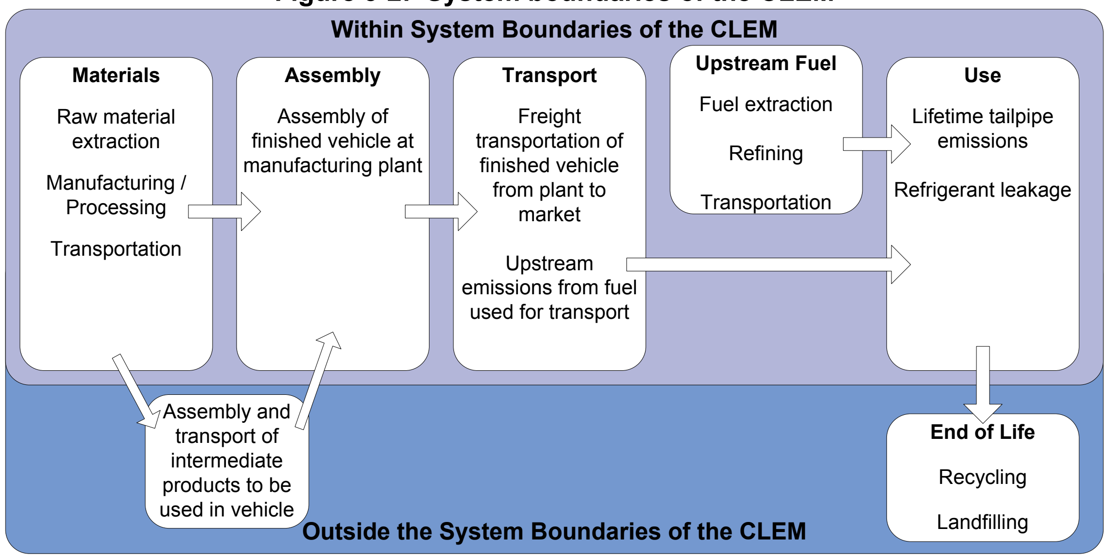
$Emission_{GHG,LS}$ = the amount of a greenhouse gas, GHG, emitted during the lifecycle stage, LS;

GWP_{GHG} = the Global Warming Potential of a greenhouse gas, GHG.

3.1.4 System Boundaries

The CLEM quantified the lifecycle GHG emissions of one vehicle – the functional unit of the CLEM model. The specific boundaries of each section of the CLEM and known omissions of potential impacts are described below. Figure 3-2 shows the boundaries of the lifecycle activities analyzed by the CLEM.

Figure 3-2: System boundaries of the CLEM



Materials

The *Materials* section of the CLEM calculated the GHG emissions attributable to the lifecycle of the materials used in vehicles and their components, based on the methodology in Delucchi's (2003) Lifecycle Emissions Model (LEM). The *Materials* lifecycle stage in this model included the raw material extraction, processing, and transport necessary to create and deliver the finished materials for use in the assembly of a vehicle. The end of life treatment of the materials was not included in the CLEM because prior studies have shown that GHG emissions from the vehicle end of life are minimal (Stodolsky et al., 1995).

Assembly

The *Assembly* section of the CLEM calculated the GHG emissions generated when the vehicle is manufactured. The assembly of vehicles was defined in this study as the set of processes that occur at the manufacturing plant where a completed vehicle is produced. Assembly of vehicle components at intermediate manufacturing facilities was not included in this analysis.

Transport

The *Transport* section analyzed the impacts of transporting a vehicle to market. This included the use of rail, ship, and truck freight services between the automobile manufacturing facilities and the destination city or state. Emissions from the upstream production of the fuels used by the transportation vehicles were also included.

Upstream Fuel

Upstream fuel emissions are due to the extraction, refining, and transportation of vehicle fuel to a fueling station. This lifecycle stage is theoretically a subset of the use phase because upstream fuel emissions depend directly on the amount of fuel consumed during the operation of the vehicle. *Upstream fuel* was delineated in the CLEM as a separate section of a vehicle's lifecycle because it is rarely considered when addressing automobile emissions.

Use

GHG emissions directly from the operation and maintenance of vehicles were calculated in the *Use* section of the CLEM. Often referred to as "tailpipe emissions," use emissions are primarily due to the combustion of fuel (gasoline). Other GHG emissions from vehicle use, most notably from leaks in air conditioning systems, were also included in this section of the CLEM.

3.1.5 Impact Assessment

Vehicle-specific data were used to calculate total GHG emissions for each phase of the lifecycle. These emissions were then normalized to CO_2e units using the GWPs in Table 3-1.

Materials

Delucchi (2005) derived CO_2e emission factors that account for the lifecycle of several materials commonly used in automobiles. The total emission rate for a material over its lifecycle (ERML) was calculated by adding the emissions from manufacturing energy, other manufacturing processes, other inputs, and product transportation. When a material's lifecycle included emission saving processes, like the co-production of other materials or scrap recycling, these savings were deducted from the ERML. The emission factors used in the CLEM did not include credits for end of life recycling in order to avoid double-counting of emissions savings. Other than this adjustment, ERMLs from Delucchi's work were used to calculate the emissions attributable to the materials used in each vehicle. Table 3-2 is an abbreviated list of the CO_2e emission factors derived by Delucchi and adjusted for use in the CLEM. The ERMLs for each material were multiplied by the quantity of that material in a given vehicle.

Table 3-2: Lifecycle CO_2-equivalent emissions for materials (g CO_2e / kg material)			
Material	**Total ERML**	**Material**	**Total ERML**
Virgin plain carbon steel	3,497	Rubber	9,387
Virgin high strength steel	3,779	Glass	1,541
Virgin stainless steel	4,855	Virgin Copper	15,144
Recycled plain carbon steel	1,078	Zinc die castings	6,358
Iron	4,290	Virgin lead	2,910
Advanced composite	15,534	Recycled lead	414
Other plastics	13,003	Nickel	9,103
Virgin aluminum	29,057	Potassium hydroxide	1,753
Recycled aluminum	3,186		

Assembly

Emissions of GHGs due to energy use and manufacturing processes were input for vehicle assembly facilities. Annual vehicle production numbers were used to calculate the GHG emissions attributable to the production of a single vehicle at the plant.

Transport

Based on data in the *Transportation Energy Data Book* (Davis & Diegel, 2003), transport emission factors were calculated as emissions per tonne-kilometer (the movement of one tonne of cargo over a distance of one kilometer) for ship, rail and truck transport modes. The CLEM multiplied these emission factors by the vehicle mass and the distance transported by each mode. An intermediate step in this calculation was to determine the amount of fuel used, based on the fuel efficiency of each transport mode. This allowed emissions from upstream processing of the fuel used for transport to be included in the analysis.

Upstream Fuel

The emission factors for the extraction, refining, and transportation of vehicle fuels used in this analysis were determined by Delucchi (2003). These factors were converted to emissions per gallon of fuel, and were multiplied by the number of gallons of fuel used over the lifetime of each vehicle.

Use

The base scenario in the CLEM assumed a vehicle lifetime of 241,000 kilometers (150,000 miles). EPA fuel economy estimates (US EPA/DOE,

2005) were used for the fuel economy of each vehicle, and it was assumed that this efficiency did not deteriorate over the vehicle lifetime. The two major components of use phase emissions evaluated by the CLEM were fuel combustion emissions and fugitive refrigerant emissions.

EPA fuel economy estimates over a 241,000 km vehicle lifetime were used to determine the quantity of fuel consumed during the vehicle's lifetime. A conversion factor of 8,904 grams CO_2 per gallon of combusted gasoline was used to convert fuel usage into CO_2 emissions (Raney, 2005). Tailpipe emissions of CH_4 and N_2O were based on the fuel economy of the vehicle (US EPA, 2003).

Schwarz (2002) estimated the loss of refrigerant (HFC 134a) due to normal and irregular vehicle operations as a percentage loss per year of the original refrigerant volume. The CLEM used these estimates to calculate the emissions from refrigerant leakage.

3.1.6 Output

Output from the CLEM consisted of the CO_2-equivalent emissions for the materials, assembly, transport, upstream fuel, and use of a given automobile. Emissions were calculated in tonnes of CO_2e, by lifecycle stage and in total.

Because only one impact category was investigated by this model, any further valuation or weighting of the results was unnecessary. Evaluating the monetary implications of different levels of GHG emissions, or comparing these climate change impacts to those of other impact categories, was outside the scope of this model.

3.1.7 Comparison of Honda Civics

The CLEM was used to analyze the difference in lifecycle GHG emissions between the Honda Civic Hybrid and the Honda Civic LX. See Appendix A for a more detailed description of the data and assumptions used for the comparison of Civics.

The material composition of each vehicle was determined from Civic specific data from Honda, as well as industry averages and estimates when needed. The bodies of the Civics were assumed to have the same material composition percentages; the difference in total material composition was due to the specialized components (batteries, electric motor, ICE, electronics system) and added weight of HEVs.

Production of all ICEV Civics was assumed to occur at Honda's East Liberty Plant in Ohio and HEV Civic assembly was assumed to occur at the Suzuka Plant in Japan. Although emission data for these facilities were not available, emission estimates were created based on annual electricity and natural gas consumption of the East Liberty Facility (Honda Motor Co., 2004). Estimates were adjusted for the Japanese facility based on national energy data (IEA, 2004). Production quantities for different models built at each facility were provided by Honda (Raney, 2005), allowing for the calculation of GHG emissions attributable to the assembly of a single Civic.

The transport distances from the two manufacturing facilities to nine major California markets (counties with population exceeding one million people) were calculated using internet mapping software (Yahoo! Inc, 2005; Byers, 2003). The fraction of the transportation distance that was covered by a particular mode was estimated using data from the *Commodity Flow Survey* (Bureau of the Census, 2004) and estimates from Honda (Raney, 2005).

The fuel economy figures used to calculate use and upstream fuel emissions were EPA city and highway estimates adjusted for 55% city and 45% highway driving shown in Table 3-3 (EPA/DOE 2005).

Table 3-3: Fuel economy of different Honda Civic models and transmissions (MPG)

	2005 Civic Hybrid (CVT)	2005 Civic Hybrid (Manual)	2005 Civic LX (Auto)	2005 Civic LX (Manual)
City	48	46	29	32
Highway	47	51	38	38

3.1.8 Emission Calculations for use in the FCM

The CLEM also estimated the lifecycle CO_2e emissions from average ICEVs and hypothetical HEVs for use in the Fleet Composition Model (see Section 3.4 below).

Average attributes of ICEVs for each manufacturer and vehicle class were determined based on California fleet data (CARB, 2004 [3]). These vehicle attributes were weighted based on the sales of each manufacturer to create an "average ICEV" for each vehicle class. The Hybrid-Electric Vehicle Emissions Estimator created hypothetical HEVs for each manufacturer and vehicle class (see Section 3.3 below) by applying the emission differences between available HEVs and ICEVs to the hypothetical ICEVs.

When analyzing these average vehicles in the CLEM, the material composition of the vehicles' bodies was estimated using Table H-3 in Delucchi (2003). The sizes and material compositions of many HEV components were scaled relative to Honda Civic Hybrid components.

Assembly emissions for the average vehicles were assumed to be the same, on a per-kilogram of vehicle basis, as those of the Civics produced in Ohio. Transport distance and mode data were based on data in the *Commodity Flow Survey* (Bureau of the Census, 2002). Use and upstream fuel emissions were estimated based on the calculated average fuel economy characteristics of the ICEVs and hypothetical HEVs.

The FCM calculated emissions of HEVs and ICEVs by vehicle class and manufacturer. Fuel economies specific to each vehicle class and manufacturer were used to calculate upstream fuel emissions and use emissions of CO_2. The CLEM output, specific to HEVs and ICEVs by vehicle class only, was used to account for emissions from the materials, assembly, transport, and non-CO_2 use emissions for HEVs and ICEVs in each vehicle class.

3.2 HEV-ICEV Lifetime Cost Model (HILC)

3.2.1 Motivation

The costs of developing and incorporating hybrid-electric technologies into new vehicles translate into higher retail prices (currently $2,500 to $7,000) for HEVs than for comparable ICEVs. However, the increased fuel efficiency achieved by HEVs leads to lower fuel expenses throughout the vehicle lifetime. Whether or not the premium paid for HEVs can be fully recovered through the fuel savings depends on many factors. The HILC was developed to determine the economic value to a consumer of owning and operating an HEV rather than a comparable ICEV.

3.2.2 Conceptual Framework

The HILC is a spreadsheet-based model that calculated the lifetime cost of a vehicle, the lifetime savings or added cost of an HEV compared to a similar ICEV, and the breakeven point and breakeven fuel price of HEVs. The breakeven point is the length of time an HEV must be operated before it recovers its price premium for a given fuel price. The breakeven fuel price is the minimum fuel price per gallon of gasoline that will allow an HEV to recover its price premium by the end of its lifetime. All of the calculations utilized present value accounting and were computed for a range of gas prices and discount rates in order to conduct a sensitivity analysis.

<u>*Assumptions*</u>

Based on a literature review, the HILC model assumed:

- A vehicle lifetime of 241,000 kilometers (150,000 miles)

- An annual mileage of 19,300 kilometers (12,000 miles)
- A city to highway driving ratio of 55 to 45
- Vehicle fuel economies based on EPA ratings

Calculations

Lifetime costs include the discounted purchase price, fuel costs, and maintenance costs of the vehicles. The purchase price of a vehicle was assumed to be equal to published manufacturer suggested retail price (MSRP). Fuel costs were calculated based on fuel economy, assumed fuel price, and annual mileage. Maintenance costs were based on manufacturer maintenance schedules and dealership service costs. The primary calculations from the HILC are shown below:

Equation 3-2

$$Lifetime\_Cost = MSRP + \sum_{t=0}^{t=T} (FuelCost_t + MaintenanceCost_t) \times e^{-rt}$$

Where:
MSRP = the vehicle purchase price;
t = the time period;
T = the end of the vehicle's lifetime;
$FuelCost_t$ = expenses for fuel in time period *t* (see Equation 3-3);
$MaintenanceCost_t$ = expenses for vehicle maintenance in time period *t*;
r = the discount rate.

Equation 3-3

$$FuelCost_t = \frac{Mileage_t}{(0.45 \times HwyMPG + 0.55 \times CityMPG)} \times FuelPrice$$

Where:
$Mileage_t$ = the distance traveled in period *t*;
HwyMPG = the rated highway fuel economy;
CityMPG = the rated city fuel economy;
FuelPrice = the price of gasoline, in dollars per gallon.

Equation 3-4

$$Lifetime\_Savings = Lifetime\_Cost_{ICEV} - Lifetime\_Cost_{HEV}$$

Where:
ICEV and *HEV* are similarly equipped conventional and hybrid-electric vehicles, respectively.

The breakeven point is the vehicle lifetime (*T* in Equation 3-2) that causes the value of the lifetime savings (Equation 3-4) to equal zero.

The breakeven fuel price is the per gallon price of gasoline (*FuelPrice* in Equation 3-3) that causes the value of the lifetime savings to equal zero, keeping the vehicle lifetime constant.

3.2.3 Lifetime Costs of Honda Civics and Ford Escapes

The HILC model was initially used to compare the lifetime costs of a Honda Civic Hybrid and a Honda Civic LX. The lifetime costs of an HEV and ICEV version of the Ford Escape, a small SUV, were also calculated. A baseline scenario with a fuel price of $2.50 per gallon and a 3% discount rate was used, although several other scenarios were analyzed for parameter sensitivity.

3.2.4 Lifetime Cost Calculations for Use in the FCM

The HILC was also used to calculate the lifetime costs of average ICEVs and hypothetical HEVs for use in the Fleet Composition Model. Average ICEV prices were calculated by manufacturer and vehicle class (Table 3-4), based on 2002 model year data from Automotive News (2003). The HEV price premiums for different vehicle classes, estimated by Lipman & Delucchi (2003), were added to these average ICEV prices to get average HEV prices. The average HEV price premiums used for this analysis are shown above in Table 2-2.

Table 3-4: Average Vehicle Prices (with Air Conditioner)

	Toyota	Nissan	Honda	General Motors	Ford	Daimler - Chrysler	Other
Small Car	$19,985	$16,801	$21,022	$20,673	$32,284	$32,860	$24,274
Large Car	$30,607	$28,170	$25,209	$30,791	$31,112	$50,912	$34,574
Minivan	$26,401	$25,336	$28,310	$29,695	$26,291	$26,970	$27,565
Small truck	$24,314	$24,309	$26,941	$24,941	$23,334	$26,698	$19,145
Large truck	$33,091	N/A	N/A	$30,939	$36,331	$29,343	N/A

The HEVEE model (see Section 3.3) estimated the fuel economy of average ICEVs and HEVs for each vehicle class and manufacturer. These estimates were used to calculate lifetime fuel costs. Maintenance costs were assumed to be the same for HEVs and ICEVs and were therefore excluded from these calculations.

3.3 Hybrid-Electric Vehicle Emissions Estimator (HEVEE)

3.3.1 Motivation

Only a few HEV models are currently available in the U.S. market, and only six are based on similar ICEVS: one small car, one large car, two small trucks and two large trucks. An analysis of the impacts of an increasing HEV market share required estimates of the characteristics of HEVs yet to be developed. The HEVEE was created to estimate fuel economies and other attributes of hypothetical HEVs so that lifecycle GHG emissions and lifetime consumer costs for these vehicles could be estimated in the CLEM and the HILC model, respectively. The impacts of HEVs on California vehicle fleet GHG emissions and consumer costs could then be developed in the Fleet Composition Model. Therefore, the outputs from HEVEE results were used as inputs for these models.

3.3.2 Model Framework

The HEVEE is an empirical model based on a dataset of vehicle attributes and performance characteristics for 180 cars and light-duty trucks from MY 2002 (CARB, 2004 [3]) (Appendix C). Linear regressions of adjusted fuel economy were performed on curb weight, horsepower, engine displacement, transmission type (either manual or automatic), and drive (4WD or 2WD) for MY 2002 vehicles from the database. One regression was performed per vehicle class (small car, large car, minivan, small truck, and large truck), resulting in five different formulas relating class fuel efficiency to the above characteristics. The general formula is shown in Equation 3-5 and the values of each coefficient for each vehicle class are shown in Table 3-5. Not all characteristics impact the fuel efficiency for each vehicle, and therefore some coefficients are left blank.

Equation 3-5

$$Fuel\_Economy = \alpha_1 CW + \alpha_2 HP + \alpha_3 ED + \alpha_4 T + \alpha_5 D + c$$

Where:

CW = curb weight (lbs);
HP = horsepower;
ED = engine displacement (liters);
T = transmission (1=manual, 0=automatic);
D = drive (1=4WD, 0=2WD);
c = constant.

Table 3-5: Coefficient values for HEVEE estimations						
Vehicle Class	**α_1**	**α_2**	**α_3**	**α_4**	**α_5**	**c**
Small Car:	-0.0056	-0.352	-0.013	1.20		44.56
Large Car:	-0.0032	-0.0120		0.936		36.10
Minivan:	-0.0029		-0.299		-0.549	32.82
Small Truck:	-0.0012		-2.086	0.058	-1.401	30.90
Large Truck:			-0.897	0.475	-1.362	20.55

To estimate the fuel economy of theoretical HEVs using this regression analysis, vehicle characteristics were adjusted within the model to reflect a conversion from an ICEV to an HEV. The HEV technology used in the theoretical conversions was assumed to be the same as that used in the Honda Civic Hybrid. Large trucks were the exception, and were assumed to incorporate a lower level of hybrid technology in order to be consistent with the current technology of the GMC Sierra and Chevy Silverado. These assumptions were intended to reflect the attributes and performance of currently available HEVs.

In the HEV characteristic estimates, large trucks were assumed to weigh more than similar ICEVs (based on currently available HEVs), but other parameters were held constant. HEVs in other classes were assumed to also have increased weights, as well as reduced engine displacement and horsepower compared to the ICEV. New fuel efficiencies were derived and an HEV performance premium was added. This performance premium was used to estimate the increase in fuel efficiency for HEVs and depended on the class to which the vehicle belongs. Small cars, large cars, minivans, and small trucks used the average performance premium from the Honda Civic and Ford Escape (which perform very similarly) while large trucks used the premium from the GMC Sierra/Chevy Silverado. The model is flexible so that new HEVs can be added to the model as they come onto the market in order to influence future projections.

3.3.3 Model Inputs and Outputs

The vehicle characteristics used in the regression analysis (curb weight, drive, transmission, horsepower, engine displacement) are the inputs for HEVEE. The model also accepts city and highway fuel economies for the ICEV if the data are available in order to assess the accuracy of the model. The user may input whether the HEV being projected should have a manual, automatic, or continuously variable transmission (CVT).

The outputs from HEVEE include curb weight, engine displacement, adjusted fuel economy, and grams per mile CO_2 emissions for theoretical HEVs.

3.3.4 Use of the HEVEE

For analysis in the CLEM and HILC models, hypothetical average ICEVs for each vehicle class were run through the HEVEE to produce average characteristics of hypothetical HEVs for each vehicle class. The hypothetical ICEVs were average vehicles based on sales-weighted composites of the 2002 new vehicle fleet, as used by NESCCAF (2004) and CARB (2004 [3]). The results from HEVEE, which were used in the FCM, HILC, and CLEM models, are contained in Appendix B.

3.4 Fleet Composition Model (FCM)

3.4.1 Motivation

The CLEM and HILC models performed vehicle analyses that established the differences in lifecycle GHG emissions and lifetime costs between specific HEV and ICEV models. Expanding this analysis beyond the single vehicle level was the next step in exploring the potential of HEVs to reduce GHG emissions in California. The FCM was developed to estimate the effects of HEV market diffusion on GHG emissions and consumer expenses for vehicles in the California fleet. Used in conjunction with the HEVEE model, the lifecycle emissions and lifetime costs of average ICEVs and HEVs for different vehicle classes and manufacturers in the California fleet were calculated. Then, an assessment was made regarding GHG emission reductions and the resulting economic impact on consumers based on projections of new vehicle sales and HEV market diffusion in the state.

3.4.2 Model Framework

The FCM was first used to calculate the GHG emissions inventory and the average purchase prices of new vehicles added to the California fleet during model year (MY) 2002. The MY 2002 data was provided by CARB (2004 [3]) and represented 13% of the MY 2002 new vehicle sales of the U.S. The MY 2002 fleet was made up of 180 different models from the six major auto manufacturers, as well as an “Other” category to encompass smaller manufacturers. Each of these vehicle models were classified into the five vehicle classes used in the NESCCAF (2004) study shown in Table 2-3 and into CARB’s manufacturer divisions shown in Table 2-4.

The California Department of Transportation’s (CADOT) projection of annual growth in new vehicle sales was used in conjunction with an internally-derived projection of HEV market diffusion to estimate GHG emissions and consumer costs associated new vehicle sales, in scenarios with and without HEVs (CADOT, 2000). The FCM assumed that the proportion of the market share from each manufacturer and vehicle class would remain constant in each model year of the study. For the 2002 baseline year, all vehicles in the fleet were assumed to be ICEVs. HEV market diffusion was assumed to first occur in MY 2003 and to increase each model year from 0% of the new vehicle market in MY 2002 to 20% in MY 2025. The HEV diffusion was assumed to occur uniformly across all manufacturers and vehicle classes. No additional technological changes were assumed to occur over the period of the study. The model calculated the GHG emissions and economic impacts to consumers for each model year in the study, based on the projections of growth and diffusion, and assuming a vehicle lifetime of 12.5 years and an annual driving distance of 19,300 kilometers (12,000 miles).

3.4.3 Fleet GHG emissions

The FCM determined CO_2 tailpipe emissions for ICEVs in each vehicle class and each manufacturer division based on the adjusted fuel economy of an average ICEV in each of these classifications. The average ICEVs were based on sales-weighted MY 2002 vehicle characteristics. These calculations accounted for the entire vehicle lifetime (150,000 miles) and were derived from a conversion factor of 8,904 grams of CO_2 emitted per gallon of gasoline burned (Raney, 2005). The same calculations were performed for the hypothetical HEVs produced in the HEVEE model.

Results from the CLEM analysis were prepared in order to incorporate GHG emissions from non-use portions of the lifecycle into the FCM (see Section 3.1.8). The non-use phase results were calculated by vehicle class and technology type (HEV or ICEV), but were not manufacturer-specific. Therefore, the additive lifecycle emission factors were the same for all manufacturers within a vehicle class and technology type.

Specifically, GHG emissions from the *Materials, Product Assembly,* and *Transport* lifecycle stages, as defined in the CLEM methodology, were added to the calculated CO_2 tailpipe emissions for both HEVs and ICEVs in a vehicle class. In addition, non-CO_2 emissions from the *Use* lifecycle stage, including CH_4, N_2O, and HFC 134a, were included. Emissions from the *Upstream Fuel* lifecycle stage are dependent upon a vehicle's fuel economy and were therefore calculated on a manufacturer-specific level.

The output of these calculations was two matrices of lifecycle emission factors for the seven auto manufacturer divisions and five vehicle classes (one matrix for ICEVs and one for HEVs). Three manufacturers (Honda, Nissan, Other) did not produce large trucks in 2002, so ICEV and HEV large trucks were not included in the analysis for these manufacturers, leaving a total of 64 average vehicle models.

To calculate the lifecycle GHG emissions resulting from new vehicle sales in each model year, the market share of each of the 64 average vehicle models was multiplied by projected total sales for each year and then by the lifecycle emission factor for that vehicle classification.

Equation 3-6

$$FleetEmissions_{MY} = \sum_{v,m} (Sales_{MY} \times Comp_{MY,v,m}) \times (Tailpipe_{v,m} + Fuel_{v,m} + Life_v)$$

Where:

$FleetEmissions_{MY}$ = the lifecycle GHG emissions resulting from the sales of vehicles in the model year *MY*;
$Sales_{MY}$ = the total vehicle sales in model year *MY*;
$Comp_{MY,v,m}$ = the percent of the fleet in model year *MY* made up by vehicle class *v* made by manufacturer *m*;
$Tailpipe_{v,m}$ = the calculated CO_2 emissions for vehicle class *v* and manufacturer *m*,
$Fuel_{v,m}$ = the calculated upstream fuel emissions for vehicle class *v* made by manufacturer *m*; and
$Life_v$ = the emissions from other lifecycle stages calculated in the CLEM for vehicle class *v*.

Although lifecycle emissions will occur over time, this methodology assigned the total lifecycle emissions from the sales in a particular model year to that year. This means that the 2002 emissions estimate included all of the GHG emissions that occur in the pre-use phases before the sale as well as the emissions occurring over the 12.5 year vehicle lifetime. This approach is justifiable because the residence time of most GHG emissions in the atmosphere are much longer than the lifetime of a vehicle (Pidwirny, 2001).

3.4.4 Lifetime Fleet Economics

The FCM projected the cost of the California fleet based on the lifetime costs of the 64 average vehicle models. Lifetime costs for each model included the initial purchase price and expenditures on gasoline, discounted to the year of purchase, as described above in Section 3.2.4. These costs were then discounted a second time to the year 2002 (see Equation 3-7). The FCM multiplied the lifetime costs of these vehicle models by the projected sales for that class and manufacturer. It repeated this process for all vehicle types and manufacturers to find a total yearly lifetime cost of the California fleet. Consistent with the emissions model, the entire present value of these costs was assigned to each single model year even though the costs would occur over time.

Equation 3-7

$$FleetCost_{MY} = \sum_{v,m}\left(\left(Sales_{MY} \times Comp_{MY,v,m}\right) \times Lifetime\_Cost_{v,m}\right) \times e^{-r(MY-2002)}$$

Where:

$FleetCost_{MY}$ = the total lifetime costs resulting from the sales of vehicles in the model year *MY*;
$Sales_{MY}$ = the total vehicle sales in model year *MY*;
$Comp_{MY,v,m}$ = the percent of the fleet in model year *MY* made up by vehicle class *v* made by manufacturer *m*;
$Lifetime\_Cost_{v,m}$ = the discounted lifetime cost of vehicle class *v* and manufacturer *m;*
r = the discount rate.

3.5 Lifetime Environmental and Economic Vehicle (LEEV) Estimator

3.5.1 Motivation

Consumers purchasing automobiles make decisions based on many criteria sometimes including both the environmental impact and overall cost of a vehicle. Unfortunately, the lifecycle GHG emissions and lifetime costs of a vehicle are not readily available to consumers or easily calculated. Consumers often base purchasing decisions on incomplete information such as basing environmental decisions solely on the fuel economy of a vehicle or cost decisions only on the purchase price. In order to aid consumer decision making, the Lifetime Environmental and Economic Vehicle (LEEV) estimator was created to provide information on the lifecycle GHG emissions and lifetime costs of a vehicle to the consumer. The LEEV estimator also allows for comparisons of the emissions and economic impacts across vehicle classes and types so that consumers can make more informed purchasing decisions.

The LEEV estimator calculates the lifecycle GHG emissions and lifetime costs of a vehicle, and ranks the vehicle based on its environmental, economic, and overall performance compared with a vehicle database. An online interface was created that accepts inputs of vehicle characteristics and returns the impact information in order to fulfill the goal of presenting the information to consumers in a simple manner.

3.5.2 Model

To determine the LEEV rankings, the lifecycle emissions and lifetime costs are estimated for a vehicle input by a user. The fuel efficiency is used to determine the use-phase emissions and the lifetime expenditures on gasoline. The non-use phase emissions, which were estimated by vehicle class and technology type in the CLEM, are added to the use phase emissions to find the total lifecycle emissions. The gasoline expenditures are added to the purchase price to give lifetime costs. This lifetime cost excludes maintenance costs because our research has shown that maintenance costs are highly variable and vehicle-specific, making generalizations about HEV and ICEV maintenance cost comparisons difficult and highly uncertain.

Both the emissions and the costs are compared with the database of average vehicles calculated for the Fleet Composition Model. The percentiles in which the input vehicle falls are also calculated for costs and emissions. The overall percentile shows how well the average of the cost and emission percentiles of the input vehicle rate compared to the database. The lifecycle emissions, lifetime costs, and the emission, cost, and overall percentiles are presented as outputs. The calculations used a discount rate of 3%, a $2.50 per gallon gasoline price, a 19,300 kilometer (12,000 mile) annual driving distance, and a lifetime of 12.5 years.

3.5.3 User Interface

The interface discussed above was designed using Microsoft Visual Basic to allow a user to input information about a specific vehicle and return the emissions, costs and percentiles for that vehicle to the user. The model inputs include highway and city fuel economies, vehicle type, vehicle class and purchase price. The outputs returned include lifecycle emissions and percentile, lifetime costs and percentile, and overall percentile ranking. An example of the user input form is shown below in Figure 3-3, as run for the top-selling vehicle in the US in 2002, the Ford F-Series pick-up truck. The results page for this example of the LEEV estimator is shown in Figure 3-4.

Figure 3-3: Vehicle Data Entry Form

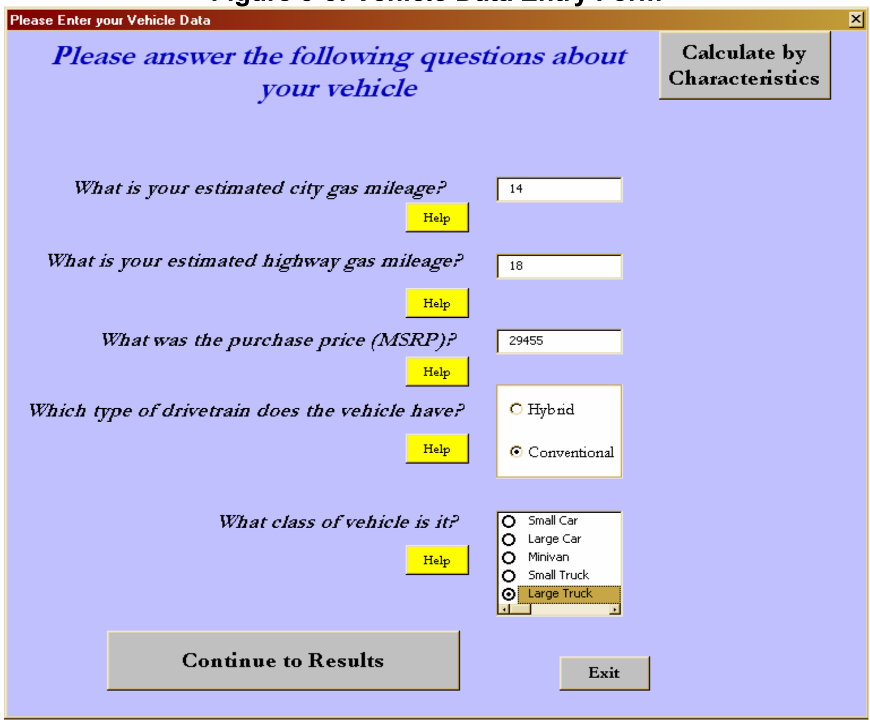
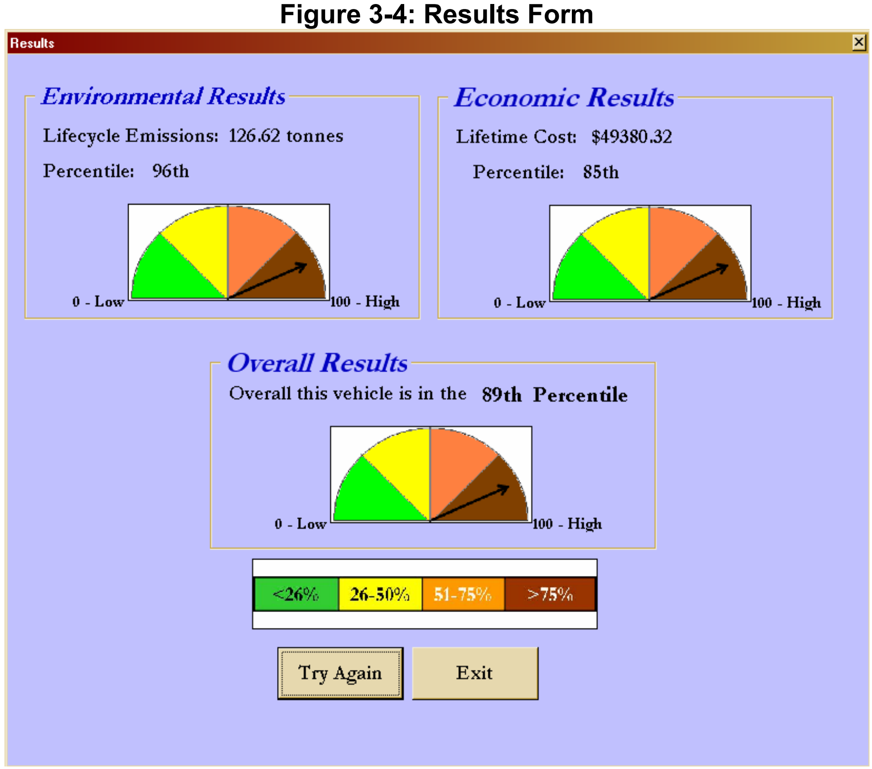
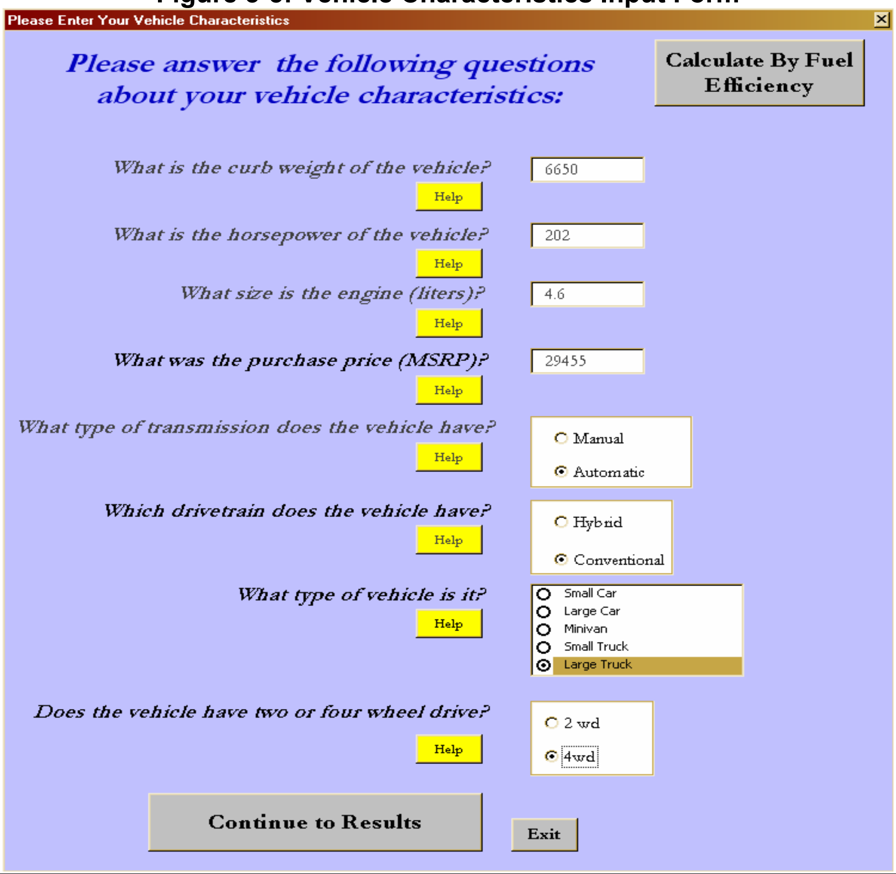


Figure 3-4: Results Form



As noted earlier, the model can also accept vehicle characteristics as inputs, calculating the LEEV score by first predicting the fuel efficiency using the HEVEE output. The user inputs on this sheet include the vehicle curb weight, horsepower, engine size and purchase price, transmission type, vehicle class, and whether the vehicle is an HEV or an ICEV. The interface is shown in Figure 3-5 also for the Ford F-Series pick-up truck.

Figure 3-5: Vehicle Characteristics Input Form



4. Results

4.1 Carbon-Equivalent Lifecycle Emissions Model (CLEM)

4.1.1 Lifecycle Emissions of Honda Civics

Hybrid electric (Civic Hybrid) and internal combustion (Civic LX) models of the Honda Civic were analyzed by the CLEM, including two transmission types for each Civic model; a manual and automatic transmission for the LX and a manual and continuously variable transmission (CVT) for the Hybrid. In a CVT, the transmission is constantly adjusted to maintain an optimal gear ratio.

The lifecycle greenhouse gas emissions calculated by the CLEM analysis are shown in Table 4-1. Comparisons of these results show that lifecycle emissions are lower for the hybrid model than the conventional model and lower for the manual transmission than the automatic (or CVT) transmission of the same model.

Table 4-1: Lifecycle greenhouse gas emissions for Honda Civics (kg CO_2e)

Lifecycle Stage	2005 Civic Hybrid (CVT)	2005 Civic Hybrid (Manual)	2005 Civic LX (Automatic)	2005 Civic LX (Manual)
Materials	7,163	7,015	6,461	6,349
Product Assembly	384	376	534	525
Transport to Market	302	294	169	166
Upstream Fuel	9,359	9,247	13,708	12,917
Product Use	30,219	29,882	43,275	40,900
Total	**47,427**	**46,813**	**64,148**	**60,858**

Table 4-2 quantifies the lifecycle emission differences between the Civic Hybrid and Civic LX for both transmission types. Lifecycle emissions from the CVT Hybrid are 26% lower than those of the automatic LX; emissions from the manual Hybrid are 23% lower than the manual LX. Although emissions are significantly lower for the Civic Hybrid over the entire vehicle lifecycle, emissions during the materials and transport lifecycle stages are higher. Emissions from the CVT Hybrid are 16,720 kg of CO_2e lower than those from the automatic LX over the full vehicle lifecycle, but are 834 kg of CO_2e higher during the materials and transport lifecycle stages. Similarly, lifecycle emissions from the manual Hybrid are 14,045 kg of CO_2e lower for the manual Hybrid than for the manual LX, but materials and transport emissions are 794 kg CO_2e higher.

Table 4-2: Lifecycle emissions difference between Civic Hybrid and Civic LX: HEV minus ICEV (kg CO_2e)		
Lifecycle Stage	**CVT/Automatic**	**Manual**
Materials	702	666
Product Assembly	(150)	(149)
Transport to Market	132	128
Upstream Fuel	(4,350)	(3,671)
Product Use	(13,055)	(11,018)
Total	**(16,720)**	**(14,045)**

Lifecycle emissions were also averaged over each vehicle's expected 241,000 kilometer lifetime (see Table 4-3). These emissions are in the same proportion as the total emissions in Table 4-1, but represent the average environmental impact of driving each vehicle one kilometer.

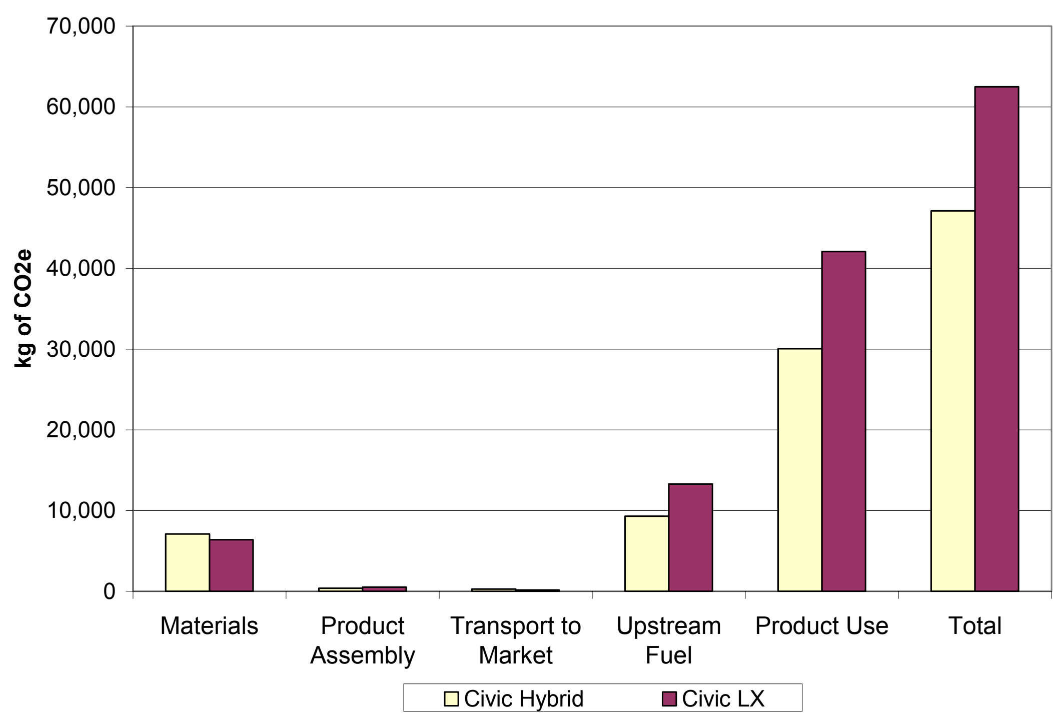
Table 4-3: Lifecycle GHG emissions for Honda Civics per kilometer driven (g CO_2e/km)				
Lifecycle Stage	**2005 Civic Hybrid (CVT)**	**2005 Civic Hybrid (Manual)**	**2005 Civic LX (Auto)**	**2005 Civic LX (Manual)**
Materials	30	29	27	26
Product Assembly	2	2	2	2
Transport to Market	1	1	1	1
Upstream Fuel	39	38	57	54
Product Use	125	124	179	169
Total	**196**	**194**	**266**	**252**

Emissions from an "average" Civic HEV and an average Civic ICEV were calculated for comparative purposes. Emissions from the average Civics are the mean emissions of the two transmission types for each model, shown in Table 4-4 and Figure 4-1. In general, lifecycle GHG emissions from the Civic Hybrid are about 24% lower than the emissions from the Civic LX.

Similar to the results found for the individual transmission types, emissions for an average Civic Hybrid are lower than those for an average Civic LX during the product assembly, upstream fuel, and product use lifecycle stages, but higher during the materials and transport lifecycle stages.

Table 4-4: Mean lifecycle GHG emissions for both transmission types of Civic Hybrid and LX (kg CO_2e)		
Lifecycle Stage	**Civic Hybrid**	**Civic LX**
Materials	7,089	6,405
Product Assembly	380	530
Transport to Market	298	168
Upstream Fuel	9,303	13,313
Product Use	30,051	42,087
Total	**47,120**	**62,503**

Figure 4-1: GHG emissions for average Civic Hybrid and LX, by lifecycle stage



Although emissions from the product use-phase dominate total lifecycle emissions, an average of 35% of lifecycle emissions are generated during the other lifecycle stages. Upstream fuel emissions, which could be considered as part of the use-phase (but are quantified separately in this study), are the second largest contributor, followed by emissions from materials processing. Product assembly and transport contributed much smaller amounts to total lifecycle emissions. The contributions of GHG emissions for each lifecycle stage, relative to total lifecycle emissions, are shown in Figure 4-2 and Figure 4-3 for the Civic Hybrid and the Civic LX, respectively.

Product use accounts for 64% of lifecycle GHG emissions for an average Civic Hybrid. When the upstream fuel emissions are included, the portion rises to 84%. In comparison, the average Civic LX emits 67% of lifecycle emissions during product use – 89% when upstream fuel emissions are included.

The extraction, processing, and transport of materials account for 15% of the lifecycle emissions of an average Civic Hybrid and 10% of an average Civic LX. The assembly and transport processes are each responsible for less than one percent of lifecycle emissions for all vehicles studied.

Figure 4-2: Contribution of each lifecycle stage to total GHG emissions – Civic Hybrid.

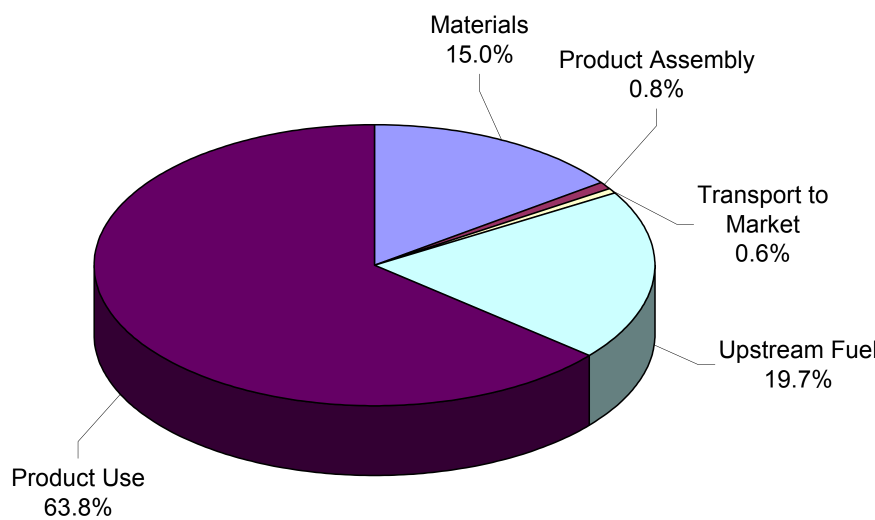
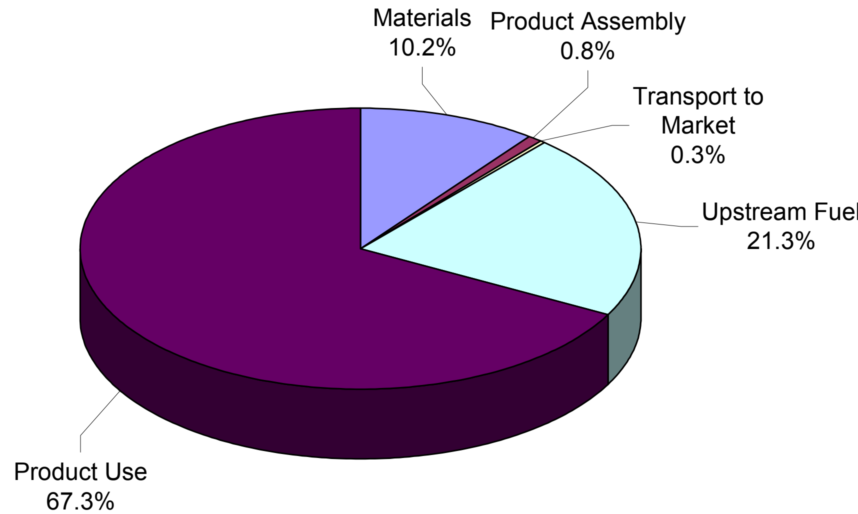


Figure 4-3: Contribution of each lifecycle stage to total GHG emissions – Civic LX.



Materials

Figure 4-4 shows the GHG emissions resulting from the inclusion of different materials in each vehicle. The steel, aluminum, plastics, and copper used in each vehicle create the majority of material emissions.

Table 4-5 displays the GHG emissions from the materials used in an average Civic Hybrid and Civic LX, and the increase (decrease) in materials emissions relative to the Civic LX. The higher emissions seen for Civic Hybrid are primarily due to increased use of virgin copper, virgin aluminum, advanced composite (plastic), and nickel.

Figure 4-4: GHG Emissions from material usage

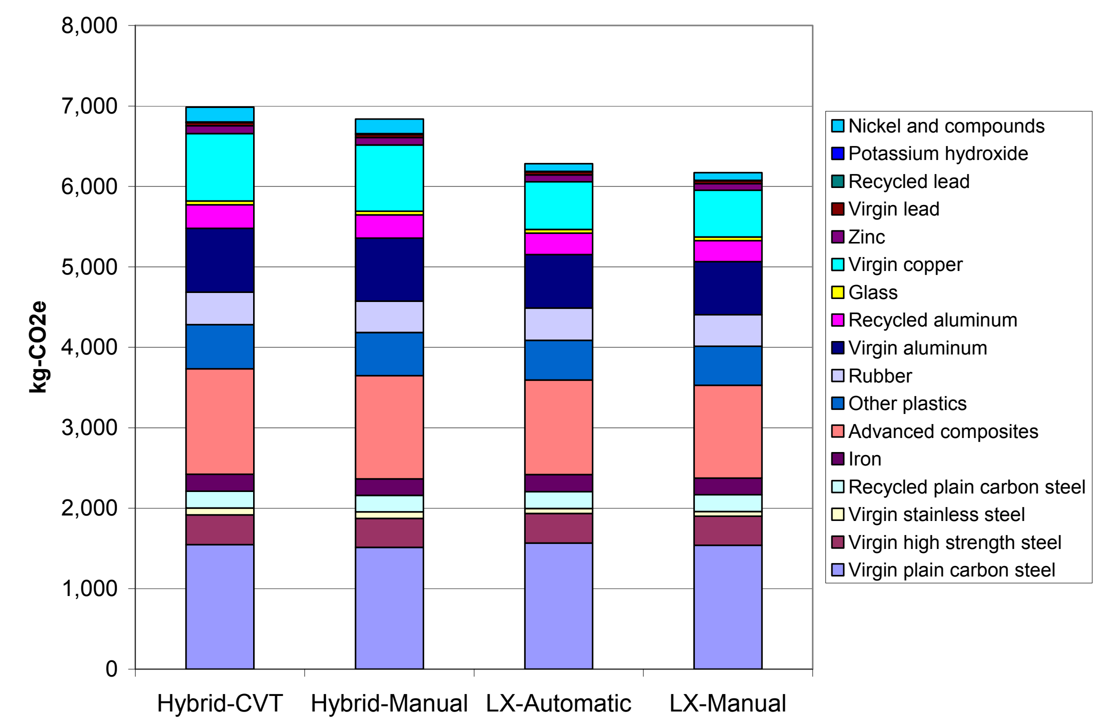


Table 4-5: Emissions from materials used in Honda Civics, and difference relative to Civic LX (kg CO_2e/km)

Material	Civic Hybrid	Civic LX	Difference
Virgin plain carbon steel	1530	1553	(23)
Virgin high strength steel	364	365	(1)
Virgin stainless steel	85	59	26
Recycled plain carbon steel	206	209	(3)
Iron	209	209	0
Advanced composites	1297	1166	131
Other plastics	543	488	55
Rubber	397	398	(1)
Virgin aluminum	788	662	126
Recycled aluminum	290	263	27
Glass	46	47	(1)
Virgin copper	830	587	243
Zinc	95	83	12
Virgin lead	38	38	0
Recycled lead	5	5	0
Potassium hydroxide	6	0	6
Nickel and compounds	181	95	86

Assembly

Assembly emissions are approximately 29% lower for the Civic Hybrid than for the Civic LX. This difference is due to the assumptions made about the energy efficiency of the plants and difference between electrical generation fuel mix in Japan and Ohio.

Transport

Emissions due to vehicle transport are, on average, 76% higher for a Civic Hybrid than for a Civic LX. The contribution to total transport emissions of each mode, including truck, rail, and ship, as well as the upstream emissions from fuel consumed during transportation, are shown in Figure 4-5. Emissions per kilometer of transport (Table 4-6) are lower for the Civic Hybrid than for the Civic LX, indicating that the higher total transport emissions are due to the longer transport distance from Japan.

Figure 4-5: Sources of transport emissions

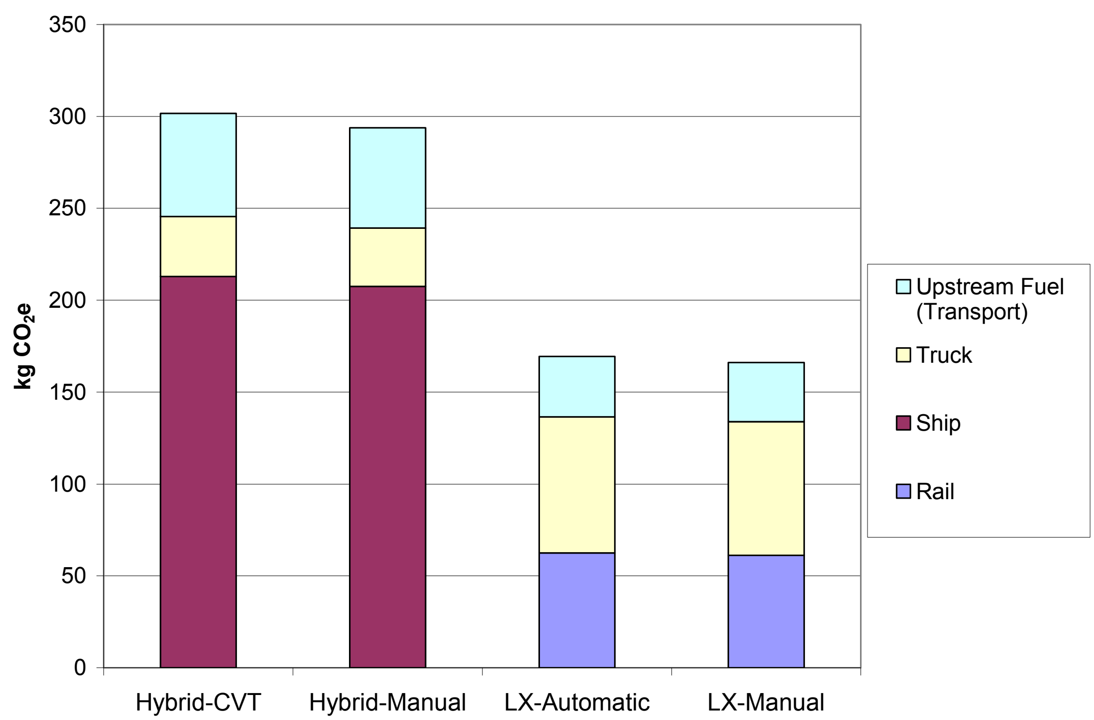


Table 4-6: Average GHG emissions over the transport distance (g CO_2e/km)				
Lifecycle Stage	**2005 Civic Hybrid (CVT)**	**2005 Civic Hybrid (Manual)**	**2005 Civic LX (Auto)**	**2005 Civic LX (Manual)**
Rail	0	0	17	16
Ship	24	23	0	0
Truck	4	4	20	20
Upstream Fuel	6	6	9	9
Total	**34**	**33**	**46**	**45**

Upstream Fuel and Use

Direct emissions from the operation of Honda Civics account for approximately two-thirds of lifecycle emissions. Indirect, upstream fuel emissions depend directly on the operational characteristics of a vehicle, and are therefore usually included in the use-phase of a vehicle's lifecycle assessment. When these indirect use emissions are added to the direct use emissions, the significance of the use phase in the lifecycle increases. In total, use emissions account for 84% of lifecycle emissions for the Civic Hybrid, and 89% of emissions for the Civic LX (Table 4-7).

Table 4-7: Use emissions for Civics, as a percentage of total lifecycle emissions		
	Civic Hybrid	**Civic LX**
Use only	64%	67%
Use + upstream fuel	84%	89%

Upstream fuel and use emissions are closely linked to a vehicle's fuel economy. Table 4-8 shows the nearly one-to-one relationship between improved fuel economy, fuel consumption, and GHG emissions due to product use. The 4.7% difference between the fuel economy improvement and the total lifecycle GHG emission reduction illustrates the significance of the other lifecycle stages.

Table 4-8: Fuel economy, fuel consumption, and use emissions for Civics			
	Civic Hybrid	**Civic LX**	**Difference**
EPA fuel economy (liter / 100 km)	4.91	6.94	-29.3%
Fuel consumed (liter)	11,871	16,988	-30.1%
Product use emissions (kg CO_2e)	30,051	42,087	-28.6%
Product use + upstream fuel emissions (kg CO_2e)	39,353	55,400	-29.0%
Total Lifecycle	**47,120**	**62,503**	-24.6%

4.1.2 Emission Calculations for Use in the FCM

Lifecycle GHG emissions were estimated for HEV and ICEV versions of vehicles with sales-averaged characteristics in each vehicle class. The results for these HEVs and ICEVs are shown in Table 4-9 and Table 4-10, respectively. The emissions savings achieved by these HEVs, when compared to the ICEVs in the same class, are similar to those achieved by the Civic Hybrids (except for the large truck class). These results were used in the FCM to estimate non-use and non-CO_2 use emissions for different vehicle classes. Carbon dioxide emissions from the use stage were derived from the fuel efficiency of each class from each manufacturer.

Table 4-9: Lifecycle greenhouse gas emissions for HEVs-by class (kg CO_2e)

Lifecycle Stage	**Small Car**	**Large Car**	**Minivan**	**Small Truck**	**Large Truck**
Materials	8,205	9,274	10,719	9,864	11,064
Product Assembly	621	761	896	836	1,029
Transport to Market	121	146	170	156	192
Upstream Fuel	11,353	13,066	14,450	13,590	25,145
Product Use	36,204	41,347	45,766	43,120	78,212
Total	**56,504**	**64,594**	**72,000**	**67,566**	**115,642**

Table 4-10: Lifecycle greenhouse gas emissions for ICEVs-by class (kg CO_2e)					
Lifecycle Stage	**Small Car**	**Large Car**	**Minivan**	**Small Truck**	**Large Truck**
Materials	7,108	7,941	9,005	8,217	10,101
Product Assembly	565	692	815	760	988
Transport to Market	113	136	162	150	191
Upstream Fuel	16,181	18,699	21,390	23,072	28,238
Product Use	50,696	58,598	66,942	71,923	87,496
Total	**74,662**	**86,065**	**98,315**	**104,122**	**127,014**

4.2 HEV-ICEV Lifetime Cost (HILC) Model

The HILC model analyzed a baseline scenario with a 3% discount rate and a fuel price of $2.50 per gallon of gasoline. Sensitivity analyses of these assumptions are shown in Section 4.2.3.

4.2.1 Lifetime Costs of Honda Civics

The discounted costs of owning and operating the different models and transmission types of the Honda Civic are shown in Table 4-11. The HEV Civic has a higher purchase price (the price premium) than the ICEV Civic, but higher fuel efficiency, leading to lower operating costs for the HEV. Based on this analysis, the HEV Civic has higher lifetime costs than the ICEV Civic. The automatic/CVT Civics also have higher lifetime costs than their manual transmission counterparts.

Table 4-11: Present value of lifetime costs of Honda Civics				
	2005 Civic Hybrid (CVT)	**2005 Civic Hybrid (Manual)**	**2005 Civic LX (Auto)**	**2005 Civic LX (Manual)**
MSRP	$20,800	$19,800	$16,560	$15,760
Fuel & Maintenance	$7,972	$7,877	$10,709	$10,260
Total	**$28,772**	**$27,677**	**$27,269**	**$26,020**

The lifetime savings shows how much the purchase of an HEV can save over a vehicle's lifetime as compared with a similar ICEV. The lifetime savings

(Table 4-12) are negative for both of the Civic HEVs, showing that the reduced operating costs do not make up for the price premium paid for the hybrid-electric technology within a 241,000 kilometer vehicle lifetime.

Table 4-12: Lifetime savings for HEV Civics

Auto/CVT	Manual
-$1,503	-$1,657

If both vehicles were operated for a longer period of time, the lower operating costs of the HEV would eventually make up for the price premium. Figure 4-6 and Figure 4-7 show the costs accumulated over time of owning and operating automatic/CVT and manual Civics, respectively. Where the two cost lines cross, the premium is recovered. This point is known as the breakeven point for the HEVs. Breakeven points for the HEV Civics are shown in Table 4-13.

Table 4-13: Breakeven point for HEV Civics (years)

Auto/CVT	Manual
22.1	25.3

Figure 4-6: Discounted cumulative costs of automatic/CVT Civics

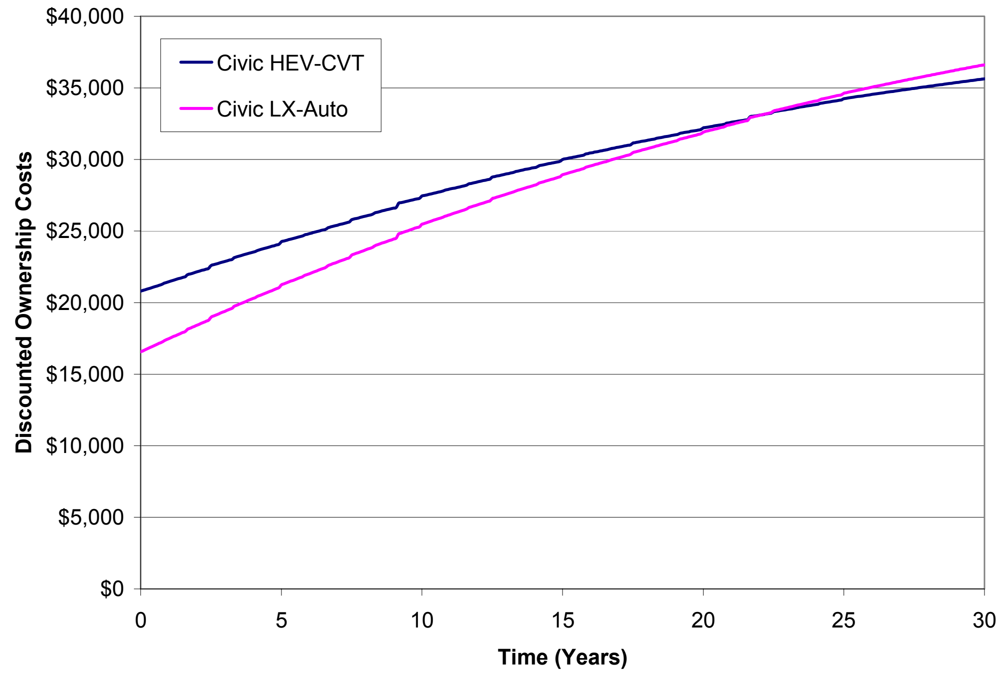
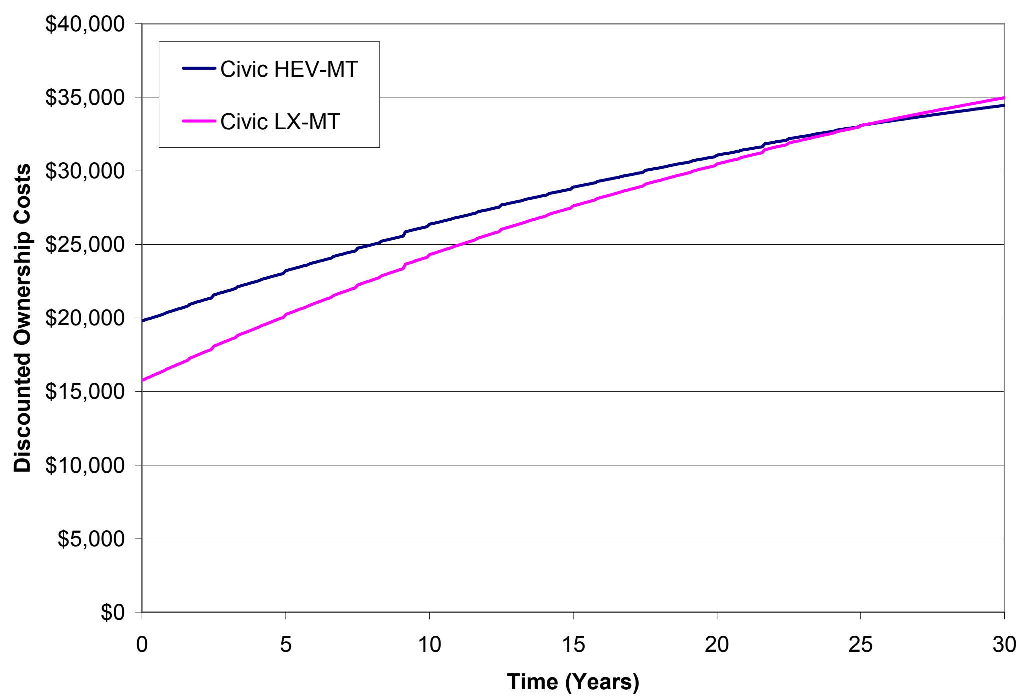


Figure 4-7: Discounted cumulative costs of manual transmission Civics



Higher fuel prices would increase the difference between HEV and ICEV operating costs, leading to an earlier breakeven point. The breakeven price represents the fuel price needed for an HEV to reach its breakeven point exactly at the end of its lifetime (12.5 years). The breakeven prices are shown in Table 4-14.

Table 4-14: Breakeven price for HEV Civics ($/gallon)

Auto/CVT	Manual
$3.80	$4.14

4.2.2 Lifetime Costs of Ford Escapes

Although Ford does not produce Escape Hybrids with manual transmissions, four wheel drive (4WD) and front wheel drive (FWD) versions of the Escape Hybrid are produced. The HILC model analyzed the lifetime costs of HEV and ICEV versions of the 4WD and FWD Ford Escape.

The discounted costs of owning and operating the different versions of the Ford Escape are shown in Table 4-11. Similar to the Civics, HEV Escapes have higher purchase prices but lower operating costs than ICEV Escapes. In general, the 4WD Escapes have higher lifetime costs than the FWD Escapes, and ICEVs have higher lifetime costs than a similar HEV.

Table 4-15: Present value of lifetime costs of Ford Escapes

	2005 Ford Escape Hybrid (FWD)	2005 Ford Escape Hybrid (4WD)	2005 Ford Escape (FWD)	2005 Ford Escape (4WD)
MSRP	$26,780	$28,405	$22,515	$24,265
Fuel & Maintenance	$10,874	$11,630	$15,304	$17,276
Total	**$37,654**	**$40,035**	**$37,819**	**$41,541**

Unlike the HEV Civics, both the 4WD and FWD HEV Escapes have positive lifetime savings (Table 4-12), meaning that the lower operating costs allow the HEVs to reach their breakeven points (Table 4-16) before the end of their lifetimes.

Table 4-16: Lifetime savings and breakeven points for HEV Escapes		
	4WD	**FWD**
Lifetime Savings	$1,506	$165
Breakeven point (years)	8.8	12.1

The cumulative discounted costs of owning and operating 4WD and FWD Ford Escapes are shown in Figure 4-8 and Figure 4-9, respectively. Compared to the cumulative costs for Civics (Figure 4-6 and Figure 4-7), the price premiums are recovered earlier.

Figure 4-8: Discounted cumulative costs of 4WD Escapes

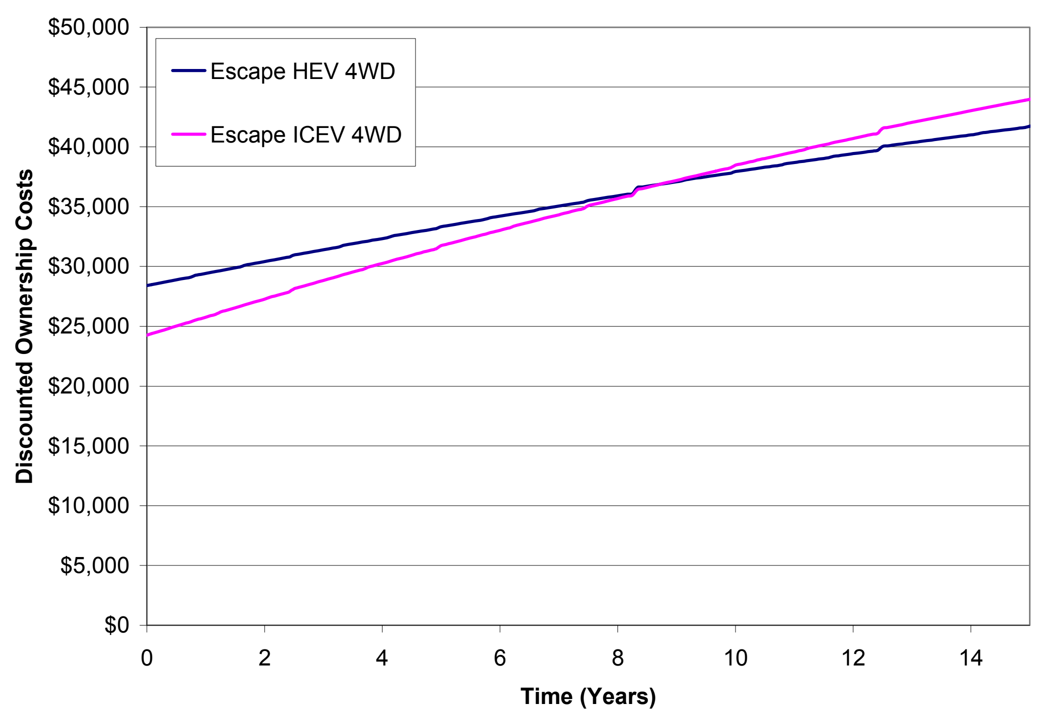
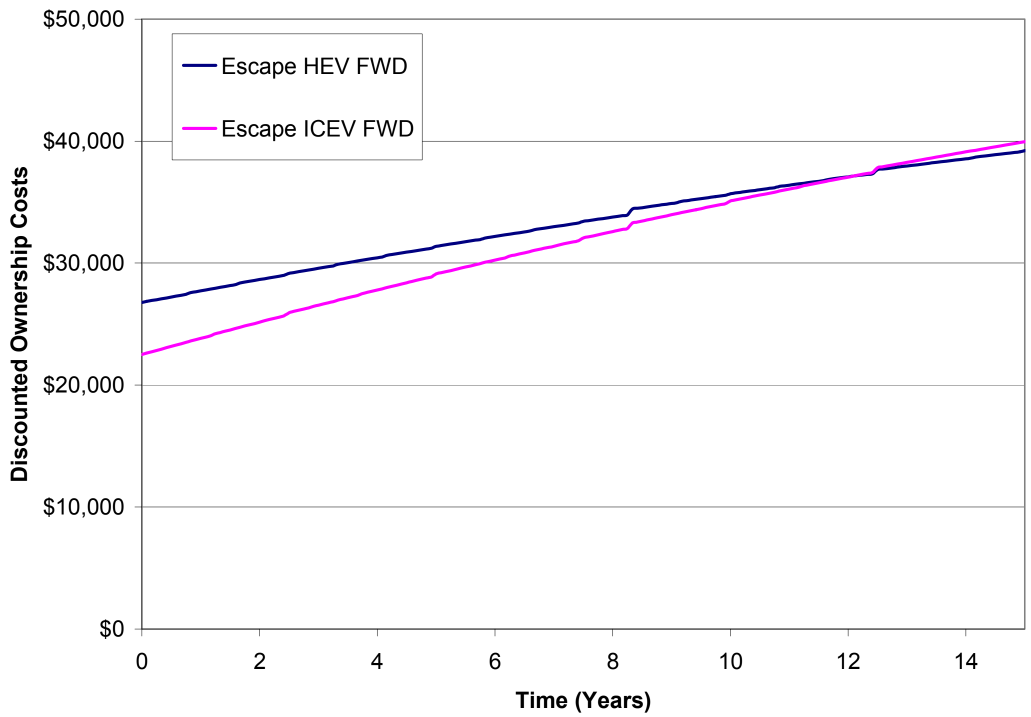


Figure 4-9: Discounted cumulative costs of FWD Escapes



At $2.50 per gallon of gasoline, both versions of the Escape Hybrid are able to break even within the lifetime of the vehicle. Table 4-17 shows the minimum gas price that would allow the Escape Hybrid to continue to breakeven before the end of its lifetime.

Table 4-17: Breakeven price for HEV Escapes ($/gallon)

4WD	FWD
$1.79	$2.40

4.2.3 Sensitivity Analysis

The HEV-ICEV Lifetime Cost model was also run with different fuel prices and discount rates, in order to determine how sensitive the results are to these parameters. Results for discount rates of 0%, 3%, and 5% and gas prices of $1.50, $2.00, $2.50, $3.00, $3.50, and $6.00 are shown below.

4.2.3.1 Honda Civic Lifetime Costs

The lifetime savings for the HEV Civics for various fuel prices are shown below. Table 4-18 presents the results for a 0% discount rate; Table 4-19 presents the results for a 3% discount rate; and Table 4-20 presents the results for a 5% discount rate. In general, higher fuel prices lead to larger lifetime savings for HEVs, while higher discount rates lead to lower lifetime savings. Figure 4-10 summarizes the lifetime savings for different discount rates and fuel prices for the CVT Civic Hybrid compared to the automatic Civic LX. A similar pattern is seen for the manual transmission vehicles.

Table 4-18: Lifetime savings for HEV Civics (discount rate = 0%)

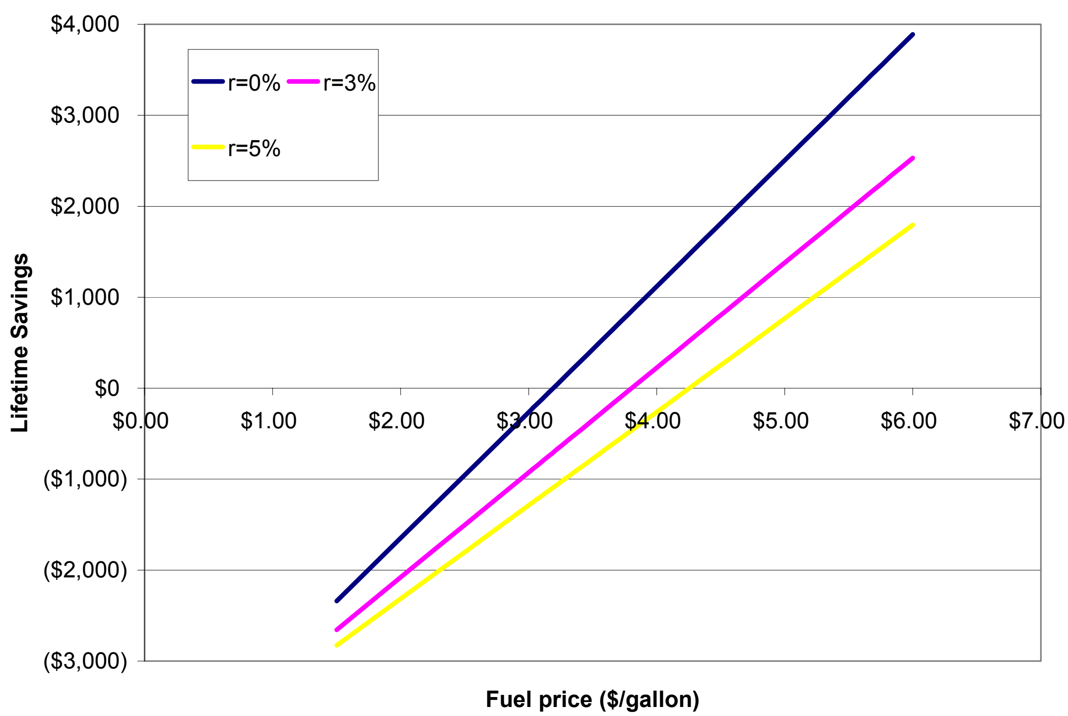
Fuel Price ($/gal)	Auto/CVT	Manual
$1.50	-$2,340	-$2,395
$2.00	-1,648	-1,788
$2.50	-956	-1,181
$3.00	-264	-574
$3.50	428	33
$6.00	3,888	3,068

Table 4-19: Lifetime savings for HEV Civics (discount rate = 3%)

Fuel Price ($/gal)	Auto/CVT	Manual
$1.50	-$2,656	-$2,668
$2.00	-2,079	-2,163
$2.50	-1,503	-1,657
$3.00	-927	-1,152
$3.50	-350	-646
$6.00	2,531	1,881

Table 4-20: Lifetime savings for HEV Civics (discount rate = 5%)		
Fuel Price ($/gal)	**Auto/CVT**	**Manual**
$1.50	-$2,827	-$2,817
$2.00	-2,314	-2,366
$2.50	-1,801	-1,916
$3.00	-1,287	-1,466
$3.50	-774	-1,015
$6.00	1,794	1,237

Figure 4-10: Lifetime savings for HEV Civics (CVT) for different fuel prices and discount rates.



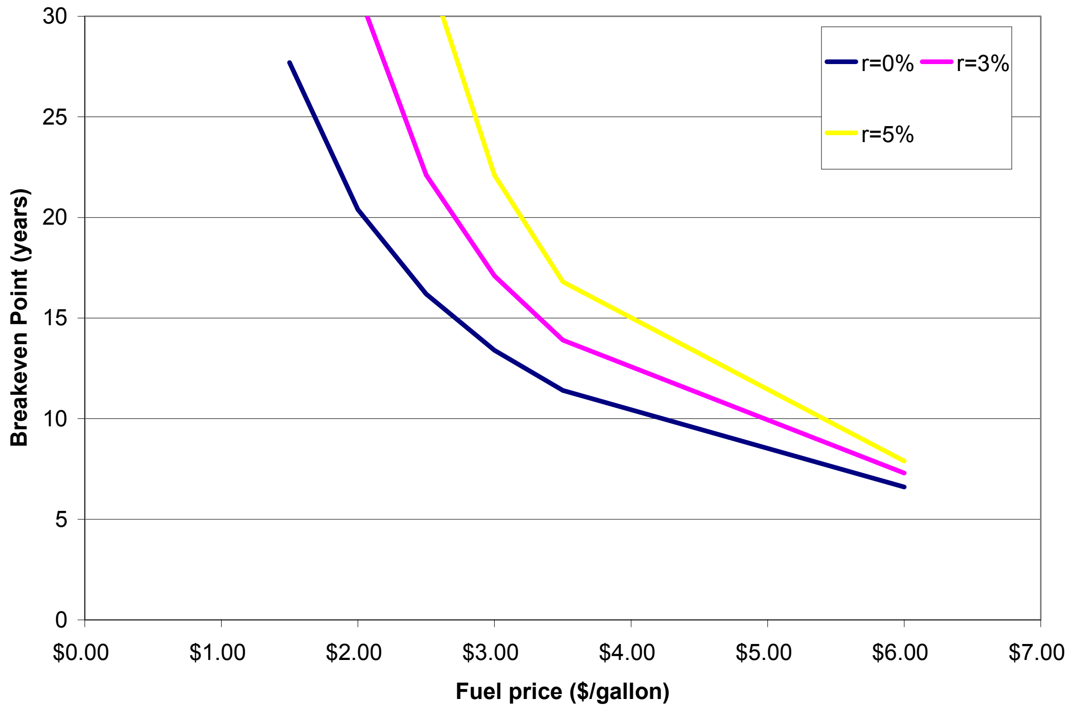
The breakeven points for HEV Civics are shown for various fuel prices in Table 4-21, Table 4-22, and Table 4-23 for discount rates of 0%, 3%, and 5%, respectively. Higher fuel prices allow the breakeven point for the HEVs to be reached earlier, while higher discount rates cause the breakeven point to occur later. Figure 4-11 shows the breakeven points for the CVT Civic Hybrid across a range of discount rates and fuel prices.

Table 4-21: Breakeven point for HEV Civics (discount rate = 0%)		
Fuel Price ($/gal)	**Auto/CVT**	**Manual**
$1.50	27.7 years	>30 years
$2.00	20.4	22.4
$2.50	16.2	17.7
$3.00	13.4	14.6
$3.50	11.4	12.4
$6.00	6.6	7.2

Table 4-22: Breakeven point for HEV Civics (discount rate = 3%)		
Fuel Price ($/gal)	**Auto/CVT**	**Manual**
$1.50	>30 years	>30 years
$2.00	>30	>30
$2.50	22.1	25.3
$3.00	17.1	19.2
$3.50	13.9	15.5
$6.00	7.3	8.0

Table 4-23: Breakeven point for HEV Civics (discount rate = 5%)		
Fuel Price ($/gal)	**Auto/CVT**	**Manual**
$1.50	>30 years	>30 years
$2.00	>30	>30
$2.50	>30	>30
$3.00	22.1	26.1
$3.50	16.8	19.4
$6.00	7.9	8.8

Figure 4-11: Breakeven points for HEV Civics (CVT) for different fuel prices and discount rates.



The breakeven fuel prices for HEV Civics are shown in Table 4-24 for different discount rates.

Table 4-24: Breakeven fuel price for HEV Civics ($/gallon)

Discount rate	Auto/CVT	Manual
0%	$3.19	$3.47
3%	$3.80	$4.14
5%	$4.25	$4.63

4.2.3.2 Ford Escape Lifetime Costs

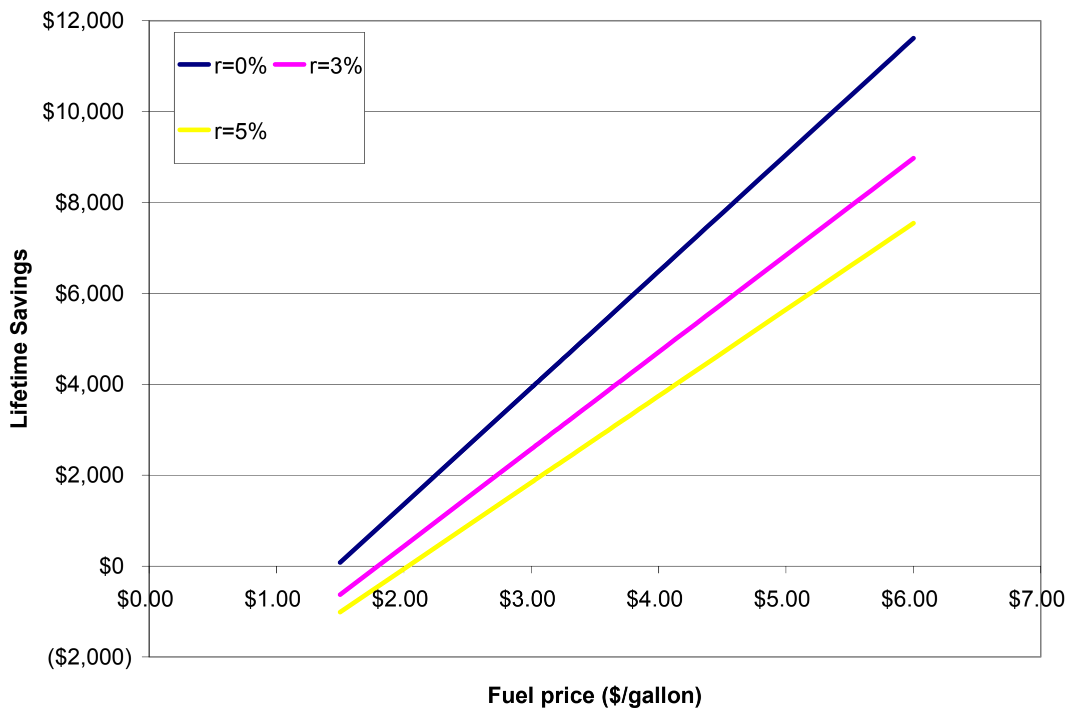
The lifetime savings for the HEV Escapes for various fuel prices are shown in Table 4-25, Table 4-26, and Table 4-27 for discount rates of 0%, 3%, and 5%, respectively. Figure 4-12 summarizes the lifetime savings for different discount rates and fuel prices for the 4WD Escape Hybrid compared to the 4WD ICEV Escape.

Table 4-25: Lifetime savings for HEV Escapes (discount rate = 0%)		
Fuel Price ($/gal)	**4WD**	**FWD**
$1.50	$80	-$921
$2.00	$1,362	$69
$2.50	$2,643	$1,059
$3.00	$3,925	$2,049
$3.50	$5,207	$3,038
$6.00	$11,615	$7,987

Table 4-26: Lifetime savings for HEV Escapes (discount rate = 3%)		
Fuel Price ($/gal)	**4WD**	**FWD**
$1.50	-$629	-$1,483
$2.00	$439	-$659
$2.50	$1,506	$165
$3.00	$2,573	$990
$3.50	$3,641	$1,814
$6.00	$8,978	$5,936

Table 4-27: Lifetime savings for HEV Escapes (discount rate = 5%)		
Fuel Price ($/gal)	**4WD**	**FWD**
$1.50	-$1,014	-$1,788
$2.00	-$63	-$1,054
$2.50	$888	-$320
$3.00	$1,839	$415
$3.50	$2,790	$1,149
$6.00	$7,546	$4,822

Figure 4-12: Lifetime savings for HEV Escapes (4WD) for different fuel prices and discount rates



The breakeven points for HEV Escapes are shown in Table 4-28, Table 4-29, and Table 4-30 for discount rates of 0%, 3%, and 5%, respectively. Figure 4-11 shows the breakeven points for the CVT Civic Hybrid across a range of discount rates and fuel prices.

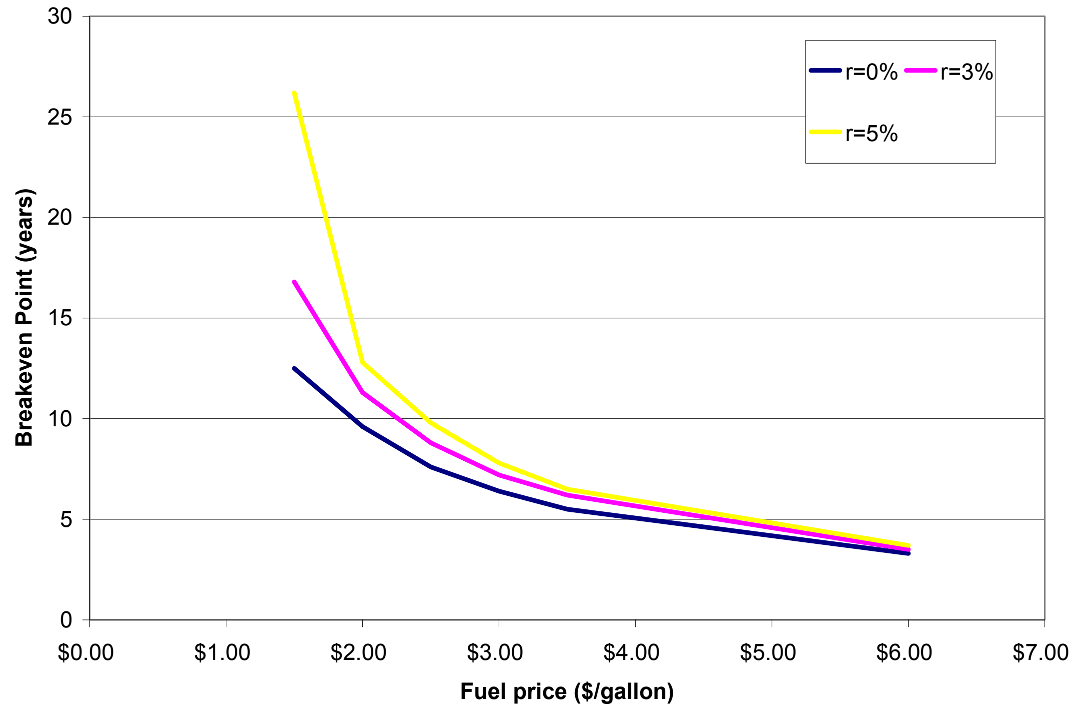
Table 4-28: Breakeven point for HEV Escapes (discount rate = 0%)

Fuel Price ($/gal)	4WD	FWD
$1.50	12.5 years	18.1 years
$2.00	9.6	12.5
$2.50	7.6	10.1
$3.00	6.4	8.6
$3.50	5.5	7.3
$6.00	3.3	4.4

Table 4-29: Breakeven point for HEV Escapes (discount rate = 3%)		
Fuel Price ($/gal)	**4WD**	**FWD**
$1.50	16.8 years	>30 years
$2.00	11.3	16.8
$2.50	8.8	12.1
$3.00	7.2	9.9
$3.50	6.2	8.2
$6.00	3.5	4.8

Table 4-30: Breakeven point for HEV Escapes (discount rate = 5%)		
Fuel Price ($/gal)	**4WD**	**FWD**
$1.50	26.2 years	>30 years
$2.00	12.8	26.0
$2.50	9.8	14.3
$3.00	7.8	11.2
$3.50	6.5	9.3
$6.00	3.7	5.0

Figure 4-13: Breakeven points for HEV Escapes (4WD) for different fuel prices and discount rates



The breakeven fuel prices for HEV Escapes are shown in Table 4-31 for different discount rates.

Table 4-31: Breakeven fuel price for HEV Escapes ($/gallon)

Discount rate	4WD	FWD
0%	$1.47	$1.97
3%	$1.79	$2.40
5%	$2.03	$2.72

4.3 Fleet Composition Model (FCM)

4.3.1 Individual Average Vehicle Class GHG Emissions

The estimated lifecycle GHG emissions from average individual ICEVs and HEVs are shown in Figure 4-14 and Figure 4-15, respectively. The emissions are shown by vehicle class for each manufacturer, as well as an average for that class. These emission estimates are based on sales-averaged MY 2002 data and calculations performed in the CLEM and HEVEE models. No emissions are shown for large trucks by Honda, Nissan or for the manufacturers that comprise the Other category since they did not sell large trucks in MY 2002. The differences in lifecycle emissions between these HEVs and ICEVs are shown in Table 4-32. The table shows that emissions difference between HEV and ICEV large trucks are not as large as the differences in other vehicle classes because currently available hybrid-electric large trucks produce only a modest increase in fuel efficiency compared to conventional large trucks.

Figure 4-14: Lifecycle GHG emissions from ICEVs (tonnes CO_2e)

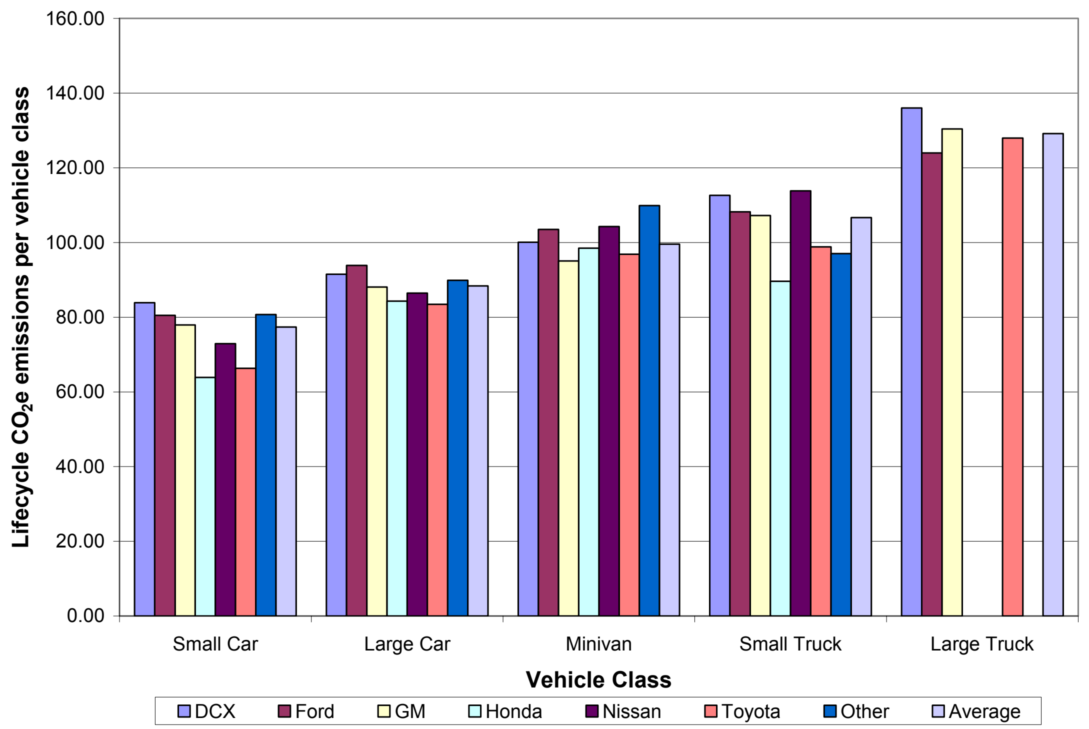


Figure 4-15: Lifecycle GHG emissions from HEVs (tonnes CO_2e)

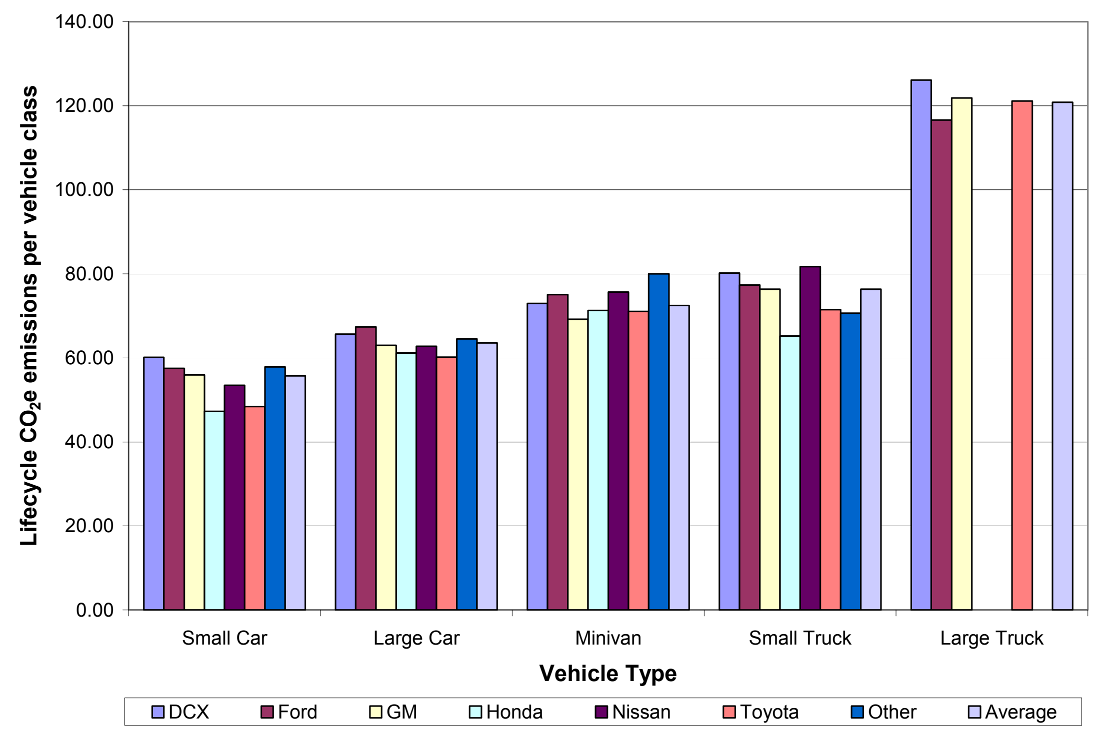


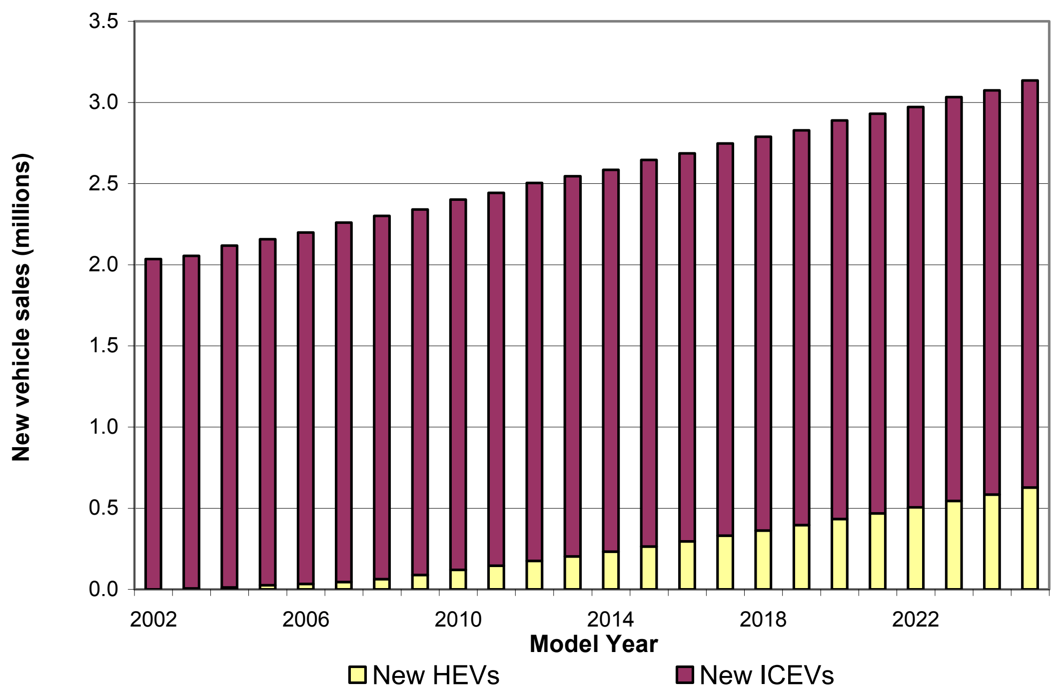
Table 4-32: Lifecycle GHG emissions and difference for average HEVs and ICEVs, by vehicle class (tonnes CO_2e)

Lifecycle Emissions	ICEV	HEV	Difference
Small Car	77	56	21
Large Car	88	64	24
Minivan	100	72	28
Small Truck	107	76	31
Large Truck	129	121	8

4.3.2 Fleet-wide Changes in GHG Emissions

In order to estimate the impact that HEVs may have on GHG emissions in California from 2002 to 2025, projections of the fleet size and HEV diffusion were necessary. Based on data from the California Department of Transportation (CADOT, 2000), new vehicle sales were projected through 2025, as well as the expected portion of HEVs (Figure 4-16). The number of new cars sold is anticipated to grow by 54% over the 24 years, with HEVs comprising an increasing percentage of these sales, from 0% in 2002 to 20% by 2025

Figure 4-16: Projected growth in California new vehicle sales through 2025



The lifecycle CO_2e emissions associated with the projected annual vehicle sales are shown in Figure 4-16. These reflect all of the emissions associated with the vehicles sold in a particular model year. Model year 2002 emissions, therefore, represent emissions that occurred before 2002 during the resource extraction, assembly, and transportation lifecycle stages. They also represent use-phase emissions that occurred after 2002, over the 12.5 year lifetime.

In Figure 4-16, the dark bars represent emissions from new vehicle sales for a scenario in which no HEVs are included in the projected fleet. The lighter bars represent emissions for the scenario in which HEVs make up an increasing percentage of new vehicle sales, as described above. Emissions increase over the time span, regardless of whether HEVs are included in the analysis. The scenario that includes HEVs results in 2025 emissions that are 47% higher than 2002 emissions, while the scenario with no HEVs results in 2025 emissions that are 54% higher than 2002 emissions.

Figure 4-17: Projected lifecycle CO2e emissions, by model year

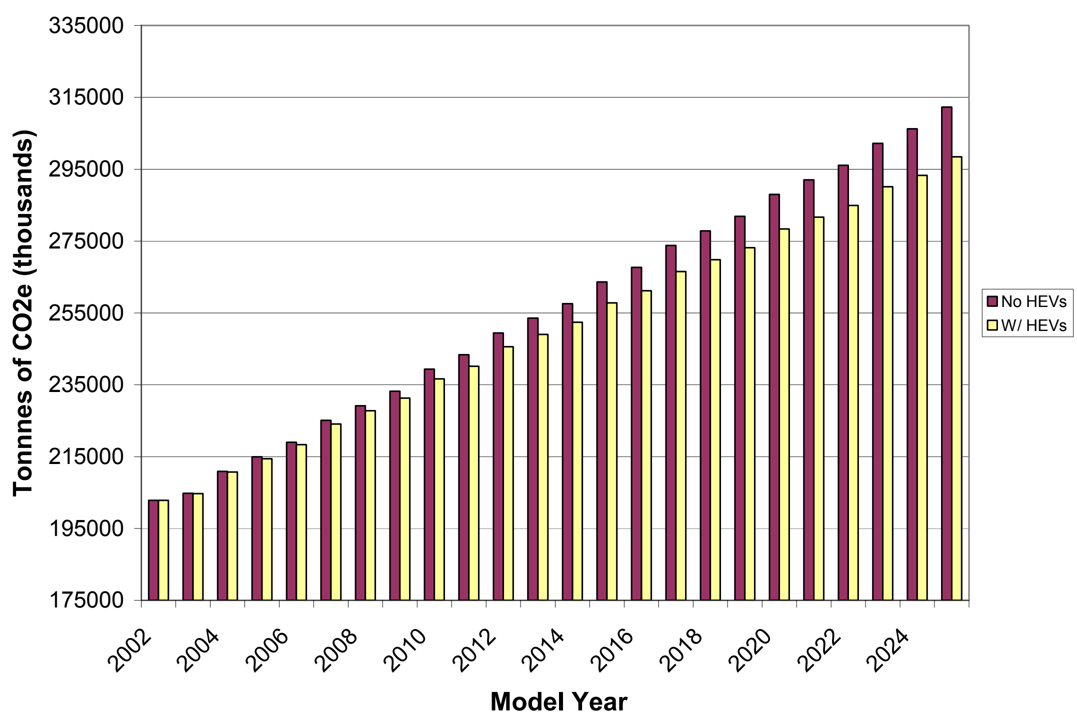


Table 4-33 quantifies the emission differences with and without HEVs for the 24 year period examined, which are graphically represented in Figure 4-17. Model year 2002 includes no HEVs and therefore the two situations have the same starting point; however as HEVs are introduced to the fleet, the emission difference between the two scenarios grows. The differences are also represented as a percentage of the situation with no HEVs. In total, the scenario that includes the introduction of up to 20% HEVs reduces lifecycle CO_2e emissions by 156.7 million tonnes, or 2.54%, compared to the scenario with no HEVs.

The table also shows a comparison of lifecycle emissions differences to use-phase-only emissions differences. HEV diffusion has a greater percentage-wise reduction when only considering use-phase emissions rather than lifecycle emissions. This is explained by the slight increases in HEV emissions from materials and transporting to the market. The increases in emissions during these other lifecycle phases increase total HEV emissions. Therefore, when only use-phase emissions are included, the scenario with HEV diffusion results in a 3.03% emission difference, an increase of approximately 24% over the difference using lifecycle emissions. However, because counting only use-phase emissions ignores many other emissions, the absolute difference in tonnes of emissions is larger for lifecycle emissions than use phase only emissions (see Table 4-33).

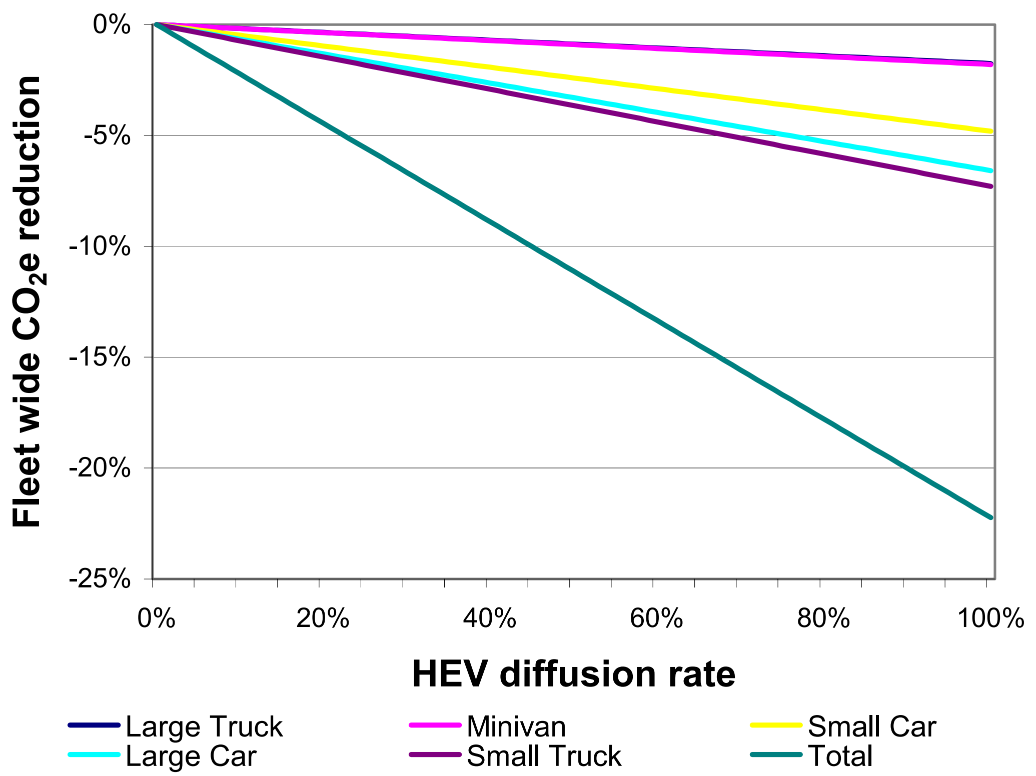
Table 4-33: Difference in GHG emissions for each model year between scenarios with and without HEVs (tonnes CO_2e)				
	Lifecycle emissions		Use phase-only emissions	
Model Year	Difference (No HEV-HEV)	% Difference	Difference (No HEV-HEV)	% Difference
2002	0	0.00%	0	0.00%
2003	424,929	0.20%	350,895	0.24%
2004	869,354	0.41%	717,888	0.49%
2005	1,333,274	0.61%	1,100,981	0.73%
2006	1,816,690	0.82%	1,500,172	0.98%
2007	2,319,601	1.02%	1,915,462	1.22%
2008	2,842,008	1.23%	2,346,850	1.47%
2009	3,383,910	1.43%	2,794,338	1.71%
2010	3,945,307	1.64%	3,257,924	1.96%
2011	4,526,201	1.84%	3,737,610	2.20%
2012	5,126,589	2.05%	4,233,394	2.45%
2013	5,746,473	2.25%	4,745,277	2.69%
2014	6,385,853	2.46%	5,273,258	2.94%
2015	7,044,728	2.66%	5,817,339	3.18%
2016	7,723,098	2.87%	6,377,518	3.42%
2017	8,420,964	3.07%	6,953,797	3.67%
2018	9,138,326	3.28%	7,546,174	3.91%
2019	9,875,183	3.48%	8,154,649	4.16%
2020	10,631,535	3.68%	8,779,224	4.40%
2021	11,407,383	3.89%	9,419,898	4.65%
2022	12,202,726	4.09%	10,076,670	4.89%
2023	13,017,565	4.30%	10,749,541	5.14%
2024	13,851,899	4.50%	11,438,511	5.38%
2025	14,705,729	4.71%	12,143,580	5.63%
Total	**156,739,325**	**2.54%**	**129,430,948**	**3.03%**

4.3.3 Potential for GHG reduction by vehicle class

The emission reduction potential differs by vehicle class, due to both the emission difference between ICEVs and HEVs, and the percent of the fleet the vehicle class comprises. This is shown in Figure 4-18, which presents the increasing reduction in CO_2e with an increasing percentage of hybrids. This figure shows the amount that total GHG emissions in California would be reduced if only one vehicle class were affected by HEV diffusion at a time. The “total” curve represents the GHG emission reductions that would result if all vehicle classes were affected by the HEV diffusion.

Large trucks and minivans have similar emissions reduction potential, and are the lowest of all vehicle classes, followed by small cars, large cars, and small trucks. Small trucks, which make up approximately 25% of the fleet, could reduce fleet-wide CO_2e emissions by a maximum of about 7.5% if all were replaced with HEVs. If 100% of all vehicle classes were comprised of HEVs, the emission reduction would be approximately 23%.

Figure 4-18: Potential for GHG reduction by vehicle class



4.3.4 Individual Average Vehicle Class Lifetime Costs

The estimated lifetime costs for individual average ICEVs and HEVs are shown in Figure 4-19 and Figure 4-20, respectively. The costs are shown by vehicle class for each manufacturer, as well as an average for that class at a 3% discount rate. These cost estimates are based on average MY 2002 MSRPs and calculations performed in the HILC model. No costs are shown for large trucks by Honda, Nissan or for the manufacturers that comprise the Other category since they did not sell a large truck in MY 2002. The difference in lifetime costs is shown in Table 4-34.

Figure 4-19: Lifetime costs for individual ICEVs (3% discount rate)

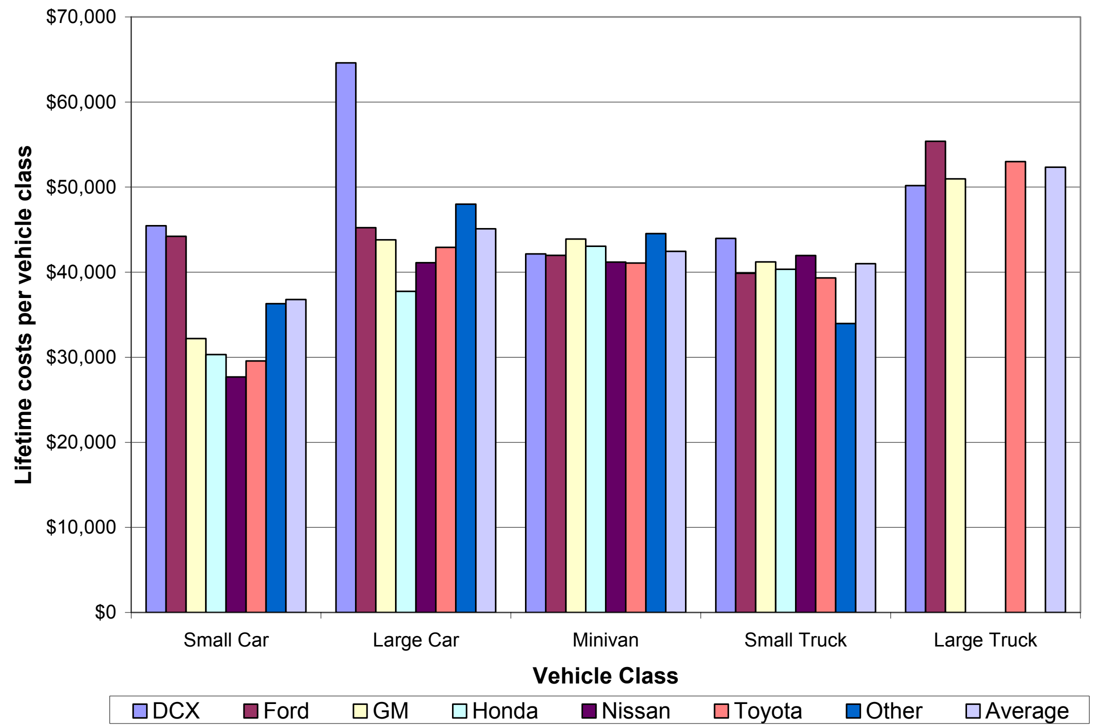


Figure 4-20: Lifetime costs for individual HEVs (3% discount rate)

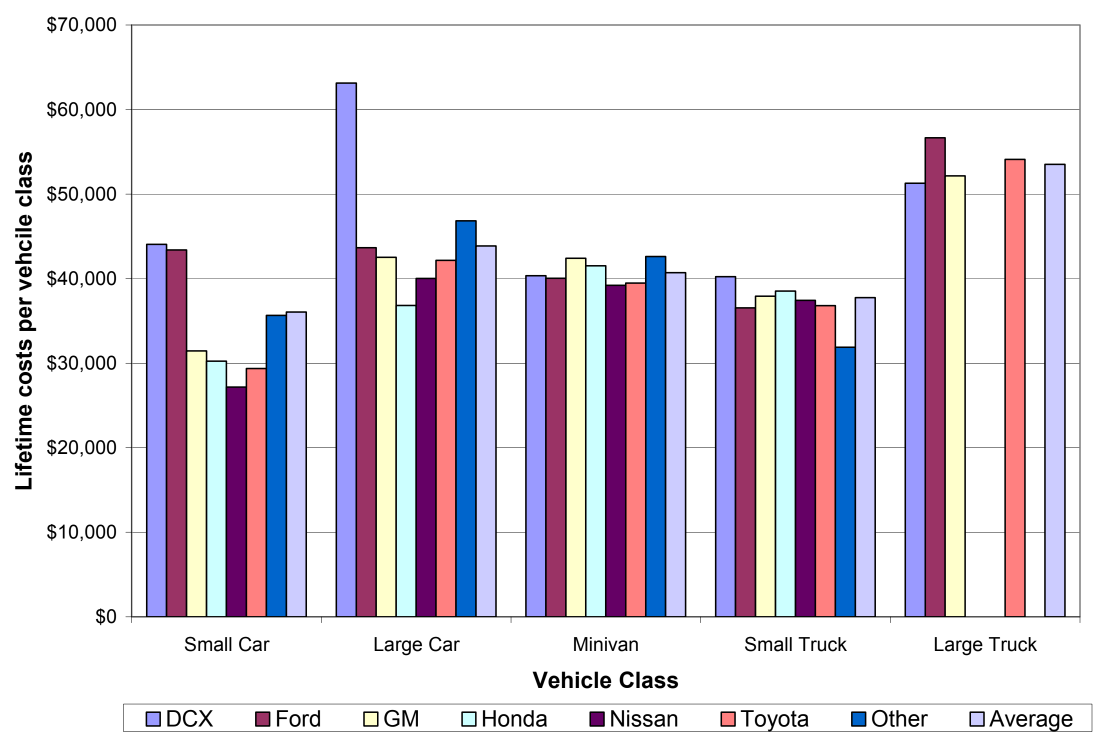


Table 4-34: Lifetime costs and differences for average HEVs and ICEVs, by vehicle class			
Lifetime Costs	**ICEV**	**HEV**	**Difference**
Small Car	$36,769	$36,038	$731
Large Car	$45,091	$43,877	$1,213
Minivan	$42,435	$40,713	$1,722
Small Truck	$40,995	$37,753	$3,242
Large Truck	$52,332	$53,532	-$1,200

4.3.5 Lifetime Fleet Economics

Table 4-35 shows the lifetime consumer costs for the projected fleet of light-duty vehicles sold in California from model year 2002 until 2025, with an assumed discount rate of 3% and a fuel price of $2.50 per gallon of gasoline. The "No HEVs" column represents expenditures with 0% HEV diffusion, and the "With HEVs" column shows expenditures with increasing diffusion of HEVs, as described above. Expenditures for a given year represent the NPV of the initial purchase price, and fuel expenditures over the 12.5 year lifetime for all vehicles sold in that year, discounted to 2002. Positive values in the "Savings" column mean that total expenditures with HEVs are lower than with no HEVs over the period of the study. The FCM found that the present value of the savings realized by California automobile consumers would be approximately $4.1 billion if the scenario for HEV market diffusion was followed.

Table 4-35: Fleet lifetime costs, with and without HEVs				
Year	No HEVs	With HEVs	Savings (No HEVs – With HEVs)	Difference (%)
2002	$88,787,269,684	$88,787,269,684	$0	0.000%
2003	$87,024,841,394	$87,019,256,678	$5,584,716	0.006%
2004	$86,961,369,687	$86,949,761,950	$11,607,738	0.013%
2005	$86,014,181,897	$85,987,686,576	$26,495,321	0.031%
2006	$85,047,023,524	$85,014,276,770	$32,746,754	0.039%
2007	$84,826,101,457	$84,782,552,538	$43,548,919	0.051%
2008	$83,802,338,517	$83,743,181,441	$59,157,077	0.071%
2009	$82,764,996,356	$82,684,263,899	$80,732,457	0.098%
2010	$82,414,197,249	$82,308,420,574	$105,776,675	0.128%
2011	$81,334,057,242	$81,208,788,833	$125,268,409	0.154%
2012	$80,903,529,390	$80,758,156,515	$145,372,876	0.180%
2013	$79,789,094,253	$79,625,242,386	$163,851,868	0.205%
2014	$78,669,865,666	$78,488,118,021	$181,747,645	0.231%
2015	$78,148,240,700	$77,947,637,859	$200,602,841	0.257%
2016	$77,005,359,006	$76,787,922,976	$217,436,030	0.282%
2017	$76,427,904,586	$76,192,480,402	$235,424,184	0.308%
2018	$75,267,920,402	$75,016,748,448	$251,171,954	0.334%
2019	$74,109,744,431	$73,843,413,734	$266,330,697	0.359%
2020	$73,471,689,263	$73,188,791,731	$282,897,532	0.385%
2021	$72,304,501,880	$72,007,538,297	$296,963,584	0.411%
2022	$71,142,130,640	$70,831,679,211	$310,451,429	0.436%
2023	$70,458,184,083	$70,132,630,990	$325,553,093	0.462%
2024	$69,293,626,422	$68,955,666,839	$337,959,583	0.488%
2025	$68,581,697,355	$68,229,605,403	$352,091,953	0.513%
Cumulative	**$1,894,549,865,085**	**$1,890,491,091,754**	**$4,058,773,332**	**0.214%**

4.3.5.1 Sensitivity Analysis:

The results for the Lifetime Fleet Economics projection were highly dependent on both the price of gasoline and the discount rate used. Results for discount rates of 0%, 3%, and 5% and gas prices of $1.50, $2.00, $2.50, $3.00, $3.50, and $6.00 are shown below in Table 4-36.

Table 4-36: Lifetime Fleet Economics Sensitivity Analysis						
Gasoline Price	Discount rate = 5%		Discount rate = 3%		Discount rate = 0%	
$/Gallon	Cumulative Savings ($)	Cumulative Savings (%)	Cumulative Savings ($)	Cumulative Savings (%)	Cumulative Savings ($)	Cumulative Savings (%)
$1.50	-$2,180,665,663	-0.169	-$2,008,072,393	-0.123	-$299,025,069	-0.012
$2.00	-$216,481,049	-0.016	$1,025,247,466	0.058	$5,692,889,165	0.215
$2.50	$1,747,836,933	0.118	$4,058,773,332	0.214	$11,685,210,340	0.406
$3.00	$3,712,021,518	0.236	$7,092,093,191	0.350	$17,677,124,575	0.570
$3.50	$5,676,118,713	0.341	$10,125,278,092	0.470	$23,668,772,220	0.712
$6.00	$15,497,152,483	0.725	$25,292,048,567	0.900	$53,628,681,537	1.209

The scenario with an introduction of HEVs has different effects on discounted consumer expenditures, depending on the fuel price and discount rate. With a discount rate of 5% and a fuel price of $1.50 per gallon, the HEV scenario results in a net cost of about $2.2 billion. With a 0% discount rate and a fuel price of $6.00, the HEV scenario results in a net savings of approximately $54 billion.

4.3.6 Savings/Costs per tonne of CO2e reduction per vehicle class

Figure 4-21, Figure 4-22, and Figure 4-23 show the average consumer savings associated with a one tonne reduction in CO_2e lifecycle emissions by selecting an HEV rather than an ICEV, by vehicle class. Each figure shows these results for a different discount rate (0%, 3%, and 5%, respectively). Values greater than zero indicate a lifetime consumer savings per vehicle associated selecting an HEV over its ICEV counterpart, while values less than zero indicate an additional lifetime consumer cost. Higher savings are associated with lower discount rates and larger vehicles (with the exception of large trucks), and small trucks achieve the greatest per tonne savings for all discount rates analyzed.

Figure 4-21: Savings/Costs per tonne of CO_2e reduction per average vehicle class (0% discount rate)

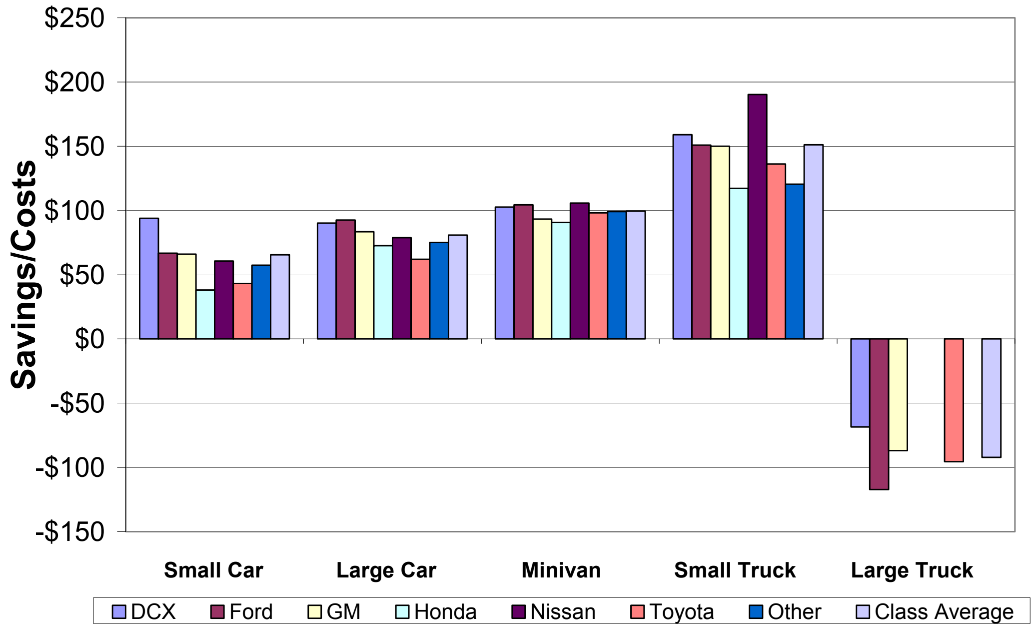


Figure 4-22: Savings/Costs per tonne of CO_2e reduction per average vehicle class (3% discount rate)

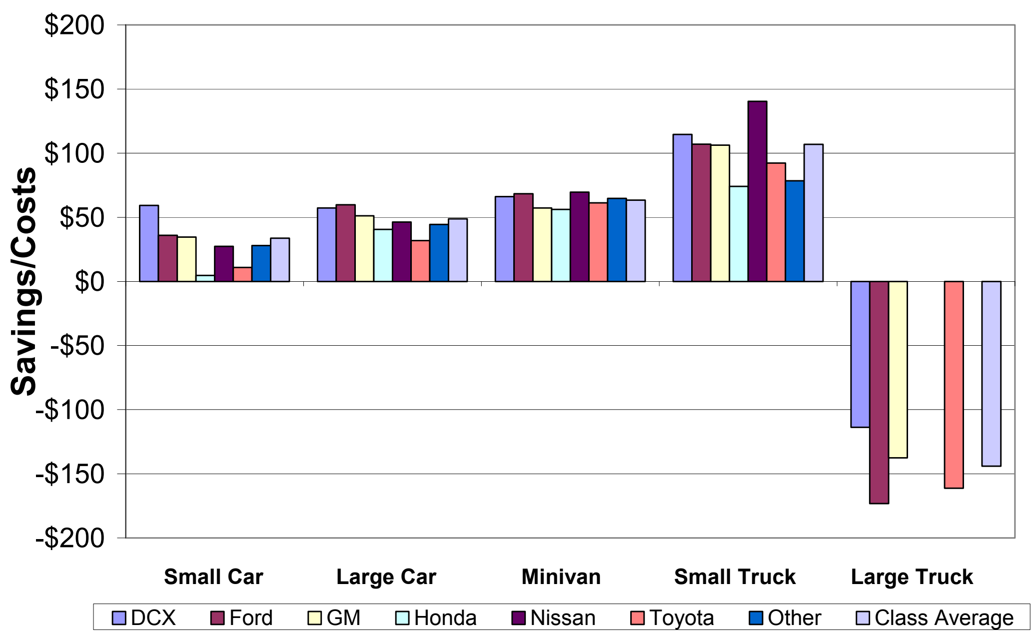
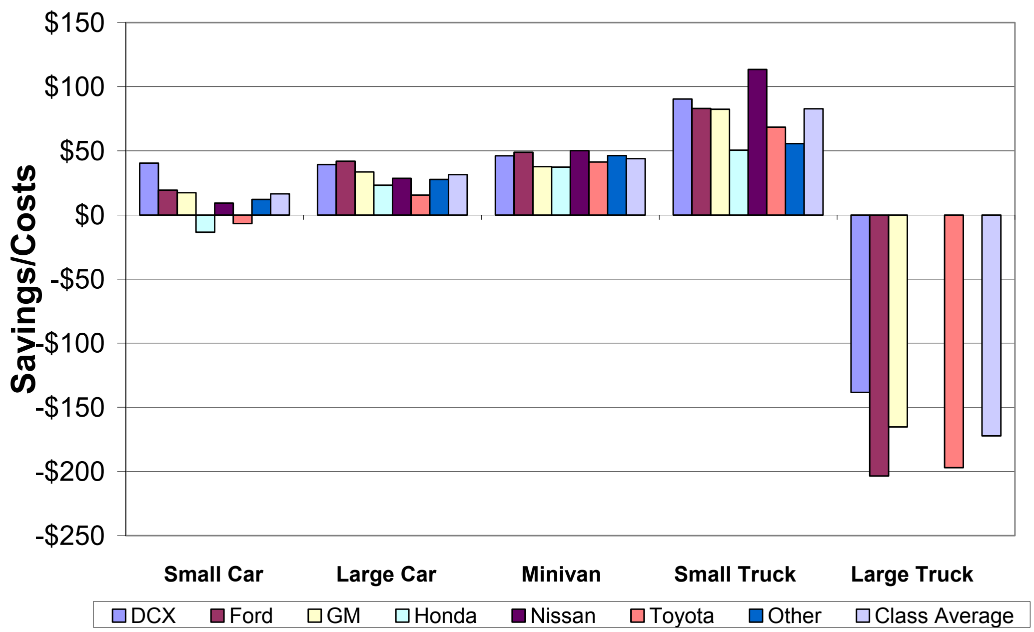


Figure 4-23: Savings/Costs per tonne of CO_2e reduction per average vehicle class (5% discount rate)



4.4 LEEV Estimator

Table 4-37 shows the lifecycle GHG emissions, lifetime costs, and LEEV score percentiles calculated for the ICEV and HEV versions of the Honda Civic (automatic/CVT) and the Ford Escape (4WD).

Table 4-37: LEEV Estimator output for Honda Civic and Ford Escape

Make & Model	Type	Class	Lifecycle CO_2e (tonnes)	Enviro. percentile	Lifetime costs	Econ. percentile	LEEV Score
Honda Civic	ICEV	Small Car	62.3	15th	$24,833	1st	6th
	HEV	Small Car	48.0	2nd	$26,325	1st	0.5th
Ford Escape	ICEV	Small Truck	90.0	64th	$37,198	24th	48th
	HEV	Small Truck	68.0	27th	$37,286	24th	17th

Table 4-38 shows the lifecycle GHG emissions, lifetime costs, and LEEV score percentiles for the top 20 vehicles sold in the US in 2002.

Table 4-38: LEEV Estimator output for the top 20 US vehicle sales in MY 2002							
Make, Model & Sales Rank	**Type**	**Class**	**Lifecycle CO_2e (tonnes)**	**Enviro. percentile**	**Lifetime costs**	**Econ. percentile**	**LEEV Score**
1) Ford F-Series	ICEV	Large Truck	125.3	95th	$49,131	85th	88th
2) Chevy Silverado	ICEV	Large Truck	132.6	100th	$51,066	88th	93rd
3) Toyota Camry	ICEV	Large Car	74.9	38th	$35,426	16th	19th
4) Ford Explorer	ICEV	Small Truck	110.8	84th	$45,810	81st	87th
5) Honda Accord	ICEV	Large Car	72.6	35th	$33,481	15th	17th
6) Dodge Ram	ICEV	Large Truck	132.6	100th	$44,729	78th	88th
7) Ford Taurus	ICEV	Large Car	85.5	58th	$35,125	16th	32nd
8) Honda Civic	ICEV	Small Car	62.3	15th	$24,833	1st	6th
9) Chevy Trailblazer	ICEV	Small Truck	105.6	80th	$48,453	84th	86th
10) Dodge Caravan	ICEV	Minivan	101.8	77th	$36,867	23rd	51st
11) Ford Focus	ICEV	Small Car	65.5	22nd	$25,908	1st	7th
12) Chevy Cavalier	ICEV	Small Car	73.5	37th	$27,839	3rd	15th
13) Ford Ranger	ICEV	Small Truck	89.3	62nd	$33,687	15th	34th
14) Jeep Grand Cherokee	ICEV	Small Truck	123.1	94th	$49,868	85th	88th
15) GMC Sierra	ICEV	Large Truck	118.8	92nd	$47,683	83rd	88th
16) Nissan Altima	ICEV	Large Car	79.8	46th	$34,385	16th	23rd
17) Chevy Impala	ICEV	Large Car	85.5	58th	$35,803	17th	33rd
18) Toyota Corolla	ICEV	Small Car	59.4	10th	$23,910	1st	5th
19) Jeep Liberty	ICEV	Small Truck	110.8	84th	$39,178	31st	87th
20) Chevy Malibu	ICEV	Large Car	85.5	58th	$31,463	11th	28th

5. Discussion

5.1 Carbon-Equivalent Lifecycle Emissions Model (CLEM)

5.1.1 Lifecycle Emissions of Honda Civics

Over the vehicle lifecycle, GHG emissions amount to approximately 47.1 tonnes of CO_2e for the Honda Civic Hybrid and 62.5 tonnes of CO_2e for a similarly equipped Honda Civic LX, a 15.4 tonne (24.6%) reduction. Although emissions are higher for the Hybrid during the material processing and transportation lifecycle stages, the net effect of purchasing a Civic Hybrid rather than a Civic LX is a substantial savings of GHG emissions. Using Civic-like hybrid-electric technology to convert any given ICEV to an HEV would likely produce a similar percentage reduction of GHG emissions.

The use phase, including upstream fuel processing, is the largest contributor to total lifecycle emissions, making up over 80% of total emissions for each vehicle. Use and upstream fuel emissions are a function of a vehicle's fuel economy and as a result fuel economy is the primary determinant of lifecycle GHG emissions. Therefore, although this study specifically analyzes the GHG emissions of HEV technology, any technology which improves the fuel economy of conventional vehicles could result in GHG emission reductions.

When upstream fuel processing is not included as a subset of the use stage, the portion of lifecycle emissions produced in the use stage falls from approximately 85% to approximately 65%. However, given that upstream fuel emissions are directly related to the distance a vehicle is driven and its fuel economy, they should be considered as part of the use stage of the vehicle. Although vehicle emission regulations typically ignore these emissions, they are important to consider, especially when comparing emissions from vehicles with different fuel sources.

Although emissions from vehicle use are the most significant, the relative contribution of other lifecycle stages increases as fuel economy improves. The materials, assembly, and transport lifecycle stages are responsible for a small proportion of lifecycle emissions, but can still have significant impacts on the environmental performance of a vehicle. For instance, the 29.3% difference in fuel economy between the Civic Hybrid and Civic LX results in a 29.0% difference in use emissions, but only a 24.6% difference in total lifecycle emissions (see Table 4-8). The 4.4% discrepancy is primarily due to an increase in material inputs for the Civic Hybrid.

Lifecycle emissions are highly dependent on the materials used in the body and components of a vehicle. If steel components were replaced with virgin aluminum components to increase fuel efficiency, an increase in emissions in the material stage would result. Whether or not this would prove to be an environmentally sound substitution would depend on an analysis of the net change in emissions from the lifecycle. The impact of material substitution is beyond the scope of this study, but the importance of evaluating environmental impacts from a lifecycle perspective is stressed by this example.

Lifecycle assessment is an especially important tool for measuring environmental impacts in the transportation sector. As alternative fuels and advanced technologies are implemented to minimize tailpipe emissions, consideration must be given to the upstream environmental impacts resulting from these changes.

5.2 HEV-ICEV Lifetime Cost (HILC) Model

5.2.1 HILC

The HILC model results show higher lifetime costs for the Civic Hybrid than for the Civic LX at the assumed gasoline price of $2.50 per gallon; the breakeven point does not occur before the end of the vehicle's lifetime. For a consumer to purchase a Civic Hybrid rather than a Civic LX, they must be willing to accept this extra lifetime cost in exchange for the emissions reductions achieved. At a 3% discount rate, the willingness to pay for lower emissions must be at least $1,500. With higher gasoline prices or lower discount rates, the difference in lifetime costs between the Civic Hybrid and the Civic LX decreases.

The lifetime costs of a Civic Hybrid (CVT) and Civic LX (automatic transmission) would be equal at a gasoline price of $3.80 per gallon for a 3% discount rate. This breakeven price increases as the discount rate increases. With a 5% discount rate, the breakeven price increases to $4.25 per gallon, while it drops to $3.20 with a 0% discount rate. Therefore, the time value of money impacts the ability of the Civic Hybrid price premium to be recovered through reduced gasoline expenditures.

According to the HILC model, the Escape Hybrid will reach its breakeven point within its lifetime with a gas price of $2.50 per gallon and a discount rate of 3%. In fact, with those parameters a consumer who purchases a conventional 4WD Escape should be willing to pay about $1,500 extra over the 4WD Escape Hybrid.

Again, the discount rate influences the net present value of the lifetime savings for an Escape Hybrid consumer. The lifetime savings for the 4WD

Escape Hybrid range from $2,643 with a 0% discount rate to $888 with a 5% discount rate. As shown by the net savings at $2.50 per gallon at each discount rate, the 4WD Escape Hybrid breaks even at gas prices lower than $2.50 per gallon. The 4WD Hybrid Escape has breakeven gas prices of $1.47, $1.79, and $2.03 at discount rates of 0%, 3% and 5%, respectively. The FWD Escape Hybrid has a slightly higher price premium and a slightly lower improvement in fuel economy than does the 4WD Escape Hybrid. This means the FWD version does not breakeven as quickly, has lower lifetime savings, and higher breakeven fuel prices than the 4WD version.

In addition to the hybrid price premiums and the fuel savings, one important reason why Civic Hybrids have later breakeven points than Escape Hybrids is because of differences in their scheduled maintenance. The Civic Hybrid has the same maintenance schedule as the Civic LX, but the services cost slightly more due to the use of advanced 0W40 oil in the Hybrid. This causes the lifetime maintenance costs of the Civic Hybrid to be about $200 more than the maintenance costs of the Civic LX, pushing back the breakeven point. Maintenance for the Escape Hybrid, on the other hand, costs about the same as the maintenance for the conventional Escape, but is scheduled less frequently (every 10,000 miles for the HEV and every 5,000 miles for the ICEV). This results in lifetime maintenance costs for the Escape Hybrid that are approximately $400 lower than for the conventional Escape, causing the breakeven point to occur sooner.

Whether or not scheduled maintenance costs reflect the actual maintenance costs for different vehicles could have a large impact on the breakeven point of an HEV. As shown above, the discount rate and price of gasoline are also important in determining the lifetime cost of a vehicle. Although operational characteristics and economic factors will influence whether or not a particular HEV's price premium can be recovered within its lifetime, these results show that HEVs based on ICEVs with lower fuel efficiencies will be more likely to breakeven than those based on ICEVs with higher fuel efficiencies.

5.3 Fleet Composition Model (FCM)

5.3.1 Vehicle Class GHG Emissions

Although emissions for vehicle classes differ by manufacturer, the general trend in emissions is similar for all manufacturers. Large trucks produce the highest emissions for both ICEVs and HEVs. For ICEVs, large trucks produce the most emissions, followed by small trucks, minivans, large cars and small cars. HEV minivans produce more emissions than HEV small trucks, but the order of the other vehicles classes is the same. Table 4-32 shows that the difference between ICEV and HEV emissions is greatest for the small truck vehicle class. This implies that HEV small trucks could be an important tool in reducing CO_2e emissions from the vehicle fleet. While a majority of HEVs currently produced are from smaller vehicle classes, a comparison of the HEV and ICEV emissions in the small car category shows that emission reduction between the two is not as great as other vehicle classes.

Because the large truck HEVs in this study are based on the less advanced hybrid-electric technology used in currently available HEV large trucks, a move from an ICEV to an HEV large truck results in a much smaller reduction in emissions. This type of hybrid-electric technology allows the engine to turn off while idling, but the electric motor is used to supply electrical power to outlets in the truck bed and to accessories such as the air conditioner, rather than to supplement the internal combustion engine for vehicle power. It is not anticipated that the large truck HEVs will employ the same technology as the other classes in the time frame of this analysis (Raney, 2005). If HEV large trucks were to incorporate the same technology as what is assumed for HEVs in the other vehicle classes, the emission reductions for this class would likely be greater than those of all the other classes. Extending the pattern of the other vehicle classes, pursuing the adoption of more advanced hybrid-electric technology in large trucks could result in the greatest emission reductions with the greatest lifetime savings.

5.3.2 GHG Emissions Reduction

The fleet emission projection analysis assumes that no HEVs are sold in California in MY 2002, and that starting in 2003 HEVs are slowly phased in (the actual fraction of HEVs sold in MY 2002 was less than 0.5%). As the number of new vehicles on the road increases, the GHG emissions from new vehicles will increase as well. Replacing a percentage of the fleet's ICEVs with HEVs will reduce the rate of increase, as shown by the increasing difference in emissions between the scenarios with and without HEVs in Figure 4-17. The overall new vehicle sales increases are projected to grow at a much higher rate than the increase of new HEVs, and therefore, the reduction potential of HEVs on total emissions is limited. Even with the projected 20% HEV fleet makeup in MY 2025, CO_2e emissions still increase by 47% over the baseline MY 2002 emissions; when no HEVs are included, emissions grow by 54%.

Table 4-33 shows the differences in CO_2e emissions between the scenarios with and without HEVs in the new vehicle fleet, as well as those differences as a percentage of the no-HEV scenario emissions. The new vehicle emissions increase yearly as the number of new vehicles sold increases; however, the difference between the HEV scenario and the no-HEV scenario also grows each year, as more HEVs are introduced. The cumulative difference over the entire timeframe of the analysis is a 2.54% decrease from the no-HEV scenario emissions, or 156.7 million tonnes of CO_2e. Although this is a small percentage change, the actual amount CO_2e saved is approximately equal to annual GHG emissions from the country of Belgium. Because the HEV market share increases over time, later years show larger emission reductions than earlier years. In fact, the emissions reductions in MY 2025 comprised 10.5% of the total emissions reductions over the 24 year span.

The impact of using a lifecycle approach on the emissions scenarios is also shown by Table 4-33. The table shows that looking only at use phase emissions causes the emission reductions from introducing HEVs to be underestimated. This is because non-use phase emissions are lower for HEVs, so not all of the emission reductions are captured by ignoring these phases. In contrast, looking only at the use phase emissions causes the percentage of emissions reductions to be overestimated when compared to the lifecycle perspective, because the use phase emissions provide a smaller number for a denominator. The emission reductions from the use phase between HEVs and ICEVs is maximized in MY 2025, with a HEV diffusion of 20%, reducing emissions by 5.96%. As with lifecycle emissions, the reduction in emissions from use increases as more HEVs are introduced. The final year of analysis, MY 2025, accounted for 10.5% of the emission reductions over the entire 24 year period.

Focusing only on emissions from the use phase does not capture the full effects of manufacturing, using, and disposing of a vehicle. HEVs do emit fewer GHGs over the vehicle lifecycle than ICEVs, showing that the technology is a useful tool in reducing overall GHG emissions from the transportation sector. In this scenario, the total number of new vehicles is anticipated to rise at a much faster rate than the percent of HEVs, causing the projected annual emissions of GHGs to rise by more than 95,000,000 tonnes of CO_2e, or 47%, between MY 2002 and MY 2025.

Accelerating the diffusion of HEVs into the vehicle market and raising the MY 2025 target diffusion rate would cause emissions to be further reduced over the period. However, because HEVs do consume gasoline and emit GHGs, there is a limit to how far these reductions can go.

5.3.3 Potential for GHG reduction by vehicle class

The total GHG emission reductions that are possible by switching to HEVs in any given vehicle class is dependent on both the emission differences between the ICEVs and HEVs in that class, and the proportion of the total fleet of vehicles made up by that class. The vehicle classes with the largest potential for GHG emission reduction in California’s fleet of new vehicles are the large car and small truck classes, due to their relatively large ICEV-HEV emission differences, and due to the fact that these vehicle classes make up a large percentage of the fleet – approximately 50% of all new vehicles sold in MY 2002.

By producing 100% HEVs in one vehicle class and producing no HEVs in the other classes, the maximum total fleet emissions reduction ranges from approximately 3-8%. The largest possible single class reduction in total fleet emissions was by the small trucks, with a 7.5% reduction. The smallest possible reduction was by minivans and trucks, with a total reduction of less than a 3% for either a 100% hybrid large truck or 100% hybrid minivan diffusion. There is a large emissions difference between ICEV and HEV minivans, but their market share is relatively small (7%). Large trucks have a large market share (21%), but a relatively low difference in emissions between the ICEV and HEV versions.

In total, a fleet comprised of 100% HEVs would decrease total fleet emissions by 22.5% from the baseline no-HEV situation. This reflects the average emission reduction for HEVs of each vehicle class, weighted by market share.

5.3.4 Lifetime Fleet Economics

The majority of the economic scenarios examined in this study show that from MY 2002 to MY 2025, a fleet with HEVs will have lower consumer costs than a fleet without HEVs. In fact, 14 of the 18 scenarios project a fleet with HEVs requiring a lower present value of consumer expenditures versus a fleet with no HEVs. The four scenarios that resulted in lower costs without HEVs included those with gasoline prices of $1.50 per gallon for all three discount rates, and the scenario with a $2.00 per gallon gas price and a 5% discount rate.

The fleet analysis shows that, unlike the Civic-to-Civic economic analysis, HEVs in general do not place an extra economic burden on consumers because lifetime gas savings make up for the expected price premium over the period of 2002-2025. The main difference between the fleet analysis and the Civic-to-Civic analysis is that the fleet analysis used the HEV price premiums developed by Lipman & Delucchi (2003) (Table 2-2). These premiums are lower than current HEV premiums to account for future economies of scale as HEV production increases. If consumers are rational economic agents, with reasonable internal discount rates, then this finding should alleviate the need for government to give incentives for the purchase of HEVs.

Although the relative magnitude of economic changes in the fleet from HEV diffusion is small, in absolute terms the potential savings represented are considerable. In the primary scenario, the net present value of discounted savings over the time period of the analysis is over $4 billion. If gas prices were to increase above $2.50, the potential for savings from HEVs would be even greater.

5.3.5 Savings per tonne of CO_2e reduction, by vehicle class

The total potential for emission reductions from diffusing HEVs into a fleet of new vehicles depends on the difference in emissions between the baseline vehicle and the HEV that replaces it. In this study, it is assumed that all HEV fleet diffusion involves replacing a baseline ICEV vehicle with its HEV counterpart. For example, it is assumed that an ICEV Honda Civic is simply replaced by an HEV Honda Civic.

The baseline ICEV vehicles differ in terms of emission rates across vehicle class (i.e. small trucks emit more than small cars). In addition, the price premium between an ICEV and its HEV counterpart differs across vehicle class. As a result there is a different level of savings to the consumer for a given level of GHG reduction depending on which vehicle class and/or manufacturer is considered (see Figure 4-21, Figure 4-22 and Figure 4-23).

Replacing conventional large trucks with HEV large trucks does not achieve the same magnitude of consumer lifetime savings as those achieved with the same replacement for other vehicle classes. In fact, the large truck class has an additional lifetime cost associated with this replacement, while the other vehicle classes generally achieve lifetime savings. This is because the technology assumed for an HEV large truck does not reduce emissions as much as the technology used in other HEVs, yet it adds a similar premium to the purchase price of the vehicle.

Replacement of ICEV small trucks with HEV small trucks would substantially reduce GHG emissions while creating an overall lifetime savings to consumers. This causes small trucks to yield the greatest economic benefit to consumers, irrespective of manufacturer. Replacement of minivans and large cars would also create an overall lifetime savings to consumers. The reduction in GHG emissions for replacing small cars sometimes results in a lifetime savings and sometimes results in additional lifetime cost, depending on the manufacturer and discount rate.

These are important results for policymakers attempting to reduce greenhouse gas emissions from the transportation sector. If HEV price premiums drop to the estimated levels used in this paper and HEVs achieve the efficiency improvements calculated in these models, the GHG emissions achieved will come at a net savings for most vehicle classes and manufacturers. Policies to reduce greenhouse gases are generally assumed to have a cost associated with them and policymakers attempt to select the most cost-effective policy option. Increasing the diffusion of HEVs, however, can result in significant emissions reductions while saving consumers money. This is an example of a classic win-win situation for the environment and the economy.

5.4 LEEV Estimator

Table 4-37 compares the lifecycle emissions, lifetime costs and overall LEEV scores of ICEV and HEV versions of the Honda Civic and the Ford Escape, as calculated by the LEEV estimator. The difference in lifecycle CO_2e emissions between the HEVs and comparable ICEVs is larger for the Escape than for the Civic. An Escape HEV would emit 22 tonnes less CO_2e than the ICEV Escape, while a Civic HEV would emit about 14 tonnes less CO_2e than the ICEV Civic over the lifetime of the vehicles. The Escape HEV would cost about $88 less over its lifetime than its ICEV counterpart while a Civic HEV would cost about $1,500 more over its lifetime than its ICEV counterpart.

Between these vehicles, the greatest savings per emissions reduction can be gained by a consumer who chooses a Civic HEV over an Escape ICEV, yielding a 43 tonne reduction and a $1,100 savings. This demonstrates the usefulness of the LEEV Estimator to compare across vehicle classes and types. In terms of LEEV score, there is a larger improvement between the Escape models than for the Civic models. The Escape HEV is a 31 percentile point improvement from the Escape ICEV while the HEV Civic is only a 6 percentile point improvement from the ICEV Civic. This is due to the already low emissions and costs associated with an ICEV Civic.

Table 4-38 shows the LEEV results for the top 20 new vehicle models sold in MY 2002 in the US. This table shows that the most popular new vehicles out of the top 20 are some of the poorest environmental and economic performers. Four out of the top six and five out of the top ten are ranked in the highest quartile for lifecycle emissions and lifetime costs, meaning they have high lifetime costs and high lifecycle emissions. Improving the overall environmental and economic performance of the most popular larger vehicles and/or encouraging the transition to smaller ones would be effective methods to reduce GHG emissions from light duty vehicles.

Switching to HEV technology improves the overall environmental and economic performance of most vehicles, but this improvement is relatively low for smaller vehicles while it is higher for larger ones. From a consumer’s point of view, focusing HEV technology on larger vehicles is a more cost-effective use of the technology as a GHG emissions reduction tool. However, the most effective method of GHG reduction on a fleet-wide basis would be transitioning the fleet to smaller vehicles.

There is a high demand for larger vehicles that are poorer environmental and economic performers; changing consumer preferences away from these vehicles is a difficult task. In order to encourage lower GHG emissions from vehicles, consumers need to be informed about their personal contribution to GHG emissions and the corresponding cost implications associated with larger vehicles. The LEEV estimator is a tool that allows consumers to compare lifecycle emissions and lifetime costs of vehicles when making a purchasing decision, which could encourage the purchase of lower emission vehicles. This change can help reduce overall GHG emissions from light duty vehicles in a fleet. Informing consumers about the potential cost savings of purchasing lower emission vehicles can give them an incentive to reduce their own personal emissions.

6. Policy options for GHG reduction in the transportation sector

Creating policies that aim to reduce GHG emissions is both technically and politically complicated. GHG emissions are a global problem, produced from a number of sources, including industry and transportation, in countries all over the world. Although a majority of GHG emissions are from industrialized nations, the impacts of the emissions are equally shared by all citizens of the world. In order to reduce GHG emissions from industrialized nations, the Kyoto Protocol was ratified on February 16th, 2005 by thirty industrialized countries (UN, 2004). The Kyoto Protocol is an international agreement to reduce overall global GHG emissions, but it does not specifically address emissions from the transportation sector, one of the largest GHG emission sources, and was not ratified by the U.S., a major contributor to global emissions.

In the U.S., the majority of transportation emissions come from passenger cars and light-duty trucks. There are currently three main ways to mechanically reduce GHG emissions from these vehicles: improve the fuel efficiency of the vehicles, improve pollution controls on their tailpipes, or convert to alternative fuels that emit fewer or no GHGs. Other options include changing the behavior of drivers by encouraging the use of public transportation or otherwise reducing the number of vehicles miles driven.

Vehicle manufacturers in the U.S. are required to comply with the Corporate Average Fuel Economy (CAFE) standards, which were enacted by Congress in the 1970s to improve the overall fuel efficiency of passenger vehicles. The federal government has the sole authority to set standards such as these for fuel efficiency for all auto manufacturers. However, under the Clean Air Act, California was granted authority to regulate air pollution emissions. These pollutants include NO_x, PM, CO, and hydrocarbon emissions from vehicles, but do not include gases like CO_2 and several other GHGs because these are not considered air pollutants by the EPA. Vehicle emission regulations from California cannot directly address fuel efficiency, but whether or not the state has the jurisdiction to regulate GHG emissions from vehicles under the Clean Air Act is unclear. The close relationship between fuel efficiency and CO_2 emissions further complicates the issue. This division in political jurisdiction results in a problem concerning the regulation of GHG emissions. In addition, the Clean Air Act grants other states the permission to adopt CA emissions standards, complicating the issue further still.

6.1 CARB Regulation

No state had attempted to reduce GHG emissions from vehicles, before the passage of Assembly Bill 1493 in California in 2002. The Bill mandates that the California Air Resources Board (CARB) create a CO_2e emissions standard for passenger cars and light-duty trucks that results in the maximum feasible and cost-effective reduction in GHG emissions. In September 2004, CARB's proposed regulation was approved by the Governor, becoming the first regulation in U.S. history to attempt to control tailpipe emissions of GHGs from motor vehicles.

The CARB regulation was designed to be flexible, allowing the manufacturers to reach compliance using their own preferred method in the most cost effective way. Soon after the passage of Assembly Bill 1493, CARB began consulting with many experts and hosting public workshops regarding their staff technology assessment to provide feasible and cost-effective options to manufacturers to achieve the desired reductions within the time frame of the regulation (2009-2016). CARB analyzed environmental, economic, social, and technological factors taking into account full lifecycle costs of the vehicle. The analysis covered numerous options for modifying existing internal combustion engines.

The regulation establishes two standard categories: one for passenger cars and the lightest trucks (PC/LDT1) and one for the heavier trucks (LDT2). It sets near-term standards that are phased in between 2009 and 2012 and mid-term standards that are phased in between 2013 and 2016. The standards are maximum emissions in carbon dioxide equivalent (CO_2e) grams per mile driven. Average fleet emissions for the two categories must be less than their respective standards. The greenhouse gases of concern include carbon dioxide, methane, nitrous oxide, HFC 134a, and HFC 152a. Similar to the analysis performed in this paper, the regulation expresses the impact of each gas in terms of CO_2e and the standards were created based on the total carbon dioxide equivalent from all of the gases. The emissions standards for each model year of the regulation are shown below in Table 6-1.

Table 6-1: Restatement of CARB ISOR Table 6.1-5, allowable average CO_2e emissions standards by year (g/mile)		
Model Year	PC/LDT1	LDT2
2009	323	439
2010	301	420
2011	267	390
2012	233	361
2013	227	355
2014	222	350
2015	213	341
2016	205	332

Credits are granted for any reductions in GHG emissions achieved prior to the operative date of the regulations. These credits for early emission reductions are available for model years 2000 through 2008, and manufacturers are able to opt into the program during any model year within this timeframe. The baseline against which manufacturer emissions are measured is the fully phased-in, near-term standard (model year 2012). Any emission reduction early credits earned can be used during model years 2009 through 2014. To ensure that the regulation ultimately achieves the greatest possible GHG reductions, the credits generated by early compliance retain full value through the 2013 model year. These credits are then worth 50 percent of their initial value in MY 2014, 25 percent of their initial value in MY 2015 and have no value thereafter (CARB ISOR, 2004). If a manufacturer complies with the regulation in one category but not in the other, then they can use any excess credits in one category for the other, or sell any excess credits to another manufacturer.

According to CARB's findings, the new regulation would add roughly $1,000 to the cost of an average vehicle which could be recouped in about five years of fuel savings (assuming a gasoline price of $1.74 per gallon). This would also be accompanied by a 27% decrease in CO_2e emissions from the baseline by 2030 (CARB ISOR, 2004). However, initial reactions from auto industry analysts are that the average increase in vehicle cost will be up to $3,000, and that the extra cost will never be realistically recouped by fuel savings (NY Times, 11/2/04). The Union of Concerned Scientists supports CARB's findings and claims that the auto industry is overestimating costs and underestimating gas prices. The industry has countered with lawsuits arguing that there are other ways to reduce GHG emissions from light duty vehicles in California that would be more efficient without forcing costly modifications exclusively for new vehicles. Further, automakers argue that GHG emission reduction is a global problem and can't be solved by one nation, let alone one state. Further, as mentioned earlier, it is uncertain whether California has the authority to regulate GHG emissions as these gases are not classified as pollutants by the US Environmental Protection Agency.

Although this particular policy may face uncertainty about its feasibility and legality, there are many other options that California and other states can pursue to reduce GHG emissions from motor vehicles within their borders. One way to reduce emissions is by changing the composition of the State vehicle fleet to include higher percentages of HEVs, as described in this study.

A brief analysis of the potential for different automobile manufacturers to comply with the CARB standards using HEVs was conducted with the models developed for this study. Using the assumed HEV diffusion rate for this study through the end of the regulation timeframe (11% of the CA fleet in 2016), HEVs alone would not allow manufacturers to achieve the regulation standards (Table 6-2). In fact, a 100% transition to HEVs for all light duty vehicles by 2016 would only allow some of the manufacturers to achieve the standard without the use of the tradable credits (Table 6-3). With the use of tradable emission credits, a scenario with 100% HEVs would allow all of the manufacturers to comply with the regulation (Table 6-4). In this scenario, Honda would have the most extra credits to sell and GM would need to buy the most credits. The use of the credit system would allow all of the manufacturers to achieve the standard, with 20 credits to spare over the whole industry. However, this regulation is based on model year 2002 vehicles as was the analysis provided here. It therefore does not include vehicles introduced after 2002, including the large trucks introduced by Honda and Nissan, which could potentially alter their ability to meet the standard or the amount of credits available to sell.

Table 6-2: 2002 baseline and 2016 projected fleet average GHG emissions with 11% HEVs (g CO_2e/mi)				
	2002 Baseline CO_2e emissions (g/mile)		2016 fleet avg. emissions with 11% HEVs (g/mile)	
Manufacturer	PC/LDT1	LDT2	PC/LDT1	LDT2
Daimler-Chrysler	326	446	315	433
Ford	332	438	322	427
GM	314	457	303	448
Honda	277	348	269	335
Nissan	306	433	296	416
Toyota	288	399	279	388
2016 Standard	**205**	**332**	**205**	**332**

Table 6-3: Projected 2016 fleet average GHG emissions with 100% HEVs (g CO_2e/mi)		
Manufacturer	PC/LDT1	LDT2
Daimler-Chrysler	234	339
Ford	238	350
GM	225	380
Honda	200	229
Nissan	219	285
Toyota	207	296
2016 Standard	**205**	**332**

Table 6-4: CARB credit summary with 100% HEVs			
Manufacturer	PC/LDT1	LDT2	Credits earned (needed)
Daimler-Chrysler	-29	-7	-36
Ford	-33	-18	-51
GM	-20	-48	-68
Honda	5	103	108
Nissan	-14	47	33
Toyota	-2	36	34
Total Credits			**20**

Despite the mathematical feasibility of achieving the standard with 100% HEVs in 2016, it may not be economically or technically feasible to do so. For this reason, CARB considered HEVs as a long-term emissions reduction solution and did not include the technology as part of the short-term cost-effective technologies suggested to meet the standard. According to the results of this study, fleet emissions could be substantially reduced with HEVs, but complying with the current CARB standards would be nearly impossible by exclusively using HEVs as a GHG reduction tool.

The CARB regulation is an ambitious step towards reduced GHG emissions, but it has some inherent flaws. Although the regulation would require emissions reductions, separating the vehicles into two categories encourages the continued use of larger vehicles by making the standards less stringent for these vehicle classes. Further, the standards ignore non-use portions of a vehicle's lifecycle which make up roughly 35% of total emissions. A standard that considers the entire manufacturer fleet of vehicles might discourage the use of larger, higher emission vehicles, while one that incorporates the entire lifecycle would prevent upstream emissions that compensate for the reductions achieved, such as the example with aluminum showed earlier.

The CARB standard is the first attempt to explicitly regulate GHG emissions from transportation at any level of government in the U.S., but individual states do have other options for reducing GHG emissions. Previously analyzed State-level options come in two broad categories: reducing vehicle miles traveled (VMT) through transportation control measures (TCMs), and making cities more livable and accessible through city and regional planning. The former option is explicitly a transportation issue, while the latter option involves a wider array of stakeholders.

6.2 Transportation Control Measures

6.2.1 Provide incentives for carpooling and alternatives to private commuting

The goal of Transportation Control Measure (TCM) policies is to reduce single-occupancy driving. The majority of vehicle miles traveled (VMT) involve only the driver with no passengers, the least efficient driving condition. Having one passenger reduces the amount of GHG emissions per person-mile by half; three passengers reduce person-mile emissions by 75%. These levels can legitimately be achieved with carpooling and ridesharing methods for certain applications, such as commuting.

Commuter miles can also be reduced by providing alternatives, such as telecommuting and flexible work-schedules. A four-day work week reduces commuting VMT by 20% compared to the traditional five-day work week. The option of telecommuting twice a week could save 40% of commuter miles, or about 1600 miles per year per person, on average. States or cities can provide high-occupancy vehicle lanes to reduce the commuting time for people who rideshare or carpool. Governments can also provide tax incentives to employers who successfully promote carpooling or commuting alternatives, including bicycling, the use of public transit, and flexible scheduling to reduce commuter miles traveled (US Congress, 1991).

6.2.2 Use transportation money for public transit

Currently the majority of government spending for the transportation sector goes to fund road construction and maintenance. In California, the 2003 State budget provided $6.5 billion in total expenditures, of which $5.6 billion was allocated for highway expenditures. Only $267 million was provided for Caltrans' mass transportation programs, equaling just over 4% of the total transportation budget (LAO, 2004).

Buses and trains can offer much greater efficiencies than private cars. Increasing ridership of existing transit systems can greatly reduce GHG emissions overall, and the introduction of new systems can offset VMT in cars in the future. The key to making transit systems work is providing service that is convenient and comparably priced to travel by car. Practically, a transit system must bring people from where they live (or park-and-ride systems can offer a compromise) to where they work. Increasing funding to public transportation could increase the appeal of public transit.

6.2.3 Make parking more expensive

Alternatives to single-occupant vehicle use must be presented as more appealing than personal driving to attract users. This objective can be achieved either through making alternatives better or by making personal driving less attractive. Constraining parking is one way to discourage people from relying on their cars. Making parking expensive or hard to find would encourage more people to take public transit for shopping or commuting purposes.

According to the Office of Technology Assessment (OTA), TCMs work best when multiple TCM types are used in combination with one another. For example, transit is most effectively used in places where parking is very expensive or where parking is restricted. Transit also works best when HOV lanes are available to allow buses to move more quickly than other vehicles (US Congress, 1991).

6.3 Make driving more expensive

According to a 1995 report by the Federal Advisory Committee prepared for President Clinton, a VMT charge of 1.22 cents per mile to pay for road building and maintenance (now covered through income and sales taxes) would both place the financial burden on those who drive more and reduce GHG emissions by reducing the demand for driving. A tax on VMT would also increase demand for fuel efficient vehicles because it would raise the marginal cost of driving (cost per unit distance traveled).

Alternatively, a tax on gasoline would directly reduce demand for gasoline. OTA estimates that a 10% increase in the price of gasoline would decrease demand (and GHG emissions) by 2% in the short term and 7% long term. An increase of 200%, making the price comparable to what consumers now pay in some European countries, would produce a short-term decline in demand of 20% and a long-term decline of 40% (US Congress, 1995). However, instituting such a dramatic tax increase at the State level could have many negative consequences such as discouraging the movement of people and businesses to California and perhaps even driving some residents away. OTA also admits that gas taxes disproportionately affect low-income households. Furthermore such a policy would likely be protested by citizens and government officials alike.

The State could also use subsidy and tax structure incentives to encourage the use of other technologies that promote fuel savings. For example, use of low rolling-resistance tires can increase fuel efficiency by 4%, but low-resistance tires are more expensive than standard tires, and are not favored by consumers. If higher resistance tires were taxed and the revenue from the tax were applied as a subsidy to low resistance tires, essentially leveling the price for the different types, consumers would be more likely to purchase the more efficient technology at little or no cost to the government (US Congress, 1995).

In addition to making driving more expensive in monetary terms, policies could also work to make automobiles more expensive in time. Automobiles are most fuel-efficient when traveling between 35 and 45 miles per hour, according to OTA (US Congress, 1995). At 65 mph, vehicles burn about 40% more fuel, and at 75 mph, 70% more. Lowering the speed limit would reduce GHG emissions in two ways: first, by increasing operating efficiency as described above, and second, by reducing demand for travel. For instance, commuting is generally measured in time rather than distance. Reducing the speed limit would likely lead people to drive fewer miles at a lower speed, encouraging work closer to the home (see also section 6.5).

6.4 Encourage Clean Technologies

The Federal and State Governments can also encourage the invention and use of cleaner ways to travel by investing more resources in research for improved transportation technologies. There are currently many such programs operating across the country and in California but increasing funding would likely increase productivity and innovation.

6.4.1 Cleaner equipment

The Carl Moyer Program, sponsored by the California Air Resources Board, provides incentive based funds to encourage the purchase and use of engines and other equipment that have lower nitrogen oxide emissions than are legally required. The Program provides grants to local air quality management districts that are able to disburse them to qualifying projects, ranging from on- or off-road vehicles to airport ground support equipment, marine projects, and stationary agricultural pumps. In January of 2005, AB 923 extended the program to include new agricultural sources, light and medium-duty vehicle projects, and projects that decrease particulate matter emissions only (rather than requiring a reduction in nitrogen oxide emissions). AB 923 also includes a new funds distribution system and requires that grant criteria and guidelines be published by January 2006 (CARB, 2005).

Through the Carl Moyer Program, almost 5000 "clean engines", including alternative-fueled vehicles and cleaner diesel engines, were funded as of February 2004. These projects resulted in an estimated reduction of smog-forming nitrogen oxides by 14 tons per day and a reduction of particulate matter by 1 ton per day in the first four years. Similar programs may be able to provide incentives for projects that reduce GHG emissions.

6.4.2 Cleaner Fuels

California currently uses fuel with 5.7% ethanol by volume, offering a renewable source of hydrocarbons for gasoline engines. Ethanol is often produced from biomass like corn and although burning of ethanol still releases CO_2, net CO_2 emissions are lower since CO_2 is absorbed from the atmosphere by the growing biomass. According to a 1999 study by Argonne National Laboratory, a 10% mix of ethanol with gasoline can reduce carbon emissions by 2-9% per mile. Similarly, the replacement of conventional diesel fuel with biodiesel can reduce net carbon emissions by 78% per mile (CARB, 2004 [2]). The benefit of ethanol additives and biodiesel is that these fuels can burn in standard engines available today and do not require great infrastructure changes. Other fuels, e.g. natural gas, are also possibilities for widespread future use, and are being used currently in specialty applications (buses, etc). These fuels offer great potential for low net GHG emissions from transportation in the future.

6.5 Planning/Zoning policies

Much of the growth seen in VMT in recent decades can be attributed to population growth in suburbs, leading to greater distances for important trips such as food or work (US Congress, 1991). Reducing the need for transportation can be achieved in two distinct ways: increasing population density, and changing zoning from individual to mixed use.

Increasing population density, or allowing more people to live in a given area, increases the efficiency of public transportation systems making them more cost effective and efficient, which can lead to improved service. Similarly, increased job density reduces the need for many stops along a transit route, increasing the appeal of transit compared to driving a private vehicle (US Congress, 1995).

The approach advocated by the Federal Advisory Committee involves higher-density housing as well as mixed-use zoning, which combines multiple types of functions in the same geographical area, e.g. business, industry, and residential within the same development. This strategy allows people to live closer to their workplaces and shopping centers. Mixed-use planning is just one part of the FAC's recommendation for promoting High Access Livable Places (HALPs). HALP strategies also include redevelopment of urban city centers, making them readily accessible to transit and pedestrian transportation; promoting transit-accessible communities with efficient mortgages; and locating government offices and services in transit-accessible areas. Such plans reduce the need for transportation, eliminate GHG emissions associated with those transportation needs, and combat the problem of urban sprawl (US Congress, 1995).

6.6 Alternative Options

Programs that provide economic incentives and encourage a consumer to choose a vehicle with lower emissions than the one they currently drive would increase the demand for smaller, lower emission vehicles. These programs would also encourage technology changes (i.e. HEV conversion) in larger vehicles in order to improve fuel efficiency and keep these vehicles economically attractive to consumers.

One way to operate a program like this would be to impose a fee on individuals who purchase a higher emitting vehicle than their current vehicle and return this fee revenue as a subsidy or rebate to the individuals who purchase lower emitting vehicles than their current vehicles. This could include purchases of used vehicles, as well as new vehicles in order to better integrate low to middle income consumers, and could include different incentives or costs to encourage consumers to limit the number and type of vehicles that they purchase. The program would also encourage manufacturers to continuously reduce the emissions of their new vehicles because the added fee would entice consumers to buy the lower-emitting vehicles. If emissions from the full vehicle lifecycle were considered, other portions of the lifecycle, such as material extraction, assembly, and end-of-life practices, would offer opportunities for GHG emissions reductions.

7. Further Research

The models used in this study could be improved with more information, more accurate data, and more comprehensive scenarios. The current results are derived from rather generalized assumptions. It would be meaningful to simulate these scenarios with additional information and improved assumption of data changes over space and time. The following suggestions could be used, in addition to the current study, to produce more accurate results.

For each of the models derived for this study, fuel economy is a very important parameter in determining the results. Anecdotal data has shown that HEV fuel economy tends to be 10-20% lower than the EPA fuel economy ratings. If the EPA's ratings are systematically inaccurate for HEVs, the results of this study are inaccurate to the same degree. Further research into the actual fuel economy figures for HEVs would reduce these inaccuracies from the model results.

For the CLEM, more accurate data about several of the processes and materials used in the HEVs and ICEVs would improve the accuracy of the results. Including the emissions from intermediate component assembly and end of life processes could have a significant impact on the results and should be done in future studies. The change in fuel efficiency as the vehicle ages could also play an important role in the total lifetime emissions of the vehicle. Rather than assuming emissions stay constant, future studies could also examine the degradation of fuel economy over time. In addition, environmental impact category other than climate change could be investigated. Analyzing the differences between HEVs and ICEVs for additional environmental impact categories, including air quality, eutrophication, resource depletion, etc., would better assess the total differences in environmental impacts between the two types of vehicles.

The HILC model could also be improved by using assumptions that more accurately reflect real world experiences. The price of each vehicle was based on the MSRP, which is not always what the customer pays for the vehicle. In general, ICEVs can often be purchased for less than MSRP, while some dealerships are currently charging premiums due to the scarcity of hybrids, causing them to cost more than MSRP. This discrepancy would cause the breakeven points for HEVs to be later than estimated in this study. An analysis of the actual price customers pay on average for both vehicle types would allow the HILC model to more realistically estimate the lifetime cost of both vehicles and to more accurately calculate the breakeven point.

The HILC model had a limited number of total vehicle models that were analyzed. It also only considered constant gas prices, constant yearly mileage, and constant vehicle lifetimes. Further research should include a larger volume of vehicle models as well as varying gas prices, mileage traveled, and vehicle lifetimes into the future (e.g., gas prices increasing from current to future projections within the model). Due to the lifetime chosen for a vehicle, no battery replacements costs were included. The state of California currently guarantees the nickel metal hydride battery for 150,000 miles. Other lifetimes that include battery replacement could have dramatically different cost profiles, and should therefore be included in further studies.

The HEVEE model should include more vehicle models to better estimate the true emissions of HEV equivalent vehicles. It is difficult to project an HEV that is comparable to an ICEV counterpart, given the limited number of HEV models currently available. Adjustments could also be made to accommodate future changes in standard technologies for vehicles that would greatly reduce CO_2 emissions. In this study, it was assumed that vehicle technology is stagnant and that HEVs improve emissions in terms of the current available technology. It would be helpful to examine the inclusion of other types of HEV technologies. The model is highly sensitive to the type of HEV projected, and the models available now may not be a good representation of what will be produced in the future.

The most significant assumption for the FCM was that the total fleet of California vehicles was a flat percentage of the US vehicle fleet over all vehicle manufacturers and vehicle types. It also assumed that changes in vehicle sales and in HEV fleet density were the same across all manufacturers and vehicle types. A more accurate study would reflect the actual number of each vehicle model in the California fleet. Additional studies could vary projected increases in sales and in HEV density over each manufacturer and each vehicle type. All of these improvements would help better reflect the real cumulative GHG emissions and lifetime costs for the California vehicle fleet. Although a sales weighted cost average would have been preferred, the datasets did not match up in such a way to enable this. Also, because the FCM depends on inputs from the CLEM and HILC model, the data limitations faced by those models also apply to the FCM.

The popularity of hybrid-electric vehicles will likely grow in coming years. Additional studies of their lifecycle environmental economic impacts will be important in determining how to best utilize their unique characteristics to reduce the burdens placed on the environment by the transportation sector.

8. Conclusions and Recommendations

The implications of this study affect three main stakeholder groups: auto manufacturers, policymakers, and consumers. Although these groups are vastly different in the stakes they have concerning HEVs, this study has pulled them together under a common theme.

Auto manufacturers that are concerned about the GHG emissions produced by the vehicles they manufacture should have a way to decide where (and whether) to pursue HEV technology. The total GHG emission reduction resulting from converting a vehicle model to an HEV depends on the reduction achieved by that specific model, as well as the total sales of the model. Therefore, manufacturers should focus on providing HEVs of models that are both popular and offer high individual reduction potential. In order to do this, they need to have that information available.

Policymakers who are trying to craft policies to reduce GHG emissions on any level (local, state, or Federal) need to have information about the processes that emit GHGs. Although the use stage of a vehicle's lifecycle is responsible for the majority of GHG emissions, strategies to reduce use phase emissions could potentially increase emissions from other lifecycle stages to the point where the strategy no longer offers a net environmental benefit. These tradeoffs are possibilities as long as vehicle policies focus only on combustion of fuels during the use phase. This study illustrates the importance of accounting for environmental impacts over the entire vehicle lifecycle rather than just over the use stage.

Policies to reduce emissions from transportation are not limited to controlling what comes out of the tailpipe. Other options include policies that involve vehicle and fuel taxes and incentives, public transit funding, and smart land use planning.

Consumers are arguably the most important stakeholder group because they drive demand for different types of vehicles. Consumer behavior has been responsive to gas prices, as seen in recent increases in HEV sales and decreases in large truck and SUV sales. However, this change in preferences may reflect perceptions rather than knowledge on the part of consumers. A tool such as the LEEV estimator can help consumers make objective, informed decisions about the impacts, both environmental and economic, of all types of vehicles.

Information is the unifying theme of these recommendations. The key to getting stakeholders to work together to reduce GHG emissions is delivering the correct information. This project creates a framework for informing each stakeholder, even if it does not provide specific answers or direct stakeholders towards specific behaviors. This framework for assessing the emission and cost impacts of different vehicle types is flexible and can continue to be useful as HEV and other technologies and markets mature.

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Appendices

A. Data, assumptions, and calculations for GHG emissions in the CLEM

This appendix describes in detail how the Carbon-equivalent Lifecycle Emissions Model calculated lifecycle GHG emissions for vehicles. Data sources and assumptions are also described. The first section of this appendix describes the general methods of calculation and assumptions of the model. The second section explains how data was collected for the comparison of the HEV and ICEV Honda Civics. The third section describes the changes and additional assumptions made when average ICEVs and hypothetical HEVs were analyzed in the CLEM for use in the fleet composition model (FCM).

A.1. Detailed Methodology of the CLEM

A.1.1. Inputs

Table A-1 lists the vehicle-specific inputs to the CLEM:

Table A-1: Description of user inputs for the CLEM.

VehicleCurbWeight	Mass of a fueled vehicle without cargo or passengers (kg).
$PercentComposition_{M,Body}$	Body composition by mass (% of total mass) of material *M*. Includes: virgin plain-carbon steel, high-strength steel, stainless steel, recycled plain-carbon steel, iron, advanced composite, other plastics, rubber, virgin aluminum, recycled aluminum, glass, virgin copper, zinc die castings, virgin lead, recycled lead, nickel compounds.
BatteryMass	Mass of the battery pack in HEVs (kg).
$PercentComposition_{M,Battery}$	Battery pack composition by mass (% of total mass) of material *M*. Includes: nickel compounds, stainless steel, potassium hydroxide (KOH), cobalt, manganese, virgin aluminum, lanthanides, zinc, and plastic.
MotorMass	Mass of the electric motor in HEVs (kg).
$PercentComposition_{M,Motor}$	Electric motor composition by mass (% of total mass) of material M. Includes: virgin plain-carbon steel, virgin aluminum, virgin copper.
ICEMass	Mass of the internal combustion engine (kg).
$PercentComposition_{M,ICE}$	ICE composition by mass (% of total mass) of material *M*. Includes: recycled plain-carbon steel, total aluminum.
ElecSystemMass	Mass of the electronics system in HEVs (kg).

$PercentComposition_{M,Elec}$	Electronics system composition by mass (% of total mass) of material *M*. Includes: copper, aluminum, steel, and plastic.
InitialRefrig	Initial mass of HFC 134a added as refrigerant (g).
$FactoryEmissions_{GHG}$	Emissions from the vehicle assembly plant (kg of emission per kg of vehicle produced at facility) of gas *GHG*. Includes: CO_2, CH_4, N_2O, HFC 134a, HFC 152a.
TransportDistance	Distance to market (km): freight distance from assembly facility to destination market.
$PercentDistance_{Mode}$	Transport contribution (% of total distance) of different mode *Mode*. Includes: truck, rail, ship.
MPG_{city}, MPG_{hwy}	City and Highway EPA fuel efficiency ratings (miles per gallon)
$Tailpipe_{GHG}$	Tailpipe emissions (g/mile), if known, of gas *GHG.* Includes: CH_4, N_2O, HFC 134a, HFC 152a.

A.1.2. Materials

<u>*Material Composition*</u>

Vehicle curb weight – the mass of a fueled vehicle without cargo or passengers – was the first input in the CLEM. The vehicle components that make up the largest differences between HEVs and ICEVs are the battery pack, electric motor, internal combustion engine, and electronics system. The masses of these components were also input into the model. *Net body mass* was defined as the vehicle curb weight minus the mass of these four components:

Equation A-1:

$$NetBodyMass = VehicleCurbWeight - Mass(Battery + Motor + ICE + Electronics)$$

The net body mass was multiplied by material composition percentages for the vehicle's body to calculate the mass of each material in the body of the car. For body material *M*,

Equation A-2: $$Mass_{M,body} = NetBodyMass \times PercentComposition_{M,body}$$

A secondary level of analysis was conducted for the battery pack, electric motor, ICE, and electronics system that estimated the approximate amount of different materials in each component. As in the equation above, the mass of each component was multiplied by the estimated percent each material, *M*, comprised of that component:

Equation A-3: $$Mass_{M,component} = ComponentMass \times PercentComposition_{M,component}$$

For the battery pack, electric motor, and electronics system, the input component masses were zero for an ICEV because these components are only present in HEVs. The internal combustion engine is present in both types of vehicles, although the engines of HEVs are often smaller.

The final component included in the material composition was the refrigerant for the air conditioning system, HFC 134a. The initial volume of the refrigerant was input directly into the model.

The equation used to calculate lifecycle CO_2e GHG emissions from the use of different materials in the vehicle is given in Equation A-4. The use of Delucchi's (2003) emission rates for a material over its lifecycle (ERML) is discussed below.

Equation A-4:

$$MaterialsEmissions_{CO_2e} = \sum_{M}\left[\left(Mass_{M,Body} + \sum_{component} Mass_{M,component}\right) \times ERML_M\right] + HFCEmissions$$

Where: *HFCEmissions* is the CO_2e amount of a HFC 134a released at the end of a vehicle's life.

Additional Assumptions

In the case of many vehicle components, additional assumptions were made about the material composition estimates. These assumptions were based on information in Delucchi (2003) and include:

- Where the type of aluminum was unspecified, 33% was assumed to be virgin and 67% was assumed to be recycled.
- Where the type of steel was unspecified, 70% was assumed to be virgin plain-carbon steel and 30% was assumed to be recycled plain-carbon steel.
- Where the type of plastic was unspecified, 67% was assumed to be "advanced composites" and 33% was assumed to be "other plastics."
- All copper in a vehicle was assumed to be virgin.
- All steel in a NiMH battery was assumed to be stainless steel.

Emission Factors

As discussed in section 3.1.5 of this report, carbon-equivalent emission factors developed by Delucchi (2003) that account for the lifecycle of each material were used in the CLEM. The derivation of the ERMLs shown in Table 3-2 is discussed in Appendix H to Delucchi's (2003) LEM. Although the CO_2-equivalent ERMLs were unpublished, Dr. Delucchi has provided them, as shown in Table A-2 below. (Note the units are different than Table 3-2).

Table A-2: LEM Table H-29. Lifecycle CO_2-equivalent emissions for materials, generic end uses, U. S. year 2020 (g-CO_2-equivalent-emissions/lb-material)									
	Manu-facture energy	***Manu-facture process***	***Co-product credit***	***Other inputs***	***Other inputs***	***Scrap recycle credit***	***End life recycle credit***	***Product trans-port***	***Total***
Material	***EEN***	***EPR***	***EDC***	***EOI-1***	***EIO-2***	***SRC***	***EOLRC***	***ETR***	***ERML***
Virgin plain carbon steel[a]	765	73	(152)	1,303	19	(498)	(83)	76	**1,503**
Virgin high strength steel[a]	951	73	(152)	1,303	19	(556)	0	76	**1,714**
Virgin stainless steel[a]	1,660	73	(152)	1,303	19	(777)	0	76	**2,202**
Recycled plain carbon steel	420	(7)	0	0	0	0	(83)	76	**406**
Iron	1,540	330	0	0	0	0	0	76	**1,946**
Advanced composites	5,649	1,328	0	0	0	0	0	69	**7,046**
Other plastics	4,501	1,328	0	0	0	0	0	69	**5,898**
Fluids and lubricants	0	0	0	0	0	0	0	76	**76**
Rubber	3,053	1,130	0	0	0	0	0	76	**4,258**
Virgin aluminum	12,715	6,763	0	0	0	(6,375)	(5,189)	77	**7,990**
Recycled aluminum	1,362	6	0	0	0	0	(5,189)	77	**(3,745)**
Glass	557	66	0	0	0	0	0	76	**699**
Virgin copper[b]	5,902	(7,930)	(126)	0	0	108	909	76	**(1,063)**
Recycled copper	1,475	(793)	0	0	0	0	909	14	**1,605**
Zinc die castings	2,808	0	0	0	0	0	0	76	**2,884**
Powdered metal	432	0	0	0	0	0	0	76	**508**
Virgin lead	1,311	(50)	0	0	0	(17)	(348)	76	**971**
Recycled lead	262	(88)	0	0	0	0	(348)	14	**(160)**
Sodium	2,588	0	0	0	0	0	0	76	**2,664**
Sulfur	0	0	0	0	0	0	0	**76**	
Titanium	9,431	0	0	0	0	0	0	76	**9,507**
Sulfuric acid	Treated as an agricultural chemical								
Potassium hydroxide	719	0	0	0	0	0	0	76	**795**
Nickel and compounds	4,053	0	0	0	0	0	0	76	**4,129**
Lithium	93	0	0	0	0	0	0	76	**169**
Cement	138	200	0	0	0	0	0	14	**352**
Concrete	Calculated with respect to cement								
Limestone	26	0	0	0	0	0	0	14	**40**
Lime	Calculated with respect to limestone								
Refractories	1,194	0	0	0	0	0	0	76	**1,269**

Notes: See equation H.2 for a complete definition of the parameters shown in the column headings of this table. Emissions "credits" are shown as negative values (in parantheses).
[a] The coproduct displacement credit (EDC) is for blast-furnace gas and coke-oven gas. Other non-energy input (EIO) #1 refers to coking coal. Other non-energy input (EIO) #2 refers to refractories.
[b] The coproduct displacement credit (EDC) is for sulfuric acid.

Rather than calculating the emissions of each GHG during each phase of the lifecycle of a given material, these ERMLs were used because they already account for the full material lifecycle. However, some modifications to these ERMLs were made. When primary materials that can be recycled are credited with an end of life recycling emission credit, the recycled materials must be debited those emissions so that the system balances out. In order to avoid this problem, the end of life recycling credits in Table A-2 were not included in the CLEM calculations. Additionally, the manufacture process credits for the production of SO_2 during the production of virgin copper were not included.

With these modified ERMLs, the extraction, processing, and transportation activities required to deliver a given quantity of finished material to an end user were taken into account. When the lifecycle of a material included processes that reduce system-wide energy use or GHG emissions (like co-production of other materials), credits were given that count against their actual CO_2e emissions.

Three materials – cobalt, manganese, and lanthanides – used in the nickel metal hydride batteries were not included in Delucchi's materials analysis. The lifecycle emissions of these materials have been left out of the CLEM analysis, but are expected to be added in the future.

Emissions data for the lifecycle of the refrigerant HFC 134a were also not available. The only emissions of HFC 134a included in the *Materials* section of the CLEM were direct emissions due to end of life processing of the refrigerant. Schwarz (2002) estimated that, on average, 50% of the initial refrigerant amount would be in the car at its end of life, and that 50% of this would be lost to the atmosphere. This 25% figure was used in the CLEM. Emissions due to system leaks are included in the *Use* section of the CLEM.

Data Sources

Delucchi, Mark. *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials*. Institute of Transportation Studies, University of California, Davis. December, 2003. Available, with appendices, at: http://www.its.ucdavis.edu/faculty/delucchi.htm

Delucchi, Mark. *Table H-29. Lifecycle CO2-equivalent emissions for materials, generic end uses, U. S. year 2020 (g-CO2-equivalent-emissions/lb-material)*. Unpublished output from the LEM, received via email, February, 2005.

Schwarz, Winfried. *R-134a Emissions from Passenger Car Air Conditioning Systems.* Frankfurt, Germany. January 2002. Available at: http://www.oekorecherche.de/english/beitraege/beitraegeVolltext/MAC-loss.html

A.1.3. Assembly

Assembly emissions were defined as the emissions from the facility where an automobile is assembled.

The input field $FactoryEmissions_{GHG}$ was an emission factor calculated as the ratio of total emissions of a GHG from the facility divided by the total mass of all vehicles produced at the facility. Multiplying the curb weight of the vehicle by this emission factor provided an estimate of the facility emissions that could be attributed to the production of one vehicle. For a given greenhouse gas, *GHG*:

Equation A-5: $$AssemblyEmissions_{GHG} = FactoryEmissions_{GHG} \times VehicleCurbWeight$$

Additional Assumptions

Because GHG emissions data were unavailable for the automobile manufacturing facilities examined, electricity and fossil fuel consumption were used to separately estimate total GHG emissions from a given facility. With the adoption of this approach, other processes (i.e. welding) at a manufacturing facility that produce GHG emissions may have been overlooked.

This calculation also assumed that energy use is distributed equally based on the mass of the vehicles, which may not be true, as some assembly lines may be more energy intensive than others.

As discussed in the body of the text, the *Materials* and *Assembly* sections of the CLEM did not address the intermediate stages of product assembly. For example, an internal combustion engine may be made in one facility and then shipped to the final automobile manufacturing facility for inclusion in the vehicle. Due to the vehicle-specific nature of CLEM calculations, collecting this data for each intermediate manufacturing facility was not possible. Although a portion of total lifecycle emissions were ignored by not including this data, it was assumed that the impacts of intermediate product assembly would be approximately equal for each vehicle. Comparisons between vehicles would therefore still be valid.

A.1.4. Transport

The emissions that result from the transport of a vehicle from the manufacturing plant to where it is sold were calculated in this section of the CLEM. Transport emissions were calculated by multiplying the emissions per tonne-km (one tonne of cargo transported one kilometer) of a particular mode of transport by a vehicle's mass and the distance a vehicle is transported using that mode. The total transport emissions are the sum of the emissions from all modes (Equation A-6).

Equation A-6:

$$TransportEmissions_{GHG} = \sum_{Mode} Emissions_{GHG,Mode} \times Distance_{Mode} \times VehicleCurbWeight$$

Where: $Emissions_{GHG,Mode}$ is the amount of a greenhouse gas, *GHG*, emitted per tonne-km using the transport mode *Mode*.

The transport modes the CLEM analyzed include truck, rail, and ship. The total transport distance and the percent of the total distance covered by each mode were accepted as inputs into the model. The emissions for each mode are discussed below.

<u>*Emission Factors*</u>

The CO_2 emission factors for each mode of transport were based on the average energy use per ton-mile for the different modes, which was found in the Oak Ridge National Laboratory's 2003 *Transportation Energy Data Book* (Davis & Deigel, 2003). Energy use was converted to grams of CO_2 per tonne-km using conversion information found in Davis & Diegel (2003), Raney (2005), and EIA (n.d.), shown in Table A-3.

Emission factors for CH_4 and N_2O were also developed for each of the transport modes, based on the emission factors in the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001, Annex E* (2003). The most advanced vehicle emission control technologies were assumed.

Table A-3: Summary of energy intensity data for different transport modes.			
	Trucks	Waterborne Commerce	Class I Railroads
Energy intensity (Btu / ton-mile)	3,337	444	346
Percent Diesel-fueled	88	100	100
Percent Gasoline-fueled	12	0	0
Btu / gallon gasoline	138,700		
Btu / gallon diesel	125,000		
g CO_2 / gallon gasoline	8,904		
g CO_2 / gallon diesel	10,342		
g CO_2 / ton-mile	247.43	33.11	25.80
g CO_2 / tonne-km	166.76	22.26	17.35
g CH_4 / tonne-km	0.0068	0.0021	0.0014
g N_2O / tonne-km	0.0059	0.0006	0.0004

Because an intermediate step in the calculation of transport CO_2 emissions was to determine the number of gallons of fuel used by each mode, emissions due to upstream fuel processing could also be calculated. Upstream fuel processing includes the extraction, refining, and transportation of gasoline and diesel fuel. The upstream fuel emission factors used in this analysis are from Delucchi (2003) and are shown in Table A-4

Table A-4: Upstream fuel emission factors for gasoline and diesel fuel (grams emitted/gallon).				
GHG emitted	CO_2	CH_4	N_2O	HFC 134a
Gasoline	2,315.38	26.5375	0.137500	0.000025
Diesel	1,679.25	25.5625	0.100000	0.000063

Additional Assumptions

The emission factors calculated for different transport modes were based on data for the domestic transport of generic goods and may not accurately represent the actual emissions from the transportation of finished automobiles. Emissions figures for the specific trucks, ships, and rail cars that are designed to carry motor vehicles would improve the accuracy of these estimates.

The ORNL data is also primarily based on domestic transport information and may therefore be inaccurate when used to evaluate the transport emissions for imported vehicles. This may be especially true for international waterborne commerce, where large container ships could potentially transport cargo more efficiently than ships designed only for domestic transport.

<u>*Data Sources*</u>

Davis, Stacy and Susan Diegel. *Transportation Energy Data Book: Edition 23.* ORNL/sub/6970, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 2003. Available at: http://www.ornl.gov/~webworks/cppr/y2003/rpt/118917.pdf

Delucchi, Mark. *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials*. Institute of Transportation Studies, University of California, Davis. December, 2003. Available, with appendices, at: http://www.its.ucdavis.edu/faculty/delucchi.htm

Energy Information Administration. *EIA-1605 Fuel and Energy Source Codes and Greenhouse Gas Emissions Coefficients.* Voluntary Reporting of Greenhouse Gases Program. No date. Available at: http://www.eia.doe.gov/oiaf/1605/factors.html

Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001. Annex E: Methodology for Estimating Emissions of CH_4, N_2O, and Ambient Pollutants from Mobile Combustion and Methodology for and Supplemental Information on Transportation-Related GHG Emissions. EPA 430-R-03-004.* Washington, DC. April 2003. Available at: http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html

A.1.5. Upstream Fuel

The impacts of upstream fuel production are dependent on the amount of fuel that is consumed during the use phase of the vehicle lifecycle. Fuel consumption, in turn, depends on the fuel economy of the vehicle and its lifetime. The EPA driving cycle estimates of 55% city and 45% highway driving were used in this calculation. The baseline assumed vehicle lifetime is 241,000 km (150,000 miles).

Equation A-7:
$$PetrolUsed = LifetimeMiles \times \left(\frac{CityPct}{CityMPG} + \frac{HwyPct}{HwyMPG} \right)$$

The total upstream fuel emissions of a greenhouse gas, GHG, were found by multiplying the extraction, refining, and transportation emissions per gallon of gasoline by the number of gallons consumed (Equation A-8).

Equation A-8:

$$Upstream_{GHG} = (PetrolExtract_{GHG} + PetrolRefine_{GHG} + PetrolTransport_{GHG}) \times PetrolUsed$$

Emission Factors

Emission factors for upstream gasoline production have been calculated in several previous studies. The CLEM used upstream fuel emission factors developed by Delucchi (2003) that aggregate emissions from the extraction, refining, and transport activities of gasoline. These factors are the same as the ones used in the *Transport* section of the CLEM.

Additional Assumptions

The calculation of upstream fuel emissions assume that the EPA fuel economy numbers approximate real world fuel economy, and that fuel economy does not deteriorate over the lifetime of the vehicle. Additional vehicle testing could verify whether or not these are valid assumptions. Delucchi (2005) has indicated that declining fuel economy over the lifetime probably does occur, but that the effect is likely to be small.

Data Sources

Delucchi, Mark. *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials*. Institute of Transportation Studies, University of California, Davis. December, 2003. Available, with appendices, at: http://www.its.ucdavis.edu/faculty/delucchi.htm

Delucchi, Mark. Email correspondence. February, 2005.

A.1.6. Use

Use phase emissions are the emissions resulting from the operation and maintenance of motor vehicles. Combustion of gasoline is the primary source of GHG emissions (tailpipe emissions) in the use phase. Leaking refrigerant is another significant source of GHG emissions from vehicle use.

Equation A-9: $Use_{GHG} = (Tailpipe_{GHG} + Refrigerant_{GHG}) \times LifetimeMiles$

Emission factors

Carbon dioxide tailpipe emission factors were calculated based on the carbon content of gasoline and the fuel economy of the vehicle. The carbon content of gasoline assumed in this study was 8,904 grams of CO_2 per gallon of gasoline. This number was provided by Honda (Raney, 2005) and is near the average of the values used in other studies.

Equation A-10: $$Tailpipe_{CO2} = \left[8904 \Big/ \left(\frac{CityPct}{CityMPG} + \frac{HwyPct}{HwyMPG} \right) \right] \times LifeMiles$$

Like carbon dioxide emissions, emissions of methane and nitrous oxide are not usually measured directly for automobiles because they are not regulated. Estimates of emissions of these gases from previous studies were used in the CLEM. Emission factors for CH_4 and N_2O were taken from the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001, Annex E* (2003). Emission factors for gasoline LEV passenger cars and light trucks were used (Table A-5) because LEVs are able to meet California emissions standards and the tests used to derive these factors were done with low-sulfur fuel, which is required in California.

Table A-5: Methane and Nitrous oxide emission factors for cars and light trucks

	Passenger Car	Light Truck
CH_4 emissions factor (g/mi)	0.0402	0.0483
N_2O emissions factor (g/mi)	0.0283	0.0354

The difference between the passenger car and light truck emission factors in Table A-5 is attributed by the EPA (1998) to the difference in fuel economy between the two vehicle classes. However, a formula relating emissions to fuel economy is not provided. In the CLEM, a fuel economy of 24.1 miles per gallon (the midpoint between passenger car and light truck CAFÉ standards) was used as the break point to determine which N_2O and CH_4 emission factor was given to a vehicle. The model assigned the light truck emission factors to vehicles with fuel economies less than 24.1 MPG, and assigned the passenger car emissions factor to vehicles with fuel economies of 24.1 MPG or greater.

Schwarz (2002) calculated average annual HFC 134a emissions as a percent of the initial refrigerant fill amount. Schwarz found that 6.3% of the initial refrigerant amount will be lost annually due to normal leaks through hoses and seals. An additional 1.9% will be lost in an average year due to irregular incidents like accidents or malfunctions. Over a full vehicle lifetime, this adds up to over 100% of the initial fill, which is justified by the fact that lost refrigerant is replaced during normal service.

Additional Assumptions

As in the *Upstream Fuel* section of the CLEM, assumptions were made that EPA fuel economy numbers approximate real world fuel economy, and that fuel economy does not deteriorate over the lifetime of the vehicle. Additionally, emissions from maintenance operations and other irregular emissions were not included in these calculations, except in the case of HFC 134a leakage.

Due to data limitations, only two possible emission factors were used for CH_4 and N_2O. More precise emission estimates of these gases from vehicle testing or further study would improve the accuracy of the CLEM's estimated use phase emissions.

Emissions resulting from vehicle refueling or due to fuel evaporating and escaping from the vehicle systems were not included in the CLEM. These processes emit hydrocarbons, which are considered smog-forming compounds. Although methane is generally considered a constituent of fugitive hydrocarbon emissions, a relationship between hydrocarbons and GHGs has not been established (CARB, 2004).

Data Sources

California Environmental Protection Agency, Air Resources Board. *Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles*. Sacramento, California. August 6, 2004. Available at: http://www.arb.ca.gov/regact/grnhsgas/isor.pdf

Delucchi, Mark. *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials*. Institute of Transportation Studies, University of California, Davis. December, 2003. Available, with appendices, at: http://www.its.ucdavis.edu/faculty/delucchi.htm

Environmental Protection Agency. *Emissions of Nitrous Oxide from Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996 (March 1998). EPA 420-R-98-009.* Washington D.C. August 1998. Available at: http://www.epa.gov/oms/models/climate/r98009a.pdf

Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001. Annex E: Methodology for Estimating Emissions of CH_4, N_2O, and Ambient Pollutants from Mobile Combustion and Methodology for and Supplemental Information on Transportation-Related GHG Emissions. EPA 430-R-03-004.* Washington, DC. April 2003. Available at: http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html

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Schwarz, Winfried. *R-134a Emissions from Passenger Car Air Conditioning Systems.* Frankfurt, Germany. January 2002. Available at: http://www.oekorecherche.de/english/beitraege/beitraegeVolltext/MAC-loss.html

A.2. Civic HEV/ICEV Comparison

This section of the appendix describes the data sources, calculations, and additional assumptions made for the comparison of Honda Civic LX and Honda Civic Hybrid models.

A.2.1. Inputs

VehicleCurbWeight: Curb weights were found in manufacturer specifications (American Honda Motor Co., Inc., 2004).

Table A-6: Curb weight of Civic models.

Civic Model	LX (automatic)	LX (manual)	Hybrid (CVT)	Hybrid (manual)
Mass (kg)	1185	1164	1244	1216

$PercentComposition_{M,Body}$: Percentages of materials in the body of a Civic were found in a LCA study of the Honda Insight and the 1996 Honda Civic (Hayashi et al, 2001). To further delineate the types of materials used, ratios derived from Table H-3 of Delucchi's (2003) LEM were applied. The values for a vehicle achieving 28.5 MPG fuel economy were used. For example, Delucchi estimated that 25% of the total steel in a vehicle will be recycled plain-carbon steel. The percent of total steel in a 1996 Civic was multiplied by this percentage to estimate the percent of recycled steel in the Civic. The results of these calculations are in Table A-7. The same percentages were used for all Civic models.

Table A-7: Materials used in Civics, as a percent of net body mass.			
Material	**Percent of body mass**	**Material**	**Percent of body mass**
Virgin plain-carbon steel	36.2%	Virgin aluminum	1.4%
High-strength steel	9.1%	Recycled aluminum	6.2%
Stainless steel	1.1%	Glass	2.8%
Recycled plain-carbon steel	15.9%	Virgin copper	3.6%
Iron	4.6%	Zinc die castings	1.2%
Advanced composite	7.0%	Virgin lead	1.2%
Other plastics	3.5%	Recycled lead	1.2%
Rubber	4.0%	Nickel compounds	1.0%

BatteryMass: The Civic Hybrid uses Panasonic NiMH Prismatic Module batteries (Reuter, 2005). A Honda engineer estimated the total mass of the NiMH batteries to be 27 kg (German, 2005).

$PercentComposition_{M,Battery}$: Battery composition estimates were not available directly from Panasonic, but the material composition was assumed to be similar to that of other nickel-metal hydride batteries. The materials safety data sheet for a Rayovac () nickel metal hydride battery was used to estimate the composition of the battery, shown in Table A-8.

Table A-8: Materials used nickel-metal hydride battery as a percent of mass.			
Material	**Percent of battery mass**	**Material**	**Percent of battery mass**
Nickel compounds	35%	Aluminum	1%
Stainless steel	20%	Lanthanides	8%
Potassium hydroxide	13%	Zinc	8%
Cobalt compounds	6%	Plastics	9%
Manganese	2%		

MotorMass: The mass of the electric motor in the HEV was estimated to be 20 kg (44 lbs) (German, 2005).

$PercentComposition_{M,Motor}$: Data was not available regarding the material composition of the electric motor. The material composition was estimated as 40% steel, 40% aluminum, and 20% copper.

ICEMass: The mass of the internal combustion engine of the Civic Hybrid was provided by Honda (Raney, 2005). The total mass of the ICE in the Civic LX was estimated by multiplying the mass of the Civic Hybrid ICE by the ratio of the engine displacements of the two ICEs (1.7 L / 1.3 L).

$PercentComposition_{M,ICE}$: The mass of the aluminum components of each vehicle's ICE was provided by Honda (Raney, 2005). All material in each ICE that was not aluminum was assumed to be steel.

Table A-9: ICE characteristics of Civic models.

Civic Model	LX (automatic)	LX (manual)	Hybrid (CVT)	Hybrid (manual)
ICE Mass (kg)	106.7	106.6	85.3	85.2
% Aluminum	23	23	28	28
% Steel	77	77	72	72

ElecSystemMass: The Intelligent Processing Unit (IPU) of the Civic Hybrid contains the electronic systems required for operation of the hybrid electric features, including a power control unit, a motor electric control unit, and a cooling system (Honda Motor Co., 2002). The NiMH battery is also included in the IPU, but this was accounted for separately in the CLEM (see above). The mass of the IPU, excluding the battery, is 34 kg (German, 2005).

$PercentComposition_{M,Elec}$: The materials used in the IPU were not found in any documentation and had to be estimated. These estimates are in Table A-10.

Table A-10: Mass and material composition of IPU components in the Civic Hybrid.

	Mass (kg)	% Copper	% Steel	% Aluminum	% Plastic
Inverter/Converter	11	20	30	40	10
Cable	10	100	0	0	0
Case, Fan, etc.	13	0	15	10	75
Total	34	36	15	17	32

InitialRefrig: The amount of HFC 134a in each Civic model was approximated to be 550 grams. This was based on data for similar-sized vehicles in the *Honda Environmental Annual Report 2004* (Honda Motor Co., 2004).

FactoryEmissions$_{GHG}$: Assembly of all Civic LX models was assumed to occur at Honda's East Liberty, Ohio facility. Assembly of all Civic Hybrids was assumed to occur at Honda's Suzuka facility in Japan. Actual GHG emissions data were not available for either of these facilities so estimates were developed, based on electricity and natural gas use.

Electricity and natural gas consumption data for the East Liberty facility were found in the *Honda Environmental Annual Report 2004* (Honda Motor Co., 2004). To account for Ohio's energy mix when estimating emissions from this facility, electricity generation and carbon dioxide emissions were found in the EIA's *State Electricity Profile 2002: Ohio* (EIA, 2004a). Carbon dioxide emissions per megawatt-hour were multiplied by the facility's electricity consumption, and divided by the total mass of all vehicles produced at the facility (Raney, 2005). The resulting emission factor represented the CO_2 emissions due to electricity use for one kilogram of assembled vehicle.

Table A-11: Derivation of electricity-only CO_2 emission factor for Honda East Liberty, OH facility.

Average CO_2 Emissions in Ohio for Electricity Generation (kg CO_2/MWh)	Electricity Used, Honda East Liberty Facility (MWh)	Combined Mass of Vehicles Assembled, East Liberty (vehicle-tonnes)	Electricity-only Emission Factor for East Liberty Facility (kg CO_2/vehicle-kg)
834	115,788	305,879	0.316

Natural gas used by the facility was assumed to have been fully combusted in a boiler, emitting 54.4 kilograms of CO_2 per thousand cubic feet of gas (EPA, 1995). This was divided by the total mass of all vehicles produced and was added to the electricity-only emission factor to get a total CO_2 emission factor for the East Liberty facility (Table A-12). Nitrous oxide emission factors from the combustion of natural gas for the East Liberty facility were similarly calculated.

Table A-12: Derivation of natural gas and total CO_2 emission factor for Honda East Liberty, OH facility.

CO_2 emissions from combusting natural gas (kg CO_2/kcf)	Natural Gas Used, Honda East Liberty Facility (kcf)	Natural Gas Emission Factor for East Liberty Facility (kg CO_2/vehicle-kg)	Total Emission Factor for East Liberty Facility (kg CO_2/vehicle-kg)
54.4	759,000	0.135	0.451

Electricity and natural gas consumption data were not available for the Suzuka facility in Japan, so emission factors were estimated relative to the East Liberty factors. Starting with the same electricity and natural gas requirements per vehicle, an adjustment was first made based on differences in national manufacturing efficiencies. Delucchi (2003) estimates Japanese manufacturing to be 5% less energy-intensive than American manufacturing.

Second, emissions estimates were adjusted for a different electricity generation mix in Japan. Information about the Japanese electricity mix was found in the International Energy Agency's Energy Statistics on Japan (IEA, 2004). Emissions for each type of electricity generation were taken from average US data (EIA, 2004b). Although these emissions figures are not specific to Japan, they are a good approximation of average emissions from different electricity fuel sources. Emissions factors for the two facilities considered in the Civic comparison are shown in Table A-13.

Table A-13: Emission factors for facilities where Civics are assembled.(kg-GHG per kg-vehicle)

East Liberty: CO_2	Suzuka: CO_2	East Liberty: N_2O	Suzuka: N_2O
0.4509	0.3089	7.2x10-7	6.8x10-7

TransportDistance: Distances were estimated from each of the manufacturing facilities to an average point in California. From the East Liberty facility, this distance was calculated as a weighted average distance to the nine California counties with populations greater than one million people. Distances to each county were estimated using Yahoo! Maps internet mapping software (Yahoo! Inc, 2005). County populations were taken from Census estimates (Bureau of the Census, 2004b) and were used to weight the distances.

All vehicles coming from the Suzuka facility in Japan were assumed to enter the U.S. through Los Angeles, before being transported to their final destinations. The surface distance from Tokyo to Los Angeles was calculated using an internet distance calculator available on the USDA website (Byers, 2003). Distances from Los Angeles to other California cities were calculated using Yahoo! Maps (Yahoo! Inc, 2005) as described above.

Table A-14: Distance from manufacturing facility to California market.

East Liberty, OH	Suzuka, Japan
3,716 km	8,978 km

Percent $Distance_{Mode}$: David Raney (2005) indicated that vehicles being transported from Ohio to California are transported by a combination of rail and truck. In the *Commodity Flow Survey,* the Bureau of the Census (2004a) finds that the average distance for a domestic freight shipment of "Motorized and Other Vehicles (including parts)" carried by a combination of rail and truck is 2,052 kilometers (1,275 miles). The split of rail and truck is not given, but the average rail-only shipment is 1,920 km (1,193 miles) and the average truck-only shipment is 237 km (147 miles). Because these average single-mode trips add to a total distance (2,157 km) that is close to the average combined rail-and-truck trip, the single-mode averages were used to estimate the modal split for domestic transport.

For vehicles being transported from Japan, the vast majority of the distance will be covered by ship. Assuming all vehicles arrive at the Port of Los Angeles from Tokyo, the distance transported by ship will be 8,807 km (5,472 miles) (Byers, 2003). The weighted average distance from Los Angeles to the counties with populations of over one million people is 171 km (106 mi) (Yahoo! Inc, 2005; Bureau of the Census, 2004b). Based on the data in the *Commodity Flow Survey (*Bureau of the Census, 2004a), a vehicle would likely be transported over this distance by truck.

Table A-15: Percent of transport distance covered by each transport mode, from each manufacturing facility.

Facility	East Liberty, OH	Suzuka, Japan
Truck	11%	2%
Rail	89%	0%
Ship	0%	98%

MPG_{city}, MPG_{hwy}: Fuel economy numbers were found on the EPA's fuel economy website (EPA/DOE, 2005).

$Tailpipe_{GHG}$: No direct tailpipe emissions were known for any of the GHGs listed. The assumptions described in appendix section A.1.6were used.

A.2.2. Data Sources

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A.3. CLEM Analysis for the Fleet Composition Model

Information about the current vehicle fleet (CARB, 2004) was used to develop a sales-weighted average vehicle for each of the five vehicle classes. Using the same sales weighting (Table A-16), and the vehicle attributes developed in the HEVEE model, an average hypothetical HEV for each vehicle class was also developed.

Table A-16: Sales weighting used to create average ICEV and hypothetical HEVs.

	DCX	Ford	GM	Honda	Nissan	Toyota	Other
Small Car	0.17	0.17	0.23	0.10	0.04	0.08	0.21
Large Car	0.09	0.20	0.30	0.12	0.08	0.15	0.06
Minivan	0.40	0.19	0.16	0.15	0.02	0.08	0.01
Small Truck	0.22	0.25	0.25	0.05	0.06	0.13	0.03
Large Truck	0.16	0.31	0.46	0.00	0.00	0.06	0.00

The representative vehicle for each class and technology was run through the CLEM to determine the lifecycle emissions of the average ICEVs and hypothetical HEVs. This section of the appendix describes the data sources, calculations, and additional assumptions made for the comparison of these vehicles.

A.3.1. Inputs

Table A-17 lists the vehicle curb weight and masses of various components, as calculated for this analysis. Descriptions of how these numbers were calculated follow the table.

Table A-17: Masses of vehicles and components analyzed for FCM (kilograms).

Vehicle Class	**Small Car**		**Large Car**		**Minivan**		**Small Truck**		**Large Truck**	
Technology	*ICEV*	*HEV*	*ICEV*	*HEV*	*ICEV*	*HEV*	*ICEV*	*HEV*	*ICEV*	*HEV*
Curb Weight	1252	1377	1533	1687	1806	1987	1685	1853	2190	2281
Battery	n/a	27	n/a	38	n/a	62	n/a	62	n/a	27
Electric Motor	n/a	20	n/a	20	n/a	20	n/a	20	n/a	20
ICE	149	113	207	157	223	169	223	170	330	330
Electronic Components	n/a	34	n/a	48	n/a	78	n/a	78	n/a	34
HFC 134 for Refrigerant	0.55	0.55	0.55	0.55	0.75	0.75	0.70	0.70	0.75	0.75

VehicleCurbWeight: Curb weights of ICEVs are the sales-weighted averages of the vehicles the current vehicle fleet (CARB, 2004). Curb weights of HEVs were estimated in the HEVEE model and adjusted with the same sales weighting.

PercentComposition$_{M,Body}$: Percentages of materials in the body of these vehicles were approximated using Table H-3 of Delucchi's (2003) LEM. Values were interpolated based on the sales weighted fuel economy (city) for each ICEV. The hypothetical HEVs were assumed to have the same material composition as the ICEVs of the same vehicle class.

BatteryMass: The masses of the NiMH batteries in each vehicle class were estimated separately, based on battery information for current hybrid electric vehicles. Using the Civic Hybrid's battery as a baseline, the mass of the battery was assumed to increase linearly with voltage. The battery for the small car class was assumed to have the same mass as that of the Civic Hybrid (144 V, 27 kg); the mass of the large car battery was scaled relative to the Toyota Prius battery (202 V); the minivan and small truck battery were scaled relative to the Ford Escape's battery (330 V) (American Honda Motor Company, 2004; German, 2005; Toyota Motor Company, n.d; Ford Motor Company, 2004). Because the large truck was assumed to be using a different type of hybridization, the mass of the Civic Hybrid battery was also used for this class.

PercentComposition$_{M,Battery}$: The same battery composition estimates used for the Civic comparison were used for this analysis.

MotorMass: The mass of the electric motor for each vehicle class was assumed to be the same as that of the Civic Hybrid.

PercentComposition$_{M,Motor}$: The same electric motor composition estimates used for the Civic comparison were used for this analysis.

ICEMass: As in the Civic comparison, ICE mass was assumed to be a linear function of engine displacement. Sales-weighted engine displacement numbers were calculated for the average ICEVs. Engine displacement estimates that were derived in the HEVEE model for hypothetical HEVs were also weighted by sales for use in this analysis. The ICE masses were calculated by dividing these engine displacements by the Civic Hybrid's engine displacement (1.3 L), and then multiplying by the Civic Hybrid's ICE mass (85 kg).

PercentComposition$_{M,ICE}$: The composition by mass of the ICEV and HEV engines were assumed to be the same as what was provided by Honda (Raney, 2005) for the Civic LX and Civic Hybrid, respectively.

ElecSystemMass: From the 34 kilogram electrical system estimated for the Honda Civic Hybrid, the electrical systems were assumed to change in proportion to the mass of the batteries.

InitialRefrig: The amount of HFC 134a in each model was approximated based on data for similar vehicle types in the *Honda Environmental Annual Report 2004* (Honda Motor Co., 2004).

FactoryEmissions$_{GHG}$: The emission factors used for the assembly stage of all vehicles were the same as the emission factors developed for vehicles being assembled at Honda's East Liberty facility in Ohio (Table A-18). This was done because this facility was believed to be representative of vehicle manufacturing facilities in the United States. Using the same emission factor for all vehicles ignores plant- and country-specific energy and emissions intensities, but assuming a constant assembly emission factor allows for the most direct comparison of the relative differences between vehicle types.

Table A-18: Emission factors used for vehicle assembly facilities. (kg GHG/vehicle-kg)	
CO_2	N_2O
0.4509	7.2x10-7

TransportDistance: The average distance of domestic transport of "motor vehicles for the transport of less than 10 people" (3-digit SCTG code 361), was used for this input (Table A-19) (Bureau of the Census, 2004a). Similar to the factory emissions calculation, the use of this single transport distance ignores imports, but allows for a comparison of relative emissions between vehicle types.

Percent $Distance_{Mode}$: All vehicles were assumed to be transported domestically only. The contributions of different modes of transport were assumed to be the same as those used for the Honda Civic LX, based on data in the *Commodity Flow Survey* (Bureau of the Census, 2004a).

Table A-19: Characteristics of vehicle transport.		
Transport Distance (km)	Portion of transport distance by truck	Portion of transport distance by rail
2420	11%	89%

MPG_{city}, MPG_{hwy}: Fuel economy numbers for average ICEVs were calculated as the sales-weighted fuel economy for each vehicle class (CARB, 2004). The fuel economy of the hypothetical HEVs were calculated in the HEVEE model and adjusted for sales. See Table A-20 for a summary of the fuel economy figures.

Table A-20: Calculated fuel economy of average ICEVs and hypothetical HEV. (average miles per gallon)					
Vehicle Class	Small Car	Large Car	Minivan	Small Truck	Large Truck
ICEV	28	24	21	19	16
HEV	39	34	31	33	18

$Tailpipe_{GHG}$: No direct tailpipe emissions were known for any of the GHGs listed. The assumptions described in appendix section A.1.6 were used.

A.3.2. Treatment of Output in the FCM

The output of this CLEM analysis was a calculation of lifecycle GHG emissions for average ICEVs and HEVs in each vehicle class. Because the

FCM used manufacturer-specific data, the CLEM output was adjusted for each manufacturer. The nature of the adjustments to the output depended on the particular stage of the lifecycle.

Materials, Assembly, Transport

Within a particular vehicle class, the emissions resulting from each of these three lifecycle stages are essentially a function of vehicle mass. The emissions calculated by the CLEM for each vehicle type were therefore multiplied by the ratio of each manufacturer's vehicle mass to the average vehicle mass used in the CLEM analysis. This provided manufacturer-specific emissions for each vehicle class.

Use

Carbon dioxide emissions from gasoline consumption were calculated within the FCM as a function of manufacturer-specific fuel economies. Emissions of other GHGs (CH_4, N_2O, HFC 134a) during the use phase of the lifecycle were calculated in the CLEM for each vehicle type, converted to CO_2e units, and added to the CO_2-only use emissions.

Upstream Fuel

Emissions attributable to the production of gasoline are dependent on the amount of gasoline used, which is in turn a function of the vehicle's fuel economy. Because the calculated CO_2-only use emissions are also dependent on the amount of gasoline consumed, upstream fuel emissions can be calculated as a constant percentage of use emissions. Specifically, CO_2e upstream fuel emissions are equal to 33.3% of calculated CO_2 use phase emissions.

A.3.3. Data Sources

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B. HEVEE Outputs

Table A-21: Lifecycle Emission (g/mile)

ICEV	Daimler Chrysler	Ford	GM	Honda	Nissan	Toyota	Other
Small Car	379	360	347	276	322	289	361
Large Car	412	425	394	375	386	371	404
Minivan	450	467	424	442	471	433	500
Small Truck	518	495	490	400	524	448	439
Large Truck	627	566	598	NA	NA	585	NA

Hybrid	Daimler Chrysler	Ford	GM	Honda	Nissan	Toyota	Other
Small Car	248	245	235	190	223	195	253
Large Car	276	285	262	258	265	256	277
Minivan	297	309	279	293	312	289	346
Small Truck	294	284	278	237	281	263	270
Large Truck	542	493	520	NA	NA	514	NA

Table A-22: Average Vehicle Weight (lbs)

ICEV	Daimler Chrysler	Ford	GM	Honda	Nissan	Toyota	Other
Small Car	2799.7	2822.7	2838.1	2462.2	2627.2	2504.7	2862.1
Large Car	3466.7	3575.2	3425.1	3179.4	3122.7	3265.0	3399.7
Minivan:	3957.3	3965.5	3806.6	4300.0	3900.0	3900.0	4300.0
Sm Truck:	3694.3	3722.3	3884.6	3500.0	4026.3	3420.2	3417.1
Lg Truck:	4899.3	5074.4	4650.5	n/a	n/a	4731.2	n/a

Hybrid	Daimler Chrysler	Ford	GM	Honda	Nissan	Toyota	Other
Small Car	3079.7	3104.9	3122.0	2708.4	2889.9	2755.2	3148.3
Large Car	3813.4	3932.7	3767.6	3497.3	3435.0	3591.5	3739.7
Minivan:	4353.0	4362.1	4187.2	4730.0	4290.0	4290.0	4730.0
Sm Truck:	4063.7	4094.5	4273.0	3850.0	4428.9	3762.2	3758.8
Lg Truck:	5099.3	5274.4	4850.5	NA	NA	4931.2	NA

Table A-23: Average Vehicle 55/45 FE (mpg)							
ICEV	**Daimler Chrysler**	**Ford**	**GM**	**Honda**	**Nissan**	**Toyota**	**Other**
Small Car	24.8	26.2	27.1	33.6	28.7	32.6	26.0
Large Car	22.8	22.1	24.0	24.9	24.1	25.4	23.3
Minivan	20.6	19.9	22.0	21.2	19.7	21.3	18.4
Small Truck	18.1	18.9	19.2	23.3	17.7	20.8	21.1
Large Truck	15.0	16.4	15.6	NA	NA	15.7	NA
Hybrid	Daimler Chrysler	Ford	GM	Honda	Nissan	Toyota	Other
Small Car	36.8	37.2	38.7	47.9	40.8	46.7	36.0
Large Car	33.0	31.9	34.8	35.3	34.3	35.5	32.8
Minivan	30.6	29.5	32.7	31.1	29.2	31.5	26.3
Small Truck	31.0	32.0	32.8	38.4	32.3	34.6	33.7
Large Truck	16.8	18.4	17.5	NA	NA	17.7	NA

C. Vehicles used in Analysis

Table A-24: Small Cars

DCX	Ford	GM	Honda	Nissan	Toyota	Other
Chrysler Sebring	Ford Cougar	Chevy Camaro	Acura CL	Infinity G20	Lexus IS 300	Audi A4
Dodge Stratus	Ford Escort	Chevy Cavalier	Acura RSX	Nissan Sentra	Toyota Celica	BMW 3-series
Mercedes C	Ford Focus	Chevy S-series	Honda Civic		Toyota Corolla	BMW 5-series
Mercedes CL	Ford Mustang	Geo Prizm			Toyota Echo	Daewoo Lanos
Mercedes CLK	Jag XJ	Oldsmobile Alero				Daewoo Nubria
Mitsubishi Eclipse	Jag XK8	Pontiac Firebird				Hyundai Accent
Mitsubishi Lancer	Jag X-type	Pontiac Grand AM				Hyundai Elentra
Mitsubishi Mirage	Mazda Millenia	Pontiac Sunfire				Kia Rio
Plymouth Neon	Mazda Protégé	Subaru Impreza				Kia Spectra
		Subaru Outback				VW Golf
		Suzuki Esteem				VW Jetta
						VW New Beetle

Table A-25: Large Cars

DCX	Ford	GM	Honda	Nissan	Toyota	Other
Chrysler 300M	Ford Crown Vic	Buick Century	Acura RL	Infinity I30	Lexus ES 300	Audi A6
Chrysler Concorde	Ford Taurus	Buick LeSabre	Acura TL	Infinity Q45	Lexus GS 300	Audi A8
Dodge Intrepid	Jag S-type	Buick Park Ave	Honda Accord	Nissan Altima	Lexus GS 430	BMW 7-series
Mercedes E	Lincoln Continental	Buick Regal		Nissan Maxima	Lexus LS 430	Daewoo Leganza
Mercedes S	Lincoln LS	Cadillac DeVille			Toyota Avalon	Hyundai Sonata
Mitsubishi Diamante	Lincoln Town Car	Cadillac Eldorado			Toyota Camry	Hyundai XG350
Mitsubishi Galant	Mazda 626	Cadillac Seville				Kia Optima
	Mercury Grand Marquis	Chevy Aurora				VW Passat
	Mercury Sable	Chevy Impala				
		Chevy Malibu				
		Chevy Monte Carlo				
		Oldsmobile Intrigue				
		Pontiac Bonneville				
		Pontiac Grand Prix				
		Saab 93				
		Saab 95				
		Saturn L-series				

Table A-26: Minivans						
DCX	**Ford**	**GM**	**Honda**	**Nissan**	**Toyota**	**Other**
Chrysler Town&Country	Ford Windstar	Chevy Montana	Honda Odyssey	Nissan Quest	Toyota Sienna	VW Eurovan
Dodge Caravan	Mazda MPV	Chevy Silhouette				
Plymouth Voyager	Mercury Villager	Chevy Venture				

Table A-27: Small Trucks						
DCX	**Ford**	**GM**	**Honda**	**Nissan**	**Toyota**	**Other**
Crysler PT Cruiser	Ford Escape	Buick Rendevous	Acura MDX	Infinity QX4	Lexus RX 300	Hyundai Santa FE
Dodge Dakota	Ford Explorer	Chevy Blazer	Honda CRV	Nissan Frontier	Toyota 4Runner	Kia Sportage
Dodge Wrangler	Ford Ranger	Chevy Bravada	Honda Passport	Nissan Pathfinder	Toyota Highlander	
Jeep Grand Cherokee	Land Rover Freelander	Chevy S-10		Nissan Xterra	Toyota RAV4	
Jeep Liberty	Mazda B-series	Chevy Sonoma			Toyota Tacoma	
Mitsubishi Montero	Mazda Tribute	Chevy Tracker				
	Mercury Mountianeer	Chevy Trailblazer				
		GMC Envoy				
		GMC Jimmy				
		Isuzu Axiom				
		Isuzu Rodeo				
		Isuzu Trooper				
		Pontiac Aztek				
		Subaru Forester				
		Suzuki Grand Vitara				
		Suzuki Vitara				
		Suzuki XL7				

Table A-28: Large Trucks						
DCX	**Ford**	**GM**	**Honda**	**Nissan**	**Toyota**	**Other**
Dodge Durango	Ford Expedition	Chevy Avalanche			Lexus LX 470	
Dodge Ram	Ford F-Series	Chevy Escalade			Toyota Land Cruiser	
Mercedes M-class	Land Rover Discovery	Chevy Sierra			Toyota Sequoia	
	Lincoln Navigator	Chevy Silverado			Toyota Tundra	
		Chevy Surburban				
		Chevy Tahoe				
		Chevy Yukon				
		Chevy Yukon XL				