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

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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, and the burning of fossil fuels in particular.[i] In the United States, the transportation sector is the second largest emitter of greenhouse gases, producing about 27% of national greenhouse gas emissions annually.[ii] Transportation has an even greater impact in California, contributing 58% of the State's total greenhouse gas emissions.[iii]

Hybrid-electric vehicles (HEVs) employ efficiency-improving technologies that may 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 stalled acceptance of other emission-reducing technologies and fuel types have, for the most part, been overcome by HEVs.

Whether HEVs are an appropriate tool for reducing greenhouse gas 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.

To determine the emission and cost implications of purchasing HEVs, a thorough and objective evaluation of the entire life of the vehicles is required. The differences in lifecycle emissions and lifetime costs for comparable HEVs and ICEVs can be applied to the California vehicle fleet to determine whether using HEVs to reduce greenhouse gas emissions is appropriate. Conveying this information to consumers will aid them in making more informed purchasing decisions.

Objectives

1) **Measure and compare the lifecycle greenhouse gas emissions and lifetime consumer costs of an HEV and an ICEV**
2) **Evaluate the emission and cost effects of increasing the portion of HEVs in California new vehicle sales**
3) **Create a tool to inform consumers about the environmental and economic performance of different vehicles**

Project Approach

The environmental and economic impacts of vehicles were analyzed from a lifecycle perspective. The lifecycle of a vehicle includes all of the processes from the extraction of raw materials used in the vehicle through the disposal or recycling of these materials at the end of the vehicle's life (Figure 1). 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.

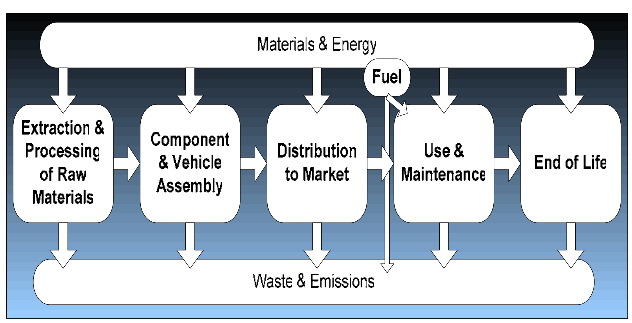

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Figure 1: Lifecycle of a vehicle

Three models were developed to compare the lifecycle greenhouse gas 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 used lifecycle assessment methodology to determine the greenhouse gas emissions of a Honda Civic Hybrid and a Honda Civic LX over their respective lifecycles. The HEV-ICEV Lifetime Cost Model calculated the present value[2] of the lifetime costs of a Civic Hybrid and a Civic LX, as well as those of a Ford Escape Hybrid and Escape XLT.

The Fleet Composition Model 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 greenhouse gas 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.[iv]

Several assumptions were consistent throughout this study, including a vehicle lifetime of 240,000 km (150,000 mile), annual driving distance of 19,000 km (12,000 mile), a discount rate of 3%, and a $2.50 per gallon gasoline price. Finally, large trucks were assumed to have a different hybrid technology than the other classes of vehicles based on current technology trends

Civic Emissions

The Carbon-dioxide equivalent Lifecycle Emissions Model found that a Honda Civic Hybrid generates 47.1 tonnes of carbon dioxide-equivalent (CO_2e)[3] over the entire vehicle lifecycle, compared to 62.5 tonnes for a Honda Civic LX (Figure 2) – 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 greenhouse gas 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 environmental impact of a vehicle. For instance, the 29% difference in fuel economy between a Civic Hybrid and Civic LX results in a 29% difference in use emissions, but only a 25% difference in total lifecycle emissions. The four percent difference is due to the additional materials used in the Civic Hybrid.

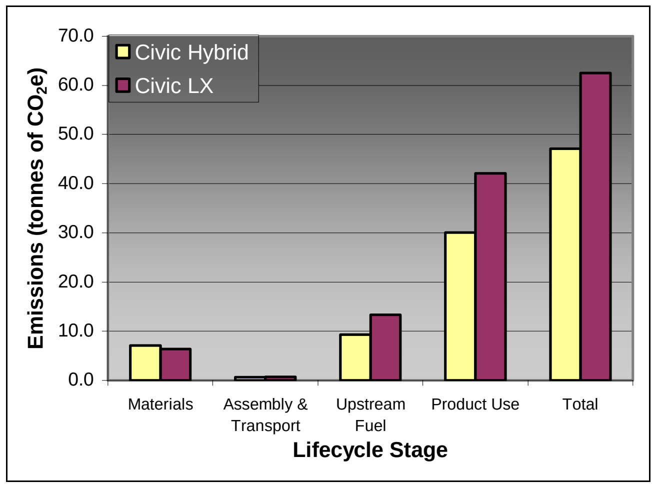

Figure 2: Lifecycle greenhouse gas emissions of Civics

Civic & Escape Costs

The HEV-ICEV Lifetime Cost Model found that the present value of lifetime costs to a consumer is $1,585 higher for a Civic Hybrid than for a Civic LX, but the present value of a Ford Escape Hybrid is $783 lower than that of a Ford Escape XLT. The breakeven point occurs when the savings in fuel expenditures completely offset the initial price premium of an HEV.

[2] The present value is the sum of all discounted cash flows

[3] Carbon dioxide-equivalent (CO_2e) is a unit commonly used to normalize the warming effects of different greenhouse gases

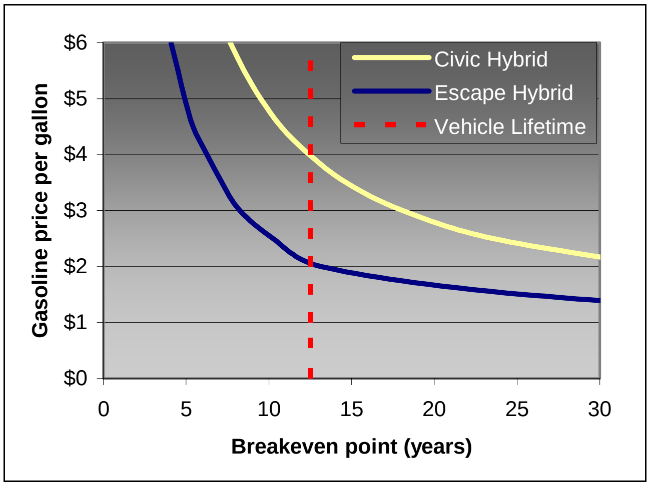

Figure 3: Breakeven point for Civic and Escape Hybrids vs. average vehicle lifetime

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 and/or increased driving distances. Figure 3 shows the breakeven points for the two HEVs for a range of gasoline prices.

Fleet Emissions and Costs

The Fleet Composition Model found that greenhouse gas emissions from California's vehicle fleet would be lower if HEVs increase their diffusion into the market. Figure 4 shows the lifecycle emission savings attributable to the vehicles sold in each model year. For the 2025 model year, our predicted 20% HEV diffusion would result in a savings of 13.9 million tonnes of CO_2e, compared to a no-HEV baseline scenario. The cumulative emission savings for the 2002 to 2025 model years would be 148 million tonnes of CO_2e.

Despite these annual emission savings, total emissions were still projected to grow during the period analyzed due to growth in the total number of vehicles on the road in California. Even with HEVs comprising 20% of all new vehicles, lifecycle greenhouse gas emissions for the 2025 model year would still be 95.6 million tonnes of CO_2e higher (47%) than the emissions from the 2002 model year.

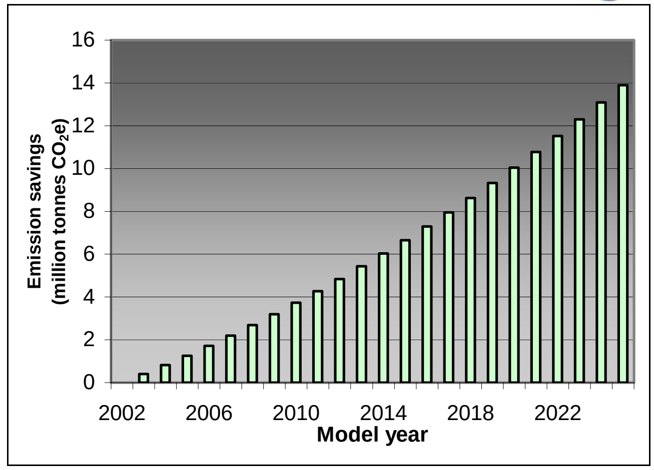

Figure 4: Fleet-wide emission reductions due to HEV diffusion, by model year

Across all vehicle types, discounted lifetime consumer costs were projected to be lower for most HEVs than for their ICEV counterparts; the savings in gasoline expenditures make up for the higher purchase price. The discounted savings for each model year are shown in Figure 5. For the 2025 model year, discounted savings of $350 million across the vehicle fleet would be achieved with 20% HEV diffusion. The cumulative discounted lifetime savings for the 2002 to 2025 model years would be approximately $4.1 billion.

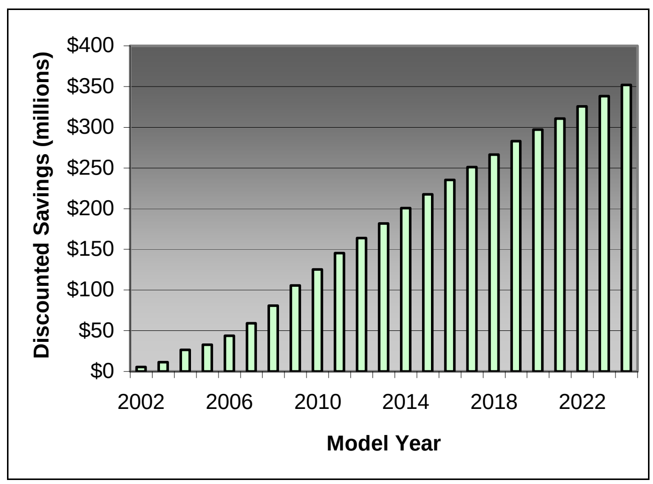

Figure 5: Fleet-wide cost reductions due to HEV diffusion, by model year

Hybrid-electric technology tends to produce a greater relative savings in greenhouse gas emissions and fuel costs for vehicles that started out with lower fuel efficiencies. On average, a small car HEV would emit fewer greenhouse gases 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 (see Figure 3). 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 (Figure 6).

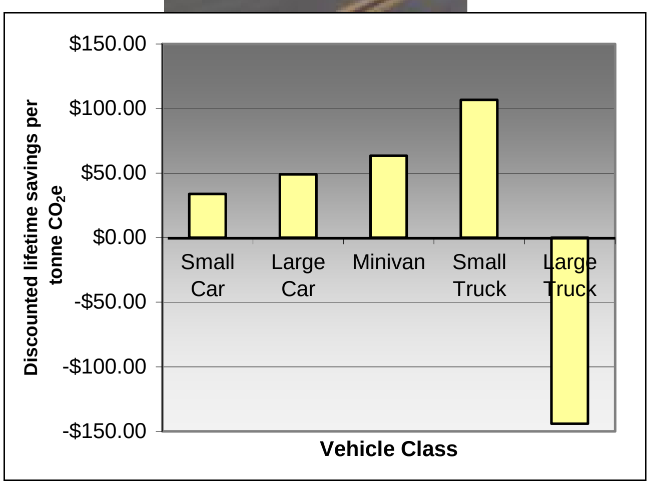

Figure 6: Discounted lifetime savings of decreasing lifecycle emissions by one tonne of CO_2e

Informing Consumers

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 potentially purchase. The Lifecycle Environmental and Economic Vehicle scoring system estimates the lifecycle greenhouse gas emissions and lifetime consumer costs based on vehicle characteristics (fuel economy, price, vehicle class, HEV or ICEV) input by a user. Environmental and economic impacts are scored based on percentiles relative to a vehicle database, ranging from 1 (low impacts) to 100 (highest level of impacts).

Conclusions

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

The Honda Civic Hybrid emits about 25% less greenhouse gases than a similar ICEV over its entire lifecycle. If future HEVs are able to achieve similar emission reductions, significant reductions in greenhouse gas 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 diffusion 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 greenhouse gas emission reductions for HEVs that do not break even. But 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 an appropriate tool for reducing greenhouse gas emissions in California.

On an individual basis, HEVs emit less greenhouse gas emissions 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.

Key Conclusions

1) **Vehicle use accounts for about 65% of lifecycle greenhouse gas emissions**
2) **Lifecycle greenhouse gas emissions are significantly lower for HEVs than for similar ICEVs**
3) **The ability of an HEV to break even depends largely on the fuel efficiency of the ICEV to which it is compared**

[i] Intergovernmental Panel on Climate Change (2001). Climate Change 2001: The Scientific Basis.

[ii] Environmental Protection Agency (2005). Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003.

[iii] California Energy Commission (2002). Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999.

[iv] Lipman and Delucchi (2004). Hybrid-Electric Vehicle Design Retail and Lifecycle Cost Analysis.