

The Benefits of Reducing Fuel Consumption and Greenhouse Gas Emissions from Light-Duty Vehicles

Thomas C. Austin, Thomas R. Carlson and James M. Lyons

Sierra Research, Inc.

Copyright © 2008 SAE International

ABSTRACT

Concerns regarding U.S. dependence on crude oil from politically unstable regions and the impact of fuel combustion on climate change have led to new state regulations and proposed additional federal regulations requiring reductions in fossil fuel use by passenger cars and light-duty trucks. Significant reductions in fuel consumption can be achieved while maintaining the performance and size of current production vehicles; however, it does not appear that the benefits will be commensurate with the costs.

Based on the same model employed by the United Nations Intergovernmental Panel on Climate Change, nationwide reductions in light-duty motor vehicle greenhouse gas emissions of 30% will have no measurable effect on ambient temperature. This calls into question the assumption that the cost of reducing greenhouse gas emissions has corresponding economic benefits related to the moderation of climate change.

Some technologies for reducing fuel consumption, such as the use of cylinder deactivation systems and lightweight steel, provide a net present value of fuel savings over the expected service life of the vehicle that exceeds the cost of the technology. However, the cost associated with the use of hybrid-electric drive systems translates to over \$200 per barrel of oil saved. Even during a time when the price of oil is substantially in excess of the marginal cost of production, hybrids do not provide an economic benefit to consumers. Given the abundance of fossil resources from which motor vehicle fuels can be produced, it does not appear that hybrids will be cost effective for the foreseeable future unless the cost of the technology can be significantly reduced.

INTRODUCTION

In 2002, California Assembly Bill 1493 (AB 1493) was passed by the State Legislature "to slow the effects of global warming." The bill required the California Air Resources Board (CARB) to adopt regulations limiting the greenhouse gas (GHG) emissions for passenger

cars and light-duty trucks. Since 97% of all greenhouse gas emissions emitted by motor vehicles are associated with fuel combustion, the principal means of compliance involves reducing fuel consumption.

In addition to reducing the effects of global warming, reduced vehicle fuel consumption could arguably alleviate concerns regarding the future price and availability of fossil fuels. Reduced vehicle operating costs would be an obvious benefit resulting from reduced fuel consumption.

Even if state standards requiring improved fuel economy are ultimately determined to be preempted by the Energy Policy and Conservation Act, it is almost certain that standards requiring improved fuel economy will be adopted at the federal level. As this paper is being written, both the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) are known to be considering new regulations.

This paper addresses the benefits (or lack thereof) associated with standards adopted by CARB in 2004 that require approximately a 30% reduction in greenhouse gas emissions from passenger cars, light-duty trucks, and medium-duty passenger vehicles (MDPVs). (A companion paper, referenced below, addresses the technological feasibility and cost of the CARB standards in greater detail.) This paper describes the cost-effectiveness of the standards from the perspective of the consumer and the effect of the standards on climate change. It also addresses whether significant reductions in fuel consumption are necessary to ensure the continued availability of fossil fuels. Although the focus is on the specific standards adopted by CARB, the results are generally applicable to any standards requiring similar levels of fuel economy improvement.

FUEL ECONOMY REQUIRED BY THE CARB STANDARDS

In September 2004, CARB adopted a regulation limiting GHG emissions from light duty vehicles on a "CO₂-

equivalent” basis. In other words, the regulations control carbon dioxide (CO₂) and several other compounds that can be translated into equivalent CO₂ emissions based on their global warming potential. For passenger cars (PCs) and light-duty trucks below 3,750 pounds test weight (LDT1), the “mid-term” (2016) CO₂-equivalent standard is 205 g/mi. For the heavier light-duty trucks (LDT2) and MDPVs, the 2016 CO₂ equivalent standard is 322 g/mi.

As explained in detail in a companion paper,¹ the 205 g/mi standard for passenger cars and LDT1 vehicles is equivalent to 43.7 mpg for a vehicle that uses a conventional, HFC-134a air conditioning system and uses no measures to reduce nitrous oxide (N₂O) or methane from the assumed baseline levels. This is 59% higher fuel economy than required under the CAFE standard for passenger cars, which is 27.5 mpg. Passenger cars converted to HFC-152a refrigerant (which reduces the CO₂-equivalent emissions due to A/C refrigerant by more than 90%) and that also use a variable displacement compressor with “external control” earn a credit of 16.6 g/mi, which allows compliance with the standard with CO₂-equivalent emissions (including methane and N₂O) of 221.6 g/mi. To account for the methane and N₂O, exhaust CO₂ emissions would need to be 219.7 g/mi, which is equivalent to 40.4 mpg.

The 332 g/mi standard for LDT2 and MDPV vehicles is equivalent to 26.9 mpg for a vehicle with a conventional air conditioning system. This is 21% higher than the 2007 federal CAFE standard for light-duty trucks of 22.2 mpg that was in place when CARB adopted the CO₂ regulations in September 2004. Since then, the National Highway Traffic Safety Administration has raised the CAFE standard for light-duty trucks to a size based standard equivalent to 24.1 mpg. CARB’s regulations require 12% higher fuel economy for vehicles with conventional air conditioning systems (however, the standards are not directly comparable because the CAFE standards for light-duty trucks cover LDT1s). With an alternative air conditioning system (earning an 18.5 g/mi credit), the required level of fuel economy to meet the CARB standard drops to 25.4 mpg.

Table 1 summarizes the CARB “Mid-Term” requirements once they are fully phased in. (More stringent standards are under consideration for post-2016, but have not yet been proposed.)

COST OF COMPLIANCE WITH THE CARB STANDARDS

The estimated cost of compliance with the CARB standards depends on assumptions made with respect to the compliance strategy that will be employed. If, for example, it is assumed that compliance will be achieved through vehicle downsizing, reduced performance, more aerodynamic vehicle shape, and/or the selection of tires with reduced rolling resistance, then significant reductions in fuel consumption can be achieved without any increase in vehicle price (or even with a price reduction). However, such measures affect vehicle attributes to which consumers assign value.

As described in the companion paper referenced above, we have estimated the increase in retail price associated with meeting the CARB standards based on the assumption that other vehicle attributes will not be changed. As a result, the size, shape, and performance of passenger cars and light-duty trucks were not assumed to change on average. This precluded the use of the lowest-cost measures available to reduce fuel consumption. The complete redesign of bodies and suspensions to maximize the use of ultralight steel was also excluded because it would not be feasible for manufacturers to produce unique bodies and suspensions for vehicles sold in California and other states enforcing the California standards. The analysis was done with and without the assumed use of gasoline direct injection (GDI) on overhead cam engines (the feasibility of which depends on whether it is needed for competitive or compliance reasons in all 50 states.)

Our analysis determined that the lowest cost combinations of design changes necessary to achieve compliance would include widespread use of measures to reduce engine friction and parasitic losses, cylinder deactivation and variable valve lift and timing, 6-speed automatic transmissions, and gasoline direct injection. Each of these measures was estimated to cost less than \$100 per percent reduction in fuel consumption when applied individually. Used in combination, however, they were not adequate to achieve compliance with the CARB standards. Each of the ten manufacturers evaluated would also require some use of hybrid systems, which were estimated to cost over \$200 per percent reduction in fuel consumption. The percent of hybrids required depends on whether the use of GDI is assumed, but,

	--- Passenger Cars/LDT1 ---		----- LDT2/MDPV -----	
	Equivalent CO ₂	Fuel Economy	Equivalent CO ₂	Fuel Economy
Conventional A/C Systems	205 g/mi	43.7 mpg	332 g/mi	26.9 mpg
Alternative A/C Systems	205 g/mi	40.4 mpg	332 g/mi	25.4 mpg

Table 1. CARB’s “Mid Term” (2016) “Climate Change Emission Standards” and Associated Fuel Economy Levels

based on our assumption that future model mix will not significantly change, each manufacturer requires at least some hybrids whether GDI is used or not. As described in more detail in the companion paper, the sales-weighted average increase in retail price was estimated at about \$3,700 per vehicle without the use of GDI. The average cost drops to about \$3,300 if GDI is used on overhead cam engines that have been resized for constant performance. The widespread use of GDI in this manner was not considered feasible for compliance with California standards in 2016 but was addressed to illustrate the longer term potential for this technology on a nationwide basis.

It should be noted that some manufacturers were shown to have significantly higher compliance costs than others, which is expected to affect their ability to remain competitive. Without the use of GDI, the average estimated increase in retail price runs from just under \$2,400 for Honda, Hyundai, and Toyota to almost \$5,000 for General Motors and Nissan. With GDI, the estimated increase in retail price runs from \$1,600 to \$1,700 for Honda, Hyundai, and Toyota to over \$4,400 for three other manufacturers.

COST-EFFECTIVENES OF CARB STANDARDS

From the perspective of the theoretical “rational consumer,” the acceptability of the design changes to reduce fuel consumption depends on how the price the consumer must pay for the technology compares to the value of the fuel savings. Based on a simplistic analysis, the cost effectiveness of a particular technology can be estimated by calculating the fuel saved over the life of the vehicle and comparing the cost of the technology to the value of the fuel saved. Assuming, for example, a baseline fuel economy of 30 mpg and a vehicle life of 150,000 miles, the lifetime gasoline cost is \$12,500 at a fuel price of \$2.50 per gallon. A 1% reduction in fuel consumption would reduce the lifetime fuel cost by \$125. But this does not mean that a rational consumer would be willing to spend \$125 per percent reduction in fuel consumption.

The simplistic analysis described above fails to account for several important factors, including (1) the time value of money, (2) the difference between fuel economy in customer service and on the CAFE test procedures, (3) differences in the fuel economy improvement that individual technologies provide in customer service compared to the CAFE test procedures, and (4) the “rebound effect” (i.e., the extra driving induced by vehicles with higher fuel economy). Higher sales taxes associated with higher priced technology must also be considered.

Accounting for the time value of money is necessary to address the fact that no rational consumer would borrow \$1,000 today to pay for more sophisticated technology that would provide a fuel savings of \$1,000 over a period of ten years. A discount rate has to be applied to future fuel savings to address this factor. We have used an 8% discount rate in our calculations, which, being close to the unsubsidized interest rate for a new car loan, is considered a lower bound.

Calculations using the fuel economy measured by the CAFE test procedures are also problematic. It has long been recognized that fuel economy in customer service is lower than the fuel economy reported using the CAFE test procedures. One obvious factor contributing to the shortfall in customer service is that the EPA Highway cycle was intentionally developed to represent vigorous enforcement of a nationwide 55 mph speed limit.²

The difference between driving patterns in customer service and on the CAFE test procedures also affects the reduction in fuel consumption associated with individual technologies. For example, a technology that reduces fuel consumption at idle will provide a different average benefit if the fraction of idle operation in customer service is different from the fraction of idle operation on the CAFE test procedures.

A 1999 paper by Greene, et al, from Oak Ridge National Laboratory³ describes the body of research that supports the existence of a “rebound effect” when automotive fuel economy increases. The rebound effect is basically an extension of the “Law of Demand”—when the cost of something decreases (in this case vehicle travel), there is a natural tendency for consumers to demand more of it. As Greene explains, numerous researchers have documented that a rebound effect exists for increasing automotive fuel economy and Greene concludes that the long-term effect is 20%. In other words, a 100% improvement in fuel economy induces a 20% increase in vehicle travel. In its recent rulemaking regarding light-duty truck fuel economy standards, the National Highway Traffic Safety Administration (NHTSA) also addressed the rebound effect and concluded that the magnitude of the effect was the same as Greene had estimated.⁴ To be conservative, we have assumed a 17% rebound effect in our analysis.

Accounting for all of the above-described factors, the following equation shows the calculation of the net present value (NPV) of the increased cost to a consumer of design changes that reduce fuel consumption:

$$NPV = -RPE * (1 + tax) + \sum_{i=1}^{i=n} \left[\left(\left(\frac{FP}{mpg_{base}} * VMT_i \right) - \left(VMT_i * \left(1 + \left(\left(1 - \frac{mpg_{base}}{mpg} \right) * REB \right) \right) * \frac{FP}{mpg} \right) \right) / (1 + DR)^i \right]$$

where:

RPE = increase in retail price equivalent (dollars),
 Tax = sales tax applied to the increase in RPE,
 N = number of years over which the fuel price savings is considered,
 FP = fuel price in dollars per gallon,
 mpg_{base} = real baseline fuel economy in miles per gallon (85% of CAFE),
 VMT_i = annual vehicle miles travelled in year i , adjusted for scrappage,
 mpg = real fuel economy after the design change,
 REB = rebound effect (% increase in VMT per % reduction in fuel cost), and
 DR = discount rate.

The first term in the equation is the increase in price the consumer pays for the design change multiplied by 1.0 plus the applicable sales tax (e.g., 1.08 for 8% sales tax). The remainder of the equation calculates present value fuel cost savings for each year, while accounting for the rebound effect and a discount rate.

For an example of how the equation is applied, we consider the case of a hybrid system applied to a passenger car with a baseline CAFE rating of 29.1 mpg (the actual 2003 model year baseline). As shown in the previously referenced companion paper, we estimate the increase in retail price for a strong hybrid system applied to a mid-size passenger car at \$5,370. When an 8% sales tax is considered, the cost to the consumer is \$5,800 ($\$5,370 \times 1.08$). The savings in the first year are calculated by subtracting the actual fuel cost from the baseline fuel cost and then applying the discount rate.

The baseline fuel cost is the fuel price, assumed in this example to be \$2.50 per gallon, divided by the baseline fuel economy and then multiplied by the annual miles of travel, calculated as follows:

$$\frac{FP}{mpg_{base}} * VMT_i = \frac{\$2.50}{(0.85 * 29.1)} * 16,071 = \$1,624$$

where:

16,071 = average annual VMT for passenger cars during their first year of operation, and
 0.85 = standard factor used to translate CAFE to customer service fuel economy.

The first year annual mileage of 16,071 in the above equation is extracted from CARB's "EMFAC" emissions model. The 0.85 factor adjusts the "composite" CAFE value to what consumers are expected to achieve in customer service when the "city" mpg is discounted by 10% and the "highway" mpg is discounted by 22%.

The actual fuel cost with the hybrid system is calculated from the following portion of the equation that accounts for the rebound effect:

$$\begin{aligned}
 & VMT_i * (1 + ((1 - \frac{mpg_{base}}{mpg}) * REB * \frac{FP}{mpg})) \\
 &= 16,071 * (1 + ((1 - \frac{(0.85 * 29.1)}{(0.82 * 39.6)}) * 0.17) * \frac{\$2.50}{(0.82 * 39.6)}) \\
 &= 16,071 * (1 + ((1 - 0.7617) * 0.17) * \$0.0770) \\
 &= 16,071 * (1.0405) * \$0.0770 = 16,722 * \$0.0770 = \$1,288
 \end{aligned}$$

As shown above, the annual miles of travel increase by 4.1% due to the rebound effect and the actual fuel cost drops to \$1,288. (The 39.6 mpg CAFE value for the hybrid reflects a 26.5% reduction in fuel consumption from the 29.1 mpg baseline. The 0.82 adjustment factor applied to the fuel economy of the vehicle equipped with a hybrid system is based on simulation modeling showing that the benefits of hybrids in customer service are somewhat less than on the CAFE test procedures.)

Subtracting the revised fuel cost from the baseline fuel cost and accounting for the discount rate involves the following calculation:

$$(\$1,624 - \$1,288) / (1 + 0.08)^1 = \$336 / 1.08 = \$311$$

Based on the above calculations, the \$5,800 cost to the consumer of the hybrid system has been offset by a fuel cost savings with a discounted present value of \$311 at the end of the first year of ownership. When performing the above calculations for additional years, it is necessary to account for the fact that annual VMT is decreasing as the vehicle ages, and some vehicles are being retired from customer service due to accidents. We have used mileage accumulation rates and scrappage rates from CARB's model in performing those calculations. We have accounted for fuel costs savings over a period of 13 years, the point at which mileage accumulation is at the lifetime average. (However, it is more likely that average consumers would consider the savings during the much shorter period of time they expect to own the vehicle.)

Using an 8% discount rate, a 17% rebound effect, an 8% sales tax, and vehicle simulation modeling to account for fuel economy in customer service, hybrid systems do not pay for themselves in 13 years unless the price of gasoline rises to \$7.05 per gallon. Accounting for the relationship between the price of gasoline and the price of oil, the associated crude oil price is over \$215 per barrel.⁵ This indicates that fuel economy or greenhouse gas emissions standards requiring the use of hybrid systems will not be cost effective unless oil prices are in excess of \$200 per barrel. (The breakeven gasoline price increases when hybrid systems are applied in conjunction with lower cost technologies for reducing fuel consumption.)