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ALAN R. WEVERSTAD

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General Motor
Public Policy Cent

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May 7, 2002

Docket Management
Room PL-401
400 Seventh Street, S.W.
Washington, D.C. 20590

Re: Docket No. 2002-11419 - 8
National Academy of Science Study and Future Fuel Economy Improvements, Model Years 2005-2010

Attached is General Motors (GM) response to the National Highway Traffic Safety Administration's (NHTSA) Request for Comments published in the February 7, 2002 Federal Register regarding the fuel economy of manufacturers' light duty trucks for MYs 2005-2010, 67 Fed. Reg. 5767.

We are providing a version to the docket with confidential information excluded. We are providing copies containing confidential information to the Chief Counsel's Office.

General Motors requests that all material marked as confidential either with brackets and a "c" superscript **[ ]**^{c} or with the word "Confidential" in this document be afforded confidential treatment by NHTSA. This information is being provided to NHTSA voluntarily, is not customarily made public by General Motors and contains trade secrets and commercial information protected under 5 U.S.C. Section 552(b)(4), 49 CFR Part 512 and Section 505(d)(1) of the Motor Vehicle Information and Cost Savings Act.

This material could enable other motor vehicle manufacturers to gain a significant competitive advantage over General Motors. By knowing the content of this material, competitors could more readily compare their product plans and market projections with General Motors and identify areas needing particular attention. In such a situation, competitors could save development expenditures normally associated with evaluation and/or development without compensating General Motors for the expense it incurred throughout the years in making plans and projections. This dual threat of competitors' unearned savings and General Motors uncompensated expense would result in a competitive disadvantage to General Motors.

GM maintains documents of the type comprising the confidential information in this document under a record keeping system which is intended to control dissemination within General Motors Corporation, and to assure that such materials are not disseminated outside of General Motors, except as described in the attached certification, which is made pursuant to 49 CFR Section 512.4(e).

documents such as those marked as confidential in this document have, to the best of our knowledge, normally been granted confidential treatment by NHTSA in the past.

We request that this document receive confidential treatment until the end of the 2010 MY except for the financial information presented in responding to Questions 3 and A11 for which we request an indefinite period for confidential treatment.

This document for which confidential treatment is being requested is being submitted to the Office of the Chief Counsel of NHTSA. It is requested that notice concerning the Agency's determination of confidentiality for these materials be sent to my attention. We also ask to be notified before NHTSA releases to the public any information for which confidential treatment is being sought.

If you have any questions regarding this response, please contact me or Mr. Richard W. Schneider of my staff at (313) 665-2964.

Sincerely yours,

Alan R. Weverstad, Director
Public Policy Center

General Motors Response to NHTSA Request for Comments Regarding the Fuel Economy of Manufacturers' Light-Duty Trucks for Model Years 2005-2010

Overview

The following 15 pages include a summary of many of the main points from Attachment I, as well as GM's comments on critical issues, which we believe should be considered by NHTSA as it moves into a Notice of Proposed Rulemaking phase.

NHTSA has responsibility under the Energy Policy and Conservation Act to set CAFE standards for light trucks, and we plan to participate fully in the rulemaking process. Nevertheless, we continue to be concerned for many reasons that CAFE standards are an inefficient and ineffective way to reduce fuel usage. CAFE standards distort the market and put some manufacturers at odds with their customers. Furthermore, as the National Academy of Sciences (NAS) recognized in its 2002 fuel economy study, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards", CAFE standards tend to benefit foreign manufacturers at the expense of domestic manufacturers. The NAS study also recognized the adverse safety consequences of CAFE and the problems it creates for consumers.

Organization of Response

Our response to the 36 questions asked by NHTSA is contained in Attachment 1. The attachment identifies each of the 20 questions listed in the body of the NHTSA's Request for Comments sequentially 1 through 20. The 16 questions asked by NHTSA in its Appendix to the Request for Comments are identified as A1 through A16. Our response to some of the questions include reference material, provided in additional attachments as follows:

Attachment 1	GM's response to NHTSA's 36 questions
Attachment 2	List of coding conventions used in truckline model descriptions
Attachment 3	Detailed listing of GM's CAFE forecasts
Attachment 4	SAE paper, "Aggregating Technologies for Reduced Fuel Consumption: A Review of the Technical Content in the 2002 National Research Council Report on CAFE", SAE 2002-01-0628
Attachment 5	Andrew N. Kleit, "Short- and Long-Range Impacts of Increases in the Corporate Average Fuel Economy (CAFE) Standard", February 7, 2002
Attachment 6	"Analysis of the Relationship Between Passenger Vehicle Weight and the Risk of Traffic Fatality and Injury", Exponent Failure Analysis Associates, Inc, July 17, 2001
Attachment 7	Letter from R.C. Lange, Executive Director, Safety Integration, General Motors, and NAS Panel on CAFE, Fleet Safety and Vehicle Mass, March 20, 2001
Attachment 8	GM Comments on Executive Order 13045 Regarding Disproportionate Impact of CAFE on Children

CAFE and National Goals

Congress established CAFE standards to help reduce U. S. dependence on foreign oil and reduce total U.S. fuel consumption. Initially, CAFE was intended to address energy security concerns. More recently, some have advocated higher fuel economy standards as a means of reducing CO_2 emissions to address climate change.

During the two oil crises of the 1970's and the period of rapidly increasing gasoline prices in the early 1980's, the goal of higher CAFE was relatively compatible with the needs and priorities of our customers. Customer acceptance of new technologies and, more importantly, new vehicle configurations (i.e. smaller front-wheel drive cars and smaller engines) resulted in large gains in

CAFE for the major domestic auto manufacturers. At that time the truck market was clearly split between domestic manufacturers' full-size trucks and import manufacturers' small trucks. In the early 1980's the domestic truck manufacturers entered the small truck market, resulting in domestic truck CAFE improvements. GM's truck CAFE from 1979 to 1983 exceeded the standards, demonstrating that market forces can and do drive higher fuel economy. During this period, GM's light truck CAFE increased 81% from 11.3 mpg in 1979 MY (representing trucks with less than 6000 lbs. gross vehicle weight (GVWR)) to 20.5 mpg in 1983 MY (representing trucks with less than 8500 lbs. GVWR). Since that time and coincident with the fall in fuel prices, GM's truck CAFE has been relatively stable as fuel economy improvements have largely been offset by consumer demand for larger vehicles with more powerful engines and expanded features. During this same period, the CAFE of unconstrained manufacturers has declined.

GM now offers a full range of trucks with a wide diversity of powertrains and fuel economy levels varying from 15 mpg to 29 mpg. However, currently consumers have little incentive to make fuel conservation a priority. Survey data show fuel economy ranking 23rd out of 25 in the "Top 3 Most Important Reasons for Purchase/Lease" (see our response to Question 6). Gasoline is relatively cheap and plentiful, and the cost to drive an average new GM truck has decreased from $0.16 per mile in 1980 to $0.09 per mile today. As a result, GM's ability to "sell" fuel economy is limited. We approach fuel economy increases largely through technology improvements in individual products that are cost-effective and do not adversely affect other vehicle attributes, but our ability to improve our fleet average depends on the mix of vehicles that consumers choose to purchase.

It is critical to GM to meet the needs of truck buyers. If GM does not offer the vehicles expected and demanded by consumers, they will select another manufacturer's product. The demand for full-size trucks will continue to be met even if some manufacturers cannot participate because of CAFE constraints. Since CAFE standards primarily impose a constraint on full-line manufacturers, such as GM, it can be argued that establishing binding CAFE standards for these automakers only redistributes the share of market segments to those less constrained manufacturers. Binding CAFE, in effect, allows unrestrained conquest of sales from GM by manufacturers not currently competing in, or with smaller shares of, certain market segments. To the extent redistribution of market shares takes from the domestic manufacturers and adds to overseas manufacturers, there is a loss of U.S. auto industry jobs. Moreover, such a redistribution of market shares does not result in any reduction of fuel consumption of the total U. S. fleet.

Truck Fuel Economy Technologies

In the past, the domestic industry, including GM, has relied heavily on vehicle downsizing, conversion to front-wheel drive, and smaller engines to meet the demand for more fuel-efficient cars. Other new technologies, such as four-speed automatic transmissions with locking torque converters, lower rolling resistance tires, fuel injection, improved aerodynamics and mass reduction have also been used. These changes were generally accepted in the marketplace. Two notable exceptions in the GM product line-up occurred in the 1980s. In 1986, the second downsizing of the Cadillac Eldorado, Oldsmobile Tornado, and Buick Riviera produced vehicles that were simply too small for their intended markets. Also, the initial introduction of the Chevrolet Cavalier with a 1.8 liter engine was found to be substantially underpowered by consumers.

The application of front-wheel drive conversions in cars improved fuel economy because it allowed more efficient packaging and improved traction. Engine downsizing was also generally accepted so long as performance levels compatible with customer expectations were

maintained. While many of these technologies and strategies can be and are used for trucks, there are limitations on their implementation due to the unique requirements of the truck market.

GM markets trucks in a wide range of sizes and drivetrains, and many of today's basic truck dimensions are dictated by functional requirements. Trucks are purchased to carry many passengers, carry cargo or load, or tow a trailer. Items such as a 4' x 8' sheet of plywood have become an industry standard for determining minimum width and length dimensions for many trucks. The capability to carry heavy and/or bulk cargo determines the size and strength of components such as tires, brakes, axles, and frames, as well as the location of the drive wheels. These components are determined by the rated capability of the truck, even if some owners use that capability only infrequently. Our response to Question 6 shows that customers do indeed use their trucks at these peak performance levels. It also shows that over 50% of truck owners use their vehicles for towing and that overwhelmingly, sport utilities are used to transport children not just solo commuters.

Trucks are predominantly rear or four-wheel drive vehicles. While front-wheel drive yields an improvement in traction for cars, it is not so for most trucks. The traction advantage in cars is due to weight distribution over the drive wheels, which is typically front biased for cars with the engine located over the front wheels. Even with a full load, most cars retain a front biased weight distribution. For trucks with the capability and requirement to carry heavy payloads, the weight distribution should also be over its drive wheels. In contrast to passenger cars, however, when a truck is loaded most of the cargo weight is carried on the rear wheels. Therefore, when the need for traction is greatest, the highest load is on the rear wheels. The need for rear-drive is also required because of the weight shift rearward on hills, and by reduced traction in off-road driving.

The potential for engine downsizing in trucks is limited by the requirement to perform with heavy payloads and trailers. Truck powertrains are sized to have adequate performance at these higher loaded weights. Furthermore, body-on-frame integral construction, which was used to reduce weight across most of GM's passenger car fleet, is less appropriate for large trucks due to their wide range of configurations and performance requirements (see our response to Question A7).

Aerodynamics and tires can improve truck fuel economy, but not as much as in passenger cars. Open beds, boxier designs (necessitated by the need to carry standard cargo), and higher ride contribute to higher drag forces on trucks. Similarly, tire construction for heavier loads and off-road use limits the gains achievable from truck tires relative to car tires.

While there are limitations, many efficiency improvements utilized by GM in the car fleet have also been incorporated in our truck fleet. For example, four-speed automatic transmissions and locking torque converters are now used in all GM trucks sold with automatic transmissions. Our engines have incorporated low friction, some have variable valve timing, and others will soon offer displacement on demand technology (see our response to Question A6). Lower rolling resistance tires are used in most applications and sequential port fuel injection has been applied across the board in all engines. GM's aerodynamics laboratory is also working to improve the aerodynamic drag of GM trucks such as the new Silverado/Sierra, the Yukon/Tahoe/Suburban and the Trailblazer/Envoy.

Further improvements in fuel economy through the application of cost-effective technologies that are compatible with customer expectations is a key part of GM's future product plans. Customers of vehicles in every size class want their product to be fuel efficient – but only while

maintaining all other necessary features. As a result, we work to provide our customers with fuel-efficient vehicles that also satisfy their other more important requirements. There is no incentive for a manufacturer to withhold reliable and cost-effective fuel economy technologies because they provide a marketing advantage, even in a market where consumers do not give fuel economy the priority they did in the 1970s and early 1980s.

CAFE Effects on Customers and Manufacturers

GM believes that CAFE standards above our capability will do little to meet the statutory goal of energy conservation for the nation, but rather cause a redistribution of sales to other less constrained manufacturers or slow the fleet turnover as vehicle owners keep their existing vehicles longer. These market shifts could have the unintended consequence of greater fuel usage nationwide if the shift is from a GM truck to another manufacturer's model. This is because on a model-by-model and powertrain comparison, GM is frequently the highest fuel economy performer. For example, when GM's 2001 truck models are matched up with Honda and Toyota's comparable models and powertrains, our truck models, on average, match or beat theirs. Another way of looking at GM's fuel efficiency is to wash away differences in sales mix. For example, an analysis of 2001 model year data showed that GM's truck CAFE would be comparable to Toyota's 2001 MY truck CAFE if we sold the same sales mix. Differences in CAFE do not represent different levels of technology as much as they represent the vehicle mix of individual manufacturers.

Only when there is an economic incentive, such as the higher fuel prices we saw in the early 1980's, will consumers act to change their preference towards vehicle attributes that favor better fuel economy. At low gasoline prices, stringent CAFE requirements do not reflect the market, but rather they create a hidden tax on the consumer. For CAFE to have any effect, it must, by definition, be set higher than the natural market demand for fuel economy. Constrained manufacturers must then either raise vehicle prices (because of the additional technology implemented on vehicles that the customer otherwise would not want to pay for) or change their models/features (so the customer does not get what he/she really wants).

CAFE forces an artificial level of fuel economy relative to prevailing fuel prices. If GM invests in and builds products customers do not want, CAFE standards become counter-productive. Customers will retain older less fuel-efficient, higher polluting vehicles or simply switch to another manufacturer who is less unconstrained by CAFE. It is worth noting that the truck CAFE of manufacturers such as Toyota and Honda has been on a downward CAFE trend, as they seek to become more successful players in the larger light truck segments. For example, Toyota's truck CAFE as reported to NHTSA has dropped 4.3 mpg between 1985 and 2001. Honda's truck CAFE has dropped 2.0 mpg since it began reporting truck CAFE in 1997. Again, any shifting of product sales from one manufacturer to another due to increases in CAFE levels does not save petroleum, but it does have a negative impact on GM's business and the U. S. economy.

CAFE and Safety

Numerous studies have shown that motor vehicle safety degrades with decreasing vehicle mass. Recent research shows that this relationship holds true even if weight reduction is concentrated in the heaviest vehicles, thereby making the fleet more homogeneous in weight. CAFE increases that push automakers in the direction of reducing vehicle mass will therefore degrade the aggregate safety performance of the motor vehicle fleet. The hypotheses that improved crash avoidance and reduced pedestrian involvement would result from lighter vehicles are shown by research to be false. GM believes there is no identified fleet mass reduction scenario in which the safety effect is neutral or beneficial.

The NAS Report concluded that "downsizing and downweighting of the vehicle fleet that occurred during the 1970s and early 1980s still appear to have imposed a substantial safety penalty in terms of lost lives and additional injuries." (NAS 2002:27) The report states that the U.S. passenger fleet downweighting and downsizing "resulted in an additional 1,300 to 2,600 traffic fatalities in 1993" (NAS 2002: 111) and "13,000 to 26,000 incapacitating injuries and 97,000 to 195,000 total injuries in 1993." (NAS 2002: 27, 72) Further, the Report states, "... the preponderance of evidence indicates that this downsizing of the vehicle fleet resulted in a hidden safety cost, namely, travel safety would have improved more had vehicles not been downsized." (NAS 2002: 69-70) This conclusion is the most significant safety-related observation in the NAS Report and CAFE's true safety toll is probably even higher (see response to Question 1). An energy program intended to save fuel that also results in the loss of up to 2,600 lives and several hundred thousand injuries annually is impossible to justify.

Uncertainties in GM's Product Plans

As part of GM's general business planning, we do not normally develop detailed CAFE forecasts as far into the future as NHTSA is requesting. Therefore, this submission provides detailed CAFE forecast information only through the 2007 model year, but it discusses our program plans through 2010 MY. We believe too much uncertainty exists in the post-2007 time period to develop detailed CAFE estimates, which require information on vehicle and powertrain parameters that are not known with any confidence so far in advance.

The estimates and product plans in this submission are based on assumptions and predictions, many of which may change or prove to be incorrect when the 2005 and later model years actually arrive. We urge NHTSA to consider the highly uncertain nature of projections so far into the future. Many factors influencing CAFE are beyond our control (e.g. fuel prices, market dynamics, future government and competitor actions, and the longer-term health of the automobile industry). Accordingly, the plans submitted here will inevitably change in ways that cannot be predicted today.

Even for 2005-2007 model years, GM's CAFE estimates may prove to be too high. History has shown that GM's forecasts, as well as NHTSA's forecasts, have overestimated the CAFE level our trucks actually achieved. For example, for 1988 through 1995 MYs, NHTSA overestimated GM's CAFE capability by an average of 0.4 mpg each year (see GM's January 25, 1994 letter to NHTSA concerning 1996-1997 MY truck CAFE rulemaking). Even our own estimates have consistently overstated our CAFE capability over this period, as unexpected market trends (i.e., the vehicle purchase decisions of our customers) have worked against higher fleet average fuel economy. In our August 3, 1994 submission to NHTSA's ANPRM, our CAFE forecasts for 1998 through 2000 MY were 1.3 mpg higher on average for each year compared to what we actually achieved. These forecasts were even 0.5 mpg higher on average than our "Higher Confidence Forecasts", which tried to reflect some of the uncertainty we foresaw for these years. Obviously, these "Higher Confidence Forecasts" did not sufficiently encompass the risk for these uncertainties.

Uncertainties that have materialized in the past and could reduce CAFE for 2005 MY and later include:

- Fuel Price – [

]^{c} Falling fuel prices would

adversely affect CAFE. Historically, both GM's and the government's forecast of gasoline prices have proven to be too high. (See our response to Question A14).

- Performance – [ ][c] but could lower CAFE if consumer demand exceeds expectations. The opportunity for automakers less constrained by CAFE to emphasize performance makes it impractical for GM to unilaterally reduce this vehicle attribute.

- Vehicle Features -- As consumers have purchased more trucks and fewer cars, they have demanded increased content to approach the comfort and convenience of cars. Additional comfort and convenience features (heated/cooled seats, automatic temperature control, heads-up displays, overhead storage, and information systems, etc.) inevitably add mass. This added weight can amount to as much as [ ][c] Customer convenience items like extra doors, better sound systems, navigational aids, dual climate controls, and larger wheels/tires add weight. Other feature such as 4WD and extended cab pickups work against increased fuel economy. Additional safety items, such as side impact roof rail air bags, 5 mph bumpers, and tire pressure monitors, also add weight. Since 1990, industry sales of 4-wheel drive trucks has jumped from 31% of light-trucks to 48% today. During this same period, the share of extended cab pickups has grown from [ ][c]

- Market Shifts -- Industry sales of large SUVs have skyrocketed from less than 100,000 in 1990 to 1.2 million in 2001. During this same time, industry sales of small pick-up trucks have actually declined. (EPA 2001 Trends Report)

- New Technology Programs -- GM's CAFE forecast is based on a product plan that includes a continuous infusion of new technologies. If some of these planned technologies do not successfully complete the development process, they must be delayed or cancelled. Some technologies may produce fuel economy improvements that are less than the forecasted gains. On balance, a clear bias can be seen over time, such that CAFE forecasts consistently exceed the actual level achieved. (See our response to Question 9 for specific examples.)

- Capital Investment – [ ][c] As discussed below, these plans are contingent on GM generating the necessary revenues and earnings thereby funding the resources necessary to develop these major programs. The capital investments required for these improvements are outlined in our response to Question A11.

Financial and Engineering Resources

These investments come at a time when the domestic industry is experiencing much uncertainty in the market. Developments since the September 11 attacks, the weak yen, and a highly competitive market, create an environment where future financial performance can have a major impact on future vehicle and engine programs. Executing the planned new models, engine programs and technology implementation in our future vehicles depends on the continued availability of necessary financial and engineering resources. Should NHTSA set CAFE standards beyond manufacturers' ability to improve fuel economy consistent with market

demand, the resultant loss of sales and jobs could lead the industry and the nation's economy into another economic downturn.

Demands on our financial and engineering resources will intensify as the industry faces additional requirements for safety features and equipment, emissions control, and other regulations. While these requirements directly limit our ability to increase the fuel economy of our vehicles (see our response to Question A5), they also have an important indirect effect in three areas:

1) demanding engineering resources (people and capital) to meet these requirements. Experienced electronics control engineers are in short supply and demands to meet more stringent emissions requirements mean fewer engineers working on fuel economy;
2) adding uncertainty and complexity to our programs as calibrations and vehicle mass change to meet these regulations; and
3) demanding capital funding that might otherwise have been invested in fuel economy.

In all, new regulatory requirements add considerably to the overall engineering challenge facing GM and add substantial uncertainty to our CAFE forecasts.

All of these demands are simultaneously competing for investment capital and engineering resources while our employees push to implement all the product programs necessary to remain competitive in the U.S. marketplace, and at the same time, expand into worldwide markets. These new requirements will not only strain financial and engineering resources but also add weight to vehicles, handicapping efforts to improve fuel economy.

<u>GM's 2005-2007 MY CAFE Forecasts</u>
In an attempt to capture some of these uncertainties and reflect the historical bias that both NHTSA and GM have experienced in CAFE projections, we are providing a range in our CAFE forecasts for 2005-2007 MY. The upper limit of our forecast represents our current "snapshot in time" estimate of our future CAFE levels, assuming successful execution of today's plans and no major changes from our base assumptions. The "Low Range" CAFE forecast for these years provides a lower value that captures some of the uncertainty and risk such as unexpected changes in technology risk, weight increases, and market shifts (see our response to Question A8 for specifics). Our projections of GM's CAFE is as follows:

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It is important to recognize the large uncertainty in these forecasts and that our previous forecasts (including our "Low Range" forecasts developed in 1994 for 1998-2000 MYs) have proven to be significantly optimistic. Many critical factors are outside a manufacturer's control, such as future fuel prices, the state of the economy, increasing competition in the small and large truck segments, new safety and emission standards, and trends in consumer purchasing patterns. In the past, none of these factors has been predicted to change in a direction that

would encourage fuel conservation. Therefore, our current forecasts are unlikely to under-predict CAFE.

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Setting of CAFE Standards for Multiple Years

In response to NHTSA's request for advice on the number of years for which truck CAFE standards should be set, GM notes that the annual approach used in the past provides the greatest certainty of what can be achieved without adversely affecting substantial share manufacturers or creating significant competitive advantages for some manufacturers relative to others. GM also recognizes, however, that there is a desire to set multiple year CAFE standards in order to provide manufacturers with a target for future years. In this regard, GM recommends that standards be considered for the 2005-2007 model years through this rulemaking process. While setting standards even this far in the future introduces substantial uncertainty, we believe it provides manufacturers the proper balance between planning uncertainties and lead-time requirements. Subsequent standards can also be considered and set in multiple year blocks, but they should not be done too far in advance and too far into the future. This will allow NHTSA to evaluate how effectively they have taken into consideration the realities of consumer demand, the development of advanced technologies, the costs of those technologies, the opportunities to move to new sources of energy (such as hydrogen), the price of gasoline, and other relevant factors.

Standard Setting Process

When setting past light truck CAFE standards, NHTSA has focused on addressing the CAFE of the "least capable" manufacturer having a significant share of the truck market. It is important to note that the "least capable" designation has often been given to the manufacturer whose CAFE is lowest, not from lagging behind in the use of technology, but due to a wider mix of vehicle offerings. GM urges NHTSA to continue using this long-standing methodology when setting 2005 MY and later standards. We believe this ensures that 1) individual manufacturer's product mixes and capabilities are recognized; 2) specific fuel economy capability assessments continue to be part of NHTSA's analysis; and 3) NHTSA continues to recognize the economic practicability of CAFE standards. To do otherwise creates a situation whereby the CAFE standard functions only to allocate market share among manufacturers. This generally benefits the limited-line import manufacturers at the expense of the full-line domestic manufacturers and does little to reduce fuel use.

Extension of CAFE Credits for Dual Fuel Vehicles

[

]c This is consistent with the requirement under EPCA that these credits be excluded by NHTSA when determining a manufacturer's capability. However, GM strongly supports extension of these credits as indicated in our April 10, 2002 response to NHTSA's Notice of Proposed Rulemaking (67 Fed. Reg. at 10873, March 11, 2002). We believe these credits are critical to continued high volume production of dual fueled vehicles, such as those capable of

operating on E85 fuel, and offer the best opportunity to break the dilemma of which will come first, the alternative fueled vehicles or the fuels that these vehicles can use. We urge the agency to extend these credits another 4 years as permitted by law.

Changes to the CAFE Program

NHTSA requests comments on changes to the CAFE program in Questions 10-15. For reasons outlined more fully in response to these questions, GM believes that NHTSA currently lacks the legal authority to adopt crucial elements of any sensible CAFE reform package, particularly credit trading. In view of these limitations, GM does not recommend a class based CAFE system at this time.

We continue to believe that if reduced energy use is a national priority, it can best be accomplished by bringing broad-based market forces to bear. Policies that affect the cost of driving would have the greatest impact in this regard. In addition, incentives for the development and purchase of promising advanced technologies can help improve vehicle and fleet fuel economy much more significantly than the incremental approach of higher CAFE standards.

Competition

With light truck market share now representing 50% of new light-duty sales, the U.S. light truck market is becoming even more fiercely competitive across all vehicle segments. Of particular significance are 1) the introduction of the Toyota full-size pickup and SUVs, 2) the introduction of larger Honda trucks, and 3) the more recent entries of Korean manufacturers into the truck market. New entrants in the small truck segments means fewer sales of high fuel economy models by full-line manufacturers, thus reducing the CAFE of substantial share manufacturers.

Competition is an issue of crucial importance to the U.S. economy and U.S. employment. For the Administration to be successful in supporting the American economy and U.S. competitiveness in the world market, the American manufacturers must not be handicapped by CAFE standards that impose an unfair burden. The anti-competitive consequences of CAFE are widely recognized and have been documented by the National Academy of Sciences as well as the Federal Trade Commission, the Department of Transportation and various international bodies.

A recently completed study by Dr. Andrew N. Kleit of Penn State demonstrated how costly higher CAFE can be to U.S. employment, U.S. companies, and consumers (see Attachment 5). Using the same model described in Attachment 5, he concluded that CAFE requirements similar to those proposed by Senators Kerry and Hollings (combined car and truck CAFE levels of 35 mpg in 2013) would lead to the loss of 100,000 U.S. jobs, loss of consumer surplus of $18 billion, and reduced annual profits by GM, Ford, and DaimlerChrysler of $9 billion. Analyses of less severe requirements of +1 mpg each for cars and trucks but without sufficient lead-time shows consumer costs of $34 billion. A longer-term increase of +3 mpg on cars and trucks costs $3 billion per year. Another conclusion that consistently surfaced in all his analyses was that CAFE is about 10 times more expensive than market mechanisms like gasoline taxes in achieving fuel savings.

A March 2002 study by the Energy Information Agency (EIA) of DOE shows even more disastrous results of significant CAFE increases. It concluded that the original proposal in S.517, to raise combined car and truck CAFE to 35 mpg by 2013, could not be met by manufacturers, would result in 300,000-450,000 lost jobs, would reduce GDP by $170 billion through 2020 (discounted to today's dollars), and would hurt the U.S. trade balance. The EIA

analysis of Senator Feinstein's proposal (S.804) to raise truck CAFE to 27.5 mpg, found that this would cost 200,000 jobs, $134 billion in GDP through 2020, would hurt the U.S. trade balance, and would result in CAFE fines of $10 billion.

Market Factors

As NHTSA has observed in past rulemakings, a manufacturer's CAFE improvement capabilities are "limited by strong consumer demand for larger trucks and larger displacement engines." 53 Fed. Reg. at 11075. This demand remains a very real factor at current and projected fuel prices. Setting light truck CAFE standards at levels that will push some automakers to make dramatic changes to their product plans, including the addition of technology that could dramatically increase the cost of vehicles, may actually be counterproductive to conserving energy. The benefits of technology to help conserve energy will be limited if the consumer rejects the resulting product and, instead, retains an older, less fuel efficient truck, switches to a larger or more powerful truck that is not subject to fuel economy standards, or buys from a manufacturer that is less constrained by CAFE.

At today's fuel prices and those forecasted for the near future, which are lower in real terms than they were in 1975, the increased costs to the consumer of fuel saving technologies cannot be ignored as a CAFE risk, especially in light of growing costs of new safety and emissions equipment for light trucks. Higher prices for vehicles incorporating new technology to meet safety standards, emission requirements, and increased fuel economy have the potential to reduce vehicle sales. Moreover, the segments most sensitive to price increases are also the most fuel efficient -- small trucks, small utilities, and mid-size vans which are, by necessity, an integral part of any full-line manufacturer's strategy to meet higher CAFE standards.

Many current trends in customer preferences are at odds with significantly higher CAFE standards. [

]^{c} While GM's extended cab pickups are as fuel efficient as our competitors', GM has a larger share of this market and we will be hard pressed to increase CAFE as we respond to the needs of the customer.

Another example of market demands that drive lower CAFE demands is the customer's choice of optional engines. GM's C/K pickup trucks offer a base V6 engine and two optional V8 engines. [

]^{c} This is despite the over 1 mpg difference in fuel economy between these engines. Another example of market trends counter to CAFE is the increased content of GM's trucks. Sunroofs on utilities have increased from less than 33% to greater than [ ]^{c}, 4 door trucks are now standard in the industry for extended-cab pickups, and more customers choose [ ]^{c}

Given the substantial uncertainties in the future, establishing overly stringent CAFE can only lead to harm. Standards set too high could cause a significant loss to consumers in truck utility and/or availability. If standards force reductions in utility, consumers may choose to purchase larger, lower fuel economy models in order to maintain their utility needs. Furthermore, such action would constrain full-line domestic manufacturers thus aggravating an already unfair competitive situation in the U.S. automotive market and providing little overall reduction in fuel consumption.

Congress intended CAFE standards to help reduce U.S. dependence on foreign oil without unduly limiting consumer choice. H.R. Rep. No. 340, 94th Cong., 1st Sess. 87 (1975). Proper regard for consumer choice is particularly crucial in setting light truck standards. Fuel economy technologies already used in cars cannot always be adopted for trucks because of the need for utility, durability, and performance.

2002 NAS Fuel Economy Study

GM agrees with many of the conclusions of the 2002 NAS fuel economy report. The NAS panel correctly recognized some adverse safety effects of the CAFE program, its disparate effect on manufacturers, the severe consequences of inadequate lead-time to meet higher standards, and the impact on the consumer.

However, we take strong issue with the panel's assessment for fuel economy potential, particularly their technique for combining the benefits of different technologies. GM, as well as the Alliance of Automotive Manufacturers, voiced these concerns in meetings during the NAS process as well as at the October 5, 2001 public meeting on this subject. A technical paper on this subject was also prepared for presentation at the Society of Automotive Engineers (SAE) 2002 Annual Meeting (see Attachment 4). The SAE held a panel discussion of distinguished automotive experts in March 2002 where nearly the entire panel agreed with the criticism of this NAS technology assessment.

The NAS assessment suffered from not having access to detailed proprietary manufacturer's data. Instead, it relied on literature reviews, input from suppliers (many of whom were undoubtedly promoting their own fuel economy technology), and panelists' judgment. In contrast, it is the purpose of this Request for Comments to provide NHTSA with much more precise and objective information on the technological potential and economic practicability that is needed to properly set CAFE standards.

As a result, NHTSA should not rely on the NAS study for its assessment of technological feasibility (see our response to Question 16 for a summary of our concerns). In fact, the NAS panel noted about its own analysis:

> "The committee cannot emphasize strongly enough that the cost-efficient fuel economy levels identified in Tables 4-2 and 4-3 in Chapter 4 are not recommended fuel economy goals. Rather, they are reflections of technological possibilities, economic realities, and assumptions about parameter values and consumer behavior. Given the choice, consumers might well spend their money on other vehicle amenities, such as greater acceleration or towing capacity, rather than on the fuel economy cost-efficient technology packages." (NAS 2002: 4)

Many of the other studies cited by advocates of dramatically higher CAFE standards suffer from the same limitations as the NAS study and from others. Some of these studies are critically reviewed in our response to Question 5. These studies clearly cannot be considered as surrogates for manufacturers' information. NHTSA is requesting detailed product plan information, technology assessments, and cost data on 2005 and later MYs from individual manufacturers who are committing to build and market these products into the 21st century. Outside studies of fuel economy potential cannot account for all the factors a manufacturer must balance in providing marketable products at affordable prices.

FreedomCAR

One of the best approaches to improvements in vehicle and fleet fuel economy is to accelerate the development of advanced technologies that have the potential to provide dramatic increases. The auto industry and the federal government have been working cooperatively on R&D of advanced technologies for several years. The latest such effort was announced earlier this year by the Secretary of Energy in Detroit. This program, called FreedomCAR, is a new Cooperative Automotive Research (CAR) partnership between the U.S. Department of Energy and the U.S. Council for Automotive Research (USCAR). FreedomCAR replaces the Partnership for a New Generation of Vehicles (PNGV), which had a more limited scope and timetable. Compared to PNGV, FreedomCAR is focused on more fundamental, higher risk activities with applicability to multiple passenger vehicle segments including trucks. This includes an increased emphasis on fuel cells and hydrogen fuel infrastructure, especially hydrogen production from domestic renewable sources. FreedomCAR also encompasses continued support for other technologies that have the potential to dramatically reduce oil consumption and environmental impacts, such as advanced diesel technology. This is intended to be a concerted long-term effort involving OEMs, the national labs, universities, automotive suppliers, the fuel industry and other appropriate parties.

The transition of vehicles from gasoline to hydrogen is viewed as critical in both reducing carbon dioxide emissions and reliance on imported oil. FreedomCAR will develop technologies to enable mass production of affordable hydrogen-powered fuel cell vehicles and assure the hydrogen infrastructure to support them. Because fuel cell vehicles can be free of petroleum, criteria pollutants, and carbon dioxide emissions, FreedomCAR is pursuing a "high-reward" strategy. However, it is also a "high-risk" strategy because of the significant technology challenges. Today, fuel cells cost $325/kW, or almost ten times the price of a comparable internal combustion engine. FreedomCAR's goal is to reduce that cost to $45/kW by 2010. FreedomCAR's long-term goal is emissions free and petroleum free cars, light trucks, and SUVs, with large-scale deployment within 20 years.

The FreedomCAR program is a new and positive approach to meeting a goal deemed beneficial to society (i.e., reduced fossil fuel use). We believe that it can achieve success. However, if stringent command-and-control regulations are imposed as well, they will co-opt other resources and compromise the FreedomCAR effort.

Light Truck Fuel Economy and the Need of the Nation to Conserve Energy

The need of the nation to conserve energy is one of the four criteria NHTSA must consider in setting the appropriate fuel economy standards for cars and light trucks. GM believes NHTSA must carefully relate any CAFE standard to the underlying need to conserve. Essentially, five rationales – energy security, oil depletion, climate change, air pollution and conservation for its own sake – have been advanced for energy conservation. In each case, increased CAFE standards have been cited as the answer. But, in reality, CAFE standards as a response to any of these concerns 1) are not effective; 2) have unintended or counterproductive results; and 3) are extremely costly (compared to other often more effective approaches). In each case, there are much more effective and less costly alternatives.

Energy security does not mean energy independence. Denying the nation's consumers and producers access to low-cost foreign energy supplies would weaken the nation's competitiveness and make it less secure. The sensible goal, and the one adopted by the European Union, is to insulate the world's economies from oil price spikes.

Government policies that advance this purpose include expanding strategic petroleum reserves, promoting alternative domestic and foreign energy sources, and eliminating regulatory barriers to oil production, refining, and distribution. Of particular importance is the extension of CAFE credits for production of dual fuel vehicles. Flexibility requires these vehicles to be available, even if economic conditions have yet to promote extensive use of alternative fuels. Ironically, programs that succeed in reducing U.S. oil consumption would actually increase, in percentage terms, U.S. dependence on the most insecure sources of supply, by increasing the market share of lower cost Middle Eastern OPEC producers. Because world energy markets are inextricably linked, disruptions in the availability or price of energy are likely to produce similar economic repercussions no matter how dependent an economy is on foreign oil.

If we are concerned about world oil depletion, the way to achieve additional conservation is to raise the price of fuel. Numerous studies, including the one by A. N. Kleit mentioned earlier, show that fuel taxes are much more effective and much less costly than increases in the CAFE standard, which have the counterproductive consequences cited previously.

Concerns about climate change from the use of petroleum fuels are inconsistent with concerns about oil depletion. If we are indeed running out of oil, then petroleum consumption will not be a long-term contributor to climate change. Broad-based policies relying on market incentives will cut carbon emissions at less than one-tenth the cost of a CAFE increase. CAFE is an expensive and counterproductive method of addressing global climate change.

CAFE does not decrease air pollution; rather it actually exacerbated air pollution concerns by increasing driving intensity and by encouraging the retention of older, higher polluting vehicles longer.

Conservation for its own sake is too narrowly focused. There is a need to conserve petroleum -- to wisely use energy resources, including oil -- just as there is a need to conserve other resources such as labor, and capital. But we should not conserve energy at the expense of the wise use of these other resources. Because there are other far more effective and less costly policies, excessive CAFE increases necessarily waste these other resources – resources that are critical to the promotion of economic growth, improved living standards, and an improved environment. For that reason, such CAFE increases violate the very premise – wise use – that underlies the need to conserve energy.

An extended discussion of these issues appears in the response to Question 20 in the Section regarding "CAFE and Energy Security."

Conclusions

Light truck CAFE depends on many factors such as fuel prices, competitive offerings, changes in consumer purchasing preferences and the nation's economy, all factors over which motor vehicle manufacturers have no control. The farther into the future that NHTSA looks in setting standards, the greater the uncertainty about these and many other relevant factors. Coupled with these significant uncertainties are the CAFE impacts and resource requirements that will result from new safety standards and emission requirements. Considering all these factors, GM's CAFE for the 2005-2007 MY time period may vary substantially from our current projections. As we have stated in past submissions, barring significant technical breakthroughs, there are no major technologies to be introduced that can provide large CAFE improvements; thus, future progress will be in small incremental steps. We request that NHTSA carefully consider and balance all of these factors as it determines the appropriate CAFE standards to propose for 2005-2007.

Appendix A to Part 512 - Certificate In Support of Request for Confidentiality

Certificate in Support of Request for Confidentiality

I, Alan R. Weverstad, pursuant to provisions of 49 CFR 512, state as follows:

1. That I am Alan R. Weverstad, and I am authorized by General Motors Corporation to execute documents on behalf of General Motors Corporation

2. The information contained in this General Motors Corporation submission in response to NHTSA's Request for Comments (67 Fed. Reg. 5767, February 7, 2002) contains confidential and proprietary data. It is being submitted with the claim that the confidential and proprietary data is entitled to confidential treatment under 5 U.S.C. Section 552(b)(4) and Section 505(d)(1) of the Motor Vehicle Information and Cost Savings Act. GM requests confidential treatment until the close of the 2010 model year except for financial information for which we request an indefinite period for confidential treatment.

3. I have personally inquired of responsible General Motors Corporation personnel, who have authority in the normal course of business, to release the information for which a claim of confidentiality is being made to ascertain whether such information has ever been released outside General Motors Corporation.

4. Based upon such inquiries, to the best of my knowledge, the information for which General Motors is claiming confidential treatment has never been released or become available outside General Motors Corporation.

5. I make no representations beyond those contained in this certificate and, in particular, I make no representations as to whether this information may become available outside General Motors because of unauthorized, inadvertent disclosure; and

6. I certify under penalty of perjury that the foregoing is true and correct, executed on this the 3rd of May, 2002.

Subscribed and sworn before me, this 3RD day of May, 2002, a Notary Public in and for Wayne County, State of Michigan.

Sherlene L. Anderson
(Signature)
NOTARY PUBLIC
My Commission expires Jan 19, 2003

Subscribed and sworn to me this 3RD day of May, 2002

Alan R Weverstad

Attachment 1:
GM's Response to NHTSA's 36 Questions

The following are GM's responses to the 36 questions in NHTSA's Request for Comments. To distinguish the twenty questions that are in the body of NHTSA's request from the 16 questions in the appendix of NHTSA's request, these latter 16 questions are identified by A1, A2,...A16. Table numbers refer to the question being answered, e.g., Table A2 refers to Question A2.

The following are some of the more significant assumptions used in answering these questions:

- Our plan is based on the fuel prices discussed in Question A14. Falling prices would most likely adversely affect GM's CAFE.
- Projected sales volumes are based on trend, not cyclic, data and assume no economic downturn in the 2005-2007 period.
- Sales volumes are based on nominal plant capacity.
- We assume sufficient revenue will be generated to support GM's capital spending for future programs.

<u>Question 1.</u>
The NAS Study found that the CAFE program, as currently structured, has contributed to traffic fatalities and injuries. As an agency whose primary responsibility is safety and is therefore deeply concerned about the NAS finding, NHTSA requests comments on this NAS finding. Among our questions are: Is the safety impact understated or overstated? Would NAS's proposed changes to CAFE reduce this safety penalty? Could CAFE standards be modified so that manufacturers are encouraged to achieve improved fuel economy through application of technology instead of through downsizing and downweighting? NHTSA requests comments on the extent to which increases in light truck fuel efficiency are feasible during MYs 2005-2010 and on whether any of these increases would involve means – such as significant weight and size reduction – that could adversely affect safety. We note that the NAS found that if future weight reductions occur in only the heaviest of the light-duty vehicles, that can produce overall improvements in vehicle safety. If there would be adverse effects, how could they be mitigated?

<u>Response 1.</u>
a. The NAS Study Underestimates the Safety Impact of CAFE

GM believes that the safety impacts of CAFE are understated by the NAS Study. There are several reasons for this conclusion.

First, the adverse safety effects discussed by the NAS committee relate solely to weight reductions driven by CAFE. These effects have long been recognized in the safety literature, see, e.g., references 1-10 (incorporated here by reference), and have been addressed in prior CAFE cases as well as in GM comments in prior rulemakings. See, e.g., Competitive Enterprise Institute v. NHTSA, 956 F.2d 321 (D.C. Cir. 1992); Comments of General Motors to NHTSA's ANPRM for 1998-2006 MY Light Trucks (August 4, 1994); see also Letter from Robert C. Lange, GM's Executive Director of Safety Integration, to NAS panel member David L. Greene (March 20, 2001) (See Attachment 7 of this response). But weight reduction is not the only technique for improving fuel economy that may have adverse safety consequences.

For example, another technique for improving fuel economy is to reduce tire rolling resistance. Reductions in rolling resistance can have negative safety consequences to the extent that they

lower the tire/roadway coefficient of friction. A reduction in tire adhesion characteristics may result in longer stopping distances, at least in certain circumstances. Vehicle limit handling performance is also strongly influenced by tire/roadway adhesion. Adhesion levels that are too low will degrade vehicle handling, particularly in extreme driving maneuvers or on more slippery surfaces such as snow or ice. The greater the reduction in rolling resistance, the greater the potential for adverse safety consequences. Thus, to the extent that CAFE drives product changes such as these in addition to weight reductions, the impacts discussed by the NAS committee are understated.

Second, by forcing improvements in new vehicle fuel economy, CAFE makes it cheaper to drive and thereby leads to increases in vehicle miles traveled (VMT). This is generally known as the "takeback effect." Although the NAS Committee recognized this phenomenon, which it called the "rebound effect," 2002 NAS Study at 19, it paid no attention to its negative safety implications. As discussed in our response to Question 7, GM and other Car Talk participants have previously agreed to use 35% as an estimate of the takeback effect. This means that a ten percent improvement in the fuel consumption of certain vehicles would cause a 3.5% increase in vehicles miles traveled for those vehicles. All else equal, a 3.5% increase in VMT will yield a 3.5% increase in fatalities and injuries. During the period studied by the NAS committee, the fuel economy of the domestic fleet rose by much more than ten percent. The conclusion is inescapable that many additional fatalities and injuries occurred as a result of this effect, which was not factored into the NAS committee's estimate.

Third, by raising the price of new vehicles, CAFE makes it more likely that people will postpone new vehicle purchases and hold on to older vehicles for a longer period. Since new vehicles are, as a group, much safer than old vehicles (due to new safety standards and technology as well as better condition), this is another way in which CAFE adversely affects safety. The NAS Study did not include this factor in its estimate of CAFE's safety cost.

Fourth, command and control regulations like CAFE standards force manufacturers to divert resources from other priorities, efforts to improve vehicle safety. This "opportunity cost" effect was not considered by the NAS in estimating the adverse safety impact of CAFE.

Finally, the impact of downweighting, as estimated by the NAS Study, is itself probably understated. The NAS committee derived its estimate based on a 1997 study by NHTSA's Charles Kahane. However, the committee's calculations did not distinguish between relationships that Kahane found to be statistically significant and those he found to be not significant. For example, Kahane found a small and statistically insignificant benefit from reducing truck weight, attributable primarily to reduced fatalities among pedestrians, bicyclists and motorcyclists. See 2002 NAS Study at 26 (Table 2-1). Other researchers have found no consistent relationship between the weight of striking vehicles and the number of pedestrian, bicyclist and motorcyclist fatalities. See, e.g., Lund, A.K., and J.F. Chapline, Potential Strategies for Improving Crash Compatibility in the U.S. Vehicle Fleet (SAE 1999-01-0066). Thus, the NAS estimate probably understates the safety penalty that can be attributed to past reductions of truck weight. Indeed, other researchers have estimated substantially greater fatalities attributable to weight reduction over the same time frame. See, e.g., Crandall & Graham (1998).

The NAS Committee also speculated whether recent changes in the fleet might alter the conclusions that Kahane and other researchers have reached about the relationship between weight reduction and safety. GM sponsored research by Exponent Failure Analysis to investigate this issue, expanding the population of vehicles studied by Kahane to include more

recent models. See Ray, et al. "Analysis of the Relationship Between Passenger Weight and the Risk of Traffic Fatality and Injury (July 17, 2001). See Attachment 6. This study also examined six different mass reduction scenarios, including some that limited weight reduction to the heaviest vehicles in the fleet. It found no scenario in which weight reduction was beneficial or neutral to safety. Again, this suggests that the NAS committee's estimate of adverse safety impacts is understated, particularly with respect to its reliance on the Kahane finding of a small net benefit from truck weight reduction.

b. The changes proposed by NAS

The NAS committee pointed out that "some additional traffic fatalities" should be expected if an increase in fuel economy is accomplished by a system that encourages either downweighting or the production and sale of more small cars. NAS Study at 5 (Finding 13). The committee added, however, that the adverse safety effects "could be minimized, or even reversed, if weight and size reductions were limited to heavier vehicles (particularly those over 4,000 lb)." Id. The committee suggested investigation of a system that "would make the fuel economy target dependent on vehicle weight, . . .up to some maximum weight above which the target would be weight independent." Id. (Finding 12). Elsewhere, the NAS committee offered examples of such a system, usually featuring a single fuel economy target for all vehicles over 4,000 pounds. See, e.g., NAS Study at 109.

GM believes that a well-designed weight-based system could substantially reduce the adverse safety effects of today's system. As explained in our response to Question 10, however, NHTSA currently lacks the legal authority to adopt an acceptable weight-based system. Similarly, the agency lacks authority to adopt many of the key features of the alternative system proposed by the NAS committee.

Of course, a change to weight based standards would do nothing to cure the other types of adverse safety effects of CAFE, such as those mentioned above. So long as the system regulates new vehicles, it will have the perverse effects of encouraging driving and postponing purchases. In addition, it will put more pressure on non-weight-based techniques for improving fuel economy, including others that may adversely affect safety. And mandatory standards for new vehicles will continue to divert resources from other priorities, including vehicle safety improvements.

Even if NHTSA had adequate authority to adopt the type of system proposed by the NAS committee, there is no sound scientific support, either in the NAS Study or elsewhere in the safety literature, for the suggestion that there may be net safety benefits of reducing the weight of vehicles weighing more than 4,000 pounds. Indeed, the existence of any such threshold is uncertain at best.

The notion of a 4,000 pound threshold apparently stems from the 1999 study by Lund and Chapline cited above. According to the NAS committee, "[Lund and Chapline] found that total fatalities in a hypothetical fleet of relatively modern passenger vehicles would be reduced by about 0.26 percent if all pickups and SUVs weighing more than 4,000 lb were replaced with pickups and SUVs weighing 3,500 to 4,000 lb." NAS Study at 72.

There are several problems with this study, which was reviewed only briefly but seems to have had an undue influence on the committee's thinking about a weight-based system. To begin with, the percentage cited in this discussion by the NAS committee does not match the percentage actually reported by Lund and Chapline in their published work. Although the

discrepancy on this point is relatively small, there are other, larger ones in the NAS discussion. This obviously should give policymakers pause.

Second, while the Lund and Chapline study may be useful for various purposes, it is far too blunt an instrument to use in making quantitative judgments about the point at which weight reductions in the truck fleet become beneficial rather than harmful. As the authors themselves point out, the rates they developed "do not adjust for factors such as driver age or seat belt use, so higher rates could reflect, for example, younger or riskier drivers or occupants with lower belt use rates." Lund and Chapline at p. 3. If these demographic factors were properly accounted for, it is possible, even likely, that the finding featured by the NAS committee would change direction. Indeed, as mentioned earlier, the Exponent study (which did account for these demographic factors) found no beneficial weight reduction scenario, even where the hypothetical weight reduction was confined to the largest/heaviest vehicles.

Another difficulty with the Lund & Chapline study stems from the authors' decision to combine cars and minivans. Lund and Chapline at p. 2. Since minivans are classified as trucks for CAFE purposes, this methodology limits the study's usefulness for drawing conclusions about the relationship between truck CAFE standards and safety.

The NAS committee took pains to point out that the "actual effects" of weight reductions in the truck fleet are "uncertain" and that additional research is necessary. 2002 NAS Study at 5. GM strongly agrees with the conclusion that additional research on this point is appropriate. The government should not lightly assume, contrary to virtually all prior research, that there is any vehicle weight above which vehicle weight reductions will begin to provide a net safety benefit. Unless and until there is compelling research on this point, NHTSA should avoid creating any pressure for weight reduction through CAFE standards.

NHTSA should also recognize that the ongoing shift in consumer demand from cars to trucks will continue to diminish any benefits of weight reductions in the truck fleet for many years to come. All respected safety researchers agree that vehicle occupants are at greater risk in collisions if the weight of the vehicle they are riding in is reduced, no matter how heavy that vehicle is to begin with. The current debate is about whether a weight reduction targeted at very heavy vehicles could lower the risk to the occupants of different vehicles enough to produce a net safety benefit. The point here is that the shift from cars to trucks (and more generally towards heavier vehicles) will constantly lower the potential benefits (if any) of reducing weight in the heaviest segments of the fleet.

c. Limiting the Adverse Safety Consequences of CAFE Standards

While a well-designed system of weight-based standards could go some way towards reducing the adverse safety consequences of the current system, NHTSA currently lacks authority to adopt a reasonable weight-based system. In the meantime, however, NHTSA is not powerless to mitigate those adverse effects.

The single most important step NHTSA can take is to avoid setting standards that may necessitate weight reduction. A CAFE improvement demand that exceeds the pace of technological improvement will give manufacturers no choice but to cut weight or shift their mix towards smaller vehicles. In determining the CAFE levels that can be achieved by the "least capable manufacturer," therefore, NHTSA should exclude any consideration of potential weight reductions, both at the model level and at the fleet level. Put a different way, NHTSA should be

sure to establish the standards at a level that "substantial share" manufacturers can achieve without any average weight reduction.

Similarly, NHTSA should avoid setting standards that would force the use of other technologies that may have adverse safety impacts. For example, as noted earlier, excessive reductions in rolling resistance would have negative safety consequences. The safety consequences of other technologies for improving fuel economy may not be so clearly understood, particularly when it comes to innovative new technologies that have not been thoroughly tested. Therefore, as a matter of public policy, NHTSA should proceed cautiously and avoid setting standards that dictate the use of technologies that are not yet fully developed and proven.

In making its determination of the maximum feasible levels, NHTSA must consider the fact that an overly aggressive CAFE standard will divert scarce resources from efforts to improve the safety performance of the fleet through research and development and applied engineering. These safety costs are difficult to quantify but nonetheless real.

Finally, GM would like to continue working with NHTSA to better understand the safety implications of vehicle weight reduction. The complexity of this issue should not discourage the agency from proceeding with the research, but it should rule out any consideration of weight reduction as a technique for improving fuel economy within the time frame of this rulemaking.

Question 1 References

1. Crandall, R. W., and J. D. Graham. 1998. The Effect of Fuel Economy Standards on Automobile Safety. The Brookings Institution and Harvard School of Public Health. NEIPRAC Working Paper Series, No. 9. Cambridge, Mass.: New England Injury Prevention Center.

2. Kahane, C.J. 1997. Relationships Between Vehicle Size and Fatality Risk in Model Year 1985-93 Passenger Cars and Light Trucks. NHTSA Technical Report, DOT HS 808 570. Springfield, VA.: National Technical Information Services.

3. Kahane, C.J., and T. Klein. 1991. Effect of Car size on Fatality and Injury Risk. Washington, D.C.: National Highway Traffic Safety Administration.

4. NHTSA (National Highway Traffic Safety Administration). 1997. Relationship of Vehicle Weight to Fatality and Injury Risk in Model Year 1985-93 Passenger Cars and Light Trucks. NHTSA Summary Report, DOT IIS 808 569, Springfield, VA.: National Technical Information Services.

5. Evans, L. 1994. "Driver and Fatality Risk in Two-Car Crashes Versus Mass Ratio Inferred." *Accident Analysis and Prevention 26: 609-616.*

6. Evans, L. 2001. "Causal Influences of Car Mass and Size on Driver Fatality Risk." *American Journal of Public Health 91(7): 1076-1081.*

7. Evans, L. and M.C. Frick. 1992. "Car Size or Car Mass: Which Has Greater Influence on Fatality Risk." *American Journal of Public Health 82(8): 1105-1112.*

8. Evans, L., and M.C.Frick. 1993. "Mass Ratio and Relative Driver Fatality Risk in Two-Vehicle Crashes." *Accident Analysis and Prevention 25 (2): 213-224.*

9. Klein, T., E. Hertz, and S. Borener. 1991. A Collection of Recent Analyses of Vehicle Weight and Safety. Technical Report DOT HS 807 677. Washington, D.C.: NHTSA.

10. O'Neill, B. 1998. The Physics of Car Crashes and the Role of Vehicle Size and Weight in Occupant Protection. Physical Medicine and Rehabilitation: State of the Art Reviews, Philadelphia, Pa.: Hanley & Belfus, Inc.

Question 2.
What is the technological feasibility and economic practicability of various fuel efficiency enhancing technologies that fall under the general headings of engine, vehicle and transmission technologies? Please comment on each of the following technologies, listed under the general headings below:

Engine Technologies
Engine friction and other mechanical/hydrodynamic loss reduction; advanced low-friction lubricants; multi-valve, overhead camshaft valve trains; variable valve timing; variable valve lift and timing; intake valve throttling; cylinder deactivation; engine accessory improvement; engine downsizing and supercharging; camless valve actuation; variable compression ratio engines; electronic engine controls; direct fuel injection for spark ignition or diesel engines; lean burn-fast burn combustion; and two-stroke engines.

Transmission Technologies
Five-speed automatic transmission; six-speed automatic transmission; continuously variable transmission; advanced continuously variable transmission; automatic shift manual transmission; and automatic transmission with aggressive shift logic.

Vehicle Technologies
Aerodynamic drag reduction; and electronic controls; lowering rolling resistance; vehicle weight reduction; substitution of lighter-weight materials; 42 Volt electrical system; integrated starter/generator; hybrid drive trains; and fuel cells.

In answering this question, please address, for each of these technologies, as well as any other relevant/related technologies:

(a) the impact on fuel efficiency;
(b) costs and benefits to the consumer;
(c) manufacturer costs;
(d) lead time;
(e) degree of current use in passenger cars and light trucks;
(f) impacts on safety, including injuries and fatalities; and
(g) potential fleet penetration.
(h) effects of environmental (especially vehicles emissions standards) and other regulations on their application/penetration.

In considering fleet penetration, please address whether some technologies might be appropriate for use on light truck models that would not need high load carrying or towing capability because of primarily personal passenger car type usage.

Response 2.
Because of the similarity of this question and Question A6, we have combined our responses to these two questions. Please refer our response to Question A6. Also see our response to Questions 3 and A11 for related information.

Question 3.
What is the cost-effectiveness of each technology identified in Question 2, as well as any other relevant technologies, assuming alternative plausible gasoline prices forecast for MY 2005-2010, and assuming alternative payback periods ranging from 3 years to 10 years?

Response 3.
Before answering the question, we believe it is useful to discuss the definition of cost-effectiveness.

Cost-Effectiveness within the Scope of the Office of Management and Budget's Executive Order 12866

We assume that by "cost-effective" the question means which technologies or set of technologies provide(s) potential benefits that justify the costs of forcing manufacturers to sell and consumers to purchase those technologies. This is the definition that is required under the Office of Management and Budget's Executive Order 12866:

> "[E]ach agency shall assess both the costs and the benefits of the intended regulation and . . . propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." (58 Fed. Reg. 51735 (October 4, 1993))

We assume also that the definition satisfies the OMB's economic analysis guidance for interpretation of EO 12866, which requires that any "proposed action will maximize net benefits to society...unless a statute requires another regulatory approach." ["Economic Analysis of Federal Regulations Under Executive Order 12866, January 11, 1996, page 1.] The term "net benefits" means benefits in excess of the costs.

Finally, we assume that the term "cost" is the full set of "opportunity costs" as defined under the OMB economic guidance referenced above. Opportunity cost, the standard for all economic or cost-benefit analyses, includes not just the engineering or hardware costs required to meet a standard, but also any accompanying loss of consumer and producer surplus as a result of the lost output stemming from a regulatory constraint:

> "The preferred measure of cost is the 'opportunity cost' of the resources used or the benefits forgone as a result of the regulatory action. Opportunity costs include, but are not limited to, private-sector compliance costs and government administrative costs. Opportunity costs also include losses in consumers' or producers' surpluses, discomfort or inconvenience, and loss of time. These effects should be incorporated in the analysis and given a monetary value wherever possible. (Producers' surplus is the difference between the amount a producer is paid for a unit of a good and the minimum amount the producer would accept to supply that unit. It is measured by the area between the price and the supply curve for that unit. Consumers' surplus is the difference between what a consumer pays for a unit of a good and the maximum amount the consumer would be willing to pay for that unit. It is measured by the distance between the price and the demand curve for that unit.) The opportunity cost of an alternative also incorporates the value of the benefits forgone as a consequence of that alternative. For example, the opportunity cost of banning a product . . . is the forgone net benefit of that product, taking into account the mitigating effects of potential substitutes." [See pages 32 and 33 of the OMB "Economic Analysis" guidelines.]

Cost-Effectiveness within the Scope of the Study by A. Kleit

The attached study (see Appendix 5) by Professor Andrew Kleit follows the required OMB methodology, estimating the relevant consumer and producer welfare losses resulting from a CAFE-imposed restriction on consumer choice. Kleit's research shows that the current car and truck CAFE regulations are binding and that a reduction of 1.5 mpg in both car and truck CAFE requirements would confer net positive benefits on auto consumers and producers. The study

shows that a 3 mpg increase above the current level for both cars and trucks over the very long run – the period of ten to fifteen years in which manufacturers are able to achieve regulations entirely by changes in technology as opposed to mix shifts among vehicles and powertrains -- would impose net economic costs of $3 billion per year.

Professor Kleit's work demonstrates that at current and projected gasoline prices, even small mandatory CAFE increases impose measured costs that exceed the benefits as judged by auto buyers and that these costs also exceed any social benefits from any reduction in environmental, global warming, or so-called "energy security" externalities. Professor Kleit finds that in the long run a CAFE standard would actually increase auto tailpipe emissions of criteria pollutants, that CAFE can have no material effect on worldwide energy supply and demand, and that any reduction in global climate externalities would be small in comparison to the opportunity costs of a binding CAFE mandate.

Kleit's work is confirmed by real world evidence from actual consumer behavior in other nations where consumers value fuel economy much more than in the U.S. For example, in Europe and Japan, where gasoline prices are $3 and $4 per gallon, the only significant additional technologies relate to diesel engines that are severely restricted under U.S. emission requirements. This work is also supported by the recent NAS study, which concludes that the current CAFE standard is, indeed, binding on the nation's consumers. The NAS also concludes that even though over the past fifteen years there have been substantial improvements in fuel efficiency (gallons per ton mile), U.S. vehicle buyers have not chosen to take these fuel efficiency improvements in the form of increased fuel economy (miles per gallon) as measured over the entire fleet of cars and trucks.

These results also are supported by ordinary common sense. If, as both the NAS report and the study by Professor Kleit conclude, the CAFE mandate is binding, by definition the costs of that mandate to consumers necessarily exceed the corresponding benefits. Otherwise, the consumers would not have to be forced to buy the required technologies and vehicles. If the mandate were not binding, consumers would have purchased the new technologies on their own in the absence of the mandate, in which case the value of that mandate is necessarily zero, again as judged by consumers. As shown below in the response to Question 20, there are no significant social benefits, no significant externalities that justify any increase in the CAFE standard: it is an ineffective and hugely costly means for addressing any policy goal.

Cost-Effectiveness within the Scope of NHTSA's Request

The preceding section pointed out the need to address all aspects of "costs" in a cost-effective analysis. However, in order to be responsive to NHTSA's request for an "engineering" cost-effective analysis, we are providing the following information.

In reviewing the following discussion, we believe it is extremely important to keep in mind the differences between engineering and economic analysis. A full blown economic analysis, like the one performed by Professor Kleit and required under the OMB guidelines for economic analysis, takes into account not just the hardware costs of increased CAFE standards, discussed below, but also the opportunity costs imposed on consumers when they are unable to obtain the kinds of safety, performance, and dozens of other automotive attributes they would prefer to spend their money on.

Richard Newell, a fellow in the Energy and Natural Resources Division of Resources for the Future, has explained the significance of this point:

"In contrast to the economists, technologists have focused on a simple 'engineering-economic' model. The technologists' definition of optimal energy efficiency is found by minimizing the total purchase and operating cost of an investment, where energy-operating costs are discounted at a rate the technologist (not necessarily the purchaser) feels is appropriate.

"However, the problem with this approach is that it does not accurately describe all the issues that can influence energy-efficiency investment decisions. * * * [T]here is evidence that energy savings from higher efficiency levels have routinely been overestimated [in the engineering approach], partly because projections are based on highly controlled studies that do not necessarily apply to actual, realized savings in a particular situation. For example, studies have found that actual savings from utility-sponsored programs typically may achieve only 50% to 80% of predicted savings. Another study found that the actual internal rate of return to residential energy conservation investments on insulation was about 10%, which is substantially below typical engineering estimates that the returns for such investments would be 50% or more.

"Requiring consumers to purchase appliances with a higher level of efficiency based on a simplistic analysis could, in effect, impose extra costs on consumers. The result might be a higher level of energy efficiency but decreased economic efficiency, because consumers could be forced to bear costs that they had otherwise avoided." [Newell, "Balancing Policies for Energy Efficiency and Climate Change," *Resources* (Summer 2000), pages 15-16.]

Table 3 contains GM's assessment of the increase in price to consumers and fuel saving benefits of various technologies as identified in Questions 3 and A6. It is very important to consider the technology benefits in Table 3 in light of the underlying detailed technology descriptions, assessments, and assumptions contained in our response to Question A6. Table 3 should not be used without our response to Question A6.

Our calculations of customer fuel savings ("payback") use the following other assumptions: miles traveled per truck and scrappage rates are from the Oak Ridge National Laboratory Transportation Energy Data Book #21, in-use mpg is assumed to be 15% lower than EPA's tested fuel economy, and a consumer discount rate of 7% is used. The "Base" gasoline price forecast is based on the EIA petroleum forecast of $1.50 discussed in response to Question A14. We are in general agreement with this forecast.

To provide a range of possible future gas prices, we have included technology fuel savings benefit calculations for a "Low Gas Price," which assumes $1.25 per gallon. Also, as requested by NHTSA, we have done the payback calculation using both a 3-year and 10-year consumer payback.

Consumer prices in Table 3 are calculated from piece cost, engineering cost, investment cost, and a dealer markup of [ ][c] Further, our cost figures do not consider any cost increases resulting from the untimely implementation of these technologies (i.e. premature retirement of capital). The costs generally assume that the technologies are introduced in a staggered time sequence with minimum disruption to previously scheduled model or powertrain product cycles.

While our analysis is based strictly on the estimated customer price and the customer's expected fuel savings, there are several other factors that need to be considered in adequately evaluating the introduction of fuel saving technologies:

- Customer Acceptance - many potential fuel economy technologies have a significant impact on meeting the needs of the customer or detract from the intended utility of the truck. For example, diesel engines have not been generally accepted by a broad market segment. Also, technologies such as front-wheel drive with its lower towing capability and vehicle downsizing reduce the inherent utility of the truck. Many fuel economy technologies also have detrimental effects on drive quality and noise vibration and harshness.

- Vehicle Affordability - an increase in the price of a vehicle will impact the customer purchase decision. For a given level of disposable income, consumers usually allocate a fixed percent to their transportation needs. If technologies add to the cost of new trucks, consumers may chose to retain their older truck, thus not purchasing a more fuel efficient and lower polluting vehicle.

- Resource Requirements - These are challenging times for the auto industry. The industry has always been highly subject to the business cycle. Further, shareholder returns are traditionally tightly coupled and highly leveraged to sales volume and general economic health. This pattern seems no longer to hold. Despite recent near record product sales volumes, and record sales of the most profitable products, the industry's most capable manufacturers cannot provide any but the most modest shareholder returns. Most investors could easily achieve much higher returns at less risk with other investments. Further, even with near record sales, very capable manufacturers are unable to provide any positive return at all. This uncomfortable industry environment is the result of many factors including the global and local (to the U.S.) industry over-capacity. Companies' abilities to generate sufficient cash to cover fixed expenses (physical plant, retiree cost burdens, etc.) and variable expenses (material, services and labor cost) is tenuous. Cash flow that can be diverted to discretionary expense categories (i.e., technology research, development, and new product programs) is under great pressure. Yet, all new spending for fuel economy and safety technologies must be funded from such expenses. Therefore, pushing too far too fast for fuel economy improvements and CAFE increases has the potential for adversely affecting motor vehicle safety (even absent forced mass reductions) if finite funding is forced to be too heavily devoted to fuel economy, rather than customer driven safety improvements.

While our cost-effectiveness calculations use assumptions noted above for discount rate, payback period, gasoline prices, miles traveled and scrappage, the highly uncertain nature of many of these factors should be noted. In the future, significantly different fuel prices, discount rates, or other parameters could prevail. These could change our estimates entirely.

Another caveat to these cost-effectiveness calculations is that they do not consider the non-additivity or mutual exclusivity of some of these technologies. It would be incorrect to merely add these technologies on top of each other. Not only would some of the percent fuel economy gains interact to produce lower non-additive results, but also some of the technologies are inconsistent or mutually exclusive with one another (see our discussion on non-additivity in response to Question A6 and our discussion of the errors in the NAS study on combining technologies in our response to Question 16). To cite one example, Displacement on Demand and Continuously Variable Transmissions both reduce engine pumping losses making the

combination of these technologies significantly less than the summation of the individual technology values.

Discussion of Results

Table 3, used in conjunction with the descriptions and limitations of these technologies contained in our response to Question A6, confirms that most proven, cost-effective technologies are being implemented by GM. Table 3 also shows GM to be implementing some technologies that may not be cost-effective to the consumer on a fuel savings basis, but are being done to satisfy other customer demands or other requirements.

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Table 3*
Estimated Consumer Costs and Benefits of Fuel Economy Technology

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Question 4.
Taking into account the response to Question 2, and the statements recently made by Ford and General Motors about the fuel economy of their vehicles by 2005, and DaimlerChrysler's response, indicate the ability of each manufacturer to improve its light truck CAFE for each model year during the MY 2005-2010 timeframe. Specify the fuel economy improvements on a vehicle-by-vehicle basis that will result in the achievement of the manufacturers fuel economy pledges. For each vehicle, please list the specific technologies that will be employed and the increase in fuel economy attributed to such technology. By what model year would maximum penetration of all current fuel economy enhancing technologies be feasible? Why wouldn't such maximum penetration be feasible earlier than that model year?

Response 4.
At the outset, we believe it is critical to clarify the statement made by GM on its future fuel economy.

NHTSA alludes to Ford's voluntary commitment to increase the fuel economy of its sport utility vehicle (SUV) fleet in the United States by 25 percent by the 2005 calendar year (67 Fed. Reg. 5770). According to NHTSA, GM "stated that its SUV fleet would have an even higher average fuel economy than Ford's sport utility vehicle fleet, and that its overall average fuel economy for light trucks in 2005 would also be higher than Ford's." Id.

There are many different views about the meaning of Ford's commitment and the likelihood of its success. Only Ford can speak authoritatively on that issue, and it is our hope that they will do so on the record in this rulemaking.

Regarding GM's response to the Ford announcement, however the comment attributed to GM by NHTSA is not accurate. While it may have been misreported in the press, GM's original statement said nothing about average fuel economy. In August 2000, then-Vice Chairman Harry Pearce said "It's simple: We lead in truck fuel economy today and General Motors intends to remain the leader in five years."

GM's leadership is not about CAFE; it is about making more fuel efficient trucks available to American consumers. Our leadership is measured in model-to-model comparisons of comparable vehicles.

It should be clear that Pearce's statement says nothing about what CAFE we will achieve in 2005 or other years. His statement speaks to a model-to-model fuel economy comparison. NHTSA well understands that CAFE is not a function of how many fuel-efficient models are offered, but what American consumers decide to buy. Unless there are dramatic changes in market conditions, it is unlikely that consumers will opt in great numbers for the most fuel-efficient trucks we offer. Consequently, we see these manufacturer "pledges" as essentially irrelevant to the task facing NHTSA.

Nonetheless, we strive to make incremental fuel efficiency gains over time in each model. But our increasing success in larger truck segments and trends in consumer demand have tended to offset our ongoing technology improvements.

Regarding the remainder of Question 4, the employment of technologies and their usage on specific models are discussed in our response to Question A6. Our response to Question A6 also identifies many of the obstacles faced in implementing technologies.

In general, the fact that a technology has been identified does not necessarily mean it will be employed. There are several reasons:

First, technologies do not get implemented because: 1) they are not cost-effective to the consumer; 2) barriers exist to their introduction or use from consumer acceptance, durability, emissions or other competing requirements; 3) the concept or design is not developed well enough so that it is functional and able to be mass produced; 4) time does not permit implementation; 5) engineering resources are not available; or 6) capital is not available.

Second, even when a technology is implemented by a particular manufacturer, it needs to provide a value to the customer or else they may choose the lower cost of another manufacturer's truck. For example, material substitution is generally recognized as not being a cost-effective means of increasing CAFE. If a manufacturer were forced to increase its CAFE through material substitution, the vehicle's price would have to increase sufficiently to recover the cost, yet the technology would not provide the customer a comparable fuel savings. The potential customer would likely purchase a competing truck at a lower price from another manufacturer that is not constrained by CAFE.

Third, forced implementation of technology to raise CAFE would put further financial strain on a manufacturer. GM's financial strength is required to provide funding to execute our current planned products and fuel economy improvements. Further requirements for additional capital spending for further technological improvements, which are not customer-driven, would place a tremendous strain on GM's resources.

Question 5.
What analyses of manufacturer light truck fuel economy capabilities for MY 2005-2010 are available? What are the strengths and weaknesses of each such analysis?

Response 5.
GM is providing comments on the following three studies:

1) "On the Road in 2020: A Life-Cycle Analysis of New Automobile Technologies", M.A. Weiss, J.B. Heywood, E.M. Drake, A. Schafer, and F.F. AuYoung, 2000. MIT Report # MIT EL 00-003. (Referred to as the "MIT Study")

2) "Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015", John DeCicco, Feng An, and Marc Ross, April 2001. Prepared for The Energy Foundation. (Referred to as the "Energy Foundation Study")

3) "Drilling in Detroit: Tapping Automakers Ingenuity to Build Safe and Efficient Automobiles", D. Friedman, J. Mark, P. Monahan, C. Nash, and C. Ditlow. 2001 Union of Concerned Scientists. (Referred to as the "UCS Study")

While individual comments are included provided below for all studies, they all share many common characteristics. These are summarized as follows:

- Underestimate technology cost
- Ignore/ trade away critical customer requirements (NVH, safety, performance and utility)
- Ignore integration challenges
- Duplication of fuel economy benefits; double-counting

- Weak analysis based on very high-level generic models or simulation
- Not requiring very specific detailed subsystem or component information
- Over-estimates of many individual technology improvements, and in many cases, compound shorter-term technologies and longer-term technologies. This is because only the manufacturers have a comprehensive understanding of all subsystems needed to develop and comprehend intended and unintended consequences of complex automotive systems.
- MIT, USC, Energy Foundation have no experience in producing salable vehicles
- Ignoring emissions compliance interaction with new technology.
- MIT, USC, and Energy Foundation have no experience in build validation of technologies. To truly understand the technical feasibility of a given technology, a demonstration vehicle must be built. However, before a vehicle is built, a complete detailed analytical model must be built to optimize the entire system. A demonstration vehicle can then be built. This vehicle must be of a similar configuration, comprehending a similar road load power, part throttle load characteristics and vehicle structure. This will ensure all drivability, emission and fuel economy performance can be measured accurately, and additional needed content to attenuate N&V and drivability issues can be done. The resulting vehicle will then demonstrate the impact of technology, allowing an accurate cost assessment while meeting customer requirements. Once this vehicle is complete, a new set of issues must be understood regarding manufacturing, durability and overall production feasibility. Many times, the actual fuel economy resulting in a production vehicle will likely decrease due to needed refinements to meet the above production constraints.

GM Review of MIT Study

Summary of MIT Study

The study makes a set of assumptions about vehicle component content, efficiencies, masses, and costs for a baseline 1996 midsize car, an "evolved baseline" 2020 midsize car, and several advanced 2020 midsize cars. No vehicle types other than midsize car are considered. A set of assumptions is used to provide inputs to a vehicle simulation, which is run to determine vehicle fuel economy for the baseline vehicles and the advanced vehicles.

The study says that it assumes similar acceleration, driveability, range, refueling ease, driver space, trunk space, and assumes meeting safety and emissions standards. However, it also states "we acknowledge that our various technology combinations do not necessarily provide equal value in all these different driveability and performance areas."

The study uses an "evolved baseline" 2020 vehicle which has 14% reduced mass, 28% reduced engine size, and 35% improved fuel economy, all relative to the 1996 baseline vehicle. The cost of the evolved baseline vehicle is put at only 5% higher than the cost of the $17,200 1996 baseline vehicle. The study indicates that the evolved baseline vehicle "represents the likely average passenger car technology in 2020 that will not incur extra costs other than those necessary to keep up with the market."

The advanced 2020 vehicles described by this study include:

- a conventional powertrain vehicle (-21% mass, -34% engine size, +43% fuel economy, +13% cost)
- hybrid vehicles with SI and CI engines (-17% mass, +66% fuel economy, +28% cost for the CI vehicle)

- fuel cell vehicles (-9% mass, +70% fuel economy, +28% cost for the direct hydrogen vehicle).

Issues with the MIT Study

While the study uses a vehicle simulation to predict vehicle fuel consumption (ordinarily considered a good method to simulate vehicle systems that do not yet exist), there are concerns about the inputs and assumptions to the simulation. In some cases, these inputs and assumptions fail to comprehend the content of current vehicles, and in other cases overestimate the impacts of future developments. These inputs and assumptions are critical to the results shown for the "evolved" baseline and "advanced" vehicles in the study. Since the inputs and assumptions are so questionable, the results become questionable. These critical assumptions are summarized below.

The MIT study incorrectly assumed several important vehicle parameters to be constant:

1) Rolling resistant coefficient, as a ratio between rolling resistance force and vehicle weight, varies with tire rotational speed, tire temperature, and tire pressure. These three factors change significantly during a drive cycle.
2) Auxiliary power, part of which is alternator power, changes with engine speed and the status of brake lights being on or off. Both alternator speed (proportional to engine RPM) and alternator load (part of which powers brake lights) affect alternator efficiency. Variation in auxiliary power can be more than 20% of average value.
3) Battery discharge efficiency is not a constant. It is affected by battery temperature and battery State of Charge (available capacity divided by nominal capacity). Both factors may change significantly during a drive cycle.
4) Indicated efficiency, as a ratio between engine-out power and fuel power, is not a constant. This depends on many things such as instantaneous engine friction, instantaneous exhaust heat loss, both of which may be affected by instantaneous engine speed and instantaneous engine load, which may be affected by ever-changing road load, shift-map, gear ratios, and etc.
5) Transmission efficiency is not a constant. This may be affected by transmission oil temperature and torque converter slip, torque converter lock/unlock, which may change during a drive cycle.

Such unrealistic assumptions essentially average dynamic variables over a drive cycle and equivalently treat ever-changing variables as constants. However, fuel consumption over a drive cycle should be calculated by integrating the instantaneous fuel flow rate which is distorted by these assumptions. The MIT methodology/model is too simplistic to be accurate. Also, there is little evidence of the application of real world constraints to the simulation methodology, which is likely to reduce the fuel economy and overestimate the performance and drive quality of all of the simulated vehicles.

There is nothing "evolved" or "baseline" about the vehicles in the MIT study. They include new body structure technology, completely different engine/transmission families and technologies (some technologies still classified as emerging), and are smaller (10% less frontal area). The "evolved baseline" characterization makes it sound like this will happen without any changes being implemented; this is simply not true. Further, it does not consider consumer preference.

The MIT study assumes application of downsized 3 and 4-cylinder engines in place of a 6-cylinder engine. This input ignores the loss of drive quality, the increased engine speed that will be required, and increased need of NVH measures required to satisfy the baseline customer requirements. The assumed higher-speed three and four cylinder engines will require remedies

such as balance shafts, active engine mounts, and increased low and high frequency noise isolation and attenuation. The study ignores these needs, and as a result, ignores the resulting impact of cost, mass, and losses associated with these needs.

The MIT study uses a 1306 kg (2883 lbs.) midsize car as its baseline vehicle curb mass. This vehicle mass is at the very low end, perhaps below the low end, of 1996 midsize vehicles. This input to the study makes it easy for the authors to replace the baseline six-cylinder engine with four and three cylinder engines in the evolved baseline and advanced vehicles, respectively. However, the actual midsize vehicle segment is not highly populated with vehicles close to this mass range. So the conclusions of the study, which the authors admit is limited only to midsize vehicles, should more appropriately be applied to only the lowest end of the midsize vehicle segment.

The MIT study applies auto-clutch transmissions in place of more conventional automatic transmissions, without making any statement as to the level of refinement that is lost or the need for increased ratio coverage with such transmissions. There is no mention of the added cost and content such as an additional clutch making such transmissions market-acceptable. Additionally, this single-dry-clutch transmission will be very troublesome for U.S. drivers to manage. This is because the U.S. market is mainly adjusted to automatic-type transmissions with very smooth driving characteristics. The driving experience with this single-clutch is very much like driving a manual transmission vehicle with the exception that the driver has no indication when a shift is going to occur. [

]^{c}

The MIT study assumes a 14% mass reduction for the evolved baseline vehicle, assuming a high strength steel structure, reduced number of cylinders, and auto-clutch transmission. These assumptions are too aggressive. [

]^{c} However, industry-accepted numbers for this technology are estimated to be 5% vehicle mass reduction. This 5% could be further reduced since the estimate does not account for the high strength steel already in use in some portions of the body structure (double counting). The replacement of a 2.5L V6 110 kW@5000rpm engine with a 1.8L GDI+VVTL 93 kW@6000rpm L4 engine is assumed to provide a 79 kg mass reduction. [

]^{c}

The MIT study assumes 21% mass reduction for the advanced vehicle assuming an aluminum structure, a further reduction in the number of cylinders, and the use of an auto-clutch transmission. These assumptions are too aggressive – the actual number should be in the [ ]^{c} for the advanced vehicle. An aluminum structure by itself is assumed in the study to provide 19% vehicle mass reduction, but more realistic numbers for this are in the [ ]^{c} The advanced conventional powertrain is assumed to be a 1.6L GDI+VVTL 85 kW@6000rpm L3 engine that provides 87 kg of mass reduction. It is highly unlikely that a 3-cylinder version of such a large engine would *ever* be built. Engine mass reduction for a 4 cylinder 1.6L engine would be less than [ ]^{c} The 34-kg of mass reduction assumed for the auto-clutch transmission would in reality be about [ ]^{c} of mass reduction relative to the 4-speed automatic transmission.

The MIT study assumes large increases in maximum engine speed and engine specific output due to addition of technologies such as variable valve actuation, gasoline direct injection, and the unsupported assumption that engine speeds will increase. There are some fundamental problems with these assumptions. Most of the VVA technologies that improve fuel economy are maximum speed-limited, due to the inherently higher mass and lower stiffness than conventional valvetrains. Direct-injection technology is also limited in its maximum speed capability because of the need for adequate mixing of the directly injected fuel with air in the cylinder. In some cases, transmission technology may be a limiting factor for engine speed. Also, low-speed engine friction will increase as maximum engine speed is raised. Consequently, the study overestimates the expected increase in realized engine specific output and it underestimates the cost and content needed.

The MIT study assumes aggressive vehicle and powertrain mass reductions combined with an assumption of 50% higher engine power-per-mass to justify very aggressive engine downsizing. While engine downsizing and vehicle mass reduction are certainly "synergistic" (go together), it is unrealistic to combine aggressive mass reduction assumptions (see above) with aggressive specific output assumptions (see above) and expect to achieve the synergistic results.

The MIT study assumes constant indicated efficiency and constant friction mean effective pressure over the complete engine speed-load range. This is a poor assumption since it does not account for the reduced operating efficiency of the higher speed and more heavily loaded engines used in the study. The result will be an over-prediction of fuel economy benefits and under-prediction of performance and drive quality capability. The study should be revised to comprehend the real world variation of engine efficiency with speed and load in order to comprehend the effects of aggressive engine downsizing.

The MIT study assumes constant transmission efficiency over the speed-load range. This is a poor assumption since it does not account for the increased spin losses present with the higher speed and more heavily loaded engines used in the study. The result will be an over-prediction of the fuel economy benefits. The study should be revised to comprehend the real world variation of transmission spin losses with speed and load in order to comprehend the effects of aggressive engine downsizing.

The MIT study does not mention of any real-world constraints applied to the vehicle simulations. Constraints such as minimum firing frequency allowed in the vehicle under drive conditions will have a significant impact on the predicted fuel consumption, and the impact grows with aggressively downsized engine. The result will be a significant over-prediction of the benefits of engine downsizing and cylinder count reduction. The study should be revised to use real world minimum firing frequency constraints in the simulation methodology.

The MIT study makes no mention of any attempt to maintain final drive ratios or shift patterns that provide equivalent driveability, even though such constraints are critical to the application of aggressively downsized, higher speed engines. The result will be a significant over-prediction of both the fuel economy and performance benefits of engine downsizing. The study should be revised to use real world customer drive quality requirements as part of the simulation methodology.

The MIT study makes no mention of adjustments made to engine idle speed with the aggressively downsized engines driving higher accessory loads. It is likely that some of the chosen downsized engines are insufficient for real-world accessory loads. Adjustment of engine

sizes to ensure satisfactory accessory load performance should also be included in the simulation methodology.

The MIT study makes no mention of the numerous studies that indicate that weight reductions would have negative safety impacts.

GM Review of the Energy Foundation Study

Summary of the Energy Foundation Study

This Energy Foundation study estimates car and light duty truck fuel economy. Performance and size are held largely constant. The approach was to establish a cross-section of five 2000 MY passenger cars and light trucks as a baseline and then redesign them to comprehend four levels of technology packages:

- Moderate conventional technology
- Advanced conventional technology
- Mild hybrid
- Full hybrid

Options for improving the vehicle efficiency of these vehicles were developed through efficiencies within engines, transmissions, ISG (Integrated starter-generator) and load reductions achieved from efficiency gains in mass, aerodynamics, chassis elements and accessories. These projections were analyzed using the Modal Energy and Emissions Model (MEEM) developed by two of the authors.

The resulting fuel economy savings were applied to three new combined fleet scenarios. The Energy Foundation study provides annual fuel savings, simple payback, conserved energy cost and avoided carbon for these scenarios.

The study concluded:

> "The resulting benefits varied by vehicle type, but overall demonstrated a capability to affordably improve average U.S. car and light truck fuel economy by 50%-70% over the coming decade. The technology packages would add 6%-8% to average vehicle price, but the fuel economy increases are cost-effective if viewed from a societal perspective over a vehicle lifetime" (page 29)

Issues with Energy Foundation Study

The Energy Foundation study underestimates the average cost per pound of mass reduction ($1/pound). It assumes mass reduction cost is $0 for the first 15% and then $1/pound of reduction up to 20%. It is not stated where the additional mass reduction estimates come from. However, many mass reduction applications cost several times more than $1/pound. For example, an aluminum passenger car brake pedal reduces mass by only [ ][c] In addition, most cost-effective mass reduction has already been done.

The Energy Foundation study concludes a large portion of the stated mass reduction is achievable using best practices, packaging techniques and premium materials. Again, many of the most cost-effective mass reduction concepts have been brought into production (i.e., aluminum cradles, aluminum rear lift-gate, aluminum block, hydro-formed frame, aluminum spare wheels) and will already be included in the baseline. There was no apparent

accountability for mass increases due to added mass of hybrid components (batteries, electric motors). These will likely offset a portion of the stated portions of mass reduction.

The Energy Foundation study's full-size pick-up configuration cannot meet GM's design specification requirements for towing capacity, grade-ability, and 50-70 mph passing time. In the study's advanced technology package for a full-size pick-up truck (Chevy Silverado), a 2.9 L engine with 210 hp replaces a baseline 4.8L engine with 270 hp. There could be safety issues for a pick-up truck driver towing a heavy trailer traveling on a ramp with a grade of 3-5% to try to merge into freeway traffic when other vehicles are traveling at 65-70 mph on the right most lane. In this scenario, insufficient acceleration may result from low engine power possibly causing a collision.

The Energy Foundation study's assumption of the applicability of belt-driven CVT for all cars is too optimistic. Many cars like the Pontiac Grand Prix, Chevy Malibu, and Cadillac Deville have wide-open throttle and maximum vehicle loads producing more torque than can be managed with a belt-driven CVT.

The Energy Foundation study's assumption of zero-price impact of advanced transmissions is unrealistic. Some of these (power-shift) transmissions require additional actuators (small electric motors) and/or microprocessor chips for the control system. Incremental cost can be more than a few hundred dollars per transmission. Even the 6-speed step- gear automatics may cost more than conventional 4-speed automatics, due to the need for new tooling equipment and early retirement of existing equipment. Also, in most cases, significant transmission calibration rework is required.

The Energy Foundation study makes unreasonable claims concerning transmissions. The study states that 5-speeds would be upgraded to six-speeds, that CVT's are becoming more popular and current belt patents are running out, and that MTA's offset the cost increase of additional controls with the cost benefit of a torque converter. Additionally, detailed simulations have revealed these transmissions require additional powertrain control and vehicle-level software controls to correctly integrate them.

The math model (MEEM) used in the Energy Foundation study to estimate fuel economy impact of various technologies is too simplistic. Further worsening the accuracy of the study's application of the MEEM model is its lack of several hundred vehicle parameters data which only available from a vehicle manufacturer. In some cases, the manufacturer does not always have every parameter value (tested in a lab) for every vehicle. It is difficult to imagine an outside consulting firm or university with sufficient resources to do as well. Because of the questionable fidelity of the MEEM model and the validity of the data used, it is reasonable to cast significant doubt on the validity and accuracy of the fuel economy estimation results.

The Energy Foundation study's simulations need detailed data to properly characterize the US FTP drive cycle. This is because the cycle has low average engine load and speed requiring detailed data. There is not sufficient data to make the engine operate at its actual load and speed condition at every time instant over the simulated driving cycle. This will cause incorrect efficiency assumptions for the engine throughout the drive cycle resulting in inaccurate fuel economy estimates.

The Energy Foundation study uses specific power (kW/L) as the single-most significant criterion for gauging overall engines technology and efficiency. In reality, powertrain efficiency varies widely with vehicle load on the engine and the engine speed. Powertrain efficiency does not

appear to be adequately accounted for in the fuel economy estimates. Clearly, peak power is not an accurate indication of an engine's ability to propel a vehicle through the US FTP cycle. This is true since some (typically car) engines trade low-RPM torque for high-RPM power while other (typically truck) engines do the opposite. A 3.8L minivan engine and a 4.3L truck engine with similar technology may both have 180-hp peak power but have significant differences in intake and/or exhaust valve timings. It would be naive to say the truck engine is significantly less efficient than the minivan engine.

The Energy Foundation study assumption that technologies (such as hybrid powertrain) yield the same percentage fuel economy gains for various sizes of vehicles is flawed. [

]^{c}

The Energy Foundation study's assumption of a 20% reduction in rolling resistance coefficient and 10% reduction in aerodynamic drag coefficient is too optimistic. Furthermore, GM's car and truck tires have some of the lowest rolling resistance in the industry. Considering the new anticipated safety standards for tires that are expected to increase rolling resistance, we would feel fortunate to maintain our current values. Over the last few years, we have been pushing the envelope on tire rolling resistance development and have found many drawbacks when exceeding our current capability. Chip and tear for truck tires is an example of a development issue when we try to lower light truck rolling resistance. Consequently, tire rolling resistance reductions of 20% (4%/yr) from the baseline are unachievable. It should also be noted the NAS stated that on tires, "the impacts on performance, comfort, durability, and safety must be evaluated" and therefore should not be considered until these evaluations are made.

Regarding the Energy Foundation study's assumption of a 10% reduction in aerodynamic drag coefficient, most ground vehicles today are asymptotically approaching a steady state drag coefficient around 0.3. As these drag coefficients proceed below about 0.30, however, the design flexibility becomes limited and the relative vehicle cost increases. Moreover, frontal areas are also increasing due to customer desires for larger vehicles and increased safety equipment. Consequently, the stated aerodynamic drag reductions of 10% in all vehicles from the baseline are unachievable.

The Energy Foundation study assumed idle speed reduction could be applied generically to reduce fuel consumption. Reducing idle speeds to very low speeds (500-600 rpm) can introduce many undesirable and unintended consequences. The first may be a safety issue, depending on several vehicle-level attributes, due to possible vehicle roll-back when releasing the brake on an inclined surface. This "creep" is also an important "cue" for drivers to know when vehicle motion has begun. Secondly, idle speed can be influenced by the noise and vibration performance of a vehicle. Many times, vibration from engines or as a result of an engine operation (cylinder-deactivation) can strongly influence idle speed. Even small disturbances can cause severe customer dissatisfaction.

The moderate technology package developed in the Energy Foundation study contains many technologies that are already comprehended in many high-volume vehicles today. For example, the moderate package contains mass reduction, efficient lightweight low-friction engine, 42-volt ISG and CVT (cars), 5/6 speed (trucks), overhead camshafts, 4 valves per cylinder, VVT&L, improved cylinder linings, low-friction rings, high-precision machining and 5W-20 oil. Many of these technologies are in high-volume production today.

The Energy Foundation study does not account for the billions of dollars invested in existing tooling that must be partially comprehended in the cost of implementing these new technologies. When a manufacturer prematurely replaces one set of tooling equipment with new ones to fabricate new hardware, it loses money in the investment made in the old equipment because the capital is amortized over fewer years.

The Energy Foundation study makes no mention of the adverse safety effects of its assumed mass reductions.

GM Review of UCS Study

Summary of UCS Study

The UCS study claims to be "a comprehensive assessment of both the technical and economic potential of achieving a safe and fuel efficient fleet." Economic assessments and computer models were used to investigate the impacts of proposed fuel economy improvements through the year 2020. The technical vehicle projections (technology content, cost, and fuel economy) are all based on simulation data and assumptions described separately in "Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015", which was reviewed previously.

The projections in the report yield the following fuel economy improvements versus their baselines:

	Conventional evolution, Moderate	Conventional evolution, Advanced	Mild Hybrid-Electric	Full Hybrid-Electric
Small car	42%	57%	83%	106%
Family sedan	56%	75%	101%	126%
Pickup truck	37%	61%	86%	110%
Minivan	55%	85%	117%	145%
SUV	70%	98%	133%	163%
Fleet Average	52%	74%	103%	128%

These projections are much higher than values from other studies (even the MIT Study which contains extreme optimism and allows diesel engines). The report claims existing ("continuously evolving") technologies could raise fuel economy for the typical family car to over 45 mpg; with a fleet average of 40 mpg. Fuel savings would "more than make up for the cost of fuel economy improvements." Hybrid vehicle technologies could raise fuel economy for the family car to 60 mpg for a family car, to over 50 mpg for an SUV, with a fleet average of 55 mpg.

Issues with the UCS Study

The UCS study assumed all technologies can easily meet future emission regulations. Technologies such as gasoline direct-injection (GDI) engine require the use of a lean NOx catalyst. This catalyst has not yet been fully developed and requires "zero" sulfur fuel to operate properly. If it does not operate properly, it cannot provide the stated fuel economy benefit. These engines are not expected to meet MY 2004 Tier 2 emission standards.

The UCS study assumes vehicle load reductions can be made through aerodynamic streamlining and advanced tires to reduce drag and rolling resistance. In addition, the study uses mass and accessory load reductions to reduce the power requirements from the engine.

However, there are trade-offs between low rolling resistance tires, vehicle handling/braking and tire wear/performance characteristics. The NAS stated that technologies "impacts on performance, comfort, durability, and safety must be evaluated" and therefore should not be considered until these evaluations are made.

The UCS study applies variable control and CVT transmissions. While variable valve control may be applicable to passenger cars, fewer than 13% of 2002 light-duty trucks are equipped with variable valve actuation. Therefore, variable valve control may not be appropriate for most light truck applications. A few cars are on the market are equipped with CVT transmissions, but they are generally used on lightweight vehicles and do not allow towing. In many cases, these CVT vehicles cannot be towed behind motorhomes.

The UCS study uses unrealistic technologies on its "evolutionary family car". As stated previously, the GDI engine cannot meet the Tier 2 emission standards unless low sulfur fuels is mandated. The integrated starter-generator is possible for future cars, but requires 42-volt systems. CVT transmissions are not suitable for use in larger, high torque vehicles due to durability concerns. There is no attempt to demonstrate a basis for the assumed 10% reduction in Cd and 20% reduction in rolling resistance.

The UCS study assumes that through 2020, the majority of the new-car and light-truck fleet would be Prius-like hybrids. This gross assumption means that there would be no trucks as we know them today. Technically, hybrid powertrains can be characterized having two states; transient and steady state. Hybrid vehicles can afford the transient performance, but ultimately, the base power requirements for towing are needed to size the engine for the steady state haul (for example: US I-70 out of Denver up to the Eisenhower Tunnel is 25 miles at a 7% grade). Prius-like hybrid systems have limited use in vehicles where any towing (or significant payload) is required.

The UCS study assumed large mass reduction. Mass reductions of 20 – 33%, which were assumed, are beyond any known industry capabilities when functionality is maintained. The study applied these huge mass reductions to hybrids seemingly ignoring the mass for batteries.

The UCS study makes no mention of the adverse safety effects of these assumed mass reductions.

The UCS study assumed large increases in powertrain efficiencies. However, these large powertrain efficiency gains are not supportable by any known technology. Powertrain efficiencies were assumed to increase by 1 – 24% relative to the baseline depending on vehicle family for moderate conventional evolution. Advanced conventional evolution is assumed to yield 9 – 30% improvements, again depending on vehicle family. These assumptions do not include lean or diesel engines, nor cylinder deactivation.

The UCS used grossly optimistic costs. Powertrain system costs, expressed as consumer price increments, appear understated by rough factors of 2 – 3 times, especially for hybrid vehicles. Since the vehicle price increments are said to include both the unachievable mass reductions and the excessive powertrain efficiency gains, it is not clear how those costs were estimated.

The UCS study used a flawed cost saving calculation. The study's lifetime fuel-cost savings are based on a simple payback basis against the technology price increase and any potential consumer hybrid tax credits. No time value of money is reflected. It is assumed that vehicles will be driven 170,000 miles over 15 years.

Question 6.
What data are available on the usage characteristics of light trucks, i.e., how many passengers and/or how much cargo the different types of light trucks typically carry? What survey and other data are available on the importance that consumers place on the fuel economy of light trucks relative to other vehicle attributes?

Response 6.
When designing trucks, manufacturers must account for the maximum loads encountered, not average loads. Average or typical loads are not the basis for the design of trucks since the design capability must be able to withstand the maximum load regardless whether that particular vehicle ever encounters the maximum load. Many of our design decisions are based on maximum loads regardless of the frequency encountered in the hands of customers. And because we cannot design for each customer, we must design for all customers. Therefore, manufacturers must design and test all its trucks for the extremes, not knowing which consumers will subject their trucks to maximum loads. To do otherwise could result in significant issues once the vehicle is in the hands of the consumer. And, it is not just about designing to the initial truck owner's use. A truck will likely have many owners over its lifetime, each with their own usage requirements.

When a manufacturer advertises a truck's maximum load capability, it does not in any way suggest limiting the number of miles a consumer can drive at these maximum loads. The issues of how much capability an individual truck owner buys and how much they utilize it is a question of buyer behavior, not design criteria. For example, the average number of passengers carried is not what drives the buyer or the designer, it is the maximum number of passengers a vehicle could carry.

We do know that a large share of truck buyers use their trucks for their truck utility features. Truck buyers use their vehicles to carry bulky, heavy, wet or dirty cargo, as well as for recreational activities. For example, some key findings from the July 1998 J.D.Power and Associates "Light Duty Truck Reference Guide" on usage patterns, are summarized below:

- *"Over half of all light duty truck owners use their vehicle to tow either a boat or trailer."*
- *"...it is the combination of favorable functional attributes as well as safety components (four-wheel drive and improved visibility) coupled with styling and image that attract buyers."*
- *"Along with the improvements in quality, consumer's satisfaction and corresponding sales were enhanced by core attributes such as functionality, including towing capacity and cargo space."*

In today's motor vehicle fleet, light duty trucks (particularly mini-vans and SUVs) are the vehicle of choice for families. GM market data show that the proportion of its full-size SUVs that "carpool" children at least once per week is about [ ]^{c} In this context, "carpooling" implies 3 or more occupants—presumably up to the number of designated seating positions in the vehicle. When considering only households with children, the usage increases substantially; the usage rate for "carpooling" children at least weekly is over [ ]^{c} for full-size utilities and mini-vans.

The overwhelming application of SUVs to the task of child transport is not at all surprising. SUVs provide similar passenger accommodation to mini-vans with superior functionality and

expressiveness in design. A CAFE standard that artificially eliminates or restricts the sales volumes of these classes of vehicles will create further market distortions, disproportionately adversely affecting U.S.-based automakers (who have a larger market share of the truck market), and degrade the safety of child occupants and their adult care givers by forcing migration into some other class of vehicle that will likely be less safe than the full-size SUV or mini-van those persons would otherwise have occupied.

GM has collected data on actual customer loading of our trucks. Figures 6.1, 6.2, and 6.3 provide examples showing maximum payload for some typical GM light duty trucks in actual use by customers. We periodically instrument trucks and put them into service by customers to determine typical customer usage. The data shows maximum "rear ballast" or the weight of cargo and/or people carried by the rear axle of the truck. The figures also show the vehicles' rated maximum payload. Note that, in spite of recommended maximum payloads, some customers do exceed the vehicle's maximum rated payload. In summary, this data illustrates customers do use the maximum load carrying capabilities of their trucks. In fact, they sometimes overload them. Our designs must accommodate these heaviest loads since we cannot predict how individual trucks will be loaded.

Figure 6.1

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Figure 6.2

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Figure 6.3

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Buyer Preference Survey

Table 6.4 shows buyer preferences for various vehicle attributes, including fuel economy. This data is obtained by GM through a survey, "Total Customer Satisfaction", which asks the customer to rank their reasons for purchase. The data is the percent of customers who listed a given attribute as one of their top three reasons to purchase. Although the answers vary somewhat by model, when looking at all light trucks as a group, fuel economy ranks 23rd in importance to the buyer. [

]c Given this lack of emphasis on fuel economy at current fuel prices, these other characteristics are key in balancing customer requirements in our designs. Because we must sell what we make, we cannot sacrifice the attributes that make trucks appealing if we are to remain competitive in the market place.

Table 6.4

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Question 7.
By their nature, fuel economy standards lower the marginal cost of driving. What effect does this cost difference have on vehicle miles traveled?

Response 7.
Econometric studies have shown that if the cost per mile driven falls, consumers "buy" more miles and travel more. When the cost per mile driven falls because of improvement in fuel economy, this increase in vehicle miles traveled (VMT) is called the "take-back" effect.

In 1994, participants in the Clinton Administration dialogue on fuel economy among auto industry, environmental, think tank, and government participants (dubbed "Car Talk") agreed to use a take-back estimate of 35%. In a recent survey article, Greening, Greene, and Difiglio (Energy Policy 28 (2000) 389-401) estimate the take-back effect at between 20% and 50%. This review concluded that energy policies were "50% to 80% effective", that is for transportation and other energy uses, the take-back effect is between 20% and 50%.

GM concludes that the Car Talk 35% estimate of the take-back effect remains reasonable, and should be used for analysis with sensitivity cases of 20% and 50%.

Question 8.
To what extent are other Federal standards likely to affect manufacturers' CAFE capabilities in MYs 2005-2010? Answers to this question should include not only the effects of such standards when first implemented, but also the prospect for reducing those effects subsequently.

Response 8.
Specific impacts on CAFE of known future Federal standards are addressed in Question A5. In addition, we offer these comments.

To achieve established CAFE standards, manufacturers balance a vehicle design to provide performance, utility, and features that consumers desire. When evaluating the content on a vehicle, manufacturers are forced to constrain the weight and other product features that have negative implications for CAFE. Manufacturers cannot delete from implementation those elements necessary for regulatory compliance. Features and structures that are voluntarily provided to consumers are at risk if their implementation means that a vehicle does not achieve CAFE goals.

The public health challenge presented by motor vehicle collisions will not naturally abate over the coming decade. On the contrary, before the decade is out, we will begin to see a reversal of a demographic tend that has been favorable for motor vehicle safety over the past two decades. Since the late 1970s, the "baby boom" generation aged out of the youth demographic and into adult-level demographic; all of the consequent behavioral changes were beneficial for motor vehicle safety. However, over the next ten years, the "baby boom" generation will begin to age beyond 60 and will begin to see an increase in collision involvement rates and consequent injury outcome as this substantial age cohort continues to mature. If nothing else changes, the aging of the "baby boom" generation will cause a deterioration in motor vehicle fatal and serious injuries and in the fatal and serious injury rates.

Over the recent past, Congress has increasingly demonstrated its general desire to improve motor vehicle safety through legislative means. Abatement of this trend seems unlikely, and Congressional activity in this area is not easily predictable based on current conditions. U.S. society (and the global society as well) continues to trend toward a desire for increasing personal safety and security. This general public demand for increasing "societal good" in the motor vehicle transportation sector will translate into increasing expectations for government regulators and vehicle manufactures to continue to add safety technology content and safety performance capability. NHTSA has a lengthy agenda of rulemaking and research regarding all aspects of motor vehicle safety. No doubt as these initiatives mature and move through NHTSA's process, they will result in various new regulations. Further, all of the consumer metric type programs conducted by NHTSA (e.g., NCAP, LINCAP) and other credible non-governmental organizations (NGOs), such as the Insurance Institute for Highway Safety (IIHS), have become de facto regulations with which manufacturers strive to comply. This is often difficult, because consumer metric performance, regulations, and real world safety can be at cross-purposes or even mutually exclusive in some cases. (For example, an overly aggressive large air bag to provide good NCAP results works at odds with out-of-position air bag inflation induced injury considerations and real world safety concerns.) However, what is key is the fact that such programs are proliferating; they can generally be implemented without the necessary rigor of demonstrating a real world safety benefit; and they become de facto rules to which each manufacturer must respond or risk negative consumer reactions in the market place as regards purchase consideration and decision making.

Perhaps most important, vehicle manufacturers also have a distinct interest in improving motor vehicle safety technology content and performance. This is reflected in industry actions during the 1990s with the widespread implementation of numerous safety initiatives independent of regulatory, legislative, competitive or, even in some cases, market pressure. The list is lengthy - daytime running lamps, anti-lock brake systems (standard and optional), automatic collision notification services, child seat installation assists (free top tether anchors), side impact air

bags, common test procedures for child friendly side air bags, child seat belt comfort guides, integrated child restraints, advanced air bag sensing technologies, seat belt pretensioners, retractor energy management or belt force limiting systems, refined seat belt geometries for improved fit and comfort, low force retractors, low friction webbing, fuel system collision protection, electronic stability control, adjustable D-rings, head curtain air bags, etc. All of these factors -- the changing public health challenge, NHTSA interest and activity, Congressional attention, market desires and demands, consumer metrics programs, and independent manufactures' initiatives -- all suggest the pace of motor vehicle safety technology / performance improvements will accelerate, not subside.

This is important, because over the period 1990 – 2002, the estimated mass increase due to safety technology / performance improvement is 200 – 350 lbs.; most of that mass will be a permanent addition not subject to much reduction in subsequent generations. Substantial efforts at mass control / reduction are already highly focused on the first generation of new safety technologies, because generally there is little or no margin for allowable mass addition and often safety technology implementation must be facilitated by mass reduction elsewhere. With current trends, NHTSA might expect the safety technology / performance mass increase during 2005 – 2010 to duplicate the industry experience of 1990 – 2000: roughly 200 – 400 lb. increase and generally there will be only limited opportunity to limit this mass penalty in development of subsequent generation designs.

Question 9.
How should the agency take technological risks into account in setting these light truck CAFE standards? What technological risks are associated with gaining the full potential fuel economy improvements from any of the available types of fuel economy enhancing technologies? What are the prospects for overcoming those risks or offsetting their effects on CAFE capability?

Response 9.
Any new technology has unknown consequences and risks in terms of its impact on other vehicle features when integrated into the vehicle. For instance, a feature may be used in a vehicle to improve fuel economy, but it may also negatively impact the noise and vibration performance. There are certain customer expectations of acceleration performance, utility, cargo capacity, electrical content, ride quality, vehicle size, handling, safety, appearance, and overall functionality that make implementing fuel economy initiatives difficult. Determining the risks of implementing these technologies is sometimes difficult since the true impact to some of these customer attributes cannot be fully comprehended until the very latest stages of vehicle development. A 50 mpg vehicle has little impact on CAFE if sales volumes are small because customer demanded features had to be traded-off for fuel economy.

To demonstrate the risks of integrating fuel economy technology into a vehicle, we cite two examples.

Electronic Converter Clutch Control (ECCC)
Electronic Converter Clutch Control (ECCC) is a technology that has been implemented for fuel economy throughout most of GM's fleet. However, early implementation of this technology resulted in little or no fuel economy gain as well as some undesirable driveability characteristics. Serious noise and vibration issues arose due to the inherent design of a fluid coupling interacting with a controlled slip clutch, resulting in driveline shudder and vibration. The best solution to these issues was to tune around the problem areas, which significantly reduced the fuel economy benefit of ECCC.

Variable Displacement (Displacement on Demand or Cylinder Deactivation)
Cylinder deactivation is a technology that has been explored to a high degree in the past, and is currently being planned for future production. The concept is to disable some cylinders in low load conditions to reduce pumping losses. In 1979, Ford Motor Company was predicting that they would launch production of a cylinder deactivation vehicle within a year. In the early 1980's, General Motors launched a Cadillac with cylinder deactivation. Due to customer complaints and reliability issues, the technology was discontinued. In the late 1990's, Daimler-Chrysler put into production two Mercedes models with cylinder deactivation. These vehicles were offered for sale in Europe, primarily because European fuel prices cause customers to place a greater value on fuel economy. It is believed that the deactivated V8 version has been discontinued.

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]c

GM is planning Displacement on Demand for future trucks. The above suggests the risks that this technology faces as it nears production.

These examples identify the technology risks and uncertainties manufacturers face when forecasting their future CAFE. We believe NHTSA should consider these risks in the rulemaking process. In developing our Low Range forecast in response to Question A8, we have tried to capture risks such as these technology risks as well as others.

Question 10.
Please comment on the idea of an attribute-based system. Provide feedback on which attribute(s) such a system should be based on and the specific classes of vehicles that might fall under each class. In addition, please suggest the fuel economy level associated with each specific class of that attribute-based system (e.g., vehicles weighing from 2,000 lbs. GVWR to 2,500 GVWR would have to meet an average of xx.x MPG).

Response 10.
A well-designed system of fuel economy standards based on vehicle attributes could mitigate some, but not all, of the problems with the current CAFE system. In particular, such a system could lessen some of the anticompetitive impacts of the current structure by making sales mix less of a factor. A well-designed system could also lessen some of the adverse safety impacts of the current structure if it reduced the incentive to reduce the weight of individual models or to shift mix towards lighter models.

Under current law, NHTSA's authority to adopt an attribute-based system of fuel economy standards is fairly limited. Specifically, NHTSA could use one or more vehicle attributes as the basis for defining various classes or categories of trucks and then use its authority to set separate standards for these different classes.

This approach has serious shortcomings. In GM's view, the most significant is that NHTSA has interpreted current law as generally forbidding credit trading between classes. Without such credit trading, an attribute based system might still have some benefits over the current system, but they would be offset by new, intolerable CAFE management problems for larger manufacturers.

A class-based approach would also create problems at the edges between classes. This would not be the case with a "continuous function" approach, but GM believes that NHTSA lacks authority to adopt such a system under current law.

It should be recognized that an attribute-based system would not cure some of the major shortcomings of the CAFE system. In particular, an attribute-based system would still focus exclusively on the fuel economy of new automobiles. As with the current system, the effect would be to raise the price of new vehicles, causing some would-be purchasers to hold on to their older vehicles, which are generally less safe, less well-controlled in terms of emissions and less fuel efficient. The standards would do nothing to discourage fuel consumption; to the contrary, if history is any guide, consumers who decided to buy more efficient vehicles, despite their higher price, would probably drive more, undercutting fuel savings and increasing collision exposure.

The following are some of the other issues that would have to be resolved in developing a successful attribute-based system:

- Definition of a "Class". By their very nature, trucks are a diverse group of vehicles with different utility attributes. Broad categories such as pickups, vans, and utilities are not homogeneous. For example, the Suburban and Envoy are designed for different functions but are usually grouped as "utilities." Further, within a broad grouping, there needs to be some identification of equivalent competing vehicles based on size (small versus large truck). However, countless efforts have been made to define size categories for trucks and all have serious defects. For example, to group Ford's Ranger or Dodge's Dakota with GM's C10/C20 pickups (as the EPA classes do) is obviously inappropriate. Using such a coarse classification would penalize a manufacturer having the heaviest pickups in the class. Other functional characteristics of trucks should be considered in class definitions, such as 2-wheel drive versus 4-wheel. Criteria such as vehicle test weight, gross vehicle weight, shadow area, towing capacity, interior volume, number of seating positions, etc. all have shortcomings as a means of fairly and objectively classifying comparable vehicles.

- Possible "Gaming" by Manufacturers. If a sensible classification scheme could be developed and if it was based on discrete categories (in contrast to a continuous measurement such as the multiplicative product of a vehicle's weight and mpg), there would be the potential for manufacturers to take advantage of the scheme and reclassify trucks into the next largest grouping where presumably the fuel economy requirement would be lower. While such actions are possible, it is really unknown to what extent manufacturers would do this (in view of possible compromises in the vehicle utility that might be involved) or whether any such "gaming" would be a one-time only phenomenon.

- Lack of Flexibility. Class based standards have the potential to reduce the flexibility of a full-line manufacturer to manage its CAFE. Not only would possible mix shifts between classes or the introduction of new, smaller models be ineffective, class-based standards would preclude improvements in one class' mpg from aiding another class' compliance

requirement (unless CAFE credits from one class could be applied to other classes). Class-based standards would likely produce numerous instances where manufacturers struggle to maintain compliance in a class with very limited options. For this reason, credit trading among classes would be a necessary feature of any class-based system. In addition, changes in the relevant attribute could not be used to assist in achieving compliance (e.g., weight reduction would not help compliance in a weight-based system). This raises the aggregate cost of achieving any preconceived level of average fleet fuel economy.

- Possible Dual CAFE Standards. The NAS Committee recommended that a weight based system be considered as a replacement for today's single fleet CAFE standards. However, some traditional CAFE proponents have argued that class-based standards should instead be superimposed on top of an average standard for the entire fleet. It is crucial to recognize that such a dual CAFE burden would be worse than the current system. In particular, such a system would have the same anticompetitive and antisafety consequences as the current system.

- Levels of Class Standards. It is unclear what mechanism NHTSA would use to establish the CAFE levels in each of the classes. Although NHTSA would have to establish the "maximum feasible" level for each class, it is not clear to what extent NHTSA would rely on the same analysis it uses to establish fleet-wide standards. For example, the current analysis focuses on the capabilities of the "least capable" manufacturer as a way of taking industry-wide considerations into account. If such a technique were abandoned in setting class-based standards, it could lead to extremely stringent standards could be set for certain classes.

- Treatment of CAFE Credits. It is unclear how CAFE credits would be treated under a class based structure. Whether credits could be transferred between classes or applied only within a class is unknown. Further, it is uncertain how the Agency would treat the 3-year carry-forward and carry-back provisions of the current law. Any class-based system would need credit trading among classes to maintain adequate flexibility

All these highly uncertain issues have a very high potential to overwhelm the advantages that class-based standards would offer to a full-line manufacturer like GM. Therefore, GM does not recommend that NHTSA adopt class based-standards at this time.

We continue to believe that if reduced energy use in the next few years is a national priority, it can best be accomplished by bringing broad-based market forces to bear with such policy options as carbon, oil, or gasoline taxes. Over the long term, policies such as FreedomCAR to accelerate the development of cost effective new energy technologies are the best approach. Taking a flawed regulatory structure such as CAFE and splitting it into pieces with class based standards may only multiply rather than resolve the problems.

Question 11.
Please comment on the possibility of tradable fuel economy credits and the potential cost and benefits to each manufacturer.

Response 11.
As mentioned above, NHTSA takes the position that it currently lacks authority to permit credit trading even between classes within a single manufacturer's truck fleet. Given that view, new statutory authority would be required to adopt any form of broader credit trading.

In general, credit trading has the potential to significantly lower CAFE compliance costs, which are currently substantial for General Motors. As a general rule, the broader the credit trading design, the greater the potential that lower cost compliance options can be found and used, thereby lowering total compliance costs. Allowing credit trading for energy conservation or emission reductions outside the mobile sector promises even greater cost efficiency.

GM agrees with the National Academy of Sciences that "Changing the current CAFE system to one featuring tradable fuel economy credits and a cap on the price of these credits appears to be particularly attractive." (NAS 2002: 5). As the NAS recognized, such a system would increase the incentive for all manufacturers to exceed the CAFE standards; would give manufacturers more flexibility to meet consumer preferences; would limit the cost of CAFE compliance if the standards prove more difficult to meet than expected; and would reveal information about the true costs of fuel economy improvements. Setting a price cap would also aid CAFE planning by providing companies a firm, known benchmark price against which to evaluate potential vehicle modifications. A credit price cap would also avoid the extreme costs for small fuel economy gains that manufacturers have periodically incurred when emergency programs have had to be implemented at the last minute to maintain CAFE compliance.

Some observers have pointed out that adopting a credit trading system would bestow a windfall on some manufacturers who unfairly benefit from the current system due to their product mix. In GM's view, this problem could be avoided by transition provisions and in any case should not be an obstacle to allowing credit trading.

The benefits of credit trading, however, would be neutralized if it ended up becoming an excuse for setting standards above the levels that can actually be attained by manufacturers with a substantial share of the market, taking into account economic practicability and technical feasibility. In GM's view, this perverse effect could be avoided by a statutory provision akin to the one that prevents NHTSA from considering credits for dual-fuel vehicles in setting standards.

Question 12.
Please comment on the effect that elimination of the two-fleet rule [i.e. separate standards for domestic and import car fleets] would have on manufacturers, consumers, employment, the U.S. marketplace, and on the automotive industry in general.

Response 12.
The original intent of the two-fleet rule was to keep small car production in the U.S. The two-fleet rule has had no major impact on keeping GM small car production in the U.S. On occasion, this rule has perversely encouraged overseas product sourcing by some manufacturers. However, the total impact of this rule has been small compared to other impacts of the CAFE system. Thus, we believe that elimination of the two fleet rule would not have major impacts on manufacturer actions.

Question 13.
Please provide suggestions for modifications of the vehicle classification. These suggestions should be as detailed as possible and should state the logic and rationale for the modification, as well as suggested definitions. An analysis of the pros and cons of each suggested modification should also be provided.

Response 13.
While the automobile market is dynamic and some vehicles have been introduced that combine various car-like and truck-like features, the distinction between cars and trucks has not been removed or "broken down". Some perceived partial blurring of the distinction on a few vehicles is not equivalent to, and should not be viewed as, elimination of the distinction. Virtually all products currently classified as trucks provide distinctly superior utilitarian features compared to passenger cars. These utilitarian features include cargo carrying, towing and off road capabilities that Congress sought to protect in its design of the CAFE program. Manufacturers have sought to preserve the utility of vehicles classified as trucks, while adding ride and comfort enhancements on cars. To qualify as a truck under the NHTSA definition, a vehicle must demonstrate a higher level of utilitarian capability for either cargo carrying or off-road operation.

Although many trucks may be often used to carry passengers, customers purchase vehicles to meet their peak or broadest, not their average, demands for a range of requirements. These vehicles must meet our customers' peak workload requirements, and, as such, continue to be "work vehicles". (See our response to Question 6).

It should be noted that the nature of passenger carrying has changed substantially for some customers in recent years. Virtually all jurisdictions now have requirements that infants and small children be transported in special safety seats. In addition, many jurisdictions mandate that small children not ride in the front passenger seat, and this is a recommended practice in all situations where a vehicle is equipped with a front passenger air bag. This creates a situation where any requirement to transport more than two small children makes a third row of seating desirable, or in some places mandatory.

In light of the foregoing, GM believes no change in the system of vehicle classification is warranted.

Question 14.
Please provide comments on the possibility of raising the maximum gross vehicle weight rating and on the effects that this would have on manufacturers, consumers, U.S. automotive industry employment and the automotive industry in general.

Response 14.
Raising the maximum gross vehicle weight rating for including trucks in the CAFE fleet would severely damage the domestic manufacturers and threaten their employees involved in truck manufacture since the sales of these vehicles are concentrated among the domestic manufacturers. This action would immediately exacerbate the problems and inequities created by the CAFE system. It would also severely compromise the work-like features of these large vehicles if they are held to light-duty truck standards.

Within the General Motors fleet, all models within the 8,500-10,000 lb. segment that also meet other CAFE inclusion criteria have parallel models with equivalent passenger carrying capability in the under 8,500 lb. category. For example, the base level K1500 series Chevrolet Suburban is rated at 7,400 lbs. GVWR, while the 2500 series Suburban is rated at 8,600 lbs. GVWR. The passenger capacity of all Suburbans is the same. Customers that are solely interested in passenger carrying would not be interested in the heavier models, which cost more to purchase and operate but yield nothing extra in passenger capability. With the exception of the 12 and 15 passenger vans, the heavier models in the 8,500-10,000 lb. segment are purchased because they provide superior non-passenger attributes such as towing and cargo carrying capacity, compared to the under 8,500 lb. parallel models and customers are willing to pay for these

additional features. Including these vehicles in the light truck CAFE fleet would diminish the ability of consumers to obtain vehicles with the special capabilities that they are clearly seeking by purchasing over 8,500 lb. vehicles. Including these vehicles might actually increase fuel use if these vehicles are replaced by larger trucks that customers need.

Question 15.
NHTSA requests comments on the above possible modifications to the CAFE program and other modifications that have been discussed, such as those mentioned in the National Academy of Sciences study. In addressing these possible modifications, please identify their positives and negatives; their estimated costs and benefits; their effect on manufacturers, suppliers, employees, and consumers; and the policy implications of each. The agency requests that each manufacturer specify how much lead time would be needed to respond to each possible modification and provide that information in terms of product planning cycles. To assist NHTSA, please be as specific as possible and provide any information that you believe will be helpful.

Response 15.
The NAS CAFE panel study concentrated on a weight-based system as the preferred attribute-based alternative because of the advantage it offers in mitigating the adverse safety impacts of the current CAFE regime. Our previous comments on weight-based systems apply to the frameworks considered by the NAS panel, and we do not recommend adoption of a weight-based system at this time.

The panel was correct that a weight-based system may mitigate to some extent the adverse effects of the current CAFE standards and potentially offer greater equity among manufacturers. However, a weight-based system must be accompanied by certain necessary features such as credit trading among classes, no redundant fleet aggregate "backstop" standards and proper accommodation of technical and economic feasibility in establishing the standards for each class. Other attribute-based systems that might appear to accomplish similar objectives would probably do so by functioning as proxies for weight, which research points to as the primary causal attribute for CAFE's negative safety impacts. By continuing to leave incentives for weight reduction, alternative attribute-based systems would be expected to be inferior at addressing CAFE's adverse safety impact, although they could lessen CAFE's inequities among manufacturers.

The NAS panel's CAFE study presented two weight-based frameworks in Attachment 3A of its report, "weight-specific fuel consumption" and "load-specific fuel consumption", and then in Attachment 5A modifies each of these into the "E-CAFE" system. The associated analyses show that there are differing weight/fuel economy relationships between different types of vehicles such as cars vs. trucks, pickups vs. SUVs, vans vs. pickups, etc. This is to be expected given the functional differences between these segments. For example, pickups tend to have higher aerodynamic drag than cars of comparable weight due to the effect of the open pickup bed. Other differences appear in the fuel economy/weight relationships due to less obvious design differences, such as the differing powertrain requirements or drivetrain configurations. A system that lumps together differing types of vehicles and estimates or assigns the same weight/fuel economy function across these differing classes will create advantages for certain types of vehicles compared to others. For example, such different vehicles as the Honda Odyssey 2WD V6 mini-van (24.1 mpg) and the Dodge Dakota pickup 4WD 5.2L V8 (16.9 mpg) fall in the 4500 test weight class for 1999 MY.

This will lead to competitive impacts since different manufacturers have different sales penetrations among these vehicle segments. Some manufacturers would be advantaged. Trucks would be especially disadvantaged compared to cars, and manufacturers with a larger proportion of truck sales would correspondingly be those most disadvantaged. In addition, consumers would be worse off if the chosen system reduced vehicle choices for certain types of vehicles or caused the functional attributes of the disfavored vehicles to be diminished (e.g., load carrying ability of trucks reduced). For these reasons, cars should be kept separate from trucks in the establishment and operation of any weight-based system, and consideration should be given to keeping different types of trucks separate from each other, as well.
The NAS panel estimated continuous functions for the weight/fuel economy relationships they analyzed. Continuous functions have advantages compared to the use of discrete segments. If discrete weight classes were used, this creates edge effects for vehicles that are just above or just below the relevant segment cutoff weights. Correspondingly, this brings competitive effects and incentives for gaming -- designing vehicles to be barely within a segment. While these impacts may be minor compared to other CAFE effects, use of continuous weight/fuel economy functions has advantages over use of weight classes. A good credit trading system among classes would reduce some of the disadvantages of a discrete class-based framework, but not alleviate the edge concerns.

The E-CAFE framework outlined in the NAS report contains an unexplained discontinuity at 4000-lbs. curb weight. Vehicles above this weight are sharply penalized compared to vehicles below this weight, and the vehicles above 4000 lbs. would retain the incentive to reduce weight. While some might argue there are safety benefits of downweighting these heavier vehicles (which is not supported in safety studies – see response to Question 1), it is certain that this arbitrary cutoff point at 4000 lbs. would perpetuate many of the competitive inequities of the current CAFE system. In fact, if the system combines car and truck fleets, the competitive distortions could be worse than the current CAFE system. Most trucks exceed 4000 lbs. curb weight, and even those below 4000 lbs. have lower fuel economy for their weight than comparable passenger cars, so they too would be penalized. (The average curb weight for all 2001 MY vehicles was 4210 lbs., according to estimates based on EPA Fuel Economy Trends Report.) Because an arbitrary cutoff for the weight-based system has uncertain benefits but clear disadvantages, any weight-based system should not have this type of a cutoff point.

Question 16.
In examining the three paths that were chosen, please comment on whether they represent likely scenarios for technology bundling. If not, please comment on which technologies are likely to be bundled together and please identify the specific vehicle types and vehicles/models that might include them. In addition, please comment on the technologies already included on the vehicle types/models, the projected vehicle weight and the percent of total model sales anticipated for each model (i.e., CVT - 45%, 5-Speed Automatic - 40%, 5-Speed Manual – 5%). Finally, please comment on the assumptions the NAS made in evaluating the three paths. Are there more plausible alternative assumptions?

Response 16.
Because of the overlap with Question 18, we are combining our responses to this question and Question 18.

GM takes strong issue with the analysis of fuel economy potential reported in the NAS report. We believe their analysis is fundamentally flawed and overestimates the achievable levels of future fuel economy. GM, as well as the Alliance of Automotive Manufacturers, voiced these concerns in meetings during the NAS process as well as the Oct 5 hearing public meeting on

this subject. A subsequent SAE paper more fully documents these concerns (see Attachment 4). The SAE convened a panel meeting of distinguished automotive experts including several members of the National Academy of Engineering in March 2002 where nearly all of the panelists agreed with the criticisms of the NAS technology assessment.

Below are summaries of our concerns. As a result, we believe NHTSA should not rely on the NAS study for its assessment of technological feasibility. In fact, the NAS panel noted about its own analysis:

> "The committee cannot emphasize strongly enough that the cost-efficient fuel economy levels identified in Tables 4-2 and 4-3 in Chapter 4 are not recommended fuel economy goals. Rather, they are reflections of technological possibilities, economic realities, and assumptions about parameter values and consumer behavior. Given the choice, consumers might well spend their money on other vehicle amenities, such as greater acceleration or towing capacity, rather than on the fuel economy cost-efficient technology packages." (Finding 6, page 4)

Similar to the other fuel economy studies critiqued in our response to Question 5, the NAS assessment also suffered from not having access to detailed propriety manufacturer's data. Instead, it relied on literature reviews, supplier input (many of which were promoting fuel economy technology), and panelist judgment. In contrast, it is the purpose of this Request for Comments to provide NHTSA with much more precise information on the technological potential and economic practicability that is needed to properly set CAFE standards.

Errors in the NAS Technology Assessment

The NRC report made a critical error in its failure to examine system-level effects when combining technologies

The primary flaw – a failure to examine system-level effects – is sufficiently serious that the fuel consumption results in the Report should not be used as a basis from which to formulate policy. An SAE Paper was delivered in March 2002 which reviews the technical content of the NRC Report and highlights issues with the method used in the Report. A primary conclusion of this published, peer-reviewed paper is that the NRC Report over-counts the aggregated effects of technologies by using a simple "shopping-cart" approach which fails to comprehend the fact that losses in any given energy category (such as pumping losses) can only be reduced or eliminated once. The errors in the NRC Report are so extreme that the fuel consumption reduction projected in the Report for paths 2 and 3 fail an energy balance test. In other words, the simple addition of all of the various technologies identified to address pumping losses in the engine would more than reduce all of the actual losses that occur. Clearly this is unrealistic even on a theoretical basis and certainly cannot be achieved in the real world of engine design. This challenge of the NRC results applies to all paths and all vehicle segments, because the same method was used throughout the Report. Five of six members of an SAE World Congress panel – including three National Academy of Engineering members – agreed with the content and conclusions of this SAE paper.

The Report assumes that some technologies could be applied across a wide range of vehicle sizes and types

For example, the NRC Report applies variable compression ratio (VCR) technology to all vehicle segments in path 3. It is well-known that VCR technology is suited to downsized, boosted engines because it is an enabler for high boost levels. This is likely to be the only instance where VCR technology might be applied (assuming a viable hardware solution is

developed). Yet the NRC Report applies VCR technology to Subcompact and Compact Car vehicle segments where there is little potential for aggressive downsizing and less ability to support the cost. In this case the generic NRC approach (apply VCR everywhere) results in the overuse of this technology. In addition, it should be noted that the publicized applications of VCR technology so far have not demonstrated or even described a realistic concept for implementing VCR technology on Vee engines, which make up the vast majority of minivan, SUV, and truck engines. This technology does not belong in any path for Vee engines.

Another example of misapplication is the use of downsized, supercharged, VCR engines in path 3 for any trucks or SUVs that have towing requirements. The application of downsized, supercharged VCR engines to these types of vehicles will be limited by their ability to deliver adequate launch and acceleration torque at low engine speeds. As a result, it is much more likely that these types of vehicles will not use such engines, or at the very least will use engines that are much less aggressively downsized. Again, the generic use of a technology (and the technology benefit) results in an overestimate of its use in the NRC Report. In this particular case, the NRC Report is assigning a 10% fuel consumption benefit for those two technologies, so the size of the overestimate is quite large.

Some technologies <u>will not</u> be combined together
For example, in Path 2 for all vehicles the Report combines variable valve timing (VVT), variable valve lift and timing (VVLT), and intake valve throttling (IVT) technologies. A careful reading of Appendix F, Attachment E, pages E-3, E-4, and E-9 indicates that the Report assumes that the VVT and VVLT benefits build on basic 4-valve DOHC engines, and that the IVT benefit also builds on basic 4-valve DOHC engines. In fact, VVLT and IVT will never be combined together because the IVT function obsoletes the VVLT function. Yet these technologies and their benefits are combined in every path 2 case. The result is a significant overestimate of the use and benefit of these valvetrain technologies.

Some technologies <u>are not likely</u> to be combined together
For example, in path 1 for small pickup trucks and in path 2 for nearly all trucks, SUVs, and minivans, the Report combines downsized multi-valve DOHC engine technology with cylinder deactivation. Even though it is technically possible for these two technologies to be combined, it is highly unlikely due to the fact that they are not well-suited to each other. The use of a downsized multi-valve DOHC engine significantly reduces the benefit that will be obtained with cylinder deactivation, because the downsized engine spends more of its time operating at higher loads where cylinder deactivation is not possible. In addition, the hardware solution for DOHC cylinder deactivation is costly and complicated. The generic application of both multi-valve DOHC and cylinder deactivation overestimates the benefit and underestimates the cost.

Some technologies are included in multiple NRC technology line items
The Report shows individual line items – and corresponding fuel consumption reductions – for engine accessory improvement, 42V electrical systems, integrated starter generator (ISG), and electric power steering. In the descriptions of these technologies, there is considerable overlap. For example, engine accessory improvement, 42V electrical system, and electric power steering *all* include a fuel consumption benefit from the addition of electric power steering, even though this benefit can only be counted once. For the majority of path 2 vehicles and all path 3 vehicles, the benefits of electric power steering were counted *three* times. The Report significantly overestimates the aggregated benefits of these technologies as a result.

Some technologies are not well-suited to some vehicle segments

For example, in the Small Pickup and Midsize SUV vehicle segments, the Report applies the generic benefit of cylinder deactivation in paths 1 and 2. In these vehicle segments, it is likely that this technology will either not be applied, or will be applied with a less-than-typical benefit, due to the fact that noise and vibration concerns with smaller, lower-cylinder-count engines makes cylinder deactivation difficult to apply successfully. As a result, the Report overestimates the fuel consumption benefit of this technology in these applications.

Some technologies that are applied in paths 1, 2, and 3 are in fact already in volume production

Because the Report includes the benefits of these technologies in vehicle segments where they are already applied, it double-counts the fleet impact of these technologies. In its baseline assumptions for the 1999 model year, the Report only accounts for technologies that are at least 50% incorporated into the current fleet. By ignoring current usage while adding technologies to some vehicle segments, the Report overstates the potential fleet fuel economy gain.

An example of this is multi-valve OHC technology. The Report assumes the baseline technology for four vehicle segments is 2-valve technology, when in fact, there is significant 4-valve OHC technology already in production in those segments. Sales volume fraction data for those segments is shown in Table 16.1. The result of this inaccurate baseline is an over-estimate of the improvement of adding multi-valve OHC technology to the five vehicle segments listed. This inaccurate baseline is used in all three NRC development paths.

A similar situation exists for transmissions and VVT technology. The Report assumes that the baseline technology content for all vehicle segments is 4-speed automatic transmission technology, when in fact, in 1999 there was significant usage of manual transmissions, as is shown in Table 16.2. Replacing a manual transmission with either a 5-speed or a 6-speed automatic transmission would not improve fuel consumption. The Report itself makes this judgment when it credits automated shift manual transmission with a 3% - 5% fuel consumption reduction relative to 6-speed automatic transmission. Tables 16.3 and 16.4, which show sales volume fractions for 5-speed automatic transmissions and VVT engines, illustrate two other cases where the Report does not account for technologies already in production.

Segment	Percent with 4V engines
Midsize SUV	26.0%
Large SUV	4.7%
Minivan	15.8%
Small Pickup	20.3%

Table 16.1: Model Year 1999 vehicle segments with 4-valve engines [Source: EPA]

Segment	Percent with Manual Trans
All Cars	13.7%
All Trucks	13.4%

Table 16.2: Model Year 1999 vehicles with manual transmissions [Source: EPA]

Segment	Percent with 5-Speed Auto Trans
All Cars	4.3%
SUVs	15.4%
Pickups	1.8%

Table 16.3: Model Year 1999 vehicles with 5-speed automatic transmissions [Source: EPA]

Segment	Percent with VVT
All Cars	36%
All Trucks	13%

Table 16.4: Estimate of Model Year 2001 vehicles with variable valve timing

The NRC report ignores the added weight of the technologies added to the vehicles
At least one half of the fuel economy technologies applied by the NRC report will increase vehicle weight, a fact ignored in the analysis. See Table 16.5.

NRC Technology	Vehicle Weight Increase?	Comments
engine friction reduction	yes	increased cylinder block structure or higher density materials generally required
low friction lubricants	no	
multivalve OHC (2V vs 4V)	yes	addition of camshafts, cylinder head structure, camshaft drive, valves, springs, retainers
VVT (cam phasing)	yes	addition of cam phasers, control valves, larger oil pump
VVLT (2-step)	yes	addition of cam lobes, switching valve lifters, control solenoids, possible larger oil pump
cylinder deactivation	yes	addition of switching lifters, control valves, NVH remediation to vehicle
engine accessory improvement	probably	addition of electrical motors to replace mechanical drives
supercharging & downsizing	yes	structural improvements and higher density materials req'd, boost mechanism, intercooler
5 speed auto	yes	additional gearset
CVT	no	
auto w/aggressive shift logic	no	
6 speed auto	probably	additional gearset
aero drag	no	
rolling resistance	no	
intake valve throttling (variable lift)	yes	addition of variable lift mechanism and control motors
camless	yes	addition of power supply system (electrical or hydraulic)
variable CR	yes	addition of VCR mechanism and control motor(s)
manual transmission automatic	no	
high torque CVT	no	
42V	yes	batteries, substitution of electric motor driven components for mechanically driven
ISG w/idle off	yes	addition of higher power belt alternator starter or flywheel alternator starter, power electronics
electric power steering	probably	substitution of electric motor driven for mechanically driven, additional mounting hardware
weight reduction	no	

Table 16.5: Fuel Consumption Reduction Technologies that Increase Vehicle Weight

The NRC Report assumes engine downsizing even for technologies where engine downsizing potential is miniscule
Several of the technologies in the Report increase the brake torque and power available from the powertrain for a given engine size. It is true that some potential for engine downsizing exists when engine output is increased. However, several of the technologies for which engine downsizing was assumed have a very small impact on engine torque and power, and as a result their engine downsizing potential is so small that in practice, downsizing would not actually occur. The overuse of engine downsizing tends to overestimate the benefits of five technologies in the Report, especially if the technologies are assumed to apply to already-existing engine designs. Table 16.6 lists the NRC technologies where a downsizing assumption is made and lists whether or not those assumptions are reasonable.

NRC Technology	NRC Assumed Downsizing?	Downsizing Assumption Reasonable?	Comments
engine friction reduction	yes	no	output increase too small
multivalve OHC (2V vs 4V)	yes	yes	
VVT (cam phasing)	yes	no	output increase too small
VVLT (2-step)	yes	yes	
engine accessory improvement	yes	no	output increase too small
supercharging & downsizing	yes	yes	
intake valve throttling (variable lift)	yes	no	no increase in peak power
camless	yes	no	no increase in peak power
variable CR	yes	yes	
weight reduction	yes	yes	

Table 16.6: Technologies Which Assumed Engine Downsizing

The Report fails to differentiate technology benefits for cars and trucks
The generic application of technologies to cars and trucks without any consideration or adjustment for the fact that vehicle requirements (such as traction, towing, cargo capacity, and passenger capacity) are different for trucks makes the NRC conclusion questionable.

The evaluation of paths 1, 2, and 3 in the NRC Report, when carefully examined, conveys an unacceptable level of uncertainty.
Although the Executive Summary and main text of the Report convey confidence in the methods used, there are sections in the Attachments to the Report where a careful reading of the text might lead one to draw a different conclusion. Concerns about the methodology used in the Report were raised by the auto industry, and as a result, the NRC held a public hearing and issued a letter report describing modifications to the Report. While the modifications did address some of the concerns raised, they did not substantially affect the results of the Report, and they did not at all affect the method used to project fuel consumption reductions. A careful review of the Report and it Appendices and Attachments is required to gain a full understanding of the committee's confidence in its results. Several criticisms result from this review of the committee's detailed discussion:

1. The committee itself indicates that some overestimation compared to "aggressive development targets" occurred in paths 2 and 3.
2. The committee never defined "aggressive development targets" yet it uses this terminology in its confirmation of its methodology.
3. The committee uses an example that it describes as "not currently feasible for production engines" in comparison to its results.
4. The committee drops the upper and lower bounds in its analysis (although it still uses these in the economic analysis) in favor of the arithmetic average of the upper and lower bounds. If these results were not useful enough to retain, why is their average relevant?
5. The committee in multiple instances substantially qualifies its results, and at one point describes its results as "plausible under some conditions." This is different from the "technically feasible" standard that was requested by Congress.
6. After excluding path 3 results from what it calls "reasonable", the committee states that all path 3 results are presented as examples only.

There is a fundamental concern with the NRC fuel consumption calculation that is based on the average of the lower and upper bounds efficiencies assumed for each technology

The use of the terms "average" and "bounds" in the Report implies that the probability of a given technology achieving this value is relatively high. In fact, the Report in commenting about the upper bound states "It is a bound, by definition, as is the lower bound, and plausible projections lie somewhere in between." This statement, which is crucial to the methodology used and the results shown, is simply not true. It is a fact that the probability of a given technology achieving the "lower bound" is much higher that the probability of that technology achieving the "upper bound." The use of an arithmetic average of the two does not contribute to improved accuracy. The Report itself states that "The committee did not regard the upper bound as a viable production-intent projection," yet it still uses this value to calculate an average. There are many reasons (discussed elsewhere) why nearly all of the upper bounds and many of the lower bounds are too optimistic. Their average is also optimistic.

The Report lists several reasons why ranges are used. It states:

> "The ranges in fuel consumption improvement represent real-world variations that may results from many (sometimes competing) factors, including the baseline state of the engine, transmission, or vehicle; effectiveness in implementation; tradeoffs associated with exhaust emissions, driveability, or corporate standards; tradeoffs between price and performance; differences between new system design, on the one hand, and carryover or product improvement on the other; and other calibration or consumer acceptance attributes such as noise and vibration."

But, all of these "variations" contribute to *reductions* in the benefits of the technologies. To treat the upper end of the ranges as relevant by using it to calculate the average fuel consumption reduction is much too simplistic, and by definition, it results in an overestimate of the fuel benefit, because all of the projected "variations" act to reduce the benefit.

In some cases, the cited reference gives results that are lower than what the NRC Report used

For example, in the case of engine accessory improvement, the Report cites an EEA, Inc. report which states that a 0.5% - 1% fuel economy improvement is possible with such technology. Yet, the Report assumes a 1% - 2% reduction in fuel consumption for engine accessory improvement. No supporting information is given for this assumption, which is applied to all paths for all vehicle segments.

In some cases, the baseline hardware used in the reference is not the same as the assumed NRC baseline

For example, in the case of low friction lubricant technology, the Report cites a 1995 Toyota SAE paper which showed benefits due in part to the addition of molybdenum-based compounds that are known to improve the boundary friction characteristics of sliding interfaces. The Toyota paper used an engine with a flat follower valvetrain. However, the assumed baseline for all paths and all vehicles was a lower friction roller follower valvetrain, which would not benefit from such lubricant modifications. This inaccurate baseline assumption, which was made for all paths and all vehicle segments, results in an overestimate of the benefits of low friction lubricant technology.

In some cases, the baseline state of the hardware assumed in the NRC Report is not accurate

For example, in the case of engine friction reduction, the Report assumes a fuel consumption benefit of 1% - 5%. This benefit is applied to all paths for all vehicle segments. It is generally accepted in the industry that it would take approximately 35% reduction in engine friction to achieve a 5% fuel consumption reduction. Such a large reduction in engine friction levels is not realistic. The Report confirms this itself on page 4 of Appendix F when it says that 30% - 40% friction reduction is "theoretically possible but not currently feasible for production engines." One reason why the Report makes this error is that it assumes an unrealistically high friction level as a baseline in its calculations. Attachment C in Appendix F of the Report is an "Energy Balance Analysis" which the committee performed to "determine whether some fundamental flaws" exist in its methodology. It uses as baseline friction mean effective pressure (fmep) levels values of 0.60 bar City and 0.65 bar Highway. These numbers are much too high, as the following paragraphs will show. The result is a poor baseline that is much easier to improve than the actual 2001 baseline.

Table 16.7 provides excerpts from material to the NRC in a letter from the Alliance of Automobile Manufacturers in October 2001. It does not appear that this information was used in the NRC calculations, even though the Report states that "the committee did not have sufficient proprietary technical data to conduct highly detailed simulations." In this particular case, the committee *did* have good data from the industry.

As can be seen from Table 16.7, measured engine friction levels over the last decade are significantly lower than the levels used by the committee in their Attachment C Analysis. As already stated, this inaccurate baseline results in inaccurate estimates for engine friction reduction technology. More importantly, it brings into question the accuracy of the "Energy Balance Analysis" used by the committee to validate its methodology.

The results from the Table 16.7 can be also used to illustrate another significant error in the individual technology line items in the Report. In the case of multi-valve OHC (2V vs. 4V) technology, the Report states that a primary benefit is reduced friction. No supporting data is given. It is clear from Table 16.7 that 2-valve OHV engines have significantly lower friction than 4-valve DOHC engines. So not only does the Report overestimate the benefit of multi-valve OHC technology, it actually ignores a significant friction penalty that exists when these engines are substituted for 2-valve OHV engines. This is one reason why General Motors has a significant number of OHV engines that deliver competitive fuel economy when compared to supposedly "higher-tech" OHC and DOHC engines in similar vehicles.

An additional source of error is the use of fuel economy data derived from non-EPA driving schedules. Even attempts at trying to adjust this data can lead to inaccuracies. This concern – which exists with at least eight of the studies cited in the Report – is described in more detail on page 10 of SAE paper 2002-01-0628 (see Attachment 4).

In some cases, technology assessments were based on very few test points. The study used optimistic results from organizations developing the technology.

Another source of error in the individual technology results is the use of studies whose fuel consumption results are from engine dynamometer tests where very few test points are run While such development tests are important in the evaluation and development of new technologies, they should not be use to infer EPA driving cycle fuel consumption results. This concern – which exists with many of the studies cited in the Report – is described in more detail on page 8 of SAE paper 2002-01-0628, which is incorporated in the answer to Question 16. As

indicated in the paper, only 15 of the 44 cited studies in the NRC Report produce results for the appropriate EPA driving cycles.

Another problem with several of the individual technology results in the Report is the use of relatively optimistic results from specific development studies to infer generic results that can be applied to all types and sizes of vehicles.

Generally, an organization that is involved in the development of a new technology will select a well-suited application on which to perform subsystem development. In some cases, the development will focus on determining the maximum potential benefit possible with the new technology. These are important steps that must be taken in the development process, *but they should not be confused with tests that determine the actual benefit in complete vehicle systems* running the EPA driving cycles. For example, in one study cited in the Report (SAE paper 1999-01-0329), a fuel consumption reduction "goal" that is not supported by any test results is used to justify a fuel consumption reduction. In another case, an article from a magazine quoting a company promoting a technology with a "potential" fuel consumption benefit is used. This type of information, while helpful in identifying new technologies with potential benefits, should not be used to help guide CAFE policy.

Table 16.7: Material on Engine Friction Provided to NRC

Another example of direct measurement of engine attributes is shown in Table 2, which is a small part of a comprehensive benchmarking study evaluating the friction characteristics of many engines and engine components over a variety of operating conditions. The table lists engine friction data (expressed as friction mean effective pressure, fmep) for several OHV and DOHC engines at 1300 and 2000 rpm.

Engine	FMEP @ 1300 rpm (bar)	FMEP @ 2000 rpm (bar)
'92 DOHC V6 (non-roller)	0.69	0.80
'93 DOHC V6 (non-roller)	0.60	0.73
'98 DOHC V6 (roller)	0.51	0.66
'97 OHV V6 (roller)	0.44	0.57
'94 OHV V6 (roller)	0.42	0.53
'95 OHV V6 (roller)	0.36	0.49
'95 DOHC V8 (non-roller)	0.56	0.66
'90 DOHC V8 (non-roller)	0.47	0.57
'93 DOHC V8 (roller)	0.42	0.55
'96 OHV V8 (roller)	0.40	0.51
'94 OHV V8 (roller)	0.34	0.42

Table 2: FMEP Data at 1300 and 2000 rpm for 11 Production OHC and OHV

Benchmarking data is a valuable source of information for making somewhat general conclusions about the attributes of a given technology, since it is based on results from multiple tests of multiple sets of hardware. It also makes clear the point that there is no single, simple answer to the question of how much benefit a specific technology might provide.

The benchmarking data in Table 2 can be used to help partition the fuel consumption benefit assigned to 4-valve DOHC engines relative to 2-valve OHV engines, which is important when considering the partitioning of the NRC fuel consumption benefit for multi-valve OHC technology. The table it shows that OHV V6 engines have up to 30% lower fmep than DOHC V6 engines (assuming all have roller valvetrains). In addition, OHV V8 engines have up to 24% lower fmep than DOHC V8 engines (assuming all have roller valvetrains).

This conclusion makes sense when the oil pump size and the number and dimensions of bearings, valves, camshafts, camshaft drive components, and sliding interfaces for the two engine types are considered. Nonetheless, this conclusion disagrees with a statement made on page 3-8 of the NRC report attributing lower friction to OHC engines when compared to OHV engines. No source was given by NRC for the multi-valve OHC friction statement, so it is difficult to specifically address the root cause of the disagreement. However, the measured data is clear.

Comments on Individual Technologies Used in the NRC Report

Engine Friction Reduction: The Report states that this technology (which is in fact not just one technology, but the combined effects of many engine design changes) will reduce engine friction by reducing component weight, improving thermal management, and improving hydrodynamic systems. Reduction of reciprocating and rotating masses will contribute to *very small* improvements in engine friction. Improved thermal management through base engine design changes such as improved coolant passages will contribute even smaller improvements. There is some potential in improving "hydrodynamic systems" by optimization of bearing sizes, reduction of structural distortions, modification of mechanisms to reduce loads, and reduction of sliding/rotating contacts, but much of this has already been implemented (especially in OHV engines). It should be noted that many of the proposed technologies in the NRC Report will have a negative effect on engine friction. The NRC 1% - 5% range should be changed to [ ]^{c}

Low Friction Lubricants: The Report states that "low-friction, multiviscosity" oils will reduce fuel consumption. Such oils (i.e., 5W-30) have been implemented in most GM applications. The remaining potential in going from 5W-30 to 5W-20 or 0W-20 is smaller. The NRC 1% value should be changed to [ ]^{c}, assuming a 5W-30 baseline.

Multi-Valve OHC (2V vs. 4V): The Report states that this technology reduces pumping losses due to reduced flow losses and increased specific output which enables engine downsizing. The level of downsizing – and thus the potential pumping loss reduction – is dependent on specific customer requirements. The Report assigns positive benefit to improved thermal efficiency; this is due to a more centrally located spark plug and smaller bore diameter providing reduced flame travel distance and enabling higher knock-limited compression ratio. However, as shown previously, a penalty must be attributed to multi-valve OHC friction (unlike the statements in the Report) due to increased number of camshafts, cam drive components, and valvetrain sliding components, and due to required increased oil pump capacity. Contemporary OHV engines already have multiple rolling elements. The NRC 2% - 5% range should be changed to [ ]^{c}

Variable Valve Timing (VVT, Intake and Exhaust Cam Phasing): The Report states that this is primarily a pumping loss reduction technology. However, some small benefit should be attributed to improved thermal efficiency due to ability to delay exhaust valve opening (thus increasing expansion ratio), due to ability to control intake valve closing (thus allowing limited optimization of effective compression ratio), and due to improved gas properties and in-cylinder heat losses. The baseline assumption for this technology should be current non-phaser engines with EGR systems, not engines with zero EGR (thus reducing the benefits claimed in the Report). In addition, some penalty must be attributed to friction due to the increased oil flow requirements (and resulting larger oil pump losses) for multiple cam phasers (all of which must be hydraulically controlled at low speed), particularly for Vee engines with four cam phasers. The NRC 2% - 3% range should be changed to [ ]^{c}, assuming a baseline of an engine with EGR and with a properly sized oil pump.

Variable Valve Lift & Timing (VVLT, 2-step lift): The Report states that this is a pumping loss reduction technology, which is true in applications where it is combined with intake VVT. The Report also states that there will be benefits due to improved air/fuel mixing, so some small benefit must be attributed to improved thermal efficiency. However some penalty must be attributed to friction due to the increased number of sliding components required to realize some

2-step lift systems, and increased oil pump losses due to the need for more oil pump capacity, which is required for robust hydraulic actuation of the VVLT feature. These negative aspects offset the potential for reduced friction from lower valve lift in low-lift mode. It is important to point out that implementations of VVLT that significantly increase engine specific output will tend to degrade the base engine efficiency at a given low-speed / low-bmep level; as a result, it is likely that this technology could be used to either increase specific output or improve low speed efficiency, but not both at the same time. The NRC 1% - 2% range [ ]^{c}, assuming a baseline of a DOHC engine with VVT on intake and exhaust.

Cylinder Deactivation: The Report states that this is primarily a pumping loss reduction technology due to the ability to run active cylinders at higher loads with less throttling losses. The Report also states that increased thermal losses occur, but in fact the opposite is true. Combustion performance (and thus thermal efficiency) may be improved because the active cylinders running at higher load have increased burn rates and lower relative heat losses. Friction losses in the inactive cylinders are less than they would be if the cylinders were active, and this may offset the additional friction in the more heavily loaded active cylinders and the heat lost in the inactive cylinders. So some small positive benefit must be attributed to improved thermal efficiency, and a small positive benefit may be attributed to reduced friction. The NRC 3% - 6% range should be changed to 1% - 2%, assuming a baseline of a DOHC engine with VVLT, and assuming a V8 engine. Using a baseline of a current production OHV V8 engine, cylinder deactivation on an OHV engine (what GM calls Displacement on Demand) will reduce fuel consumption [ ]^{c} in applications that are lightly loaded such as pickup trucks. In other applications with more heavily loaded engines, the benefit will be smaller because there are fewer pumping losses to reduce. In other applications with lower cylinder counts, the benefit will be smaller and the cost will be higher because there are additional problems with engine vibration, induction noise, and exhaust noise. [ ]^{c}

Engine Accessory Improvement: The Report indicates that 42V electrical systems will facilitate the cost-efficient application of engine accessories with reduced energy consumption such as oil pumps, coolant pumps, and power steering pumps. However, increased demand for engine oiling systems to provide control capability for technologies such as VVT, VVLT, and Cylinder Deactivation will make overall oil system energy consumption increase. Electrically driven coolant and power steering pumps will both contribute to reduced energy consumption due to their ability to reduce flow rates when flow is not needed. However, the reduced pump work is offset by the reduced drive efficiency resulting from the conversion of mechanical (engine) energy to electrical energy and back to mechanical (pump) energy. The NRC 1% - 2% range should be changed to [ ]^{c} to reflect these facts and to reflect the fact that Electric Power Steering is included as a separate technology in the NRC Report. The cost of conversion to 42V electrical systems must be comprehended if these technologies are assumed to be included.

Supercharging and Downsizing: The Report does not explicitly state that this is primarily a pumping loss reduction technology, but it is implied since the benefit is attributed to engine downsizing at equal performance. The Report does not mention friction benefits due to the potential for reduced number of cylinders and/or smaller displacement, but this should be included as well, because it helps to offset the potential for parasitic losses from the boost device, which are the most important determinant of fuel consumption reduction for this technology. If engine downsizing is carried too far (resulting in a system that requires the boost device to run during the EPA driving cycles), there is a significant friction penalty resulting in

increased fuel consumption. There are offsetting factors (increased cylinder loading versus the need to reduce compression ratio) which affect thermal efficiency, so no benefit is attributed to it. The NRC 5% - 7% range should be changed to [ ]^c, assuming a baseline of a DOHC VVLT engine with cylinder deactivation (in other words, the chosen NRC baseline results in the effects of this technology being double-counted). See comments for Variable Compression Ratio technology, which is well-suited to downsized boosted engines.

5 Speed Automatic Transmission: The Report states that 5 speed automatic transmissions allow the engine to operate in a more efficient speed-load range. This implies operation at lower engine speeds and higher loads, which implies reduced pumping losses and engine friction. So small positive benefits must be attributed to pumping losses and engine friction. The Report does not mention the fact that 5 speed automatic transmissions have higher spin losses than current GM 4 speed automatic transmissions, especially in top gear. A penalty must be attributed to transmission losses to account for this. The benefits of 5-speed automatic transmissions are more applicable to high-performance applications than they are to conventional moderate-performance applications where higher N/V's are used and spin losses are very important. The NRC 2% -3% range should be changed to [ ]^c to reflect the limited benefits of 5-speed transmissions and to reflect the actual NRC baseline engine assumption (DOHC VVLT with Cylinder Deactivation) which already has significant pumping loss reduction.

Continuously Variable Transmission (CVT): The Report does not state which loss mechanisms are affected when using CVTs. The effect on the benefit categories is similar to the effect for 5 speed automatic transmissions: positive benefits for pumping losses and engine friction (due to lower engine speeds and higher loads), and a significant penalty for transmission losses (due to increased spin and pump losses as well as reduced torque transfer efficiency of the belt and gear set in the CVT). A small benefit may be attributed to thermal efficiency due to higher loading of the engine resulting in improved combustion performance. The NRC 4% - 8% range should be changed to [ ]^c to reflect realistic transmission losses and the actual NRC baseline assumption (5-speed auto, DOHC VVLT with Cylinder Deactivation) which already has significant pumping loss reduction.

Auto w/Aggressive Shift Logic: The Report states that more aggressive torque-converter-clutch lockup calibrations will reduce the losses associated with torque converters (thus this is mainly a transmission loss technology). However, a significant fraction of the fuel consumption improvement is also due to the fact that the engine operates at lower speeds and higher loads, which reduces friction and pumping losses. So positive benefits must be attributed to engine friction and pumping losses. This technology is already in production in GM and competitor vehicles. The NRC 1% - 3% range should be changed to [ ]^c to reflect the fact that this is already implemented and that the NRC assumes it will be implemented on 5-speed auto, DOHC VVLT engines with cylinder deactivation.

6 Speed Automatic Transmission: The Report does not state the loss mechanism, which is reduced when using 6 speed automatic transmissions. However, the effects on the benefit categories are the same as they are for 5 speed automatic transmissions: positive benefits for pumping losses and engine friction and a penalty for additional transmission losses (due to increased spin losses in the 6 speed transmission). The benefits of 6-speed automatic transmissions are more applicable to high-performance applications than they are to conventional moderate-performance applications where higher N/V's are used and spin losses are very important. The NRC 1% -2% range should be changed [ ]^c to reflect the actual

NRC baseline assumption (5-speed auto, DOHC VVLT with Cylinder Deactivation) which already has significant pumping loss reduction.

Aero Drag Reduction: The Report indicates that aero drag reductions can be achieved cost-effectively if improvements are made during vehicle "upgrades." The Report assumes a 10% reduction in aerodynamic drag. The NRC 1% - 2% range is [ ]c

Improved Rolling Resistance: The Report indicates that advances in tire technology can be achieved without compromising handling, comfort, or braking. Today, GM's car and truck fleet tires have some of the lowest rolling resistance in the industry. Further, considering new safety standards coming for tires, we would feel fortunate to maintain our current values. Over the last few years, we have been pushing the envelope on tire rolling resistance development and have found many drawbacks when exceeding our current capability. Chip and tear for truck tires is an example of the development issue when we try to lower the rolling resistance. Consequently, tire rolling resistance reductions of [ ]c The NRC 1% - 1.5% fuel economy range [ ]c

Intake Valve Throttling (continuously variable lift): The Report states that this is primarily a pumping loss reduction technology. However, some penalty must be attributed to friction due to the increased number of actuation and valvetrain components required for this complex system to be realized, even though reduced valve lift at lighter loads partially offsets the fundamental friction differences. There are offsetting factors affecting thermal efficiency (reduced overall in-cylinder bulk motion, increased throttling at valve to improve fuel atomization, reduced residual gas heating of incoming fuel-air charge), so no benefit or penalty is attributed to thermal efficiency. The NRC 3% - 6% range should be changed to [ ]c to reflect the actual NRC baseline assumption (5-speed auto, 6-speed auto, manual shift automatic, DOHC VVLT with Cylinder Deactivation) which already has significant pumping loss reduction.

Camless Valve Actuation: The Report states that this is primarily a pumping loss reduction technology. The Report also mentions the fact that energy consumption (electrical or hydraulic) of this technology is a remaining challenge. As such, a penalty must be attributed to friction loss in order to account for the significant energy consumption of camless systems. The Report does not mention thermal efficiency benefits, but they may exist due to more precise optimization of exhaust valve opening and intake valve closing timing, which helps to offset the potential for degraded combustion performance at light loads. As a result, a small benefit should be attributed to thermal efficiency if it is assumed that the camless system can provide total control of lift, timing, and duration (which is not the case for the electromechanical systems cited in the Report). The NRC 5% - 10% range should be changed to [ ]c to reflect the actual NRC baseline assumption (CVT, Advanced CVT, DOHC VVLT) which already has significant pumping loss reduction.

Variable Compression Ratio: The Report states that this is primarily a thermal efficiency improvement technology, due to the ability to optimize compression ratio as engine load and speed change. This technology is an enabling technology that may enable downsized boosted engines (which by themselves offer no fuel consumption improvement over the NRC baseline of a DOHC VVLT engine with Cylinder Deactivation) to achieve some fuel consumption reductions. It is likely that Variable Compression Ratio technology is only well-suited to downsized, boosted engines. The Report does not mention the fact that additional friction and parasitic losses resulting from the variable CR actuation mechanism will be incurred; this requires that some

penalty be attributed to friction or parasitics. The NRC 2% - 6% range should be changed to [ ]^c to reflect the actual NRC baseline assumption (CVT, Advanced CVT, camless) which already has significant pumping loss reduction and thermal efficiency improvement.

Automatic Shift Manual Transmission: The Report indicates that the use of single-clutch or dual-clutch automated manual transmissions can reduce losses that are incurred in conventional hydraulic torque converters used with automatic transmissions. This reduces transmission losses. The benefits of this technology are highly dependent on the ability to deliver acceptable launch and shift quality. The NRC 3% - 5% range [ ]^c if it is assumed that a dual clutch system is used.

Advanced (High Torque) CVT: The Report does not state which loss mechanisms are reduced when advanced CVTs are applied. The Report implies that broader market penetration might be achieved with higher-torque-capacity Advanced CVTs. However, this would not increase the benefit of CVTs; rather, it would increase the number of applications on which CVTs could be applied. The NRC 0% - 2% range should be changed to [ ]^c to reflect this fact..

42V Electrical System: The Report indicates that 42V technology will be implemented to enable manufacturers to meet increased electrical load requirements. It also indicates that some new technologies "such as electric power steering" will improve vehicle efficiency. This is true; however, electric power steering technology was already accounted for in two other NRC technologies (Engine Accessory Improvement and Electric Power Steering). The NRC 1% - 2% range should be changed to [ ]^c to reflect the fact that 42V technology by itself will not reduce fuel consumption (it is the applications that use 42V – counted elsewhere in the NRC Report – that may improve fuel consumption).

Integrated Starter Generator (ISG) w/Idle Off: The Report states that the benefit for ISG is achieved by shutting the engine off at idle. In a conventional powertrain at idle, there is work done to overcome transmission losses (converting work into heat by rotating the torque converter), engine pumping losses, and engine friction losses. It has been suggested that some benefit should be assigned to thermal losses. However, those losses are only the result of the need to perform work on the transmission, engine pumping losses, and engine friction losses. As with other pumping and friction reduction technologies, thermal losses are reduced as a byproduct of the fact that less indicated work is required. At idle, more than 1/3 of the indicated energy is sent to the transmission and accessories, roughly 1/4 of the indicated energy is used to overcome engine friction, and roughly 1/3 of the indicated energy is used to overcome engine pumping losses (these numbers are application dependent). Therefore, positive benefits can be attributed to transmission losses, pumping losses, and engine friction, since this work is no longer done during idle shutoff. The Report does not include benefits attributable to regenerative braking, because this technology drives significant energy storage content into the vehicle. The NRC 4% - 7% range should be changed to [ ]^c to reflect the actual NRC baseline (DOHC VVLT engine with Camless or Intake Valve Throttling and Cylinder Deactivation) which already has significant reductions in pumping losses at idle. The 4% - 7% range [ ]^c

Electric Power Steering: The Report does not include a separate description for Electric Power Steering (perhaps because benefits are claimed for this technology in Engine Accessory Improvement and 42V Electrical Systems), but a separate fuel consumption reduction is used in

the NRC calculations (resulting in triple-counting of the benefits of this technology). The NRC 1.5% - 2.5% range should be changed to [ ][c], and it should be counted only once.

NAS Treatment of Direct Injection and Hybrids
The NRC Report excluded direct injection gasoline (DI gas), direct injection Diesel (DI Diesel), and aggressive gasoline-electric hybrid technologies from its study. The fuel consumption benefits of these technologies are well known. However, these technologies negatively affect other important vehicle attributes such as emissions or cost, and as a result do not meet the standards used in the NRC Report for technical feasibility and/or economic practicability. The Report (in Finding 5 and Finding 14) was correct in its exclusion of these technologies.
DI gas engine technology, which enables lean operation, reduces fuel consumption by reducing pumping losses (due to less throttling) and increasing thermal efficiency (due to higher compression ratio, increased ratio of specific heats). These improvements offset efficiency *reductions* caused by reduced combustion efficiency (due to unburned fuel) and increased frictional losses (due to increased reciprocating friction and high pressure fuel pump losses). DI Diesel engine technology, which also enables lean operation, has similar but more pronounced effects on pumping losses, thermal efficiency, and frictional losses. (See also our discussion of these technologies in our response to Question A6.)

There are significant concerns with emissions from engines that operate lean. As noted in the NRC Report, lean burn engines "face significant technical challenges to meet the Tier 2 emission standards established by the Environmental Protection Agency under the 1990 amendments to the Clean Air Act and California's low-emission-vehicle (LEV II) standards. The major problems are the Tier 2 emission standards for nitrogen oxides and particulates and the requirement that emission control systems be certified for a 120,000-mile lifetime." An additional requirement for these technologies is the need for low-sulfur fuel, which will not be widely available throughout the United States in the timeframe being considered.

Mild hybrid electric vehicles (using integrated starter generators) were included in the projections in the NRC Report. However, as noted in the Report, "hybrid electric vehicles face significant cost hurdles." Any study that accurately evaluates cost-effectiveness of technologies will identify hybrid technology as one that is not yet cost-effective. (See also our response Question A17.)

Question 17.
Should hybrid and fuel cell vehicles have been included in the [NAS] paths? If so, which ones and which specific vehicle types? What technologies would be included with these types of vehicles?

Response 17.
Fuel Cells
The NAS report correctly stated that viable fuel cell technology is at least 10-15 years away:

> "However, most researchers and automotive manufacturers believe that successful commercial applications of fuel cells for passenger cars is at least 10-15 years away." (NAS 2002:40)

Thus fuel cells should not be considered by NHTSA in this rulemaking. Longer-term fuel cell technologies hold the potential for significant future improvements in energy efficiency, petroleum reduction and greenhouse gas emission reductions. However, there are significant hurdles to overcome before commercialization including cost, infrastructure, hydrogen

generation, and storage. The pacing element for fuel cell vehicle availability will likely be the development of the hydrogen infrastructure. Fuel cell vehicles operating on hydrogen produced from renewable energy sources offer the long-term vision for vehicles.

Hybrids

Making hybrid systems cost-effective is a major challenge and one that continues to prevent high volume introduction in all types of vehicles. Any valid cost-effectiveness calculation will identify hybrids as having lower cost-effectiveness than most other fuel economy-enabling technologies. While it would be expected that as system development progresses and the capabilities of energy storage devices, power electronics, and other system and subsystem attributes grow, the cost of hybrid systems should decrease. However, NHTSA should not project that hybrids will be a cost-effective solution to improve light truck fuel economy for this rulemaking.

The discussion of commercialization of hybrids in trucks needs to be separated into a discussion of Integrated starter/generator (ISG) hybrids (called "mild hybrids" by the NAS) and a discussion of the more extensive vehicle hybridization (i.e. larger proportion of energy requirements provided by the electric drives).

Non-Mild Hybrids

The NAS did not include non-ISG hybrids (the NAS referred to them as "fully parallel hybrids" and series hybrids). This exclusion is appropriate for NAS and is also appropriate for NHTSA in its consideration of light truck fuel economy potential for this rulemaking. The NAS cited complexity and cost as critical obstacles:

> "In general, series hybrids are not yet intended for even limited production, owning to the relative poor performance of electric power propulsion and the low efficiencies of current battery systems compared with mechanical drive systems" (NAS 2002:40)
>
> "For fully parallel systems, which operate for significant periods entirely on the electrical drive, especially in city driving, the cost premium can escalate to $7500 or more" (NAS 2002:40)

ISG Hybrids

ISG hybrids (without regenerative braking) were included in NAS' Paths 2 and 3 across all vehicle segments. [

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]c

[

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Special Issues for Hybridization of Trucks

Hybrids are an emerging technology and have special issues when applied to trucks. Unlike cars, trucks are designed to haul or tow a significant cargo relative to their mass. The power for this capability must be available on a continuous basis; meaning it must be supplied by the internal combustion engine alone, without the assistance of any electrical component in the hybrid powertrain. The use of downsized internal combustion engines with electric machines and electrical energy storage devices, as has been done on the recently introduced hybrid small passenger cars, has the potential to significantly degrade all aspects of truck utility. Consider using a loaded hybrid SUV while driving up a long hill or mountain such as I-70 out of Denver; 15-20 miles long at a 7% constant grade. Such degradation is unacceptable even for consumers who use their vehicle's utility only a few times per year. Therefore, the hybrid system design architectures and the complimentary fuel savings from downsized engines possible in trucks, SUVs, and minivans is more limited than it would be in less utilitarian vehicles, such as small cars.

With the fuel savings of the ISG system limited to engine-off operation, one needs to be aware that the use of an air conditioning system during warm/hot weather and for defrost/defog operation could significantly reduce the real-world fuel savings attributed to the engine-off operation. The engine would need to be running to drive the A/C compressor during these zero vehicle speed times.

If the fuel savings from the regenerative braking capability of a truck hybrid system is being estimated, it should be noted that the potential savings from a rear-wheel-drive (RWD) truck will be much lower than that of a front-wheel-drive vehicle (FWD). Weight transfer under braking will result in very little weight over the rear wheels. Unless additional electrical devices are added to the front wheels at a greater expense, less regenerative braking energy can be extracted than on a FWD vehicle. With a high percentage of the truck vehicles being of a RWD configuration, this is an important consideration in NHTSA's studies. The regenerative braking energy recapture potential for truck vehicles is also low because of their large frontal areas and high drag coefficients that result from providing a maximum amount of utility for the vehicle's owner. The higher aerodynamic power required to maintain vehicle speed will decelerate the vehicle more rapidly than a passenger car, reducing the opportunity for regenerative braking usage.

Finally, it is important to repeat the point that adding a hybrid system to a vehicle that is designed to provide a maximum amount of utility will reduce that utility. The components of the system have to be located in the vehicle in such a way that their presence is transparent; that is, there is no loss of usable space. The added mass of the motor(s), battery pack and motor controllers will decrease the vehicle's fuel economy somewhat, and the hybrid system has to first recover that loss before it can provide a net plus.

Question 18.

Do you believe that the NAS study over or under estimated the fuel economy benefits from specific technologies? If so, which ones and why? Please provide NHTSA with your data that suggest a different benefit resulting from the application of these technologies.

Response 18.
Because of the similarity of this question and Question 16, we have combined our responses to these two questions. Please refer to Question 16.

Question 19.
Do you agree with the figures derived in the NAS break-even analysis? If not, why? Please address specific areas of differences, explain your reason(s) why, and provide supporting data for your reasons and arguments.

Response 19.
We do not agree with the NAS break-even analysis for two reasons. First, we fault the NAS break-even analysis for failure to consider all aspects of consumer cost as outlined in our response to Question 3. Second, the fuel consumption reduction and incremental cost results presented in Chapter 3 of the Report are the basis for the "cost-efficient" analysis in Chapter 4. As such, since this analysis relies on the estimates of fuel consumption benefit from individual and aggregated technologies, it suffers the same significant problems that were described in our response to Question 16.

Some have suggested that the technologies used in NAS' "cost-efficient" calculation were not technologies suffering from the flawed systems-level analysis cited in Question 16. This is incorrect. Figure 19 below demonstrates that the Path 3 technologies used in this analysis were the ones that suffered from the technology aggregation problem identified in response to Question 16. Figure 19 lists technologies used on the Midsize SUV vehicle segment that use pumping loss reduction as the primary means for fuel consumption reduction. A "X" indicates those technologies which were used by the NRC analysis. The simple and incorrect method used for aggregating these technologies results in the significant overcounting fuel consumption reduction any time two technologies that affect the same loss mechanism are combined.

	3-Yr Payback with 0% Discount Rate		**14-Yr Payback with 12% Discount Rate**	
	Low Cost/ High MPG	**High Cost/ Low MPG**	**Low Cost/ High MPG**	**High Cost/ Low MPG**
Multi Valve OHC	X		X	X
Variable Valve Timing	X		X	X
Supercharging & Downsizing			X	X
Camless Valve Actuation			X	

Figure 19: Pumping loss technologies included in NRC cost effective analysis (Midsize SUV vehicle segment)

Question 20.
For the forthcoming rulemaking and future CAFE rulemakings, benefit analysis will play an important role in NHTSA decision making. NHTSA therefore seeks comments on the following specific benefit issues: Can you provide, in addition to the material in the NAS report, any methods and data that would be helpful in identifying, quantifying, and expressing in dollar units the potential benefits of alternative CAFE standards (including energy security, environmental, and other considerations)? Are there any ancillary studies that NHTSA or other federal agencies should commission to provide a stronger technical foundation for making benefit estimates in future CAFE rulemakings?

Response 20.
This is an important question, because it is the first question required by Executive Order 12866 in determining the need for any regulation. Specifically, EO 12866 and the accompanying economic analysis guidelines of January 1996 require that a "Statement of Need" must make two determinations:

> (1) Whether there is a "significant market failure" or "compelling need" that warrants the proposed regulatory intervention and (2) whether the proposed intervention is superior to a non-regulatory approach for achieving the statutory objective. Other non-regulatory alternatives could include, for example, subsidizing actions to achieve a desired outcome; such subsidies may be more efficient than rigid mandates. Similarly, a fee or charge...may be a preferable alternative to banning or restricting a product or action." [Economic Analysis of Federal Regulations Under Executive Order 12866, January 11, 1996, pages 3, 5-6]

The following analysis shows that neither requirement is met in the case of CAFE standards for light trucks. There is no market failure that justifies any increase in the CAFE standard and there are other far more cost-effective non-regulatory approaches for achieving any and all of the statutory objectives.

The following discussion first addresses the issues of energy security, environmental, and global warming concerns. In each case our point of departure is the NAS study, which concluded that each gallon of gasoline consumed imposes externality costs of $0.26 per gallon, 12 cents per gallon for energy security, 12 cents per gallon for global climate concerns, and 2 cents a gallon for environmental pollution. In each case careful analysis finds that the relevant CAFE-related externalities are either zero or, if positive, the costs of CAFE outweigh the externality. Next we look at other societal impacts of the CAFE standard – especially at its impacts on safety and consumer choice.

For purposes of this analysis, it should be emphasized that the mere existence of an oil consumption externality does not justify a CAFE constraint unless, in the words of the OMB guidance, there is a "significant market failure."

On this point, please see: Douglas R. Bohi and Michael A. Toman, *The Economics of Energy Security*, Resources for the Future (1996), p. 10:

> "Even in cases where it is clear that an improvement in economic efficiency is possible in principle, the government may have no practical option for addressing the problem, or the cost of taking action may be greater than the benefit to be achieved from the action. . . . [W]hen a policy action yields benefits that are smaller than its corresponding costs, the policy should not be adopted and the externality that gives rise to the policy need not be measured. All such externalities can be ignored for purposes of designing a particular public policy, for the same reason that all externalities that do not affect efficiency can be ignored." (Bohi 1996: 10, emphasis added.)

Critique of NAS Conclusions
Contrary to the conclusions of the NAS report, there are no "significant market failures" that an increase in the CAFE standard might address. Energy security, global climate change, and the overall environment pose serious issues that require effective and cost-effective policy responses; but increasing the CAFE standard is neither an effective or cost-effective policy option.

(1) Energy Security Externality (NAS 12 cents per gallon):
The NAS study concludes that there is an "oil import" premium of 12 cents a gallon, which it breaks into a 6 cents per gallon "monopsony component" and a 6 cents per gallon "oil security" premium. Because CAFE is a costly, ineffective, and even counterproductive "solution" the appropriate CAFE-related premium is zero to negative.

(A) "Monopsony Component" (NAS 6 cents per gallon)
The NAS presumes the U.S. consumes so much oil that we can influence the price at which it sells on world oil markets. A reduction in our imports would, according to this view, mean a reduction in world oil prices and an improvement in the balance of trade.

The NAS argument fails on the following four grounds:

First, it is by no means clear that modest changes in U.S. oil consumption could have a measurable impact on world prices, especially since oil producers would likely respond to U.S. policies. Resources for the Future (RFF) economists Bohi and Toman in the reference cited above conclude:

> "The monopsony premium could be negative if major OPEC producers are influenced by target-revenue considerations or if attempts to exploit monopsony power provoke a retaliatory response." (Bohi 1996: 46)

See also: Congressional Research Service, Report for Congress: "Oil Imports: An Overview and Update of Economic and Security Effects," John L. Moore, Carl E. Behrens, John E. Blodgett, Environment and Natural Resources Division, December 12, 1997:

> "If OPEC cut production to offset the U.S. cuts in demand for imports by an equal amount, then there would be no decline in price and no gain to U.S. consumers. If OPEC made no change in output . . . savings to U.S. consumers could be several dollars per barrel. . . . It seems unlikely however, that OPEC would not take some retaliatory action, meaning that benefits would be small. Such hypothetical ranges also beg the question of how and at what cost reduction in imports would be achieved. <u>Beyond contentious international trade restrictions, it could cost more to achieve reductions than the savings realized to consumers.</u>" (Moore, et.al 1997:5-6, emphasis added.)

Regarding the empirical evidence, Bohi and Toman argued that:

> "The evidence of anti-competitive behavior by OPEC in the current market was too weak to justify efforts to justify monopsony power and the mere existence of monopsony power did not justify using neighbor-beggaring policies (especially since such policies could stimulate the exercise of unexploited collective market power by exporters.)...[M]oreover, it is important only to account for the increase in import costs that private hedging transactions do not address." (Bohi 1996: 60)

Second, any successful effort to reduce oil consumption would only increase OPEC market power in the U.S. market. That's because U.S. oil producers are the highest-cost, marginal producers. Any reductions in U.S. oil consumption would come at the expense of U.S. oil producers, thus increasing OPEC market share and their power to raise prices in the U.S. market.

Third, should CAFE reduce energy consumption and oil imports, it would do so by swapping foreign cars for foreign oil. CAFE binds domestic more than foreign producers. Any increase in CAFE promotes auto imports at the expense of domestic producers and workers. Recent EIA studies of CAFE increases indicate that they would increase the U.S. trade deficit. In any event, the U.S. balance of trade is determined by macroeconomic variables – the relationship between domestic saving and investment – not by microeconomic variables like net exports in any one sector.

Fourth, CAFE is simply not capable of reducing U.S. consumption enough to influence worldwide markets for oil supply and demand. Even the most ambitious projections for fuel savings under a CAFE mandate would not make a dent in worldwide deliveries of 100 million barrels per day and more.

In short, any "monopsony premium" is purely speculative. Increasing CAFE would just as likely increase as decrease U.S. oil prices and would leave the U.S. trade balance unaffected – substituting imports of foreign vehicles for imports of foreign oil.

(B) "Oil Security Component" (NAS: 6 Cents per gallon)
"Oil security" typically has two meanings: military expenditures to keep Mid East oil sources secure and to maintain oil price stability. Neither issue has anything to do with CAFE. Energy security is an extremely important objective. However, CAFE does nothing to promote energy security and diverts attention from what must be done.

(1) Premium for Military Security Expenditures
As RFF scholars Bohi and Toman conclude, this argument "rests on several logical flaws."

> "First, to the extent that military security expenditures are related to oil imports, they are a cost of mitigating energy insecurity, rather than a cost of energy insecurity itself. To assume that the level of military expenditures is a good approximation of the externality mistakenly implies that the size of the policy response defines the size of the externality." (Bohi 1996: 25)

Second:

> "[M]ilitary expenditures in the Middle East are made to serve a variety of national security interests other than securing oil flows or stabilizing oil prices. . . . [S]ince the expenditures are a common cost for many purposes, any assignment of cost shares among different purposes is arbitrary." (Bohi 1996: 25)

See also Congressional Research Service above:

> "In terms of military expenditures related to the Middle East, even if oil imports from the region could be minimized, U.S. geopolitical interests there relate to far more than foreign oil." (Moore et.al. 1997:1-2)

Third, and most importantly, again quoting Bohi and Toman:

> "It seems unlikely . . . that a reduction of U.S imports by one or two million barrels a day would systematically lower the U.S. military commitment in the Middle East for energy or other geopolitical purposes. Instead, the military outlay, to the extent that it can be

associated with energy protection, may be seen as a fixed cost that cannot be altered by marginal changes in energy prices and demands. As such, it is not relevant to energy policy." (Bohi 1996: 26)

See also Congressional Research Service:

> "It is sometimes argued that any reduction in U.S. imports would reduce the 'pressure' on the world market, but that position is conceptually flawed . ... Reducing U.S. consumption would reduce [the] world production rate, but it is hard to see how this would increase the stability of the market. . . . [T]here may be other reasons for supporting efforts to reduce imports, but they will have little effect on the amount spent for security in the Persian Gulf." (Moore et.al. 1997: 8, emphasis added.)

Or see Michael Boskin, Chairman, former President Bush's Council of Economic Advisors:

> "Whether one considers our own situation, or, more properly, that of the world economy as a whole, even the most optimistic assessment of the oil consumption effects of higher CAFE standards cannot conceivably put us past a threshold where we would no longer have a vital security interest in the major oil-exporting regions of the world." (Statement before the National Academy of Sciences Panel on Corporate Average Fuel Economy, July 10, 1991, pages 1-2.)

(2) Oil Price Volatility

As RFF scholars Bohi and Toman conclude, spending for "oil security" has nothing to do with the level of U.S. oil imports: the harm of an oil price shock will occur whether or not the U.S. imports any oil.

> "It is plausible...that even a complete elimination of oil imports to the United States will not eliminate the need for military spending for oil security, or to put it another way, will not reduce the economic cost of a disruption in foreign oil supplies by enough to ignore the events that may affect the international flow of oil. The reason, based on our discussion of externalities above, that the principal economic cost of a disruption arises because of the economic harm caused by an oil price shock and this harm will occur whether or not the United States imports any oil. The harm will be largely the same even if imports are completely eliminated because the price of domestically produced oil is still determined by the world price, and any disruption that affects the world price will continue to affect the domestic price." (Bohi 1996: 53-54, emphasis added)

Some believe that the U.S. should pursue a policy of complete oil independence. Such a policy would be disastrous. Denying us abundant, low cost energy imports would devastate our economy. The United States, with 2% of the world's reserves, consumes 25% of its petroleum each year. Even a massive increase in domestic oil production could not begin to close such a gap in the absence of draconian restraints on energy consumption. It would hasten the day on which the U.S. has no more reserves.

Again, to quote the 1997 Congressional Research study:

> "In sum, external costs associated with oil imports remain an ambiguous concept with some arguing that the SPR, energy R&D, and other energy policies already may provide a cost-effective response for current oil market risks.

As the above research shows and common sense suggests, the correct oil security premium for purposes of CAFE analysis is zero to negative. Because CAFE addresses long-term levels of consumption, it is powerless to affect the kinds of short-term supply and demand adjustments needed to cope with oil supply disruptions. Indeed, focusing on CAFE as a way to address energy security problems merely deflects attention from effective policies, making matters worse.

Government policies should focus on improving policy instruments that actually deal with the underlying problem. This means expanding strategic petroleum reserves, promoting alternative domestic and foreign energy sources, and eliminating regulatory barriers to oil production, refining, and distribution. Of particular importance here will be the extension of dual fuel vehicle credits for CAFE compliance. Flexibility requires these vehicles to be available, even if economic conditions have yet to warrant their extensive use of alternative fuels.

(2) Global Climate Concerns (NAS 12 cents per gallon)
Once again, because CAFE is a costly, ineffective, and counterproductive "solution" the appropriate CAFE-related premium is zero to negative.

The NAS comes up with a 12 cents a gallon estimate for the global climate costs imposed by U.S. auto drivers. The NAS overestimates any potential carbon externality. The NAS report states:

> "The committee has used a figure of $50/tonne C as an estimate of the environmental externality of additional carbon emissions, although this figure is significantly higher than typical estimates in the published literature. This estimate translates into a cost of $0.12/gal (gasoline), the values used in the examples in this chapter." [NAS 2002:85.]

The NAS goes on to state in footnote 4:

> "At one of the committee's public meetings, a representative of an environmental advocacy organization indicated that there was much uncertainty but offered a figure of $50/tonne. That figure is viewed as high, but not implausibly high, by committee members who have been involved in the global climate debates."

In fact, the $0.12 per gallon estimate and corresponding $50/tonne climate externality estimate is between two and ten times the upper bound found in most of the literature. [See Toman and Shogren, "How Much Climate Change is Too Much: An Economic Perspective," *Climate Change Issues Brier No. 25,* Resources for the Future (September 2000), page 12.]

William Nordhaus, for example, a leading expert, estimates an optimal climate tax of $4 per ton of carbon in 2010, rising to $16 per ton in 2050 (Nordhaus 1994). This equates to a range of gasoline taxes between 1 and 4 cents per gallon.

The costs of even the smallest mandatory CAFE increase exceed the benefits. Numerous studies, including the attached report by Professor Kleit and even the NAS report, conclude that there are far more effective and less costly ways of addressing climate issues than CAFE. Under any scenario, CAFE is an ineffective, costly and counterproductive approach. The appropriate CAFE-related externality for climate change is therefore zero. Once again, as Bohi and Toman point out:

"[W]hen a policy action yields benefits that are smaller than its corresponding costs, the policy should not be adopted and the externality that gives rise to the policy need not be measured." (Op.cit. page 10)

Please note this does not mean that the underlying global climate externality is zero and that there is no cause for concern. All it means is that CAFE is an ineffective, costly, and counterproductive approach. It means that other approaches such as fuel taxes and carbon taxes can cut emissions at a cost of one-tenth or less. It means that focusing on myopic measures like CAFE diverts attention from the kind of long-term research, development, and commercialization of vehicles and vehicle technologies that ultimately will make a difference.

(3) Environmental Externalities (NAS two cents per gallon)
The CAFE-related externality for environmental externalities is unambiguously negative. CAFE would actually increase pollution, imposing a negative externality.

The NAS study concludes that motorists impose 2 cents per gallon of environmental costs. The attached study by Professor Kleit demonstrates that increases in vehicle miles traveled resulting from CAFE's reduced cost to travel and other factors lead to an increase of about 2% in the emissions of criteria pollutants. Criteria pollutants tend not to vary with fuel economy since emission standards are established based on grams per mile. Also, by focusing on new cars and trucks, the CAFE standard encourages the retention of older, higher emitting vehicles. It has been estimated that as few as 10% of the vehicles account for 50% of the emissions on the road. Some argue that this analysis ignores oil refinery emissions. However, those emissions are under a strict EPA cap and do not vary by amount of petroleum refined.

Other Disbenefits (Negative Externalities) Associated with CAFE
CAFE has two other perverse effects. Aside from harming the environment and doing nothing to promote energy security and nothing to alleviate global climate concerns, CAFE reduces highway safety and consumer choice.

CAFE and Safety
Motor vehicle safety degrades with decreasing vehicle mass. CAFE increases that produce consequent vehicle mass reductions degrade safety performance. This has been the consistent conclusion of many studies (see GM's response to Question 1). For example, the NAS study confirmed that downsizing and weight reductions have caused a loss of 1300 to 2600 fatalities and 13,000 and 26,000 fatalities in 1993 and that a proportion of that loss is attributable to CAFE.

CAFE and Consumer Choice
Consumer choice is a fundamental societal benefit. The principle is that so long as one person's actions impose no harm on another, she should be free to choose. Denying mothers and fathers the kind of safe and affordable transportation they need to transport themselves and their children to work, school and play violates this most fundamental concept of liberty and social justice. This is especially objectionable, where as with CAFE, there are no offsetting societal benefits arising from the restriction on consumer choice.

Professor Kleit's study, attached, shows that even small increases in the CAFE standards would impose billions of dollars of costs on the nation's consumers and that these and other costs of CAFE would be far in excess of any benefits. By definition, any mandatory increase in CAFE – any increase above free expression – will necessarily impose costs on consumers that exceed the benefits as judged by consumers. Otherwise the standard would not be necessary. Even

with gasoline prices of $3 and $4 per gallon, in Europe and Japan the only significant additional technologies relate to diesels that are constrained under U.S. environmental laws.

Summary and Conclusions Regarding the Potential Benefits of CAFE
CAFE fails to satisfy OMB's requirement for statement of need. There is no significant market failure or compelling need that increased light truck CAFE levels might effectively address and there are many other ways to achieve any of the objectives of national energy policy. There are four things any proposed regulation can do: it can impose benefits that exceed the costs, benefits that just match the costs, benefits that fall short of the costs, and impose negative benefits. CAFE falls in the last category: imposing substantial negative societal disbenefits in terms of environmental harms and increased highway injuries and fatalities, while doing nothing to promote energy security and nothing to address global climate concerns.

CAFE and the Need to Conserve

Everyone supports the wise use of energy. The question is not whether there is a need to conserve oil, but rather what is the purpose, how much should we conserve and how should we do it? In particular, are current market forces sufficient to achieve the "right" amount of conservation? If not, how should governments intervene to increase conservation beyond the free-market level?

Five rationales have been advanced for mandatory conservation programs like CAFE. We consider the above questions – how much to conserve and how to do it – in each of these contexts:

Rationale #1: Mandatory conservation is necessary to enhance energy security.
Rationale # 2: Mandatory conservation is necessary to avoid depletion of a non-renewable resource.
Rationale # 3: Mandatory conservation is necessary to address climate change.
Rationale #4: Mandatory conservation is necessary to reduce air pollution.
Rationale #5: Mandatory conservation is good for its own sake.

Rationale #1: Mandatory conservation is necessary to enhance energy security.
Energy security does not mean energy independence. Denying the nation's consumers and producers access to low-cost foreign energy supplies would weaken the nation's competitiveness and make it less economically secure. The sensible goal, and the one adopted by the European Union, is to insulate each oil-consuming nation and the oil-consuming world from oil price spikes.
Government policies that advance this purpose include expanding strategic petroleum reserves, promoting alternative domestic and foreign energy sources, and eliminating regulatory barriers to oil production, refining, and distribution.

Programs that succeed in reducing domestic oil consumption would increase, in percentage terms, U.S. and world dependence on the most insecure sources of supply, by increasing the market share of low-cost Middle Eastern OPEC producers. Because the world energy markets are inextricably linked, disruptions in the availability or price of energy are likely to produce similar economic repercussions no matter how dependent an economy is on foreign oil.

Rationale #2: Mandatory conservation is necessary to avoid depletion of a non-renewable resource.

This concern is that we might leave our heirs without enough low-cost energy to support their living standards. However, there is no reason to believe that we are ever going to "run out" of petroleum or any other depletable resource. Saudi Arabian and other oil producers will not pump and sell oil in the current period so long as they think it will get them a larger profit (discounted at the appropriate rate of interest) in a future period. As a result, we would expect never to "run out" of oil – we would just slowly convert to alternatives in the future as the price of oil began to approach and then exceed that of some substitute (e.g. natural gas, coal, nuclear, solar, wind, etc.)

Historically, moreover, the empirical evidence reveals that nearly every non-renewable resource has become more abundant, not less abundant over time. This increased abundance has left each ensuing generation endowed with increasingly abundant and less expensive fuels with which to power their economies, raise living standards, feed the poor and attack environmental, health and safety concerns. (Environmental, health and safety amenities are positive economic goods: demands for each grow with increasing incomes fueled by economic growth. Wealthier is healthier.) The reason for this increasing abundance of non-renewable fuels is that over the years, and especially in recent years, technological improvements have increased the ability to find and utilize non-renewable resources at lower and lower costs. In the rare instances where this has not been true – for example, whale oil – cheaper and more widely available substitutes have been discovered or innovated such as oil and natural gas. We have every reason to believe this process will continue in the future.

If, nonetheless, the concern is that the world is prematurely running out of fuel, the way to achieve additional conservation is to raise the price of fuel. Numerous studies show that fuel taxes are much more effective and much less costly than increases in the CAFE standard.

Rationale #3: Mandatory conservation cuts global warming.
Concerns about climate change from the use of petroleum fuels are inconsistent with concerns about oil depletion. If we are indeed "running out" of oil, petroleum consumption will not be a long-term contributor to climate change. Furthermore, CAFE has not proven to be helpful in reducing U.S. dependence on foreign oil or U.S. consumption of gasoline, both of which have increased during the existence of the CAFE program. Higher fuel economy levels may help address consumption concerns by having each individual vehicle consume less energy per mile driven, but it does nothing to limit the number of miles consumers drive each year and it does not affect the size of the vehicle fleet, both of which have more than offset the substantial gains in vehicle fuel economy that have been made since 1975. In any event, broad-based policies relying on market incentives will cut carbon emissions at less than one-tenth the cost of a CAFE increase. CAFE is a wasteful method of addressing global climate change – diverting scarce engineering and capital resources from developing long-term breakthrough technologies such as fuel cells. (See also the critique of the NAS study above).

Rationale #4: Mandatory conservation is necessary to reduce air pollution.
CAFE does not reduce pollution. Emission standards are based on grams per mile with vehicles meeting the same standard regardless of their fuel economy. CAFE standards can actually be expected to increase, not decrease aggregate emissions of criteria pollutants and particulates, as documented in the attached research by Professor Kleit. That is because CAFE promotes increased driving intensity (more miles driven per vehicle) through its "take-back" effect, and it encourages the retention of older, higher polluting vehicles longer. A basic principle of sound public policies is that blunt instruments seldom work. Policies are best tailored to the issue at hand. To cut pollution, policies should be designed that will reduce pollution. Policymakers

should not depend on policies that do something else and that might or might not cut pollution in the bargain.

Rationale #5: Mandatory conservation is good for its own sake.
There is a need to conserve petroleum -- to wisely use energy resources, including oil -- just as there is a need to conserve other resources such as labor, and capital. But we should not conserve energy at the expense of the wise use of these other resources. Because there are other far more effective and less costly policies, excessive CAFE increases necessarily waste labor and capital – resources that are critical to the promotion of economic growth, improved lived standards, and an improved environment. For that reason, such increases violate the very premise – wise use – that underlies the need to conserve energy.

It is important to distinguish "waste" from increased levels of use. "Energy efficiency" is a vacuous, if not misleading concept. As RFF's Richard Newell observes, "There are tradeoffs between economic efficiency and energy efficiency . . . It is possible to get more of the latter, but typically only at the cost of less of the former." ("Balancing Policies for Energy Efficiency and Climate Change, Resources," Summer 2000, page 15.) Or, as former President Bush's chief economist Michael Boskin observed:

> "The 'inverse energy theory of value'—the notion that social welfare is necessarily furthered by all actions to reduce energy use—finds little support in either economic theory or in past experience. The reduction of energy use is not always the highest and best use of our limited and human capital resources." (Op.cit., page 2.)

Mandatory conservation forces the substitution of more expensive materials and components that drive up the cost and increase the price of mobility, which economists view as a major source of economic growth and development. Mandatory conservation programs like CAFE have significant costs. For example the Kleit study (attached) shows that even very small increases in CAFE standards impose billions of dollars in welfare losses on consumers and workers – losses in product values, profits and workers' incomes that would have been generated by the jobs and output that CAFE destroys. Numerous studies show that automotive transportation is among the highest valued uses of energy. Forcing mandatory reductions on auto consumers is thus especially wasteful -- especially harmful to economic growth, prosperity, and the creation of productive jobs for the nation's workers.

Question A1.
Identify all light truck models currently offered for sale in MY 2001 whose production you project discontinuing before MY 2005 and identify the last model year in which each will be offered.

Response A1.

Table A1
2001 MY Light Truck Models To Be Discontinued Before 2005 MY

TABLE IS CONFIDENTIAL

Question A2.
Identify all basic engines offered by respondent in MY 2001 light trucks which respondent projects it will cease to offer for sale in light trucks before MY 2005, and identify the last model year in which each will be offered.

Response A2.

Table A2
2001 LIGHT TRUCK BASIC ENGINES TO BE DISCONTINUED BEFORE MY 2005

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Question A3.
Does the respondent currently project offering for sale for the time period of MY 2005-2010 any new or redesigned light trucks, including vehicles smaller than those now produced? If so, provide the following information for each model (e.g., Chevrolet C1500, Ford F150). Model types that are essentially identical except for their nameplates (e.g., Dodge Caravan/Plymouth Voyager) may be combined into one item. See Table A for a sample format; 4x2 and 4x4 light trucks are different models.

a. Body types to be offered for sale (e.g., regular cab, super cab).
b. Description of basic engines, or power sources (i.e., fuel cell) including optional horsepower and torque ratings, if any; displacement; number and configuration of cylinders; type of fuel injection system; fuel type; number of valves per cylinder, and whether it is 2-cycle or 4-cycle or uses variable valve timing.
c. Transmission type (manual, automatic, number of forward speeds, hybrid, overdrive, etc., as applicable), including gear ratios and final drive, alternative ratios offered, driveline configuration, and special features such as torque converter lockup clutches, electronic controls or CVT design.
d. (i) The range of GVW ratings to be offered for each body type.
(ii) The range of test weights for each body type.
e. All wheelbases.
f. Estimated power absorption unit (RLHP) setting, in hp.
g. The range of projected EPA composite fuel economies for each body type in the initial model year of production.
h. Projected introduction date (model year).
i. Projected sales for each model year from the projected year of introduction through MY 2010, expressed both as an absolute number of units sold and as percentage of all light trucks sold by respondent.
j. Projections of:
(i) Existing models replaced by new models.
(ii) Reduced sales of respondent's existing models as a result of the sale of each of the new models.
(iii) New sales not captured from any of the respondent's existing models.

Response A3.

New model information is listed in Table A3. Where no reliable estimates exist, items are coded TBD (To Be Determined). Engine coding conventions are shown below, and Attachment 2 defines the body and model type coding.

This information represents GM's best projection of its new models at the current time. However, new programs are often delayed or altered because of the many uncertainties beyond our control. [

]c

In addition, factors such as customer purchasing preferences, the nation's economy, fuel price and availability, and competitive influences could substantially alter GM's plans. Further, most of the fuel economy and vehicle weight values are projections from development programs and prototype test results. These may not represent the vehicles finally brought to market 4-8 years from now.

Table A3

New or Redesigned Truck Models To Be Introduced In MY 2005-2010

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Question A4.
Does respondent project introducing any variants of existing basic engines or any new basic engines, other than those mentioned in your response to Question 3, in its light truck fleets in MYs 2005-2010? If so, for each basic engine or variant indicate:

a. The projected year of introduction,
b. Type (e.g., spark ignition, direct injection diesel, 2-cycle, alternative fuel use),
c. Displacement,
d. Type of induction system (e.g., fuel injection with turbocharger, naturally aspirated),
e. Cylinder configuration (e.g., V-8, V-6, I-4),
f. Number of valves per cylinder (e.g., 2, 3, 4,6),
g. Horsepower and torque ratings,
h. Models in which engines are to be used, giving the introduction model year for each model if different from "a," above.
(See Table B for a sample format.)

Response A4.
GM does not expect to introduce any variants of existing basic engines or any new basic engines, other than those mentioned in our response to Question 3, in its light truck fleets in model years 2005-2010. The costs associated with new engine introductions mentioned in our response to Question 3 are included in our response to Question A11.

Question A5.
Relative to MY 2001 levels, for MYs 2005-2010, please provide information, by truckline and as an average effect on a manufacturer's entire light truck fleet, on the weight and/or fuel economy impacts of the following standards or equipment:

a. Federal Motor Vehicle Safety Standard (FMVSS 208) Automatic Restraints
b. FMVSS 201 Occupant Protection in Interior Impact
c. Voluntary installation of safety equipment (e.g., antilock brakes)
e. Environmental Protection Agency regulations
f. California Air Resources Board requirements
g. Other applicable motor vehicle regulations affecting fuel economy.

Response A5.
Safety
Manufacturers implement numerous structure and feature applications to comply with federal safety standards and to voluntarily strive to satisfy consumer metrics and provide consumers with desired safety-related features. Structure and technologies have mass and many also have electrical load implications that affect fuel economy. Table A5.1 lists structural components and features necessary to comply with FMVSS regulations on today's light trucks. Table A5.1 lists the structural components and features implemented voluntarily on many vehicles that exceed federal regulations and that consumers desire. Additionally, Table A5.1 shows the approximate mass and electrical load of each technology.

ENTIRE TABLE CONFIDENTIAL

Table A5.1
Safety Feature Mass Summary

ENTIRE TABLE CONFIDENTIAL

The following responds to NHTSA's Request for Comments on specific safety standards.

FMVSS 208

Manufacturers are developing systems to comply with revised FMVSS 208 requirements, including new tests, test dummies, and injury criteria. The revisions, which were issued in final

rules in 2000 and 2001, were largely initiated and supported by the industry. Phase-in periods for new provisions begin in 2003 and continue through 2010, depending upon the provision. FMVSS 208 covers all of GM's U.S.-sold light trucks with a GVWR of 3855 kg (8500 lb) or less.

Revised FMVSS 208 requires implementation of air bag suppression or low-risk deployment systems, and the use of more and different testing protocol using a wider range of test dummies and injury criteria than were required in 1994. Phase-in occurs from September 2003 through September 2006.

Some of the current technologies that will help enable GM's light trucks to meet FMVSS 208 requirements include:

[

]c

In addition to added mass, some technologies also place a load on the electrical system that has the potential to degrade fuel economy. The combined additional technology necessary to comply with FMVSS 208 is estimated to increase GM's truck fleet weight, on average, [

]c

Alternate suppression and airbag technologies are being studied but are too undefined at this time for meaningful mass estimates.

FMVSS 208 revisions also require manufacturers to meet higher speed, belted, full-barrier vehicle test requirements at 35 mph, with a phase-in starting in September 2007. Full implementation of this 35 mph testing will be complete in September 2010.

The safety technologies listed above are not the only changes necessary to meet the higher speed belted test FMVSS 208 requirements. Revised frame geometry, increased vehicle length, high strength bumpers, and structural reinforcements on the frame or body are all enablers for managing the increased energy of this 35 mph barrier event. Estimating the vehicle mass increase due to the addition of these structural features is difficult since mass changes for crashworthiness are integrated into the total vehicle design and share mass with performance improvements in other areas. For example, as part of continuous improvement, [

]c

Although the additional mass and size are not fully attributed to meeting just one crashworthiness goal or regulation, it is estimated that [ ]c are attributed to improving front crashworthiness on a representative full-size truck. [

]c

NHTSA has suggested two other changes to FMVSS 208 that may affect vehicle mass and aerodynamics, though specifics cannot be supplied without knowing the exact requirements. The anticipated but not yet proposed changes are a) the 95% anthropomorphic test dummy (ATD) unbelted test condition and b) the inclusion of lower leg criteria. Compliance with these proposed revisions could require changes in vehicle architectures such as higher roof lines, steeper windshield angles, changed toepan geometry, or increased vehicle length.

Directionally, we know these changes would decrease fuel economy but the effect has not been quantified.

FMVSS 201

In August 1998, NHTSA issued a final rule (FMVSS 201(U)) to require compliance of vehicle upper interior areas with a subsystem impact testing requirement in which a free motion head form is projected at multiple upper interior locations to help reduce the risk of head injury. Compliance tests using the head form are conducted by impacting the front and rear header, the right and left side rails, sliding door tracks, pillars, and seat belt anchorages. All cars and light trucks (except buses with a GVWR greater than 3860 kg (8500 lb)) must meet this requirement by September 2002.

Compliance with FMVSS 201(U) requires the implementation of more space between the interior trim A-Surface and the sheet metal plus energy absorbing materials filling the space between trim and sheet metal. The mass associated with trim growth and energy absorbing materials on a full size utility is approximately [

]^{c}

Voluntary implementation of safety-related technologies.

GM, like other manufacturers, implements safety technologies that consumers desire and help improve roadway safety. Also, GM, like other manufacturers, develops and implements structural and other performance features that help achieve higher consumer information metrics. These voluntary actions have impact on fuel economy and CAFE.

All GM vehicles, including all light duty trucks, offer anti-lock brakes (ABS) as either standard or optional equipment. ABS systems add about [ ]^{c} on average to light duty trucks. Since 1997, virtually all GM vehicles sold in the U.S., including all light duty trucks, offer daytime running lamps (DRLs) as standard equipment.

GM is currently implementing shoulder belts in center rear seating positions. [

]^{c} Depending on the existing floor and seat structure of the vehicle into which this feature is being added, this value could vary a few pounds more or less. This safety feature may become a federal requirement, as Congress is considering legislation to mandate this voluntary safety feature. [

]^{c}

Manufacturers are also voluntarily implementing side air bags that help protect occupants in side impacts and help protection and containment of occupants' heads, limbs, and bodies in side impact and roll over crashes. The added restraint content, sensing hardware, and structural modifications to implement the head curtain on the next generation full size utility for example is estimated to weigh [ ]^{c} While restraint use is the most effective method to help reduce injury risk in rollover and other crashes, higher mass from side air bags, which also help reduce injury risk, has fuel economy implications.

Although GM does not believe the use of IIHS's 40mph 40% front ODB evaluation is appropriate for heavier mass vehicles, [

]^{c} As noted before, it is difficult to separate out all the mass of the structure added to vehicles for a specific event. However, in general some of the reinforcements and therefore some of the required structural mass increase can be attributed exclusively to controlling the loads during this event. [

]^{c}

GM is currently evaluating how the IIHS side impact test may affect light truck designs. Countermeasures to help achieve better performance may include head protection in the form of a roof rail air bag (curtain bag) or a head-torso seat mounted side impact air bag and significant structural changes, such as door interlocks, reinforced pillars, and reinforced cross car floor structure. Although, it is too early to provide a realistic mass estimate beyond the roof rail airbag technology, which has already been described above, adding structure (mass) typically will be necessary for compliance with any upgraded or more stringent side impact standard.

Consumers often classify personal and property security features as "safety" features. To help reduce the risk of vehicle and property theft, manufacturers are evaluating the potential use of advanced glazing for side windows as a vehicle personal security enhancement. Other personal security technologies include approach and egress lighting, panic alarms, and telematic systems. These technologies add mass, and some also have electrical load implications.

Other safety applicable motor vehicle regulations affecting fuel economy.
Safety technologies and structure necessary for compliance with FMVSS 208 and 201 are just two examples of U.S. federal standards that add mass, and in some cases, electrical load. Additional FMVSS standards implemented since 1994 or anticipated during the 2005 to 2010 time period will have a negative impact on CAFE.

FMVSS 301 (fuel system integrity) is expected to be updated, affecting vehicles during the 2005 – 2010 time period. [

]^{c}

The Transportation Recall Enhancement, Accountability and Documents (TREAD) Act compels NHTSA to update the tire performance standards. However, the proposed new FMVSS 139 tire performance standard and the proposed changes to FMVSS 110 and 120 tire selection requirements could require manufacturers to use larger-sized tires in some applications, which would increase mass and rolling resistance.

There are particular concerns about the impact of the TREAD Act on fuel economy. GM is an industry leader in original equipment rolling resistance tires. Revisions in tire construction, materials, and rubber compounds will be required to meet laboratory test requirements of the proposed FMVSS 139. These revisions, such as added nylon tread reinforcement, revised rubber component gauges, and revised rubber compound chemical and physical properties, will have a negative impact on fuel economy. Many of these revisions will add mass to the vehicle, decreasing fuel economy further. [

]c

The implementation of current FMVSS 214 (side impact) dynamic impact requirements for light trucks with a GVWR of 6000 lb or less occurred in 1998. Changes in FMVSS 214 that increase the striking vehicle size, contour, and weight from this standard would have a similar effect on vehicle designs as the IIHS side impact evaluation already addressed earlier.

Auto manufacturers responded to a NHTSA Request for Comments on FMVSS 216 (roof crush). Adding structure to a vehicle's roof does not necessarily enhance rollover crash safety benefits for occupants and, in fact, increases the vehicle's center of gravity and, hence, potential to experience a rollover. Therefore, added roof structure is not an appropriate direction for reducing the risk of occupant injury in rollover crashes. While improving restraint use is the most effective method to reduce occupant risk, any future regulatory revisions that require additional roof mass will have negative fuel economy implications.

Effective in September 2002, light duty trucks with a GVWR of 3500 kg or less must comply with the upgraded brake standard, FMVSS 135. The changes required to meet the FMVSS 135 requirements varied depending on model line. In some cases it required only pipe modifications, additional brackets, and the addition of proportional valve. In others, it also required the addition of supplemental boost assist device. In the most extreme case, it required a conversion from disk-drum system to disk-disk system and required a number of new parts associated with disk brakes plus an increase in wheel and tire size. The mass associated with these changes ranged from [

]c

Tire pressure monitor systems, to be required in FMVSS 138, add both mass and electrical loads.

Manufacturers and NHTSA are evaluating seat and head restraint designs. Some designs that provide additional seat and head restraint strength add mass to seats. NHTSA has indicated that upgraded FMVSS 202 (head restraint) requirements may be proposed later in 2002. NHTSA also has stated the potential for proposed revisions to FMVSS 207 (seat back strength) in 2002.

NHTSA and manufacturers are conducting tests on latch and hinge designs. Manufacturer's door retention system upgrades and/or potential revisions to current FMVSS 206 (door retention hardware) requirements could have mass implications.

Technologies to equip vehicles with child restraint anchorages and to comply with FMVSS 225 (Lower Anchorage and Tether for Children – LATCH) add mass. Phase-in started in September 1999 and will be completed by September 2002.

Several of the above regulations have a small effect on vehicle mass when considered individually, but combined they may become significant.

Vehicle Emissions

Environmental Protection Agency Regulations

Tier 2 Exhaust Standards

The final Federal Tier 2 FTP exhaust emissions standards for trucks less than 6000 lbs. GVWR are phased-in during the 2004-2007 model years according to a 25%/50%/75%/100% phase-in schedule. Trucks in the 6000-8500 lbs. GVWR weight range are phased-in to interim Tier 2 standards during this same timeframe, and then to the final Tier 2 standards at 50% in 2008 and 100% in 2009. The final Tier 2 standards require that manufacturers meet a sales-weighted fleet average NOx level of 0.07 grams per mile based on the full useful life standard (120,000 miles). This represents a NOx reduction of up to 95% compared to 2001 standards. Manufacturer may certify individual products to any of eight different standard categories or "bins", ranging from 0.00 - 0.20 grams per mile NOx, as long as the fleet average NOx requirement is met. HC, CO, and PM standards are also reduced significantly under Tier 2. The eight final Tier 2 "bins" are shown in the following table.

Table 5.2
Final Tier 2 Standards (g/mi @ 120,000 Miles)

BIN	NOx	NMOG	CO	HCHO	PM
8	0.20	0.125	4.2	0.018	0.02
7	0.15	0.090	4.2	0.018	0.02
6	0.10	0.090	4.2	0.018	0.01
5	0.07	0.090	4.2	0.018	0.01
4	0.04	0.070	2.1	0.011	0.01
3	0.03	0.055	2.1	0.011	0.01
2	0.02	0.010	2.1	0.004	0.01
1	0.00	0.000	0.0	0.000	0.0

Final Tier 2 Standards (g/mi @ 50,000 Miles)*

BIN	NOx	NMOG	CO	HCHO	PM
8	0.14	0.100	3.4	0.015	--
7	0.11	0.075	3.4	0.015	--
6	0.08	0.075	3.4	0.015	--
5	0.05	0.075	3.4	0.015	--

* 50,000 mile standards do not apply if manufacturer opts to certify to 150,000 miles.

Tier 2 requirements also include more stringent supplemental federal test procedure (SFTP) standards. The SFTP test has two driving cycles. One test cycle (US06) is based on driving during high speed and high load conditions. The other test cycle (SC03) is based on driving with the air conditioner on. SFTP standards apply to all 2004 and later model year gasoline and diesel vehicles up to 8,500 lbs GVWR.

Impact on Conventional Gasoline Powertrains

GM expects that meeting Federal Tier 2 exhaust standards for vehicles equipped with conventional gasoline powertrains (i.e. port fuel injection systems operating near stoichiometric air:fuel ratios) will have a minor adverse impact on truck CAFE relative to MY 2001 standards. The most significant impacts are as follows.

- *Addition of AIR System* – [ ][c] are expected to require AIR systems. AIR systems operate for a short period of time at the beginning of each cold start. AIR systems add about [ ][c] per FTP test cycle.

- *Larger Catalytic Converter* – [ ]^{c} are expected to require larger catalytic converters, adding about [ ]^{c}

- *Slightly Richer Calibration* – [ ]^{c} are expected to be calibrated slightly richer, perhaps [ ]^{c}, to achieve the lower NOx standards. These calibration adjustments are expected to be made initially when a product must meet the interim Tier 2 standards, with further adjustments once a product must meet the final Tier 2 standards.

This information is detailed in the following Table A5.3:

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Diesel and Lean-Burn Direct-Injection Gasoline Engines

For diesel engines and lean-burn, direct-injection gasoline engines, the Tier 2 exhaust standards will be far more challenging. The following requirements present major challenges.

- *FTP Exhaust Standards* - It is well-documented that the Tier 2 FTP exhaust standards present a major challenge for these engines. For example, the NAS Study states, "...Tier 2 NOx and PM standards will inhibit, or possibly preclude, the introduction of diesels into vehicles under 8,500 lb unless cost-effective, reliable, and regulatory-compliant exhaust gas aftertreatment technology develops rapidly." (NAS 2002:35) With regard to direct-injection diesels in light-duty trucks, the NAS study further states " the ability of this technology to comply with the upcoming Tier 2 and SULEV standards is highly uncertain." (NAS 2002:38) GM agrees with these statements.

- *SFTP Exhaust Standards* - The high speed and high load driving of the SFTP test cycle results in high NOx emissions due to the higher load conditions that increase NOx formation and the higher engine throughput. These standards may preclude the introduction of diesels, and will be challenging for lean-burn, direct-injection gasoline engines.

- *OBD* - A third major challenge will be on-board diagnostic (OBD) requirements. OBD basically requires that all emission control components and systems are monitored to ensure that they are functioning properly. OBD also requires that deterioration of components be detected if the deterioration would result in the vehicle exceeding emission standards by a specified amount. Major OBD challenges, which must be overcome, for diesels and lean-burn, direct-injection gasoline engines include monitoring of the lean NOx trap and monitoring of the particulate trap.

Several aftertreatment technologies are under development to try to achieve Tier 2 levels. These include lean NOx traps and selective catalytic reduction with urea for NOx control, particulate traps for PM control, and oxidation catalysts for HC and CO control. However, these technologies face significant challenges. The status of these technologies, as well as the major challenges, can be summarized as follows.

- Lean NOx Traps - Stores NOx during lean operation and is regenerated by brief excursions of rich/stoichiometric operation. As a result, fuel economy is traded off for NOx control. These excursions also result in HC emissions that are difficult to control, PM emissions and white smoke. Sulfur-free fuel is essential to enable this technology. Major technical challenges remain relative to exhaust emission levels (both FTP and SFTP), durability/robustness, on-board diagnostics, overall system cost, and precious metal usage (Platinum, Palladium, and Rhodium).

- Selective Catalytic Reduction with Urea - Offers more promise for achieving Tier 2 NOx levels than lean NOx traps. However, this requires urea to be stored on the vehicle and periodically refilled. One technical issue is that urea freezes. A major practical issue would be getting a urea refueling infrastructure in place, which would impact thousands of refueling stations. EPA has recently indicated that this technology is not an option despite acceptance by European regulators.

- Particulate Traps - Traps particulate matter which must periodically be burned off. Negative impact on fuel economy. Issues include achieving the required PM reduction efficiency, durability/robustness, on-board diagnostics, and precious metal usage (platinum).

- Oxidation Catalysts - Oxidation catalysts are required to meet HC and CO standards, which is made more difficult by lower exhaust temperatures compared to conventional gasoline engines.

Four additional points should be made in relation to the development of these technologies. First, sulfur-free fuel is essential to enable these technologies. Second, these control technologies add substantial cost to these engines. GM estimates that, in the case of the light-duty diesel, [ ][c] Third, achieving lower emission levels via engine calibration and aftertreatment technologies will take away much of the efficiency advantage that diesel and lean-burn gasoline engines provide. Fourth, the new regulations require the creation and development of NOx and particulate matter control technologies, which can function effectively and simultaneously in light-duty vehicles. These technologies have conflicting requirements, and are not concurrently employed in <u>any</u> global market where diesels are sold and used. Concurrent introduction of NOx after-treatment devices and particulate traps is very high risk because of the uncertainty regarding regeneration strategies and in-use performance of each device.

In addition, a heavier chassis is needed for a model to be capable of being equipped with a diesel engine. This adversely impacts the fuel efficiency of not only those vehicles within the model that are equipped with the diesel engine, but all vehicles of that model, including those equipped with conventional gasoline engines.

While the Tier 2 regulations provide more flexibility than the California standards (discussed later), any significant penetration of diesels or lean-burn gasoline vehicles will require that they achieve levels at or near the required fleet emission average.

It should also be noted that diesels face major hurdles in terms of cost (which, as noted above, is made worse by adding expensive emission control components) and market acceptance in the U.S.

Other EPA Requirements

More stringent evaporative emission standards are being phased-in according to the same schedule outlined above for the final Tier 2 exhaust standards. The weight gains associated with meeting these more stringent standards are small.

Federal Onboard Refueling Vapor Recovery (ORVR) for under 6000 lbs GVWR trucks will begin in 2001 MY with a 40/80/100% phase-in, and 6000-8500 lbs GVWR trucks in MY 2004 with a similar phase-in schedule in subsequent MYs. The weight gains associated with meeting this requirement are small and the corresponding CAFE impact would be negligible.

In addition to the Tier 2 SFTP requirements, SFTP standards that were previously adopted take effect prior to the 2004 and later Tier 2 timeframe. Specifically, SFTP requirements are being phased-in from 2001-2004 for trucks under 6,000 lbs. GVWR, and from 2002-2004 for trucks 6,000-8,500 lbs. GVWR. For conventional gasoline powertrains, the weight gains associated with meeting this requirement are small and the corresponding CAFE impact would be negligible.

While each one of these by themselves is small, the cumulative effect of these, as well as other mass increases, can become non-negligible.

California Air Resources Board Requirements

LEV II Exhaust Standards

California LEV II exhaust emissions standards for trucks up to 8,500 lbs. GVWR are phased-in during the 2004-2007 model years according to a 25%/50%/75%/100% phase-in schedule. Instead of a fleet average NOx requirement, the California standards have a fleet average NMOG (non-methane organic gas) requirement. The LEV II program basically results in the same fleet average level of NOx and PM control as the Federal Tier 2 standards, but uses a less flexible approach. There are only four standard categories, with the NOx standard ranging from 0.00 to 0.07 grams per mile at full useful life. The standard categories are shown in the following Table A5.4.

Table A5.4

California LEV II Standards (g/mi @ 120,000 Miles)

	NOx	NMOG	CO	HCHO	PM
LEV	0.07	0.090	4.2	0.018	0.01
ULEV	0.07	0.055	2.1	0.011	0.01
SULEV	0.02	0.010	1.0	0.004	0.01
ZEV	0.00	0.000	0.0	0.000	0.0

California LEV II Standards (g/mi @ 50,000 Miles)

	NOx	NMOG	CO	HCHO	PM
LEV	0.05	0.075	3.4	0.015	NA
ULEV	0.05	0.040	1.7	0.008	NA
SULEV	NA	NA	NA	NA	NA
ZEV	0.00	0.000	0.0	0.000	0.0

Impact on Conventional Gasoline Powertrains

Like the Federal Tier 2 standards, GM expects that meeting the California exhaust standards for vehicles equipped with conventional gasoline powertrains (i.e. port fuel injection systems operating near stoichiometric air:fuel ratios) will also have a minor adverse impact on truck CAFE relative to MY 2001 standards. [

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Diesel and Lean-Burn Direct-Injection Gasoline Engines

At the California Board hearing in November of 1998 where the CARB Board considered the LEV II standards, the CARB staff proposed a TLEV standard category that it believed could be used by diesel vehicles. However, the Board voted to eliminate the TLEV category. The Notice of Availability of Modified Text issued subsequent to the hearing states: "The Board concluded it was inappropriate to establish LEV II TLEV standards, since it is the standard most likely to be met by diesel vehicles that emit considerably more toxic particulate than other vehicles." As a result, for diesel engines and lean-burn, direct-injection gasoline engines, the California exhaust standards will be even more challenging than the Federal standards due to the less flexible structure of the California standards (i.e., 0.07 gram per mile NOx cap in California versus 0.20 federally). SFTP standards will likely be more challenging as well. As part of its Clean Air Plan, CARB is planning a second round of SFTP standards (SFTP II) for implementation beginning in the 2007 model year. CARB is also in the process of adopting more stringent OBD II requirements.

ZEV Regulations

One unique aspect of the California emission regulations is the zero emission vehicle (ZEV) regulations. The ZEV regulations apply to passenger cars and trucks up to 3,750 lbs loaded vehicle weight (LVW) beginning in 2003. Trucks between 3,750 lbs LVW and 8,500 lbs GVWR are phased-in to the ZEV regulations from 2007-2012. GM believes efforts to comply with the ZEV regulations will take away from efforts to increase fleet average fuel economy. The ZEV regulations effectively require that manufacturers produce a limited volume of vehicles that achieve large fuel economy increases as well as zero or near zero emissions. For example, the ZEV regulations provide credit for hybrid electric vehicles with fuel economy levels that are more than 30% greater than the size class average and also meet the partial ZEV (PZEV) emission standards. CARB projects that manufacturers will produce hybrids that meet this threshold as part of their ZEV compliance plans. The ZEV regulations also provide credit for zero emission vehicles (e.g., battery electric vehicles) with fuel economy levels that are at least twice the class average.

Efforts to comply with these requirements by making large fuel economy improvements on a small number of products will divert resources away from making smaller fuel economy improvements on a larger number of products. In addition, the products developed for the ZEV regulations will have little or no benefit on truck CAFE for two reasons. First, the products will be relatively low volumes. For example, CARB projects that of the entire industry only 26,494 advanced technology partial ZEVs (e.g., hybrids) and 4,817 ZEVs industry-wide in California in model year 2005 under the ZEV regulations (see CARB's FINAL STATEMENT OF REASONS section II.B.2 dated December 2001). Second, the products will most likely be smaller cars. Hybrids produced for the ZEV regulations are more likely to be cars because they must also meet the PZEV emission standards, and cars are more capable of achieving such low emission levels than trucks. ZEVs are more likely to be cars because electric vehicle batteries provide limited range, and such batteries will provide significantly more range in a lighter weight, more

aerodynamic car than in a truck. For these reasons, the ZEV regulations will have a negative impact on our ability to improve truck CAFE.

Future Requirements

California has a long way to go to meet all of its air quality standards. California's first milestones will be to meet the federal one-hour ozone standard and the federal PM10 standard. Beyond that, the federal eight-hour ozone, state one-hour ozone, federal fine particulate matter (PM2.5) and state PM10 standards will drive even more stringent requirements for HC, NOx and PM emissions. CARB is also considering more stringent PM10 and PM2.5 state standards. CARB has recently proposed a Clean Air Plan to outline additional control measures needed to meet these many air quality standards. New vehicle emission requirements include LEV III and SFTP II emissions standards, and OBD III requirements. Furthermore, in 1998 CARB took action identifying diesel particulate matter as a toxic air contaminant. CARB views diesel particulate matter as the dominant source of ambient cancer risk from air toxics in California. In 2000, CARB adopted a comprehensive plan to reduce diesel particulates. Given CARB's continuing drive toward zero emissions and its specific focus on diesel emissions, the future of diesel and lean-burn direct-injection gasoline vehicles in California becomes even more uncertain. This also creates additional uncertainty about the future of these technologies in states with Federal requirements, since EPA requirements have tended to follow those established by California.

Volume of California Vehicles

The number of trucks that meet California emission standards will depend on how many states adopt California standards. Under section 177 of the Clean Air Act, states are allowed to adopt emission standards that are identical to California's. Currently, New York, Massachusetts, Maine and Vermont, as well as California, have California emission standards. Dealers in contiguous states are also permitted, but not required, to sell California vehicles. Currently, about 20% of GM's nationwide vehicle volume are California vehicles. This percentage will increase if more states adopt California requirements.

Question A6.

For each of the model years 2005-2010, and for each light truck model projected to be manufactured by respondent (if answers differ for the various models), provide the requested information for each of items "6a" through "6q" listed below:

(i) description of the nature of the technological improvement;
(ii) the percent fuel economy improvement averaged over the model;
(iii) the basis for your answer to 6(ii), (e.g., data from dynamometer tests conducted by respondent, engineering analysis, computer simulation, reports of test by others);
(iv) the percent production implementation rate and the reasons limiting the implementation rate;
(v) a description of the 2001 baseline technologies and the 2001 implementation rate; and
(vi) the reasons for differing answers you provide to items (ii) and (iv) for different models in each model year. Include as a part of your answer to 6(ii) and 6(iv) a tabular presentation, a sample portion of which is shown in Table C.

a. Improved automatic transmissions. Projections of percent fuel economy improvements should include benefits of lock-up or bypassed torque converters, electronic control of shift points and torque converter lock-up, and other measures which should be described.

b. Improved manual transmissions. Projections of percent of fuel economy improvement should include the benefits of increasing mechanical efficiency, using improved transmission lubricants, and other measures (specify).
c. Overdrive transmissions. If not covered in "a" or "b" above, project the percentage of fuel economy improvement attributable to overdrive transmissions (integral or auxiliary gear boxes), two-speed axles, or other similar devices intended to increase the range of available gear ratios. Describe the devices to be used and the application by model, engine, axle ratio, etc.
d. Use of engine crankcase lubricants of lower viscosity or with additives to improve friction characteristics or accelerate engine break-in, or otherwise improved lubricants to lower engine friction horsepower. When describing the 2001 baseline, specify the viscosity of and any fuel economy-improving additives used in the factory-fill lubricants.
e. Reduction of engine parasitic losses through improvement of engine-driven accessories or accessory drives. Typical engine-driven accessories include water pump, cooling fan, alternator, power steering pump, air conditioning compressor, and vacuum pump.
f. Reduction of tire rolling losses, through changes in inflation pressure, use of materials or constructions with less hysteresis, geometry changes (e.g., increased aspect ratio), reduction in sidewall and tread deflection, and other methods. When describing the 2001 baseline, include a description of the tire types used and the percent usage rate of each type.
g. Reduction in other driveline losses, including losses in the non-powered wheels, the differential assembly, wheel bearings, universal joints, brake drag losses, use of improves lubricants in the differential and wheel bearing, and optimizing suspension geometry (e.g., to minimize tire scrubbing loss).
h. Reduction of aerodynamic drag.
i. Turbocharging or supercharging.
j. Improvements in the efficiency of 4-cycle spark ignition engines including (1) increased compression ratio; (2) leaner air-to-fuel ratio; (3) revised combustion chamber configuration; (4) fuel injection; (5) electronic fuel metering; (6) interactive electronic control of engine operating parameters (spark advance, exhaust gas recirculation, air-to-fuel ratio); (8) variable valve timing or valve lift; (9) multiple valves per cylinder; (10) friction reduction by means such as low tension piston rings and roller cam followers; (11) higher temperature operation; and (12) other methods (specify).
k. Naturally aspirated diesel engines, with direct or indirect fuel injection.
l. Turbocharged or supercharged diesel engines with direct or indirect fuel injection.
m. Stratified-charge reciprocating or rotary engines, with direct or indirect fuel injection.
n. Two cycle spark ignition engines.
o. Use of hybrid drivetrains
p. Use of fuel cells; provide a thorough description of the fuel cell technology employed, including fuel type and power output.
q. Other technologies for improving fuel economy or efficiency.

Response A6.
Table A6 provides GM's estimates of the fuel economy benefits and our forecasted penetration rates for the technologies in 2005-2010 MY. The notes included with the table are integral to understanding the data. Preceding Table A6 is a discussion of the individual technologies. Because of the non-additivity of many technologies, a cautionary discussion is included at the end of the technology discussion.

Many of these fuel economy estimates must be viewed as engineering assessments until these technology improvements are evaluated in actual future vehicles that meet all applicable requirements, including safety, emissions, durability, and customer expectations. New or untested technology must be integrated with the total vehicle design that often necessitates trade-offs. These estimates are not adjusted for constant performance unless specifically noted. This is because during this time frame significant additional engine costs would be required to re-sizing the engines to constant performance.

As can be seen in Table A6, [

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Cost information for fuel economy technologies is provided in our responses to Questions 3 and A11. We urge the agency to give proper weight to GM's cost estimates and not the estimates provided by others who have not designed, manufactured, and implemented these technologies in real world applications. It is also noteworthy to point out that our estimates represent our best estimates for truck applications, which may be different from passenger car costs. One must factor in the different technology baseline points of the various products of the truck manufacturers. Not all technologies are applicable from these various starting points or will provide the same benefits. Also not all technologies are applicable to vehicles with widely different missions. Vehicles that tow or haul a significant payload are vastly different in design than those that carry passengers only.

Under Section 32902(f), NHTSA must consider "economic practicability" in determining the "maximum feasible average fuel economy level." Thus, the light truck CAFE standards cannot be based exclusively on the fuel economy assessment of technologies. Rather, the standards also should be based on an assessment of which fuel economy technologies are cost-effective at today's fuel prices and those prices forecasted for the 2005 and later time frame. Furthermore, in assessing the full cost of a fuel economy technology, indirect costs must be considered as well as the direct costs. These indirect costs include all effects in which the fuel economy technology may diminish consumer utility, including durability, maintenance, gradeability, comfort, safety, seating or cargo capacity, and towing capability. (See our response to Question 3).

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Description of Technologies

The following paragraphs contain supporting information and explanations for the technologies in Table A6 as well as some additional technologies not included in the table. Technologies that were in common use in 2001 were not included.

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Non-Additive Fuel Economy Technologies

When assessing technologies, it is important to realize that many technologies are non-additive. Many of the technologies either reduce engine pumping work or reduce the mechanical friction in a component. Many previous analyses have double counted these effects (See our response to Question 16). For example, all of the following technologies would have at least some interaction with how they reduce engine pumping losses: torque converter clutch, five and more speed automatic transmission, continuously variable transmission, reduced engine displacement, lower numerical axle ratio, exhaust gas recirculation (EGR), lean burn, gasoline direct injection, cylinder cutout, electronic throttle control, variable valve timing, variable valve lift and timing, intake valve throttling, camless, supercharging, turbocharging, stratified charge, and diesel engines.

- The torque converter clutch, five-speed and six-speed automatic transmission, automated manual transmission, and continuously variable transmission all reduce fuel consumption through two mechanisms. First, the engine is operated at a lower engine speed, and hence wider throttle opening to achieve the same power level to propel the vehicle. Second, there is also a reduction in engine mechanical friction due to lower RPM, but the majority of the improvement is the throttling loss reduction. Of note is that the driveline efficiency of continuously variable transmissions is actually significantly worse than epicyclic gear-sets and it is only through the reduction in engine pumping work and mechanical friction that a fuel economy benefit is derived.
- Reduced engine displacement or lower axle ratio has a similar effect as above since to produce the same road load power the engine must be operated at a more open throttle. There is also a somewhat scaled reduction in engine mechanical friction, though valvetrain, bearing and accessory loads such as water and power steering pumps remain the same. Engine sizing in trucks is normally determined by gradeability with maximum rated load and not acceleration performance. If the engine size is reduced significantly, then the axle ratio must be increased to restore the required grade climbing ability, which could even result in lower fuel economy.
- EGR acts to dilute the air/fuel mixture in the cylinder, allowing operation at the same power level with a much wider open throttle. This has much the same benefit as gasoline direct injection with lean burn, without the same emissions difficulties.
- Lean burn systems improve economy in a similar manner, using air as the diluent. This is somewhat more effective than EGR in improving fuel economy since more can be tolerated with clean combustion, allowing for even wider throttle operation. However, lean burn is dependent on a lean reducing catalyst and air/fuel ratio sensor for practical usage at LEV or more stringent emissions levels. All known forms of lean NOx reducing catalysts are rapidly poisoned with the high sulfur gasoline offered in the US.
- Electronic control of the throttle gives a precise control of its operation, with the throttle being opened and closed in unison with actual fuel delivery. The actual throttle opening is separated from the customer's power request, enabling other technologies such as continuously variable transmissions to be better optimized.
- Variable valve timing on the exhaust camshaft increases engine breathing across a wider speed range, potentially increasing engine power and allowing downsizing, but unless low RPM torque is also increased, gradeability demands will prevent the smaller engine size. This technology can also improve the exhaust emissions tradeoff somewhat. Variable valve timing on the intake cam allows the expansion ratio of the engine to be increased under some operating conditions, improving the thermodynamic efficiency of the engine.
- Supercharging and turbocharging both increase engine power, providing the potential to reduce engine size, reducing throttling and mechanical engine losses under some operating

conditions. However, engine knock limits will require the compression ratio to be decreased even if premium fuel is used. This will reduce the base thermodynamic efficiency of the engine. The parasitic losses of the supercharger could negate any reduction in engine size. A turbocharger increases exhaust backpressure, reducing the fuel economy benefit, and absorbs some exhaust heat, slowing the catalyst warm-up. The boost provided by the turbocharger under lower engine RPM gradeability limit conditions would again limit how much the engine can be downsized.

- The gasoline direct injected, stratified charge engine is an extreme case of lean burn where the throttle is completely eliminated for most operating conditions, with engine load control being solely determined by fuel rate. The pumping work reduction of any previously applied technology must be subtracted from the gross benefit of gasoline direct injection to get a proper net benefit of this concept. Stratified charge, like lean burn, is also dependent on a lean reducing catalyst and air/fuel ratio sensor for practical usage at LEV or more stringent emissions levels. All known forms of lean NOx reducing catalysts are rapidly poisoned with the high sulfur gasoline offered in the US. The cooling effect of the fuel being injected directly into the combustion chamber does raise the engine knock limit and allow for an increase in compression ratio.
- Finally, the diesel engine also derives a large portion of its fuel economy benefit from the total elimination of the throttle related engine pumping work.

Similarly, fuel economy benefits from reducing mechanical friction must be evaluated in light of other technologies employed so as not to double count benefits. For example, once roller rocker arms and lifters are used, there is much less of an improvement available for technologies such as cylinder reduction. An overhead cam can allow for more optimized intake ports and simplifies implementation of variable valve timing. The friction power of any engine mechanical improvement is proportional to engine speed. The effect of these improvements will be reduced by five and six-speed automatic transmissions, MTAs, CVTs and six speed manuals, since the engine will be operating at a lower average speed.

Table A6: Utilization of Fuel Economy Technologies in GM's Light Truck Models

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Question A7.

For each model of respondent's light truck fleet projected to be manufactured in each of MYs 2005-2010, describe the methods used to achieve reductions in average test weight. For each specified model year and model, describe the extent to which each of the following methods for reducing vehicle weight will be used. Separate listings are to be used for 4x2 light trucks and 4x4 light trucks.

a. Substitution of materials.

b. "Downsizing" of existing vehicle design to reduce weight while maintaining interior roominess and comfort for passengers, and utility, i.e., the same or approximately the same, payload and cargo volume, using the same basic body configuration and driveline layout as current counterparts.

c. Use of new vehicle body configuration concepts, which provides reduced weight for approximately the same payload and cargo volume.

Response A7.

Mass reduction at GM has been and continues to be an ongoing project. Several examples of light weight materials currently used on GM trucks include the following:

- Aluminum engine blocks
- Aluminum heads
- Aluminum lift gates
- Aluminum spare tire wheels
- Aluminum propeller shafts
- Aluminum differential carriers
- Aluminum radiator support
- Plastic intake manifolds
- Composite bed liner
- Hydro form frames

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As an example of how weight increases can offset our efforts to reduce weight, a detailed accounting of the change in estimated mass is provided in Table A7.2 for [

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Table A7.2

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Table A7.1

Question A8.

For each model year 2005-2010, list all projected light truck model types and provide the information specified in "a" through "k" below for each model type. The information should be in tabular form, with a separate table for each model year. Each grouping is to be subdivided into separate listings for models with 4x2 and 4x4 drive systems. Engines having the same displacement but belonging to different engine families are to be grouped separately.

The vehicles are to be sorted first by truckline, second by basic engine, and third by transmission type. For these groupings, the average test weights are to be placed in ascending order. List the categories in terms "a" through "k" below in the order specified from left to right across the top of the table. Include in the table for each model year the total sales-weighted harmonic average fuel economy and average test weight for imported and domestic light trucks for each truckline and for all of the respondent's light trucks.

a. Truckline, e.g., C1500, F-150, B-150. Model types that are essentially identical except for their nameplates (e.g., Chevrolet S-10/GMC S-15 and Dodge Caravan/Plymouth Voyager) may be combined into one line item.

b. Light truck vehicle type, e.g., compact pickup, cargo van, passenger van, utility, truck-based station wagon, and chassis cab. Other light truck designations, which are adequately defined, can be used if these are not suitable.

c. Basic engine: Include the engine characteristics used in Definition 3.

d. Transmission class (e.g., A3, L4, A40D, M5, CVT): Include the characteristics used in Definition 16.

e. Average ratio of engine speed to vehicle speed in top gear (N/V), rounded to one decimal place.

f. Average test weight.

g. Average RLHP setting: Provide the value and show whether the value (or estimated value) is based on coastdown testing (T) or calculated from the vehicle frontal area (C). Round the RLHP value to one decimal Place.

h. Composite fuel economy (Sales weighted, harmonically averaged over the specified vehicles, rounded to the nearest 0.1 mpg).

i. Projected sales for the vehicles described in each line item.

Response A8.

GM does not as part of its normal business planning activity make CAFE forecasts for the full period requested by NHTSA. Therefore, we are providing CAFE projections for only 2005-2007 MYs. Table A8 and Attachment 3 provide GM's CAFE forecasts for 2005-2007 MY.

However, past forecasts by GM and past assessment by NHTSA have overestimated GM's actual CAFE levels due to unexpected technology risks, weight increases, and market shifts. For example, for 1988 through 1995 MYs, NHTSA overestimated GM's CAFE capability by an average of 0.4 mpg each year (see GM's January 25, 1994 letter to NHTSA concerning 1996-1997 MY truck CAFE rulemaking). Even GM's own estimates have consistently overstated our CAFE capability over this period, as market trends (i.e., the vehicle purchase decisions of our customers) have worked against higher fleet average fuel economy. In our August 3, 1994 submission to NHTSA's ANPRM on light truck fuel economy, our CAFE forecasts for 1998 through 2000 MY were 1.3 mpg higher on average for each year compared to what we actually achieved. These forecasts were even 0.5 mpg higher on average than our "Higher Confidence Forecasts", which tried to reflect some of the uncertainty we foresaw for these years. With this submission we are also providing a "Low Range" forecast for 2005-2007 MY akin to the "Higher Confidence" forecasts of our previous submission. We believe NHTSA should give significant weight to GM's "Low Range" forecasts.

Past overestimates in CAFE levels can be attributed to such factors as continued low gas prices, product delays, technology risk, capital unavailability, and continued market demand for increased performance, larger vehicles, and more features. Table A8 provides some of the quantifiable sources of these potential overestimates. We are identifying and quantifying risks in three areas.

- First, our forecasts include technical risk in implementing new technologies. Examples of past technology risk were discussed in our response to Question 9.

- A second source of error is the continuous increase in vehicle content that has historically increased vehicle mass, on average, at a rate of about [ ]^{c} per model year. This increased content includes additional desired customer features as well as required and desired safety and emissions hardware.

- A third source of risk is increased market demand for larger vehicles and more powerful engines. Increasing customer desire for full-size trucks has led in the past to significant increases in their volume compared to the submitted forecast data. For example, our 1994 submission to NHTSA overestimated our 2000 MY CAFE by about 1.5 mpg, much of which was due to unanticipated increase in full-size truck demand.

There is substantial potential that even these factors do not capture all the risk. For example, in response to Question A3, [

]^{c} In addition, there are other significant uncertainties which GM cannot control such as fuel price, the economy, and type of competitive entries which could further erode our CAFE forecasts.

To try to capture some of this risk, below we develop Low Range CAFE forecasts based on a quantification of these factors. The need for a Low Range CAFE forecast is underscored by the past unanticipated factors that have lead to overestimates by GM and NHTSA in our past CAFE forecasts. Needless to say, significant uncertainties exist in our CAFE forecasts for the future, especially for CAFE forecasts reaching this far into the future.

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Table A8

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Attachment 3 contains detailed forecast in the format requested by NHTSA for GM's 2005-2007 MY CAFEs, respectively. These forecasts do not reflect the risks included in our Low Range forecasts. Attachment 2 provide coding and naming conventions used in the CAFE forecasts as well as elsewhere in this document.

[

]c

Question A9.
For each transmission identified in response to 8(d) above, provide a listing showing whether the transmission is manual or automatic, the gear ratios for the transmission, and the models that will use the transmission.

Response A9.

TABLE IS CONFIDENTIAL

Table A9

Question A10.
Indicate any MY 2005-2010 light truck model types that have higher average test weights than comparable MY 2001 model types. Describe the reasons for any weight increases (e.g., increased option content, less use of premium materials) and provide supporting justification.

Response A10.

TABLE IS CONFIDENTIAL

Table A10

The following identifies reasons for these models' increased mass.

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[

a)

b)][c]

Question A11.

For each new or redesigned vehicle identified in response to Question 3 and each new engine or fuel economy improvement identified in your response to Questions 3, 5, and 6, provide your best estimate of the following, in terms of constant 2001 dollars:

(a) Total capital costs required to implement the new/redesigned model or improvement according to the implementation schedules specified in your response. Subdivide the capital costs into tooling, facilities, launch, and engineering costs.

(b) The maximum production capacity, expressed in units of capacity per year, associated with the capital expenditure in (a) above. Specify the number of production shifts on which your response is based and define "maximum capacity" as used in your answer.

(c) The actual capacity that is planned to be used each year for each new/redesigned model or fuel economy improvement.

(d) The increase in variable costs per affected unit, based on the production volume specified in (b) above.

(e) The equivalent retail price increase per affected vehicle for each new/redesigned model or improvement. Provide an example describing methodology used to determine the equivalent retail price increase.

Response A11.

(a) Refer to Table A11. This table is segregated by new vehicle programs, new powertrains and new technology. Table A11 responds to this and other sub-parts of question A11. For consistency throughout this response, constant 2001 dollars are used.

(b) Refer to Question A15, Table A15.

(c) Refer to Question A3, Tables A3.1 to A3.15 for new/redesigned models.

(d) [

]c

(e) [

]c

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Table A11

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Question A12.

Please provide respondent's actual and projected U.S. light truck sales, 4x2 and 4x4, 0-8,500 lbs. GVWR and 8501-10,000 lbs., GVWR for each model year from 1996 through 2002, inclusive. Please subdivide the data into the following vehicle categories:

i. Standard Pickup Heavy (e.g., C2500/3500, F-250/350, Ram 2500/3500)
ii. Standard Pickup Light (e.g., C1500, F-150, Ram 1500)
iii. Compact Pickup (e.g., S-10, Ranger, Dakota)
iv. Standard Cargo Vans Heavy (e.g., G3500, E-250/350, B3500)
v. Standard Cargo Vans Light (e.g., G1500/2500, E-150, B1500/2500)
vi. Standard Passenger Vans Heavy (e.g., G3500, E-250/350, B3500)
vii. Standard Passenger Vans Light (e.g., G1500/2500, E-150, B1500/2500)
viii. Compact Cargo Vans (e.g., Astro, Aerostar, Mini Ram Van)
ix. Compact Passenger Vans (e.g., Astro, Villager, Voyager)
x. Standard Utilities (e.g., K1500 Tahoe, Expedition)
xi. Compact Utilities (e.g., Blazer, Explorer, Wrangler, RAV4)
xii. Other (e.g., Suburban)

See Table D for a sample format.

Response A12.

Table A12

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Question A13.
Please provide your estimates of projected total industry U.S. light (0-10,000 lbs, GVWR) truck sales for each model year from 2005 through 2010, inclusive. Please subdivide the data into 4x2 and 4x4 sales and into the vehicle categories listed in the sample format in Table E.

Response A13.
See Table A13

Table A13

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Question A14.
Please provide your company's assumptions for U.S. gasoline and diesel fuel prices during 2005 through 2010.

Response A14.
DOE's Energy Information Agency, in its Annual Energy Outlook 2002, projects world oil prices to stay in the $20 to $25 per barrel range through at least 2020. GM recommends using the average price of gasoline over the last few years, about $1.50 as the midpoint of gas prices.

The same source estimates petroleum prices possibly averaging $6 per barrel less in a Low World Oil Price scenario. This would reduce gasoline prices by about $0.16 per gallon. GM recommends using about $1.25 as a low price for modeling purposes.

Of course, circumstances could change oil and gas prices for short periods, and if the public perceived those circumstances as permanent, then demand for fuel economy could change temporarily. But neither the EIA nor GM expect long-term prices to deviate significantly from the EIA forecast.

Question A15.
Please provide projected production capacity available for the North American market (at standard production rates) for each of your company's light truckline designations during MYs 2005-2010.

Response A15.

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Table A15

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Question A16.
Please provide your estimate of production lead time for new models, your expected model life in years, and the number of years over which tooling costs are amortized.

Response A16.
GM defines Product Development Process and Cycle Time boundaries as starting with Concept Initiation and ending with Production Approval. [

]c These goals are assuming significant carry-over content and no significant technology addition.

[

]c

[

]c

Lead-time limits what manufacturers can do to increase fuel economy. Some 2003 models are currently in production, [

]c

The recently completed NAS study recognized the interaction of higher CAFE standards on lead-time. The Committee found "Technology changes require very long lead times to be introduced into manufacturers' product lines. Any policy that is implemented too aggressively (that is, in too short a period of time) has the potential to adversely affect manufacturers, their suppliers, their employees, and consumers" (NAS 2002:5). Additionally, such a policy may increase the risk of introducing a new technology that is not fully integrated and optimized for fuel economy. NHTSA also has identified the adverse impacts of insufficient lead-time on the automotive industry as well as a wide range of other businesses. See NHTSA final rule for 1996-1997 light truck CAFE at 59 Fed. Reg. at 16312.

While GM is continually trying to shorten its lead-time requirements, we face constraints by our need to design, develop, validate and build high quality products for our customers. We follow a structured process to deliver high quality products in the least possible time. Our process is structured around 4-5 hardware pre-production builds occurring sequentially, but in parallel to the design and manufacturing of production tools (dies). These pre-production builds are used to validate various performance aspects of the vehicle design, ensure that high levels of quality are achieved, and verify that all federally mandated regulations are met. Analytical modeling is done before each of these hardware builds to reduce the validation testing necessary to confirm performance to requirements, increase the probability of success, and minimize required changes. CAFE standards that require changes during this lead-time window provide high risk that the necessary steps would not be completed, resulting either in products our customers do not want or ones that do not meet their quality and functionality needs.

Attachment 2:
List of Coding Conventions Used in Truckline Model Descriptions

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Attachment 2

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Attachment 3:
Detailed Listing of
GM's CAFE Forecasts

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Attachment 3

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Attachment 4:

"Aggregating Technologies for Reduced Fuel Consumption: A Review of the Technical Content in the 2002 National Research Council Report on CAFE", SAE 2002-01-0628

2002-01-0628

Aggregating Technologies for Reduced Fuel Consumption: A Review of the Technical Content in the 2002 National Research Council Report on CAFE

Kenneth J. Patton, Aaron M. Sullivan, Rodney B. Rask, and Mark A. Theobald
General Motors Corporation

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ABSTRACT

The National Research Council (NRC) recently published a report entitled "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards" intended to help U.S. policymakers in the formulation of CAFE policy. In the Report, the NRC projects fuel consumption reductions from the application of a wide range of engine, transmission, and vehicle technologies. The Report employs a simple multiplicative method to aggregate the effects of multiple technologies on fuel consumption. In this paper, a basic energy balance calculation is used to examine the NRC results against theoretical limits. Theoretical limits are calculated using measured and simulated breakdowns of system energy losses incurred during vehicle operation on EPA driving cycles. This analysis demonstrates the inherently optimistic results produced by simple aggregation methodologies. Methods for enhancing the accuracy of the technology-aggregation process are proposed.

INTRODUCTION

The recently issued National Research Council (NRC) report on Corporate Average Fuel Economy (CAFE) [1], hereafter referred to as the Report, is intended to serve as information helpful to U.S. policymakers in the formulation of CAFE policy. According to the charter issued by the U.S. Congress, one of the requirements of the Report is to examine the statutory criteria for CAFE, including technological feasibility and economic practicability. The Report is likely to be perceived as an authoritative source on subjects including the effects of technology on vehicle fuel consumption, the technical feasibility of certain technologies, and the cost-effectiveness of certain technologies. Because of its potential contribution to policy debates, it should meet high standards for technical accuracy.

This paper includes a summary of technical content in the January 2002 Report, and a listing of issues concerning the technical and breakeven analysis in the Report. The impact of the largest of these issues is demonstrated in Figure 10, which shows that theoretical limits based on energy balance are exceeded.

Prior to the release of the January 2002 NRC Final Report, significant issues with the technical content of the July 2001 NRC prepublication Report were raised. In response to the concerns raised, the NRC took steps including holding a public hearing and issuing a letter report describing resulting changes to the Report. While the changes to the Report resulted in *discussion* of energy balance and modification of projected overall fuel consumption reductions, there was no change made to the method used by NRC to project vehicle fuel consumption reductions. As a result, many of the earlier concerns still exist.

This paper illustrates the unreliability of studies that use the "shopping cart" approach where individual benefits are simply accumulated to aggregate the effects of technologies that reduce fuel consumption. The data and conclusions presented here reflect experience gained from implementing fuel consumption reduction technologies into production vehicles – experience that is unique to automotive manufacturers. The complexity of current automobile systems, which must optimize many fuel consumption, driveability, and emissions constraints, precludes the use of simple aggregation methods.

SUMMARY OF TECHNICAL CONTENT IN NRC REPORT

TECHNOLOGIES CONSIDERED – Selections from a list of twenty-three technologies (listed in Table 1) are used to generate the fuel consumption reduction projections in the Report. The technologies are classified as either "production-intent," which means they are in production or could be in production; or "emerging," which means they are undergoing development expected to enable introduction within approximately 15 years. According to the Report, technologies are selected based on benefits and costs of application, anticipated exhaust emissions regulations, predicted trends in fuel prices, and reported

Engine Technologies	Transmission Technologies	Vehicle Technologies
Production-Intent engine friction reduction low friction lubricants multivalve OHC (2V vs 4V) VVT (cam phasing) VVLT (2-step) cylinder deactivation engine accessory improvement supercharging & downsizing **Emerging** intake valve throttling (variable lift) camless variable CR	**Production-Intent** 5 speed auto CVT **Emerging** auto w/aggressive shift logic 6 speed auto manual transmission automatic high torque CVT	**Production-Intent** aero drag rolling resistance **Emerging** 42V ISG w/idle off electric power steering weight reduction

Table 1: Engine, transmission, and vehicle technologies used in the NRC Report

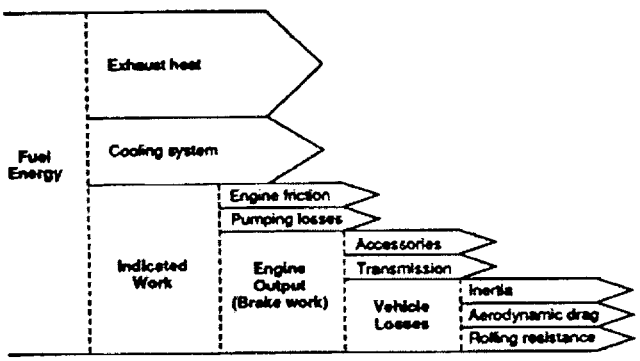

Figure 1: Qualitative energy breakdown from NRC Report [1]

customer preferences. Engine, transmission, and vehicle technologies are considered.

The technologies discussed in the Report are used to reduce energy losses in order to improve fuel consumption. The categories of energy losses that are reduced include vehicle aerodynamic drag, tire rolling resistance, transmission losses, accessory losses, engine thermal losses, engine friction losses, and engine pumping losses. These losses are qualitatively illustrated in the Report with an energy breakdown diagram, repeated here as Figure 1.

TECHNOLOGY ATTRIBUTES – The Report notes that attributes of the chosen technologies were collected from many sources, including presentations at public meetings, available studies and reports, meetings with automotive manufacturers and suppliers, and information supplied by consultants to the NRC. The panel then applied its own engineering judgement to derive the estimates for fuel consumption reduction and associated costs. The fuel consumption reductions projected in the Report assume constant vehicle performance. In addition, the Report assumes that engine downsizing occurs when many of the technologies are applied. Table 2 lists the technologies used in the Report, the engine downsizing assumptions, the estimated fuel consumption reductions, and the sources of the information provided by NRC.

APPLICATION OF TECHNOLOGIES TO VEHICLES – Three "development paths" are used in the Report to represent three levels of aggressiveness in applying vehicle technologies. Path 1 represents "likely market-responsive or competition-driven advances in fuel economy" which could be introduced within 10 years. Path 2 includes more costly technologies that are technically feasible "if economic and/or regulatory conditions justify their use." Path 3 represents additional emerging technologies that require further development prior to commercial introduction in the 10-15 year timeframe.

Each of the development paths is applied to ten different vehicle segments, spanning the range from passenger cars to minivans, SUVs, and light trucks. The vehicle segments considered are the following:

- Passenger Cars: subcompact, compact, midsize, and large
- SUVs: small, midsize, and large
- Light Trucks: small pickup, large pickup, and minivan

Table 3 lists the technologies used in the Report for each of the three development paths for one example vehicle segment, the Midsize SUV. This case is typical of the way that technologies are applied in the Report.

NRC Technology	Engine Downsize Assumed	NRC Fuel Cons. Reduction	Cited NRC Sources for Fuel Consumption Reductions
engine friction reduction	yes	1 - 5%	[2]
low friction lubricants	no	1%	[3]
multivalve OHC (2V vs 4V)	yes	2 - 5%	[4,5,6]
VVT (cam phasing)	yes	2 - 3%	[7,8,9,10,11,12,13,14]
VVLT (2-step)	yes	1 - 2%	[15,16,17]
cylinder deactivation	no	3 - 6%	[18,19]
engine accessory improvement	yes	1 - 2%	[20]
supercharging & downsizing	yes	5 - 7%	[21]
5 speed auto	no	2 - 3%	[22]
CVT	no	4 - 8%	[23,24,25]
auto w/aggressive shift logic	no	1 - 3%	[20]
6 speed auto	no	1 - 2%	[26]
aero drag	no	1 - 2%	[20]
rolling resistance	no	1 - 1.5%	[20]
intake valve throttling (variable lift)	yes	3 - 6%	[21,22,23,24,25,26]
camless	yes	5 - 10%	[27]
variable CR	yes	2 - 6%	[28,29,30]
manual transmission automatic	no	3 - 5%	[31]
high torque CVT	no	0 - 2%	[32]
42V	no	1 - 2%	[33]
ISG w/idle off	no	4 - 7%	[20]
electric power steering	no	1.5 - 2.5%	[34]
weight reduction	yes	3 - 4%	[20]

Table 2: NRC engine downsizing assumptions, projected fuel consumption reductions, and sources for individual fuel consumption reduction technologies

Technology	Path 1	Path 2	Path 3	NRC FC Reduction
engine friction reduction	x	x	x	1 - 5%
low friction lubricants	x	x	x	1%
multivalve OHC (2V vs 4V)	x	x	x	2 - 5%
VVT	x	x	x	2 - 3%
VVLT (2-step)		x	x	1 - 2%
cylinder deactivation	x	x	x	3 - 6%
engine accessory improvement	x	x	x	1 - 2%
supercharging & downsizing			x	5 - 7%
5 speed auto	x	x		2 - 3%
CVT			x	4 - 8%
auto w/aggressive shift logic	x			1 - 3%
6 speed auto		x		1 - 2%
aero drag		x	x	1 - 2%
rolling resistance	x	x	x	1 - 1.5%
intake valve throttling (variable lift)		x		3 - 6%
camless			x	5 - 10%
variable CR			x	2 - 6%
MTA		x		3 - 5%
high torque CVT			x	0 - 2%
42V		x	x	1 - 2%
ISG w/idle off		x	x	4 - 7%
electric power steering		x	x	1.5 - 2.5%
5% weight reduction			x	3 - 4%

Table 3: NRC development paths 1, 2, and 3 for Midsize SUV vehicle segment

METHOD FOR AGGREGATING EFFECTS OF TECHNOLOGIES – The Report describes the challenges associated with integrating new technologies into vehicles:

"Automotive manufacturers must optimize the vehicle and its powertrain to meet the sometimes-conflicting demands of customer-desired performance, fuel economy goals, emissions standards, safety requirements, and vehicle cost within the broad range of operating conditions under which the vehicle will be used. This necessitates a vehicle systems analysis."

The Report then makes a significant simplifying statement:

"It is usually possible, however, to estimate the impacts of specific technologies in terms of a percentage savings in fuel consumption for a typical vehicle without a full examination of all the system-level effects. Such a comparative approach is used in this chapter."

Table 3 illustrates for one vehicle segment the list of technologies in each of the three NRC development paths. In order to calculate the combined fuel consumption effect of applying the list of technologies to a vehicle, the Report treats individual effects of technologies as if they are independent of one another. It does this by using a multiplicative method to aggregate the individual effects of the applied technologies.

In the aggregation method, vehicle fuel consumption is multiplied by individual factors which represent individual average fuel consumption reductions assigned to each technology that is applied to the vehicle. The average value is the arithmetic average of the high and low values in the range estimated by NRC. As technologies are successively applied to a vehicle, vehicle fuel consumption is successively multiplied by the assigned factors. No adjustments are made to the fuel consumption factors as technologies are accumulated; this is the "shopping cart" method.

For example, multivalve OHC is estimated in the Report to be worth a 2% - 5% reduction in fuel consumption; hence its arithmetic average fuel consumption factor is 0.965, which corresponds to a 3.5% fuel consumption reduction. Cylinder deactivation is estimated to be worth a 3% - 6% reduction in fuel consumption; hence its arithmetic average fuel consumption factor is 0.955. 5-speed automatic transmission is estimated in the Report to be worth a 2% - 3% reduction in fuel consumption; hence, its arithmetic average fuel consumption factor is 0.975. Six speed automatic transmission – when replacing a 5-speed – is estimated by NRC to be worth a 1% - 2% reduction in fuel consumption; hence, its arithmetic average fuel consumption factor is 0.985. Manual transmission automatic – when replacing a 6-speed - is estimated by NRC to be worth a 3% - 5% reduction in fuel consumption; hence, its arithmetic average fuel consumption factor is 0.96. Using the NRC methodology, when the effects of these technologies are aggregated on a single vehicle, the projected fuel consumption reduction factor is 0.965x0.955x 0.975x0.985x0.96 = 0.85. So a 15% reduction in fuel consumption is projected from the application of these technologies on a vehicle. This methodology is used throughout the Report, for the entire list of technologies in each path, and for all vehicle segments.

NRC ESTIMATES OF FUEL CONSUMPTION BENEFITS– The results when using the multiplicative method for the Midsize SUV vehicle segment are illustrated in Figure 2. In the Report, only arithmetic average values are shown; however, Figure 2 also shows for reference purposes the high and low ranges calculated using the NRC aggregation method. As can be seen in the figure, the following fuel consumption reductions are projected:

NRC Path 1: 17% fuel consumption reduction

NRC Path 2: 32% fuel consumption reduction

NRC Path 3: 39% fuel consumption reduction

A summary of results for all vehicle configurations in the Report is shown in Figure 3. Each bar in the chart represents the fuel consumption reduction projected in the Report for one path for one vehicle segment. Listed near each bar is the total number of technologies aggregated for each individual configuration. Paths 2 and 3 are significantly more aggressive (in terms of number of technologies aggregated and projected benefit) than path 1, particularly for heavier vehicles. For those vehicles, there are relatively small differences between paths 2 and 3.

NRC TECHNOLOGY COSTS – The Report assigns an incremental increase in vehicle retail price to each of the chosen technologies. Cost information was gathered from multiple sources in a manner similar to that used for the fuel economy benefits. Cost data from suppliers is multiplied by 1.4 to account for systems integration, overhead, marketing, profit, and warranty issues. Figure 4 summarizes the NRC costs per NRC fuel consumption reductions for all of the technologies used in the Report, listed in order of cost per fuel consumption reduction.

NRC "COST-EFFICIENT" ANALYSIS – Chapter 4 of the Report determines a level of technology increase where the added cost of the technologies equates to the fuel cost savings from reduced fuel consumption. As the Report notes, at this point the customer only incurs lost opportunity costs. This is referred to as a "cost-efficient" point. The Report includes a quantification of the "cost-efficient" point for each of the vehicle segments for two different scenarios: a 14-year period with 12% discount rate, and a 3-year period with 0% discount rate. The "cost-efficient" analysis includes ranges for the fuel consumption values.

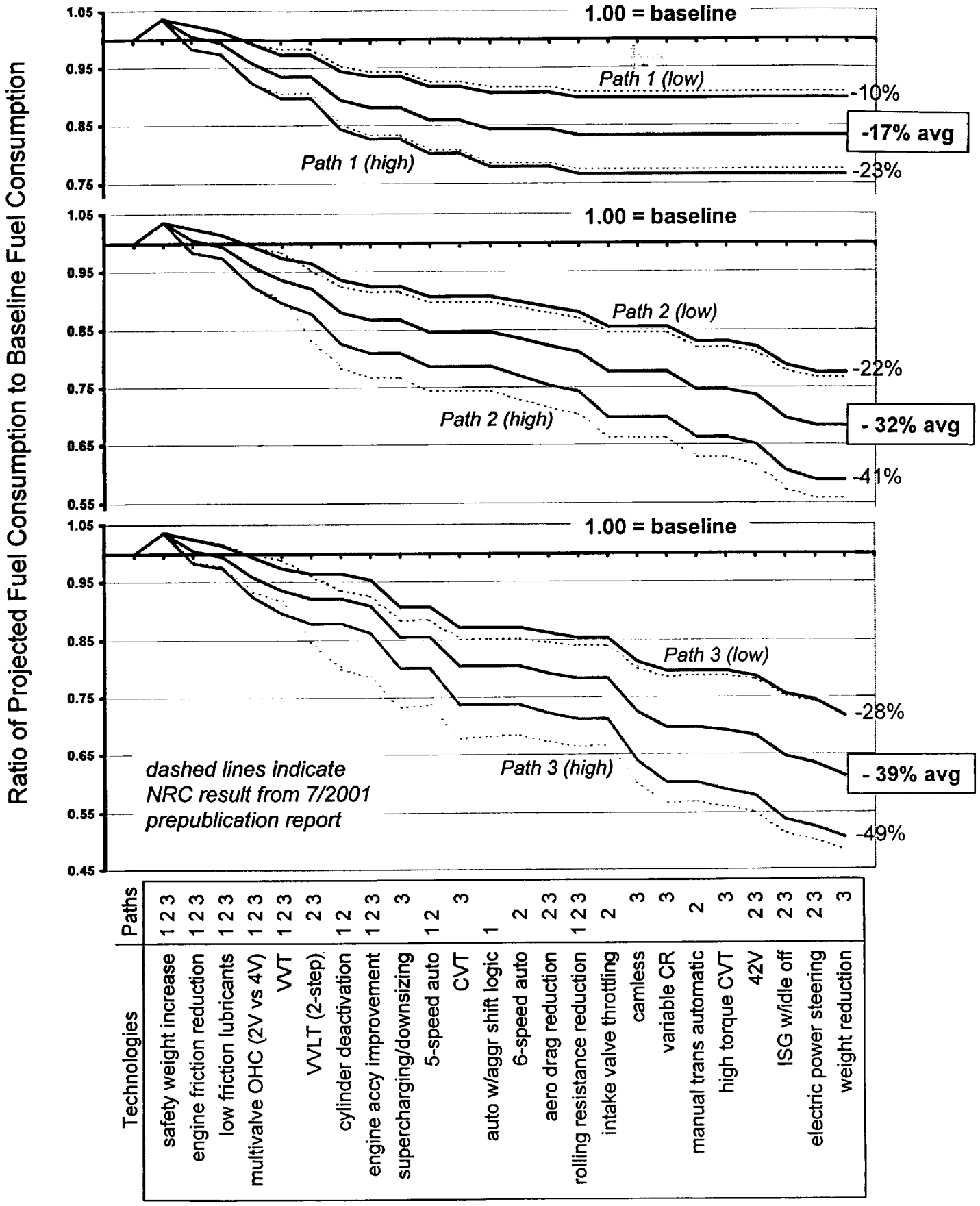

Figure 2: NRC aggregation of fuel consumption reductions for Midsize SUV paths 1, 2, and 3

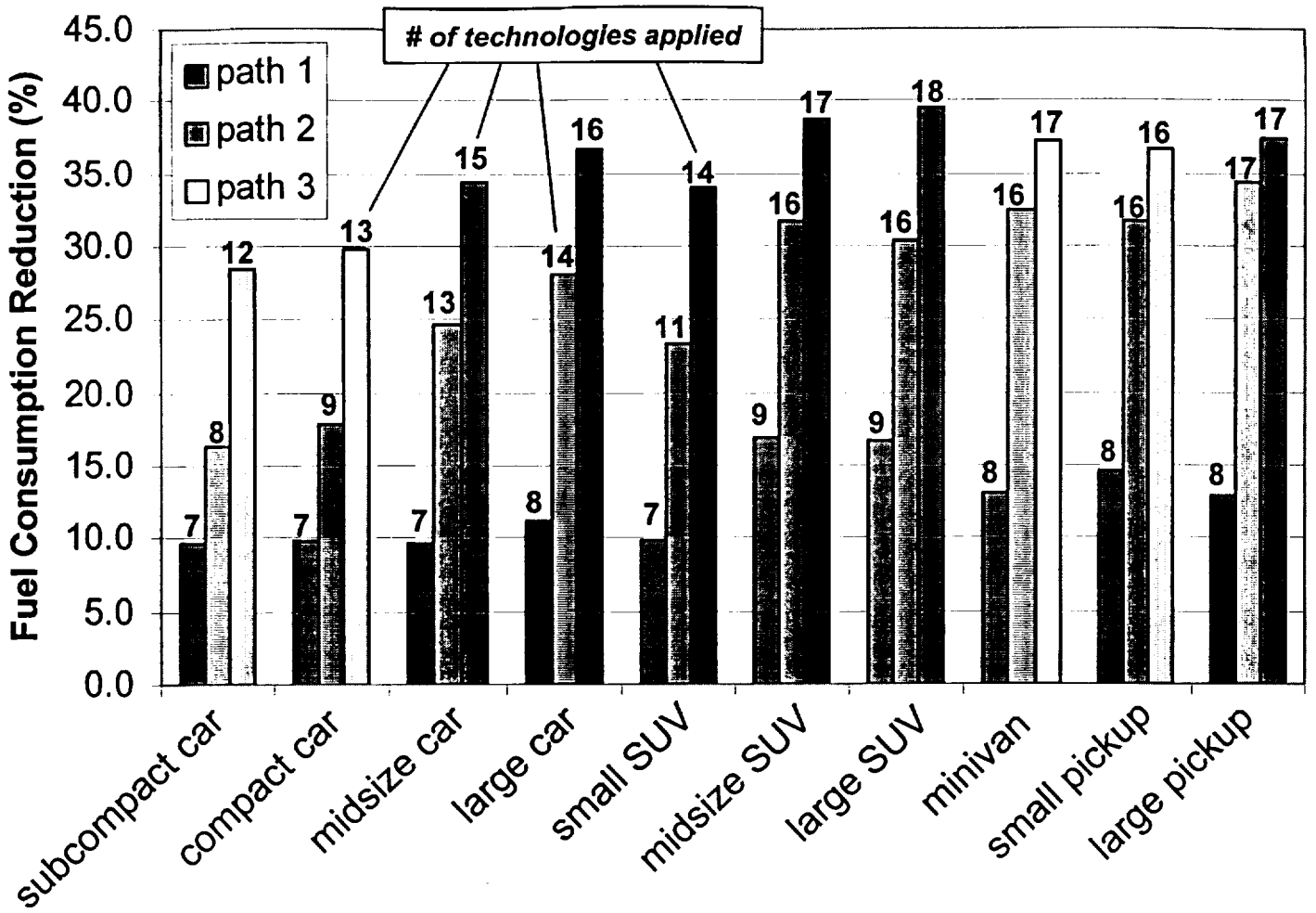

Figure 3: Summary of NRC aggregated fuel consumption reduction projections for all ten vehicle segments considered in the Report.

ISSUE #1: NRC METHODS FOR PROJECTING FUEL CONSUMPTION REDUCTIONS FAIL TO EXAMINE SYSTEM-LEVEL EFFECTS

The simple method of multiplying fuel consumption factors to aggregate the effects of technologies does not account for system-level effects. However, there is a need to do so in order to avoid double- and triple-counting of fuel consumption benefits. In this section, some important system-level effects will be described, cases will be identified where insufficient examination of those effects clearly occurred, and recommendations on how those effects should be accounted for will be described.

SYSTEM-LEVEL EFFECTS – System-level effects are defined in this context as those effects that act to change the fuel consumption reductions that are achieved with individual technologies when the technologies are integrated with other technologies in complete vehicle systems. This is important because this is the only way that such technologies will become available to consumers. In a systems approach, an accounting of the effects of technologies on the various energy loss mechanisms must be done in order to obtain an understanding of the advantages (or disadvantages) of the technologies. In addition, an accounting allows for some form of energy balance calculation to be performed for the estimated system benefits. By partitioning the benefits into energy categories, a meaningful accounting of energy – one related to the physical processes occurring in the vehicle – can be performed.

The energy categories of interest in this context are: vehicle aerodynamic drag, tire rolling resistance, vehicle inertia, transmission losses, accessory losses, engine thermal losses, engine pumping losses, and engine friction losses. Vehicle aerodynamic drag results when the vehicle shape moves through air. Tire rolling losses are the result of tire deformation while the tires are rolling. Work is done on the vehicle inertia when the vehicle is accelerated, and the resulting kinetic energy is dissipated through vehicle losses and subsequent braking of the vehicle. Transmission losses result when energy is dissipated through friction from rotating and sliding interfaces in the transmission, and through hydraulic pump and torque converter losses in the transmission. Accessory losses result when energy is used to run devices that are required to sustain

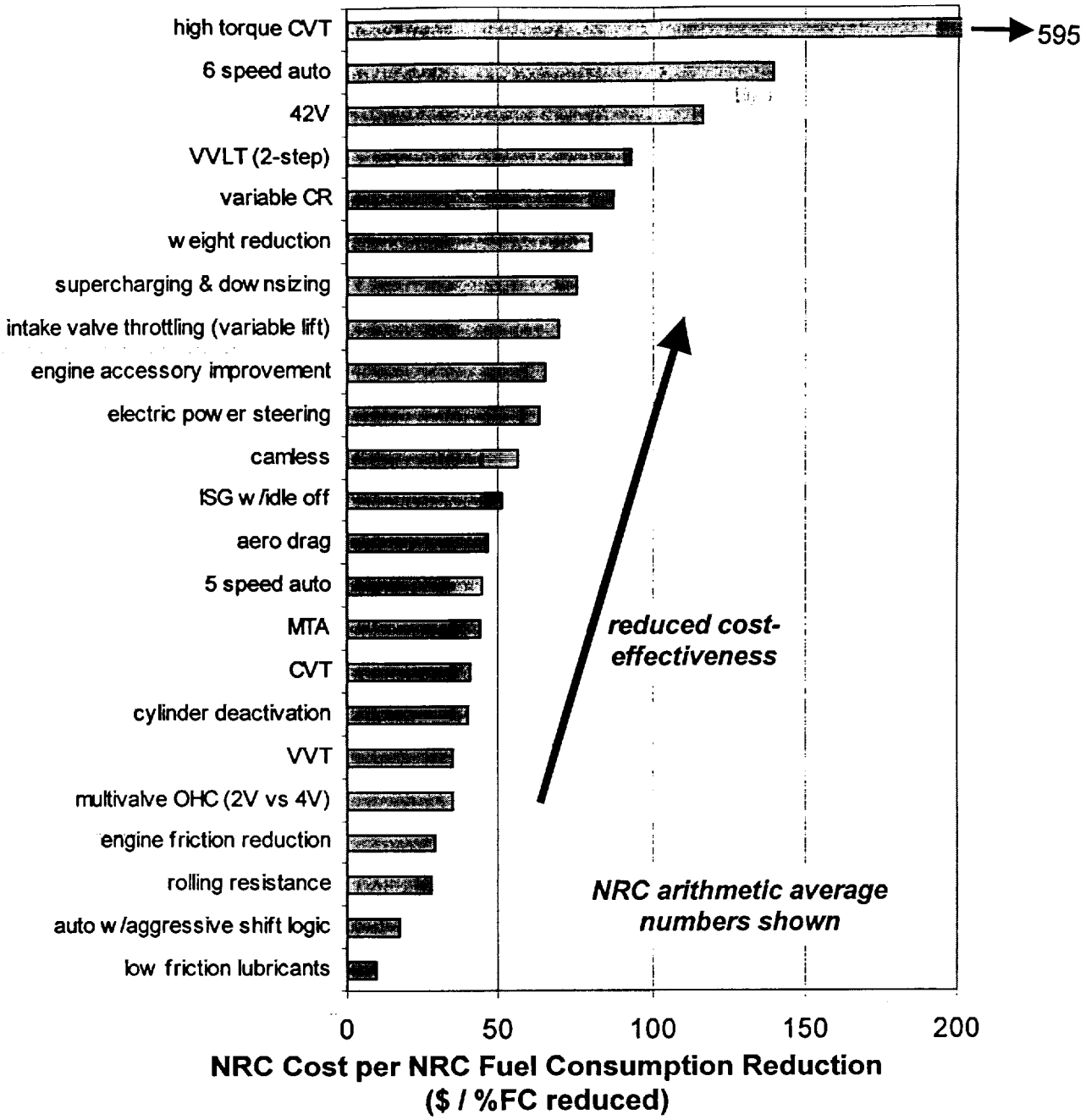

Figure 4: Chart illustrating cost per fuel consumption reductions for individual technologies used in the NRC Report (values based on NRC arithmetic average costs and fuel consumption reductions)

operation of the vehicle, including fuel pumps, power steering pumps, electrical power generators, and air-conditioning compressors. Engine thermal losses (referred to in the Report as exhaust and cooling losses) occur during the conversion of fuel chemical energy to indicated work that is done on the pistons of the engine. Engine pumping losses occur during transport of fresh air-fuel mixture from the atmosphere through throttling devices into the combustion chamber, and from transport of exhaust gases out of the combustion chamber to the atmosphere. Engine friction losses result from relative motion of surfaces in rotating and sliding components in the engine, and from engine oil and coolant pump losses in the engine.

In general, the fuel consumption effects of technologies that address *different* energy loss mechanisms tend to be independent. The reductions in fuel consumption that result when they are applied separately are usually not diminished when they are combined on a single vehicle. This is because the different technologies are affecting different physical loss mechanisms in the vehicle system. Aggregation of the fuel consumption effects of technologies such as these is relatively simple because

the individual technology effects do not change when they are combined with some technology that acts on a different loss mechanism.

Conversely, when fuel consumption effects of technologies that address *the same* energy loss mechanism are aggregated, the end result is not so simple. The impact of these individual technologies on fuel consumption is diminished when they are combined on a single vehicle.

This is because these technologies are affecting the same physical losses in the vehicle system. Once the losses in a given category have been reduced by the application of one technology, there is less energy loss remaining in that category for subsequent technology applications to reduce. Aggregation of the fuel consumption effects of these technologies requires more careful analysis.

The Report uses a simple multiplicative method for aggregating "average" fuel consumption effects of different technologies *regardless of the energy loss mechanisms affected*. This "shopping-cart" method becomes less realistic as more technologies are combined. This is the most important concern with the technical content of the Report. As will be shown in a subsequent section it results in an overcounting of the fuel consumption effects of the NRC technologies, which affects the outcome of the technical feasibility and "cost-efficient" analyses in the Report.

In order to sufficiently examine the system-level effects that result when fuel consumption reduction technologies are combined, data from detailed test measurements and results from detailed system analysis tools are required. Explicit measurements of engine friction, pumping losses, and indicated efficiency should be used as a direct measure of engine characteristics and as an input to system analysis tools such as vehicle simulations. Measurements of transmission losses which are speed- and load-dependent should be used both as a direct measure of transmission characteristics and as an input to vehicle simulations.

USE OF ENGINE TEST POINTS TO INFER EPA DRIVING CYCLE RESULTS – The quality of the estimates of fuel consumption benefit for individual engine technologies considered in the Report is diminished by the use of steady-state engine test points to infer EPA driving cycle results. CAFE is based on vehicle fuel consumption measurements from EPA driving cycles, which specify variations in vehicle speed and acceleration over specific time intervals. The driving cycles include vehicle operation from idle to approximately 60 miles per hour and a range of accelerations and decelerations. The wide variation in vehicle operating conditions precludes the use of any small number of operating conditions as representative of operation on the EPA driving cycles.

The reason that a small number of steady-state test points cannot represent performance over the EPA driving cycles is that the variations in vehicle operating condition on the driving cycles cause large variations in the distribution of energy losses within the categories of Figure 1.

For example, at a steady-state road load operating condition such as 50 mph operation on a level road, where the transmission tends to be in an overdrive gear with a locked-up torque converter clutch, losses attributable to engine friction tend to be low because the rotational speed of the engine is low. In addition, energy applied to the inertia of the vehicle is zero, because the vehicle acceleration is zero. Aerodynamic drag is relatively high because vehicle speed is high. Conversely, at idle aerodynamic losses are zero because the vehicle is not moving. Engine work at idle goes entirely to work required to keep the engine rotating: engine friction, engine pumping, accessory loads, and transmission pump and torque converter losses.

In many of the technology studies cited in the Report, fuel consumption reduction projections are taken from individual engine test points rather than from EPA driving cycle results. In the studies cited, the test points serve their purpose as a means for tracking the development of a technology, or for comparing a technology to a baseline. However, EPA unadjusted combined fuel consumption results are rarely quoted in the cited studies (at best, only 15 of the 44 cited studies produce results for the appropriate EPA driving cycles). Consequently, the quality of the estimates of fuel consumption benefit in the Report are diminished by the use of information that is not representative of fuel consumption on EPA driving cycles used for CAFE determination.

When actual test data is not available, engine and vehicle simulation tools – using inputs and constraints based on vehicle data and driving cycles – should be used to improve the accuracy of fuel consumption estimates for EPA driving cycles. Short of running complete simulations, if representative engine test points must be used in lieu of driving cycle simulations, the following guidelines should be respected:

- The representative points are specific to an engine/transmission/vehicle combination, and the combination must be specified as part of the determination of the points. Vehicle mass, engine size, engine specific output, engine speed during vehicle operation, driveline losses, and aerodynamic drag are all factors that will affect the representative points.
- Data points representing the full range of vehicle operation (speeds and acceleration levels) must be considered. This includes idle, accelerations, decelerations, and steady-state operation.
- A significant fraction of the total fuel energy used on the City and Highway cycles (>90%, preferably near 100%) should be represented in the choice of points.

A set of seven measured engine data points that enables accurate projection of EPA City cycle fuel consumption is shown in Figure 5. The points are accurate for a Midsize SUV with a 4-speed automatic transmission and a 4.2L six-cylinder engine. The points were determined using second-by-second energy and fuel-consumed results from a detailed simulation of the powertrain and vehicle in question.

INADEQUATE TREATMENT OF VEHICLE/CUSTOMER REQUIREMENTS – According to the Report, each technology has the same fuel consumption benefit regardless of the vehicle segment being considered. This assumption is an oversimplification, and it leads to overestimates of fuel consumption reduction that would be achieved in the more challenging vehicle segments.

In order to provide adequate treatment of vehicle and customer requirements when projecting fuel consumption reductions, a vehicle simulation should be used. Experience in the development and production of complete vehicle systems has shown that the constraints applied to the simulations are a critical part of ensuring accurate and consistent results. The following guidelines should be used:

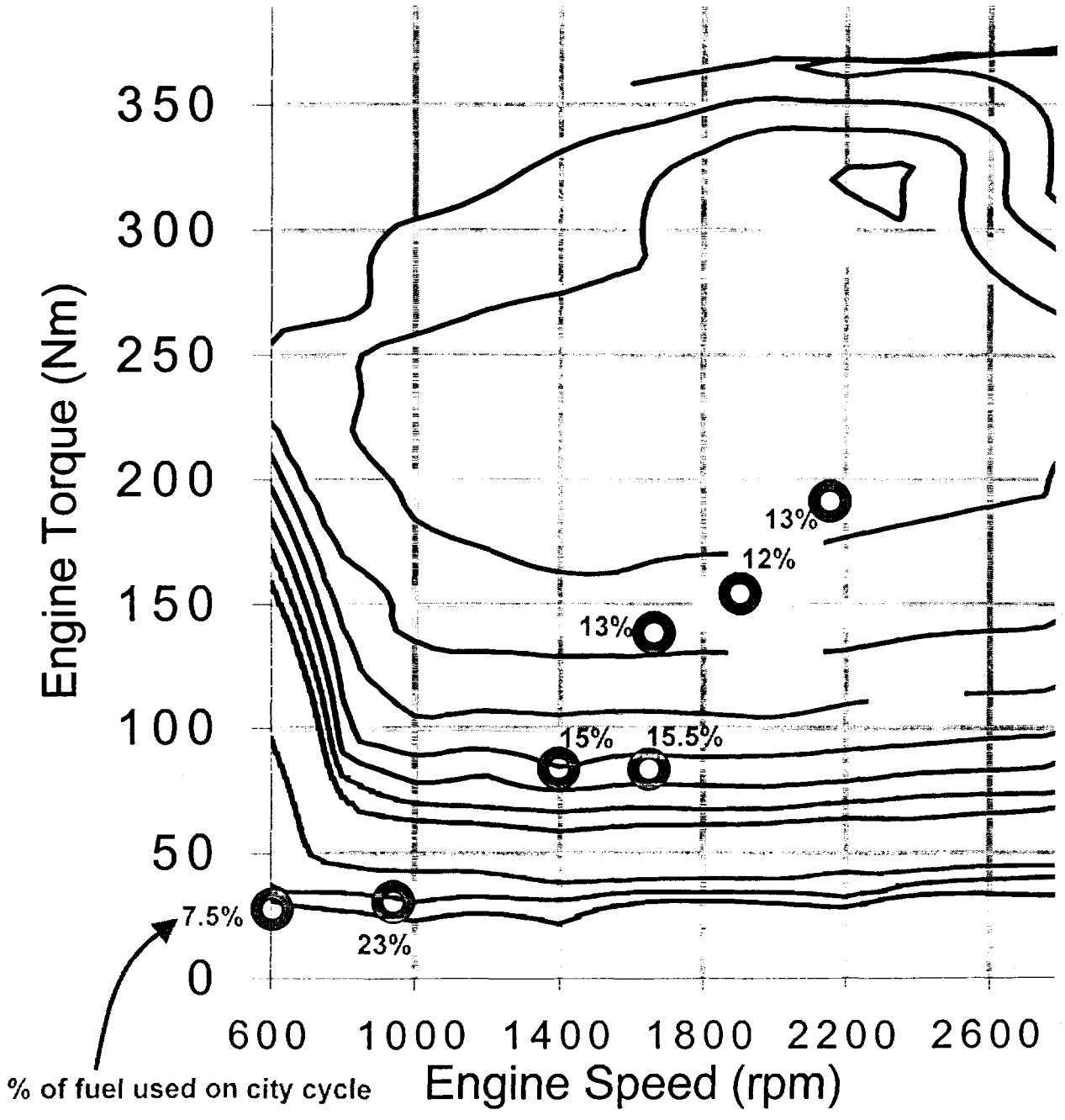

Figure 5: Engine operating points representative of operating conditions on the EPA City cycle for a Midsize SUV

- Measured engine data (as opposed to estimates or simplified maps) should be used for engine fuel consumption over the range of speeds and loads.
- Measured data (as opposed to an assumption of constant transmission efficiency) should be used when transmission technologies are being evaluated.
- Selection of final drive ratios must be done using metrics which comprehend vehicle drive quality and shift busyness. Consistent constraints for drive quality and shift busyness need to be applied to perform relevant fuel consumption comparisons. Metrics include gradeability in top gear or acceleration immediately available to the driver.
- Constraints for sufficient drive quality – perhaps related to the market segment of the vehicle – over the range of vehicle speeds should be imposed.
- Constraints for minimum idle speed and minimum engine speed while driving, based on allowable firing frequency and NVH limits, should be imposed.

USE OF AVERAGE FUEL CONSUMPTION REDUCTIONS IN AGGREGATION METHOD – The NRC panel aggregates fuel consumption results using the arithmetic average of the low and high values for each technology. However, the stated purpose of the low and high values is to represent "real-world variations" in design and execution. A more appropriate remedy to the problem of "real-world variations" would be to understand and account for their effects by performing a systematic analysis.

ISSUE #2: INACCURATE FUEL CONSUMPTION VALUES FOR INDIVIDUAL TECHNOLOGIES

The intent of this section is to describe concerns with fuel consumption reductions attributed to individual technologies in the Report.

CHOSEN TECHNOLOGIES – The list of engine, transmission, and vehicle technologies used by NRC in Paths 1, 2, and 3 is a reasonable list. The labels used to describe the maturity of the technologies, "production-intent" and "emerging," are accurate. The technologies that were considered, but not used, in the Report are direct injection gasoline, direct injection Diesel, hybrids, and fuel cells. The Report includes detailed discussion of the reasons why those technologies were not used.

APPLICATION-DEPENDENCE IS IGNORED – As previously mentioned, the fuel consumption reduction values applied in the Report are not sensitive to vehicle size or type. This is a major simplification in the analysis, particularly for technologies that address pumping losses. The amount of energy lost to pumping work depends on factors such as the size of the engine, the weight of the vehicle, and other loads on the engine. More heavily loaded engines have a lower percentage of their work applied to pumping losses. As a result, the fuel consumption improvement for pumping loss technologies is less in vehicle applications that tend to have more heavily loaded engines. While there is no general rule – the benefit is dependent on the losses associated with each vehicle application – it is true that heavier vehicles tend to have a higher ratio of engine size to vehicle mass, as is shown in Figure 6, and are probably the vehicles which respond best to technologies that address pumping loss.

The fuel consumption benefits for individual technologies quoted in the Report tend to be for vehicle applications that are well-suited to the particular technologies, so it is reasonable to expect that they are optimistic. An example of this is cylinder deactivation. According to the Report, cylinder deactivation is "applied to rather large engines (>4.0L) in V8 and V12 configurations." Yet the Report applies the same fuel consumption reduction factor for cylinder deactivation to vehicles with six and four cylinder engines, where the actual benefit would be smaller.

TECHNOLOGY STUDIES MAY BE OPTIMISTIC – Where references are provided to substantiate fuel consumption benefits in the Report, the source of information is frequently a company that sells such technologies to vehicle manufacturers. While these reports are a valuable source of information on the *development* of the individual technologies, they tend to focus on the "potential" fuel consumption reductions available in well-suited vehicle applications, as opposed to reductions that might be achieved when production versions of the technologies are applied on many vehicle applications.

A further issue with at least eight of the cited studies ([4, 9, 12, 18, 25, 27, 34, 38]) is the use of European or Japanese driving cycle results instead of EPA driving cycle results. The European and Japanese driving cycles are lighter load cycles that increase the amount of energy lost to pumping work. Thus, the expected benefits from pumping loss reduction for these technologies will be less on vehicles running the EPA driving cycles.

RECOMMENDATIONS – In order to provide more accurate values to represent fuel consumption reductions that are technically feasible with the technologies used in the Report, increased depth of analysis needs to be used. Engine and vehicle simulations that use accurate data as inputs along with a consistent set of constraints will significantly improve the fidelity of the projections, thus eliminating sources of variation quoted in the Report and improving on the limitations of existing published reports.

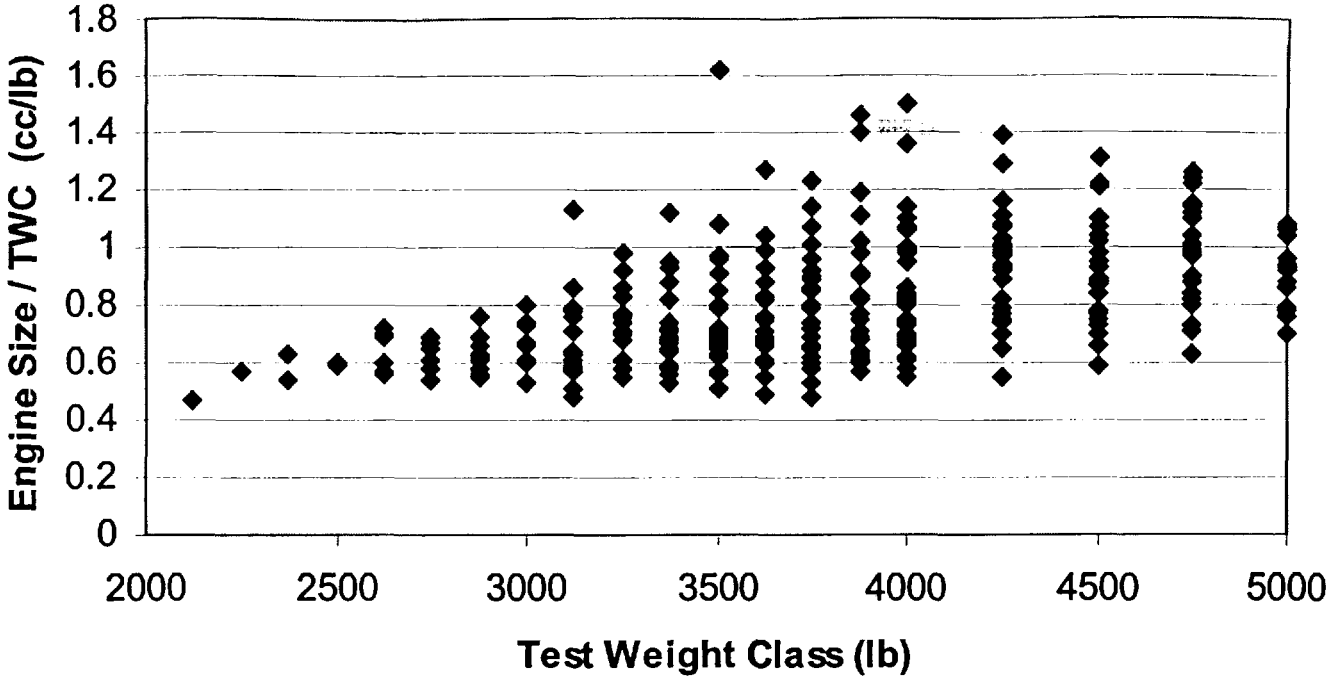

Figure 6: Plot of ratio of engine size to vehicle test weight class for Model Year 2001 vehicles certified in the U.S.

ISSUE #3: OVERCOUNTING OF FUEL CONSUMPTION REDUCTIONS RESULTS IN INACCURATE "COST-EFFICIENT" ANALYSIS

The fuel consumption reduction and incremental cost results presented in Chapter 3 of the Report are the basis for the "cost-efficient" analysis in Chapter 4. The "cost-efficient" analysis is a marginal cost analysis of path 3 technologies. Since this analysis relies on the estimates of fuel consumption benefit from individual and aggregated technologies, it has the same problems that were described for the technical feasibility analysis.

	3 Yr Payback with 0% Discount Rate		14 Yr Payback with 12% Discount Rate	
	Low Cost/ High MPG	High Cost/ Low MPG	Low Cost/ High MPG	High Cost/ Low MPG
Multi Valve OHC	X		X	X
Variable Valve Timing	X		X	X
Supercharging & Downsizing			X	X
Camless			X	

Table 4: Pumping loss technologies included in NRC breakeven analysis (Midsize SUV vehicle segment)

A review of technologies selected for the "cost-efficient" analysis shows that the aggregation problem will cause errors. Table 4 lists technologies included in the NRC breakeven analysis for the Midsize SUV vehicle segment. All of the technologies in Table 4 reduce fuel consumption primarily by addressing pumping losses. The simple method used for aggregating the effects of these technologies in the NRC breakeven analysis overestimates the aggregated fuel consumption benefits of these technologies.

ENERGY BALANCE CALCULATION

SYSTEM-LEVEL EFFECTS – The energy loss categories of interest for this analysis are:

- engine thermal losses
- engine pumping losses
- engine friction losses
- transmission losses
- accessories
- vehicle losses

The energy loss categories are important because they differentiate measurable, predictable physical processes that determine energy usage in vehicles. Thus, an accounting of the effects of individual technologies on energy losses within these categories provides a practical, physically-based means to evaluate and compare the fuel consumption effects of the various technologies. As will be shown, it also provides an energy-based means to "sense-check" the results of the Report.

ENERGY BREAKDOWN RESULTS – A quantitative breakdown of the energy categories for vehicles is needed in order to perform an energy balance calculation. There are several possible methods for obtaining such a breakdown, including in-vehicle engine test results during actual driving cycles and vehicle simulation results for driving cycles. Results from several such studies are summarized in Table 5. The values presented include indicated work, brake work, engine pumping losses, and engine friction losses, all expressed as a percentage of fuel energy used on the EPA driving cycles. It is important to note that the range of values shown in the table reflects differences in vehicle segments and not uncertainty in the allocation of energy to the various categories.

Some of the results from Table 5 came from detailed in-cylinder pressure measurements on engines in vehicles running the EPA driving cycles. Such measurements enable the real-time quantification of pumping losses and indicated work, and when supplemented by steady-state engine dynamometer data, the calculation of engine friction losses. Figure 7 shows the results of one such measurement, a plot of pumping losses (expressed as pumping mean effective pressure, or pmep) versus time on a portion of the EPA City cycle.

Table 5 also shows results from detailed simulation models of vehicles running the EPA cycles. The simulation models used for these studies are full-featured and properly constrained and use measured data for engine, torque converter, transmission, driveline, accessory, and vehicle component losses. The high level of validation of these models is illustrated in Figures 8A and 8B, which show plots of time-resolved vehicle speed and engine airflow rate for the model and the actual vehicle.

Table 5 indicates that 25.4% - 30.9% of fuel energy used on the EPA combined cycle goes to brake work. This result depends on many factors including engine size and vehicle application. The highest percentage of brake work shown is for a small truck with a 2.2L OHV L4, and the lowest percentage of brake work shown is for a large truck with a 5.3L OHV V8.

Table 5 indicates that 2.4% - 5.0% of the fuel energy used on the EPA combined cycle goes to pumping losses. This result also depends on many factors, including EGR calibration, engine size, and vehicle application. The highest percentage of pumping losses shown is for a large truck with a 5.3L OHV V8, and the lowest percentage of pumping losses shown is for a small truck with a 2.2L OHV L4. Table 5 indicates that 3.7% - 5.9% of the fuel energy used on the EPA combined cycle goes to engine friction losses.

The percentage of fuel energy used for indicated work is also listed in Table 5. In some cases where data was not available, a value of 37% indicated efficiency is assumed in the calculation of losses as a percentage of fuel energy. This is based on test data from many port-fuel-injected spark-ignition engines. Since for any given engine, indicated efficiency is relatively unchanged in the range of engine speeds and loads of interest here, it is reasonable to make this constant indicated efficiency assumption for those cases where data was not available.

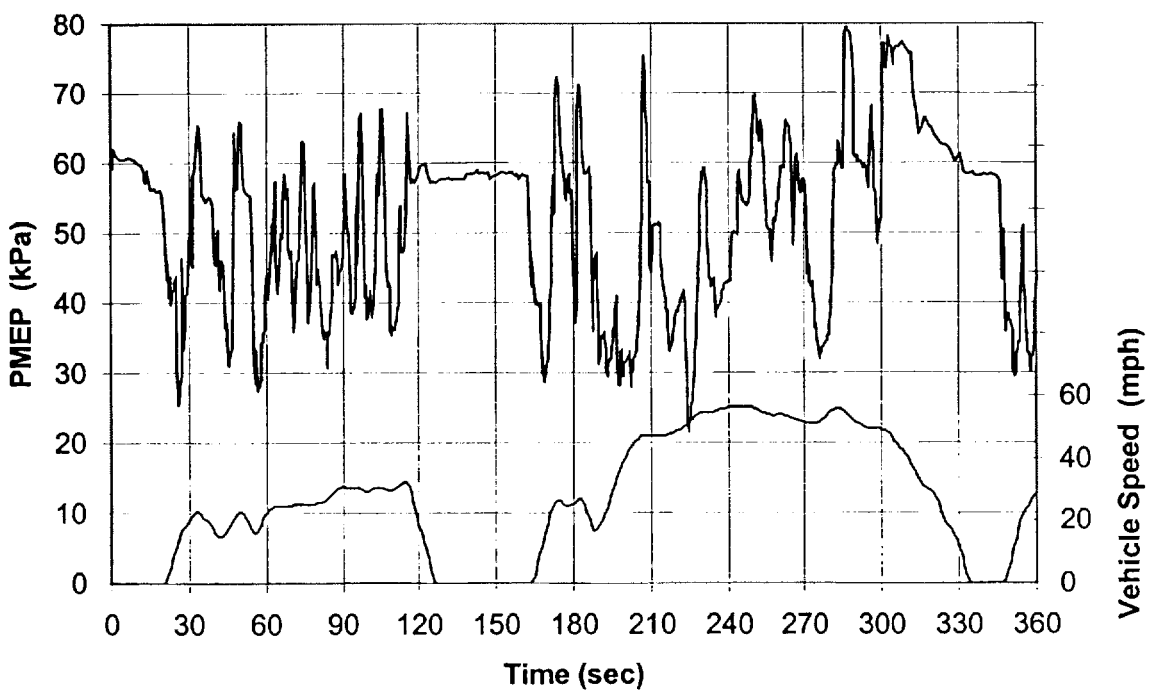

Figure 7: Plot of PMEP versus time, measured on a small car operating on the EPA City cycle

Source	Engine Data or Engine Simulation?	Vehicle Data or Vehicle Simulation?	Driving Cycle	Engine	Vehicle Type	Pumping Losses (% of fuel energy)	Friction Losses (% of fuel energy)	Pumping + Friction Losses (% of fuel energy)	Brake Work (% of fuel energy)	Indicated Work (% of fuel energy)
GM	test data	test data	city	5.3L OHV V8	2WD Large Truck			12.3		
GM	test data	simulation	city	5.3L OHV V8	2WD Large Truck			10.8	22.9	33.7
GM	test data	test data	city	2.2L OHV L4	2WD Small Truck	2.6	4.1	6.7	30.3	37.0
[42]	unknown	unknown	city	?	car			13.5	24.5	38.0
GM	test data	simulation	city	2.2L DOHC L4	FWD Small Car			14.0	24.0	38.0
GM	test data	test data	city	2.4L DOHC L4	FWD Small Car	3.7	5.9	9.6	27.4	37.0
GM	test data	test data	city	2.2L OHV L4	FWD Small Car	3.7	4.4	8.1	28.9	37.0
GM	test data	simulation	highway	5.3L OHV V8	2WD Large Truck			8.8	27.9	36.7
GM	test data	test data	highway	2.2L OHV L4	2WD Small Truck	2.2	3.3	5.6	31.5	37.0
GM	test data	simulation	highway	2.2L DOHC L4	FWD Small Car			11.4	28.1	39.5
GM	test data	test data	highway	2.4L DOHC L4	FWD Small Car	4.4	5.9	10.4	26.6	37.0
GM	test data	test data	highway	2.2L OHV L4	FWD Small Car	3.7	4.1	7.8	29.2	37.0
GM	test data	simulation	combined	5.3L OHV V8	2WD Large Truck			9.8	25.4	35.2
GM	test data	test data	combined	2.2L OHV L4	2WD Small Truck	2.4	3.7	6.1	30.9	37.0
GM	test data	data + simulation	combined	5.3L OHV V8	4WD Large Truck	5.0	5.0	10.0	27.0	37.0
GM	test data	simulation	combined	2.2L DOHC L4	FWD Small Car			12.7	26.1	38.8
GM	test data	test data	combined	2.4L DOHC L4	FWD Small Car	4.1	5.9	10.0	27.0	37.0
GM	test data	test data	combined	2.2L OHV L4	FWD Small Car	3.7	4.3	8.0	29.0	37.0
DCX	test data	engine dyno only	-	-	-	5.6				37.0

Table 5: Summary of several studies which break down energy losses into indicated work, brake work, engine pumping losses, and engine friction losses. All percentages shown are as a fraction of fuel energy.

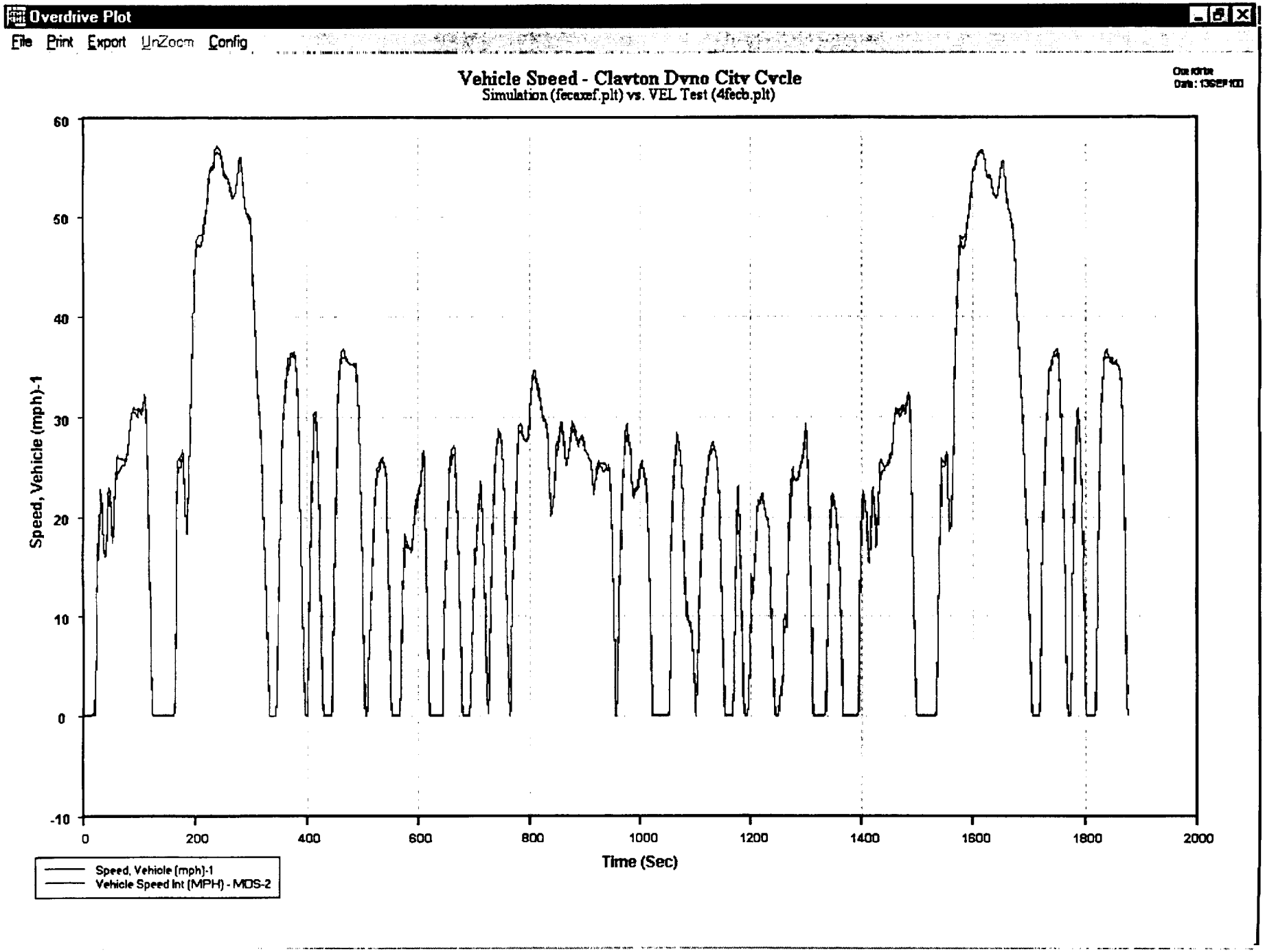

Figure 8A: Simulated and measured vehicle speed traces for vehicle operation on the EPA City cycle

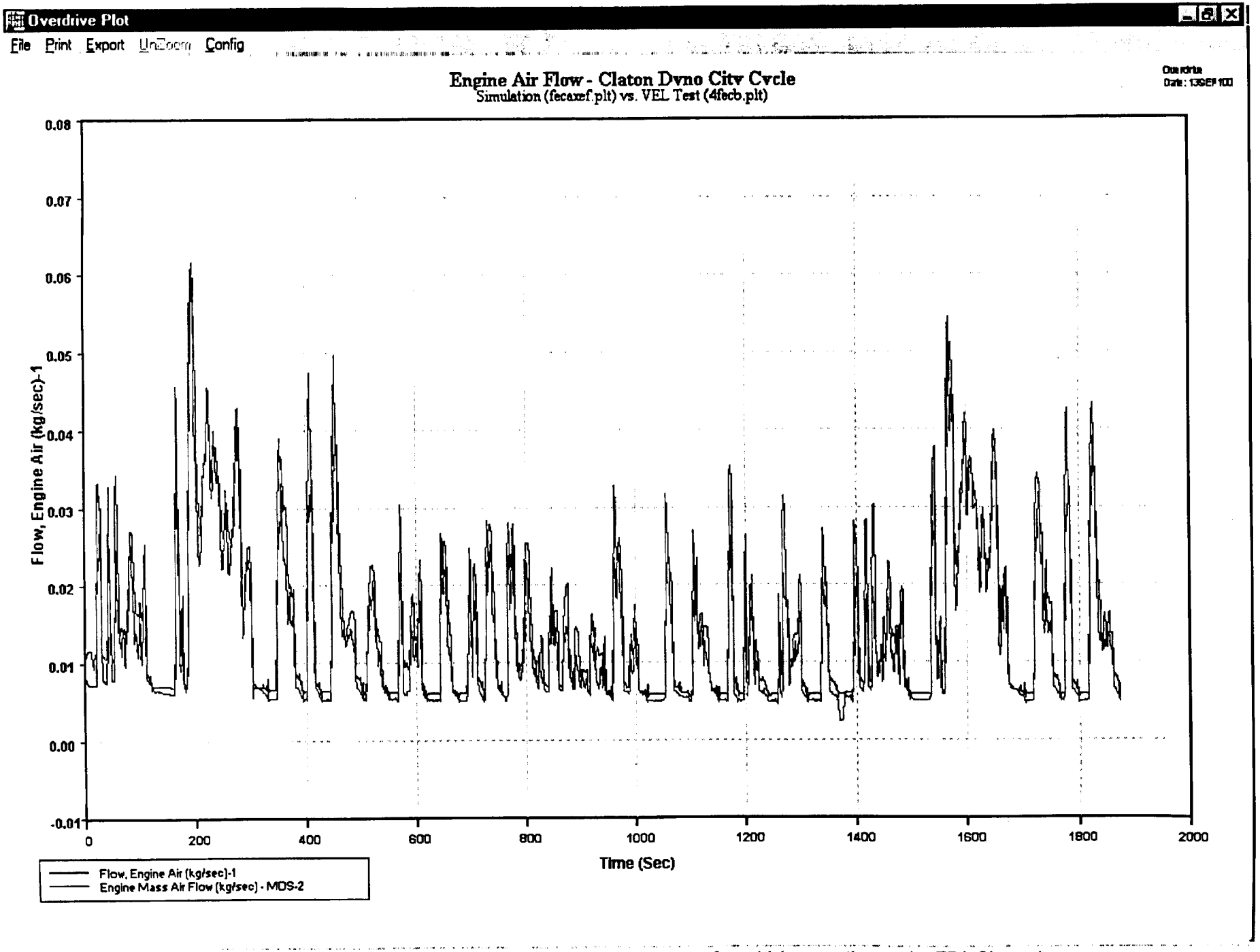

Figure 8B: Simulated and measured engine air flow rate traces for vehicle operation on the EPA City cycle

ENERGY BALANCE THEORETICAL LIMIT – The theoretical maximum fuel consumption reduction that could be achieved from the elimination of losses in any energy loss category can be calculated using the energy breakdown results. This is accomplished by setting the energy losses in the category in question equal to zero. Even though the elimination of energy losses in any category is impossible to achieve in the real world, this calculation serves to define the theoretical maximum fuel consumption reduction that could be associated with each loss category.

Fuel energy used during the EPA cycles can be expressed as a function of indicated efficiency of the engine, brake work being done on the vehicle, accessories, and driveline, engine friction work, and engine pumping work:

$$E_{fuel} = \frac{100}{\eta_{ind}}\left(E_{brake} + E_{fric} + E_{pump}\right)$$

where E_{fuel} = fuel energy used

E_{brake} = brake work done on vehicle, accessories, and driveline

E_{fric} = engine friction work

E_{pump} = pumping work

η_{ind} = gross indicated efficiency

Based on the results from Table 5, it is expected that 2.4 - 5.0 units of pumping work are performed for every 100 units of fuel energy used on the EPA cycles. A reduction in fuel energy attributable to pumping loss elimination can be calculated using the equation. For example, if 4% of fuel energy is used to overcome pumping losses, then 4.0 ÷ 0.37 or 10.8% fuel consumption reduction is attributable to the elimination of pumping losses (this assumes that indicated efficiency is 37%).

Figure 9 shows a sensitivity analysis that relates fuel consumption reduction attributable to pumping loss elimination to the magnitude of pumping losses. Based on Table 5 results, it is clear that the theoretical maximum fuel consumption reduction attributable to pumping loss elimination is in the 6.5% - 13.5% range. Even if it is assumed that a higher percentage, say 7%, of fuel energy is due to pumping losses – and no such data have been shown – the maximum theoretical fuel consumption reduction would be 19%.

It should be reiterated that it is impossible to reduce pumping losses to zero in a real engine – this example serves only to establish a theoretical maximum fuel consumption reduction. Eliminating pumping losses in an engine would mean eliminating the losses in all engine components that handle and control intake air and exhaust gases. Components that provide these functions – air cleaner, throttle, intake manifold, engine

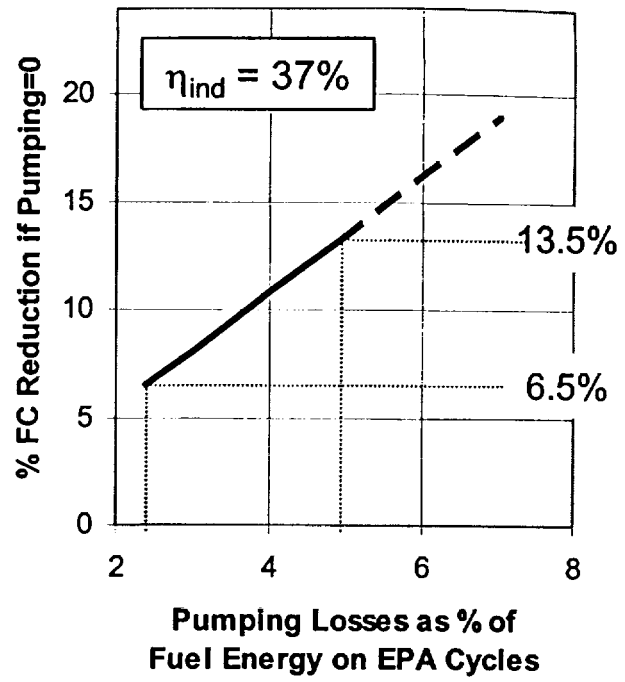

Figure 9: Energy balance theoretical reduction in fuel consumption from elimination of pumping losses (unachievable in real engines)

ports, engine valves, exhaust manifold, catalytic converters, and muffler – cannot be eliminated in real engines.

CONSEQUENCE: NRC FUEL CONSUMPTION REDUCTIONS EXCEED THEORETICAL LIMITS

As a test of the fuel consumption results in the Report, a comparison to the theoretical limits from the previous section will be made. In order to do this, the NRC fuel consumption results must be partitioned into the energy categories based on their physical effects on vehicle fuel consumption. This section will show a partitioning of the NRC results using data from engine and vehicle development programs within the auto industry, simulation results, and models. Following the partitioning, the portions of the NRC fuel consumption benefits that can be attributed to engine pumping loss reduction will be compared to the theoretical limit attributable to pumping loss reduction.

PARTITIONING OF NRC RESULTS INTO ENERGY CATEGORIES – Table 6 shows the partitioning of NRC technology benefits into the separate energy loss categories. The basis for these numbers is the list of NRC fuel consumption reductions for the individual technologies. The five loss mechanisms considered are the same as those described in the Report: exhaust and cooling losses (also referred to as thermal losses), pumping losses, engine friction losses, accessory and transmission losses, and vehicle losses. The sum of the individual benefits equals the benefit from the Report.

Technology	NRC FC Reduction		NRC FC Reduction Partitioned into Energy Breakdown Categories											
			Exhaust and Cooling		Pumping		Friction		Transmission		Accessories		Vehicle Losses	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
engine friction reduction	1.0%	5.0%					1.0%	5.0%						
low friction lubricants	1.0%	1.0%					1.0%	1.0%						
multivalve OHC (2V vs 4V)	2.0%	5.0%	0.5%	1.0%	2.0%	5.0%	-0.5%	-1.0%						
VVT	2.0%	3.0%	0.0%	0.5%	2.0%	2.75%	0.0%	-0.25%						
VVLT (2-step)	1.0%	2.0%	0.2%	0.2%	1.8%	2.8%	-1.0%	-1.0%						
cylinder deactivation	3.0%	6.0%	0.0%	0.5%	2.5%	5.0%	0.5%	0.5%						
engine accessory improvement	1.0%	2.0%									1.0%	2.0%		
supercharging & downsizing	5.0%	7.0%			4.0%	6.0%	1.0%	1.0%						
5 speed auto	2.0%	3.0%			1.5%	3.5%	0.5%	0.5%	0.0%	-1.0%				
CVT	4.0%	8.0%	0.0%	0.5%	4.5%	9.0%	0.5%	0.5%	-1.0%	-2.0%				
auto w/aggressive shift logic	1.0%	3.0%			0.25%	1.25%	0.25%	0.25%	0.5%	1.5%				
6 speed auto	1.0%	2.0%			0.75%	2.75%	0.25%	0.25%	0.0%	-1.0%				
aero drag	1.0%	2.0%											1.0%	2.0%
rolling resistance	1.0%	1.5%											1.0%	1.5%
intake valve throttling (var lift)	3.0%	6.0%			4.0%	7.0%	-1.0%	-1.0%						
camless	5.0%	10.0%	1.0%	2.0%	6.0%	11.0%	-2.0%	-3.0%						
variable CR	2.0%	6.0%	2.5%	6.5%			-0.5%	-0.5%						
MTA	3.0%	5.0%							3.0%	5.0%				
high torque CVT	0.0%	2.0%							0.0%	2.0%				
42V	1.0%	2.0%									1.0%	2.0%		
ISG w/idle off	4.0%	7.0%			1.4%	2.4%	0.9%	1.6%	1.7%	3.0%				
electric power steering	1.5%	2.5%									1.5%	2.5%		
weight reduction	3.0%	4.0%											3.0%	4.0%

Table 6: Breakdown of NRC technologies into loss categories; primary loss mechanisms are highlighted.

Information used to partition the NRC benefits comes from a variety of sources, which are described in detail in Appendix A. Those sources include measured data, results from validated computer simulations, published reports, and results from other subsystem models. *With few exceptions, the partitioning presented in this paper is in agreement with the individual technology descriptions provided in the Report.* A description of the rationale for the partitioning of each technology is presented in Appendix A.

COMPARISON OF NRC RESULTS TO THEORETICAL LIMITS – Using the partitioning of the NRC fuel consumption results from Table 6, it is possible to determine for each development path the portion of NRC fuel consumption reduction attributable to pumping loss reduction. These results can be compared to the theoretical limit established earlier.

Table 7 lists for the Midsize SUV vehicle segment the NRC-projected fuel consumption reductions for each path, compared to the fuel consumption reduction attributable to only pumping loss reduction. As can be seen in Table 7, the majority of the improvements projected in the Report are attributable to pumping loss reduction. While this observation is consistent with the individual technology descriptions in the Report, it is alarming because such large fuel consumption reductions, attributable only to pumping loss reduction, are impossible based on the theoretical maximum analysis. This error is a direct result of the NRC method for aggregating the effects of many technologies.

NRC Tech Path	FC Reduction Using All Techs	FC Reduction Using ONLY Pumping Loss Techs
1	17%	12%
2	32%	21%
3	39%	27%

Table 7: Fuel Consumption Results (Midsize SUV vehicle segment)

Figure 10 summarizes the relative magnitudes of the NRC results, the pumping-only results, and the theoretical limit for the Midsize SUV vehicle segment (vertical bars span the low-to-high ranges calculated using the NRC method). The theoretical limit is based on the measured and simulated results shown in Table 5 and on the sensitivity analysis presented in Figure 9. In Figure 10 a horizontal band from 13.5% to 17% represents the upper end of the result from Figure 9, thus defining the limit above which fuel consumption reductions due only to pumping loss reduction are not possible. Similar results can be calculated for the other vehicle segments.

For the Midsize SUV vehicle segment, path 2 and 3 NRC results do not satisfy the energy balance test.

It is important to note that the energy balance test applied here can only invalidate results that are shown to be theoretically impossible. It cannot validate a result.

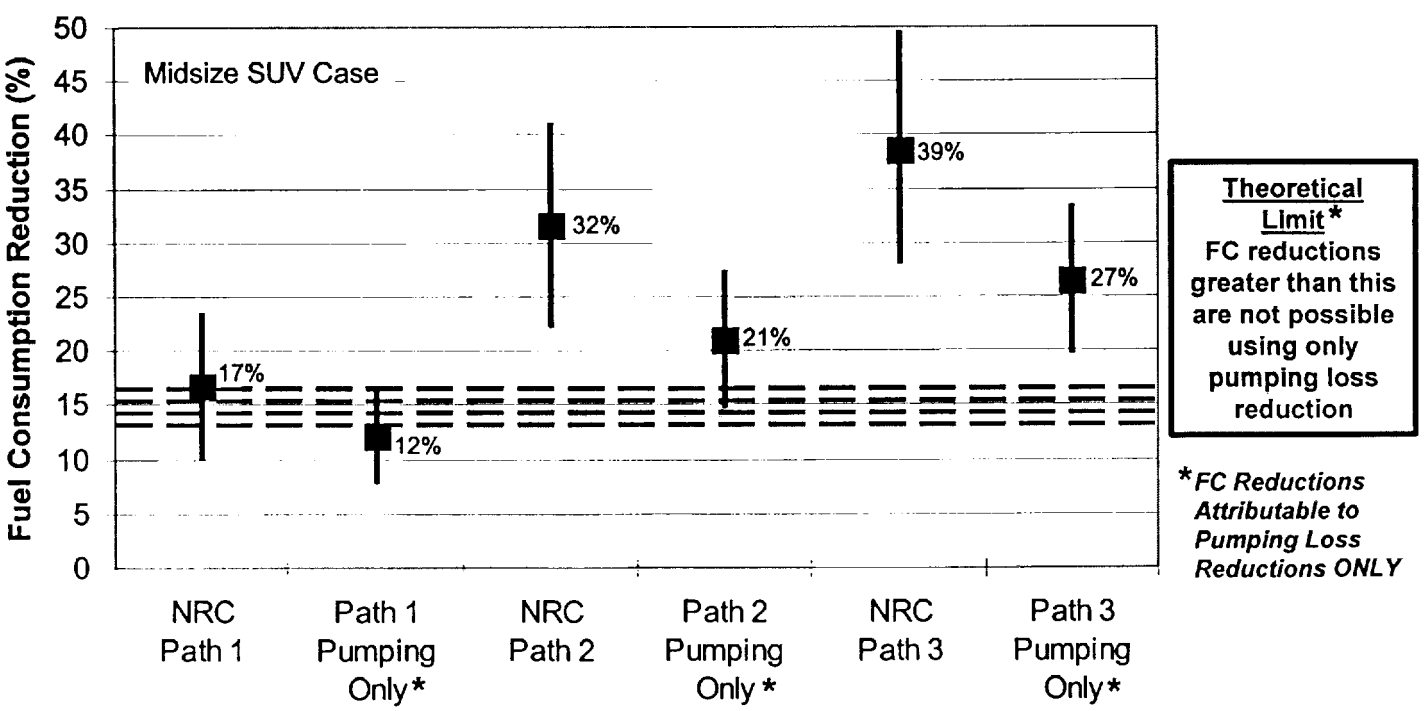

Figure 10: Comparison of NRC results, pumping-only portion of NRC results, and theoretical limit.

CONCLUSIONS

There is general agreement in the automotive industry with many of the Findings and Recommendations published in the Report. However, a number of items in the technical section of the Report, particularly the method used for aggregation of benefits of technologies, have serious flaws.

These flaws result in an overcounting of the fuel consumption reduction that is projected to occur in all three development paths of the Report. This overcounting was illustrated by a comparison of the NRC results with theoretical limits calculated using an energy balance. NRC path 2 and path 3 fuel consumption projections exceed the limit established by energy balance.

The overcounting that occurs in the technology portion of the Report has an impact on the "cost-efficient" analysis used by NRC to equate added technology content with future fuel cost savings. Because the methodology used in the Report overpredicts the fuel consumption benefits, the "cost-efficient" levels of technology content, fuel consumption and cost are not accurate.

RECOMMENDATIONS

Because of the simplifications and approximations in Chapter 3 of the NRC Report, its optimistic fuel consumption projections should not be used as a basis for CAFE decision making. In addition, Chapter 4 of the Report, which suggests "cost-efficient" levels of technically feasible fuel consumption reduction, is unrealistic and should not be used because it incorporates the aggregation method of Chapter 3. These recommendations are consistent with statements made in the Report which indicate that a vehicle systems analysis is required.

All studies which use the "shopping cart" approach for the aggregation of technologies should not be used as a basis from which to formulate policy, and they are not a reliable source for future studies intended to influence policy. The experience of automotive manufacturers in putting complete vehicle systems into volume production has resulted in detailed data and validated system models which confirm the industry position that a more thorough systems approach is required. Future analyses of this nature need to use more thorough, validated methods.

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REFERENCES

1. National Research Council, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Academy Press, 2002.
2. Schwaderlapp, M., Koch, F., and Dohmen, J., FEV, FISITA 2000-3 Seoul Congress.
3. Inoue, K., et al, "Effects of Lubricant Composition on Fuel Efficiency in Modern Engines," SAE 951037.
4. Szengel, R., and Endres, H., 6. Aachener Kolloquium, 1997.
5. Graham, D., Gerlach, S., Meurer, J., "New 4.0L SOHC V6 Engine for the Ford Explorer," SAE 962234.
6. Chon, D.M., and Heywood, J.B., "Performance Scaling of Spark-Ignition Engines: Correlation and Historical Analysis of Production Engine Data," SAE 2000-01-0565.
7. Stein, R.J., Galietti, K.M., and Leone, T.G., "Dual Equal VCT – A Variable Camshaft Timing Strategy for Improved Fuel Economy and Emissions," SAE 950975.
8. Leone T.G., Christenson, E.J., and Stein, R.J., "Comparison of Variable Camshaft Timing Strategies at Part Load," SAE 960584.
9. Moriya, Y., et al, "A Newly Developed Intelligent Variable Valve Timing System: Continuously Controlled Cam Phasing as Applied to a New 3-Liter In-Line-6 Engine," SAE 960579.
10. Boggs, D.L., Hilbert, H.S., and Schecter, M.M., "The Otto-Atkinson Cycle Engine – Fuel Economy and Emissions Results and Hardware Design," SAE 950089.
11. Goto, T., et al, "Development of V6 Miller Cycle Gasoline Engine," SAE 940198.
12. Hatano, K., et al, "Development of a New Multi-Mode Variable Valve Timing Engine," SAE 930878.
13. Shiga, S., et al, "Effect of Early Closing of Intake-Valve on the Engine Performance in a Spark-Ignition Engine," SAE 960585.
14. Gray, C., "A Review of Variable Engine Valve Timing," SAE 880386.
15. Matsuki, M., et al, "Development of a Lean Burn Engine with a Variable Valve Timing Mechanism," SAE 960583.
16. Brustle, C. and Schwarzenthal, D., "The "Two-in-One" Engine – Porsche's Variable Valve System (VVS)," SAE 980766.
17. Kreuter, P., et al, "The Meta VVH System – The Advantages of Continuously Mechanical Variable Valve Timing," SAE 1999-01-0329.
18. Kreuter, P., et al, "Meta-CVD System – An Electro-Mechanical Cylinder and Valve Deactivation System," SAE 2001-01-0240.
19. Fortnagel, M., et al, MTZ 98 Sonderheft.

20. Energy and Environmental Analysis, Inc., "Technology and Cost of Future Fuel Economy Improvements for Light-Duty Vehicles Final Report," Prepared for National Academies Committee on Impact and Effectiveness of Corporate Average Fuel Economy Standards, 2001.
21. Walzer, P., FEV, 00ELE028 Future Engines for Cars.
22. Scherer, H. and Gierer, G., "ZF 5-Speed Transmissions for Passenger Cars," SAE 970689.
23. Audi AG, "Multitronic – The New Automatic Transmission from Audi," parts 1 and 2, ATZ 8 and 9, 2000.
24. Boos, M. and Mozer, H., "ECOTRONIC – Continuously Variable ZF Transmission (CVT)," SAE 970685.
25. Sakaguchi, S., Kimura, E., and Yamamoto, K., "Development of an Engine-CVT Integrated Control System," SAE 1999-01-0754.
26. Hall, W. and Bock, C., "6-Speed Automatic Transmission for the New BMW 7-Series," ATZ 9, 2000.
27. MTZ 10, 2000, pp. 826-835.
28. Pierik, R.J., and Burkhard, J.F., "Design and Development of a Mechanical Variable Valve Actuation System," SAE 2000-01-1221.
29. Lee, J., Lee, C., and Nitkiewicz, J.A., "The Application of a Lost Motion VVT System to a DOHC SI Engine," SAE 950816.
30. Fierl, R. and Kluting, M., "The Third Generation of Valvetrains – New Fully Variable Valvetrains for Throttle-Free Load Control," SAE 2000-01-1227.
31. Takemura, S., et al, "A Study of a Continuous Variable Valve Event and Lift (VEL) System," SAE 2001-01-0243.
32. Negurescu, N., et al, "Variable Valve-Control Systems for Spark-Ignition Engine," SAE 2001-01-0671.
33. Pischinger, M., et al, FEV, Seoul FISITA World Automotive Congress, June 12-15, 2000, Seoul, Korea.
34. Drangel, H. and Bergsten, L., "The New Saab SVC Engine – An Interaction of Variable Compression Ratio, High Pressure Supercharging, and Downsizing for Considerably Reduced Fuel Consumption," 9 Aachener Kolloquium 2000, pp. 91-110.
35. Wirbeleit, F.G., Binder, K., and Gwinner, D., "Development of Piston with Variable Compression Height for Increasing Efficiency and Specific Power Output of Combustion Engines," SAE 900229.
36. Ma, T.H. and Rajbu, H., SAE 884053.
37. Carriere, D., Cherry, J., and Reed, R., "EMAT – Electro-Mechanical Automatic Transmission," SAE TOPTEC Modern Advances in Automatic Transmission Technology.
38. Mazda, "Mazda's Future – Cars and Technology for Tomorrow."
39. Wards Engine and Vehicle Technology Update, June 15, 2001, p. 7.
40. Peter, D. and Gerhard, R., "Electric Power Steering – The First Step on the Way to "Steer-by-Wire,"" SAE 1999-01-0401.
41. Environmental Protection Agency, "Light Duty Automotive Technology and Fuel Economy Trends," 1999.
42. Pinkus, O., and Wilcock, D.F., "The Role of Tribology in Energy," Lubrication Engineering, 34 (11), pp. 599-610.

CONTACT

For additional information, please contact the authors at:

Ken Patton at kenneth.patton@gm.com

Aaron Sullivan at aaron.1.sullivan@gm.com

Rod Rask at rod.rask@gm.com

Mark Theobald at mark.a.theobald@gm.com

APPENDIX A: INDIVIDUAL TECHNOLOGY PARTITIONING INFORMATION

MEASURED DATA – The most important sources of information for the partitioning in Table 6 are measured data from product development programs. These sources are important because they come from physical measurements made during development work aimed at integrating the subject technologies into production-feasible vehicle applications with real-world constraints. An example of the direct measurement of pumping losses was shown in Figure 7.

RESULTS FROM VALIDATED COMPUTER SIMULATIONS – Detailed system and subsystem simulation analyses, using models validated with test data, are another source of information for the partitioning of the NRC fuel consumption results. Such studies are often done as part of future product development programs. Accurate input data such as product specifications, component performance data, and subsystem performance data are critical to the accuracy of such simulation studies. The use of validated, detailed, and realistically constrained models allows for systematic comparisons of technologies and combinations thereof. Furthermore, an important characteristic of simulation models is implicit use of governing equations which satisfy energy balance.

OTHER MODELS AND ANALYSIS TOOLS – Other models and analysis tools are also used as sources of information for the partitioning of the NRC fuel consumption results. Zero-dimensional phenomenological models which use fundamental relationships and correlations of measured data or simulation results can be used to quantify the relative magnitudes of different loss mechanisms for individual technologies or combinations of technologies. An example of the use of such a model is the assignment of a 1.5% - 2% increase in engine efficiency for a one point increase in compression ratio (assuming baseline compression ratio is in the 9-10 range). The fundamental relationship inherent in this particular model is the ideal-cycle thermal efficiency equation. The ideal result is reduced to reflect real-world effects such as additional heat and friction losses, whose impact is known from engine test data and simulation results.

Multi-Valve OHC: The Report states that this technology reduces pumping losses due to reduced flow losses and increased specific output which enables engine downsizing. The level of downsizing – and thus the potential pumping loss reduction – is dependent on specific customer requirements. The Report assigns positive benefit to improved thermal efficiency; this is due to a more centrally located spark plug and smaller bore diameter providing reduced flame travel distance and enabling higher knock-limited compression ratio. However, a penalty must be attributed to multivalve OHC friction (unlike the statements in the Report) due to increased number of camshafts, cam drive components, and valvetrain sliding components, and due to required increased oil pump capacity. Contemporary OHV engines already have multiple rolling elements.

VVT (Intake and Exhaust Cam Phasing): The Report states that this is primarily a pumping loss reduction technology. However, some small benefit should be attributed to improved thermal efficiency due to ability to delay exhaust valve opening (thus increasing expansion ratio), due to ability to control intake valve closing (thus allowing limited optimization of effective compression ratio), and due to improved gas properties and in-cylinder heat losses. In addition, some penalty must be attributed to friction due to the increased oil flow requirements (and resulting larger oil pump losses) for multiple cam phasers (all of which are hydraulically controlled), particularly for Vee engines with four cam phasers.

Variable Valve Lift & Timing (VVLT, 2-step lift): The Report states that this is a pumping loss reduction technology, which is true in applications where it is combined with intake VVT. The Report also states that there will be benefits due to improved air/fuel mixing, so some small benefit must be attributed to improved thermal efficiency. However some penalty must be attributed to friction due to the increased number of sliding components required to realize some 2-step lift systems, and increased oil pump losses due to the need for more oil pump capacity, which is required for robust hydraulic actuation of the VVLT feature. These negative aspects offset the potential for reduced friction from lower valve lift in low-lift mode.

Cylinder Deactivation: The Report states that this is primarily a pumping loss reduction technology due to the ability to run active cylinders at higher loads with less throttling losses. The Report also states that increased thermal losses occur, but in fact the opposite is true. Combustion performance (and thus thermal efficiency) may be improved because the active cylinders running at higher load have increased burn rates and lower relative heat losses. Friction losses in the inactive cylinders are less than they would be if the cylinders were active, and this may offset the additional friction in the more heavily loaded active cylinders and the heat lost in the inactive cylinders. So some small positive benefit must be attributed to improved thermal efficiency, and a small positive benefit may be attributed to reduced friction.

Supercharging and Downsizing: The Report does not explicitly state that this is primarily a pumping loss reduction technology, but it is implied since the benefit is attributed to engine downsizing at equal performance. The Report does not mention friction benefits due to the potential for reduced number of cylinders and/or smaller displacement, but this should be included as well, because it helps to offset the potential for increased parasitic losses from the supercharger. There are offsetting factors (increased cylinder loading versus the need to reduce compression ratio) which affect thermal efficiency, so no benefit is attributed to it.

Variable Compression Ratio: The Report states that this is primarily a thermal efficiency improvement technology, due to the ability to optimize compression ratio as engine load and speed change. However, the Report does not mention the fact that additional friction and parasitic losses resulting from the variable CR actuation mechanism will be incurred; this requires that some penalty be attributed to friction or parasitics. The Report also states that this technology is suited to downsized boosted engines - it may be the case that this is the only application where the technology may have a chance of being cost-effective.

Intake Valve Throttling (continuously variable lift): The Report states that this is primarily a pumping loss reduction technology. However, some penalty must be attributed to friction due to the increased number of actuation and valvetrain components required for this complex system to be realized, even though reduced valve lift at lighter loads partially offsets the fundamental friction differences. There are offsetting factors affecting thermal efficiency (reduced overall in-cylinder bulk motion, increased throttling at valve to improve fuel atomization, reduced residual gas heating of incoming fuel-air charge), so no benefit or penalty is attributed to thermal efficiency.

Camless Valve Actuation: The Report states that this is primarily a pumping loss reduction technology. The Report also mentions the fact that energy consumption (electrical or hydraulic) of this technology is a remaining challenge. As such, a penalty must be attributed to friction loss in order to account for the significant energy consumption of camless systems. The Report does not mention thermal efficiency benefits, but they may exist due to more precise optimization of exhaust valve opening and intake valve closing timing, which helps to offset the potential for degraded combustion performance at light loads. As a result, a small benefit should be attributed to thermal efficiency if it is assumed that the camless system can provide total control of lift, timing, and duration.

5 Speed Automatic Trans: The Report states that 5 speed automatic transmissions allow the engine to operate in a more efficient speed-load range. This implies operation at lower engine speeds and higher loads, which implies reduced pumping losses and engine friction. So positive benefits must be attributed to pumping losses and engine friction. The Report does not mention the fact that 5 speed automatic transmissions have higher spin losses than 4 speed automatic transmissions, especially in top gear. A penalty must be attributed to transmission losses to account for this.

6 Speed Automatic Trans: The Report does not state the loss mechanism which is reduced when using 6 speed automatic transmissions. However, the effects on the benefit categories are the same as they are for 5 speed automatic transmissions: positive benefits for pumping losses and engine friction, and a penalty for additional transmission losses (due to increased spin losses in the 6 speed transmission).

Auto w/Aggressive Shift Logic: The Report states that more aggressive torque-converter-clutch lockup calibrations will reduce the losses associated with torque converters (thus this is mainly a transmission loss technology). However, a significant fraction of the fuel consumption improvement is also due to the fact that the engine operates at lower speeds and higher loads, which reduces friction and pumping losses. So positive benefits must be attributed to engine friction and pumping losses.

Continuously Variable Transmission (CVT): The Report does not state which loss mechanisms are affected when using CVTs. The effect on the benefit categories is similar to the effect for 5 speed automatic transmissions: positive benefits for pumping losses and engine friction (due to lower engine speeds and higher loads), and a significant penalty for transmission losses (due to increased spin and pump losses as well as reduced torque transfer efficiency of the belt and gear set in the CVT). A small benefit may be attributed to thermal efficiency due to higher loading of the engine resulting in improved combustion performance.

Advanced (High Torque) CVT: The Report does not state which loss mechanisms are reduced when advanced CVTs are applied. It is assumed that the primary benefit is the reduction of transmission torque converter losses, so the benefit is assigned to transmission losses. If the intent of the NRC was to simply broaden the application of CVTs to high torque vehicles, then there should be no additional benefit of any kind assigned to advanced CVT (relative to CVT).

Integrated Starter Generator w/Idle Off: The Report states that the benefit is achieved by shutting the engine off at idle. In a conventional powertrain at idle, there is work done to overcome transmission losses (converting work into heat by rotating the torque converter), engine pumping losses, and engine friction losses. It has been suggested that some benefit should be assigned to thermal losses. However, those losses are only the result of the need to perform work on the transmission, engine pumping losses, and engine friction losses. As with other pumping and friction reduction technologies, thermal losses are reduced as a byproduct of the fact that less indicated work is required. At idle, more than 1/3 of the indicated energy is sent to the transmission and accessories, roughly 1/4 of the indicated energy is used to overcome engine friction, and roughly 1/3 of the indicated energy is used to overcome engine pumping losses (these numbers are application dependent). Therefore, positive benefits can be attributed to transmission losses, pumping losses, and engine friction, since this work is no longer done during idle shutoff.

Attachment 5:

Andrew N. Kleit, "Short- and Long-Range Impacts of Increases in the Corporate Average Fuel Economy (CAFE) Standard", (February 7, 2002)

Short- and Long-Range Impacts of Increases in the Corporate Average Fuel Economy (CAFE) Standard

Andrew N. Kleit
Associate Professor of Energy, Environmental, and Mineral Economics
The Pennsylvania State University

February 7, 2002

2217 Earth-Engineering Sciences Building
The Pennsylvania State University
University Park, PA 16802-5010
814-865-0711
ANK1@psu.edu

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Abstract

A short-run 1.0 mile per gallon (MPG) increase in the Corporate Average Fuel Economy (CAFE) Standard above existing, binding levels would impose welfare losses on society of $33.9 billion per year while reducing gasoline consumption by 5.8 billion gallons per year. This amounts to a hidden tax of $5.85 per gallon conserved. An increase of 23 cents per gallon in the gasoline tax would save the same amount of fuel and impose costs on society of $670 million per year. Therefore, a short-run CAFE increase is 50 times more expensive to society than an increase in the gasoline tax. The marginal welfare costs of further short-term increases in the CAFE standard equal $4.10 per gallon of fuel conserved and substantially exceeds plausible estimates of the marginal societal benefits from the avoided externalities associated with reduced gasoline consumption.

A long-run 3.0 MPG increase in the CAFE standard would impose social welfare losses of $3 billion per year and save 5.1 billion gallons of gasoline per year. This amounts to a hidden tax of $0.58 per gallon conserved. An 11 cent per gallon increase in the gasoline tax would save the same amount of fuel at a welfare cost of $275 million per year. The 3.0 MPG increase is thus 11 times more expensive than the gas tax increase. The marginal welfare costs of long-term increases in the CAFE standard amount to $1.06 per gallon and exceed by a factor of four plausible estimates of the marginal societal benefits from avoided externalities associated with the reduction in gasoline consumption. Increasing the CAFE standard in either the short-or long-term is neither cost-effective nor cost-beneficial.

Executive Summary

Short-Run CAFE Increase:

A short-run increase of 1.0 mile per gallon (MPG) in both car and truck CAFE standards above existing, binding levels would impose social welfare losses on society of $33.9 billion per year. The short-run is the one-to-three year period in which auto manufacturers are locked in to existing models and technologies and thus must meet any mandatory CAFE increases by adjustments in the mix of products sold.

Such a short-run 1.0 MPG increase in the CAFE standard would reduce gasoline consumption by 5.8 billion gallons per year, for an average welfare loss to society of $5.85 per gallon of fuel conserved. Further increases beyond the 1.0 mpg would impose additional losses of $4.10 per gallon.

A gasoline tax increase of roughly 23 cents per gallon imposed at the beginning of the five-year period would also reduce gasoline consumption by 5.8 billion gallons per year by the end of the period. Welfare losses to society would amount to $670 million per year. In the short-term, fuel conservation through CAFE increases is therefore 50 times more expensive than raising the tax on gasoline.

In the short-term, the $4.10 per gallon marginal welfare costs of a 1.0 MPG CAFE increase would exceed the marginal benefits associated with reduced gasoline consumption externalities of $0.26 per gallon as derived from a recent study by the National Research Council (NRC). This is a factor of roughly 16 to one. The NRC marginal benefit estimates include values for the avoided costs of global climate externalities and from assumed increases in oil import dependence.

Long Run CAFE Increase:

In the long run, a 3.0 MPG increase above existing, binding levels in both car and truck CAFE standards decreases social welfare by $2.965 billion per year. The 3.0 MPG increase reflects the focus of the May 2001 report of the Vice President's task force on national energy policy, as well as of several congressional proposals.

The long-run mandatory 3.0 MPG increase reduces gasoline consumption by 5.091 billion gallons per year, for an average cost of $0.58 per gallon. The marginal cost of further increases in the CAFE standards is $1.06 per gallon and increases rapidly beyond that point. Smaller adverse effects on new vehicle sales drive the smaller long-term effects on fuel consumption and costs.

A gasoline tax of 11 cents per gallon would also reduce annual gasoline consumption by 5.091 billion gallons per year, for a social welfare loss of just $275 million.

In the long run, a CAFE increase of 3.0 MPG above present levels would impose welfare losses 11 times higher than the 11 cent per gallon gasoline tax.

Cost-Benefit Analysis:

The incremental short-run costs of $4.10 per gallon and long-run costs of $1.05 per gallon substantially exceed the $0.26 per gallon of marginal benefits from reduced gasoline consumption inferred from the NRC study.

The 1.0 MPG short-run increase in the CAFE standard is more than 50 times more expensive to society than a 23 cents per gallon gasoline tax that would achieve the same fuel savings. The 3.0 MPG long-run increase in CAFE is 11 times more expensive than the 11 cents per gallon gasoline tax increase necessary to save the same quantity of fuel.

I conclude (1) that mandatory increases in the CAFE standards of 1.0 MPG in the short run and 3.0 MPG in the long run impose costs on society are well in excess of any benefits from reduced fuel consumption; and (2) that they are far more costly than alternative, market-based approaches such as a gasoline or carbon tax.

I. Introduction and Background

The General Motors Corporation (GM) has asked me to update and extend earlier studies I have performed over the years regarding the consumer and producer welfare impacts of raising the Corporate Average Fuel Economy (CAFE) standards for cars and light trucks. I have written extensively on this issue. My dissertation at Yale University focused on CAFE standards. As a staff economist at the Federal Trade Commission, I was the primary author of FTC staff comments to the National Highway Traffic and Safety Administration regarding the welfare effects of mandatory increases in the CAFE standard.[1] An article I wrote in the academic literature dealt with the short-run implications of increasing CAFE standards.[2] Another article dealt with the issue of whether or not CAFE standards in the long run represent sustainable policy.[3] The approach taken here is modeled closely on the FTC study, updated with more recent literature and market situations, and significantly expanded to address the long-term implications of increases in the CAFE standards.

This report evaluates two different scenarios. The first concerns the short-term economic implications of raising the CAFE standard by 1.0 mile per gallon (MPG). The "short-run" refers to a length of time such that auto manufacturers can do little to change the fuel economy of specific vehicles and therefore must resort to marketing and pricing incentives to induce vehicle buyers to adjust the mix of cars and light trucks that they are willing to buy. In auto industry parlance this approach is often called "mix shifting." Discussions with GM product planners and engineers, and with other industry experts suggest that three years generally are required before any significant changes in vehicle and powertrain design can be made in response to a CAFE mandate.

The report also evaluates the "long-term" economic implications of raising the standard by 3.0 MPG above current levels. I chose 3.0 MPG because it reflects the focus of a May 2001 report by the Vice President's task force on energy policy and because it reflects several legislative proposals in congress.[4] The long run refers to a length of time such that manufacturers can adjust vehicle technologies and powertrain designs to reduce the amount of fuel required to move a given amount of mass or to achieve a given amount of performance or

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[1] Comments of the Staff of the Bureau of Economics of the Federal Trade Commission, Intent to Prepare an Environmental Impact Statement for the Corporate Average Fuel Economy Program, National Highway Traffic Safety Administration, November 13, 1989.

[2] Kleit, "The Effect of Annual Changes in Automobile Fuel Economy Standards," Journal of Regulatory Economics, 2:2 (June 1990) 151-172. For a similar approach see Thorpe, "Fuel Economy Standards, New Vehicle Sales, and Average Fuel Efficiency," Journal of Regulatory Economics, 11 (1997) 311-26.

[3] Kleit, "Enforcing Time-Inconsistent Regulations," Economic Inquiry 30:4 (October 1992) 639-648.

[4] See "National Energy Policy," Report of the National Energy Policy Development Group (May 2001) http://www.whitehouse.gov/energy/, at page 4-10.

acceleration per gallon of fuel consumed.[5] In industry parlance, this approach is often referred to as "technology forcing."

Both the short-run and the long-run analysis are evaluated under two different scenarios. The first scenario is that CAFE standards are not binding in the current marketplace. The second scenario takes account of the current impact of CAFE standards, and then analyzes the costs and benefits of increasing the standards. Thus, four different situations are analyzed in this report.

As we shall see, and consistent with economic intuition, technology forcing is much less expensive than mix shifting, but much more expensive than market-based alternatives such as an increase in the fuel tax. Increased gasoline taxes encourage consumers to identify and utilize many additional options to reduce fuel consumption, such as reduced driving intensity for used as well as new vehicles, as well as to purchase more fuel efficient vehicles. In addition, increased gasoline taxes result in reductions in vehicle miles traveled for used as well as new vehicles, decreased retention rates for older, less fuel-efficient efficient vehicles, and in the longer term, adjustments in residential and workplace locations and increased commuting via the "information highway."

In contrast, CAFE standard increases affect only new vehicles and do nothing to reduce driving. In fact, they tend to encourage increased driving as costs per mile driven decline. They also encourage the retention of older, less "fuel-efficient" vehicles.

The ostensible goal of CAFE standards is to reduce whatever externality is associated with the consumption of gasoline. As noted in President Clinton's Executive Order 12866, which was adopted by the Bush Administration's Office of Information and Regulatory Affairs (OIRA), any regulatory policy must pass two basic tests: it must be cost-beneficial, and it must be cost effective. That is, the marginal benefits of such a policy must equal or exceed the marginal costs and there must be no alternative that can obtain those benefits at a lower cost. A third criterion is that the policy must take into account any adverse, unintended consequences for human safety or the environment.

Any increase in the CAFE standard, therefore, must be achievable at a lower cost than the least cost alternative, and it must have a marginal cost per gallon of gasoline saved equal to the marginal benefits in terms of reduced levels of any externality. The costs presented here, therefore, should be compared to the costs achieved by other alternatives, such as a gasoline or carbon tax. They must be compared to the benefits from avoiding any external costs of gasoline consumption, including any costs associated with greenhouse gas emissions and dependence on imported oil. The recent NRC report concluded that the sum total of the external costs amounts to $0.26 per gallon.[6] Finally, any unintended adverse consequences of increased CAFE standards must also be assessed.

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[5] The long-term is based on the Sierra Research Report for changes that would occur by Model Year 2010. See note 9 below.

[6] See National Research Council, http://books.nap.edu/html/cafe/.

At the margin, consumers equate the price of gasoline (the "internal" cost) with the marginal value of its consumption. In the absence of any externality, the marginal value of the use of a gallon of gas equals its price, and there is no public benefit from reducing the consumption of gasoline. Where externalities exist, economic theory is clear that the optimal policy is to set a level of stringency at which the additional external benefit of reducing gasoline consumption by one gallon just equals the additional welfare costs imposed on vehicle consumers and producers.

The plan of this study is as follows. Section II develops a model in which the current CAFE standard is assumed to be non-binding. Section III provides estimates of total, average, and marginal costs of the 1.0 MPG CAFE increase under that assumption. It compares average and marginal costs of the CAFE increases with those incurred under a gasoline tax saving the same amount of fuel. Finally, it computes the impact of the CAFE increase on three criteria pollutants associated with automotive tailpipe emissions.

Section IV provides estimates of the above impacts for the long-term 3.0 MPG gallon mandatory CAFE increase under the assumption that the current CAFE standard is not binding. Section V then revises the model to take into account the arguably more realistic assumption that the current CAFE standard is in fact binding. It then reports estimates for both the short-term 1.0 MPG increase and the long-term 3.0 MPG increase.

Section VI provides a brief cost-benefit analysis of short-and long-term CAFE increases and Section VII provides a summary and conclusion.

II. Assumptions of the Model

Many of the theoretical details of this model used are similar to what I used in my previous work, and I will not repeat that discussion here. The model begins with a set of supply and demand elasticities, and initial conditions in prices and quantities. It then imposes a set of implicit CAFE taxes on each constrained firm such that, in equilibrium, each constrained firm reaches the relevant CAFE standard. I begin the analysis under the assumption that CAFE is not currently binding.

A. Base year and categories.

Given the availability of data, model year (MY) 1999 was chosen as the base year. (All dollar figures therefore are in 1999 dollars.) Light vehicles were broken down into eleven categories:

Cars:

1) Small
2) Mid-size
3) Large
4) Sports
5) Luxury.

Trucks:

6) Small pickups
7) Large pickups
8) Small SUVs
9) Large SUVs
10) Minivans
11) Vans.

For convenience, the data are broken down into four firms, General Motors, Ford, Daimler-Chrysler (domestic production), and "Other." The "other" firms consist of several foreign concerns, such as BMW, Honda, Mercedes-Benz, and Toyota. The relevant numbers, and the MPGs for each firm/category, are presented in Table One.

Transaction prices are generated by taking the average price for each category in the GM internal model supplied to me by GM economists. Data on MPGs was also supplied to me by GM.

B. Demand Side

Elasticities and cross-elasticities between categories are calculated using the internal GM demand model supplied to me. The elasticities and cross elasticities are calculated by raising the price of all vehicles in a particular category by one percent, and determining the resulting percentage change in demand, not only in that category, but for all other categories as well. Because 10.0 percent of cars are placed in a category designated as "Other" in the GM model, all elasticities are multiplied by 0.90. The elasticities calculated are presented in Table Twenty-Four.

C. Supply Side

Consistent with my previous work, I assume that the supply side is competitive, with an elasticity of supply in the short run of 2. In the longer-run, supply is generally more elastic, as firms have a longer time to adjust to new conditions. Therefore, for the long-run model, I assume an elasticity of supply of 4. Because CAFE standards divide cars into domestic and foreign fleets, this essentially implies for the purpose of this model that (Daimler) Chrysler is two firms, one domestic, and one foreign.

D. Treatment of Foreign Firms

CAFE standards call for a fine of $55 per car-mpg to be assessed to firms that do not meet the standard. Domestic firms have always asserted that, for corporate policy and legal reasons, paying a fine is not an option. Therefore, the standard is modeled as binding on them. Foreign firms, however, appear to view the fine as equivalent to a tax. Several foreign firms with relatively small volumes, over the years, have paid this tax to the Federal government. The larger foreign firms, however, have traditionally sold a mix of smaller, more fuel efficient

vehicle mixes and have not been bound by CAFE standards. This model, therefore, treats the foreign sector as unbound by standards.

E. The Technology Forcing Model

Unlike my previous work, here I present a model of "technology forcing," where firms increase the fuel efficiency of particular vehicles in response to CAFE standards. It is therefore necessary to present the theoretical underpinnings of this model before presenting the necessary empirical inputs.

According to the method by which the statute defines a firm's average mile per gallon, a firm that does not meet the CAFE standard has total CAFE fine equal to

$$(1) \qquad F = \lambda\left(\sum_{i=1}^{T} Q_i\right)(S - MPG),$$

where λ is the shadow cost of compliance[7] (set to a fine of $55 in the statute), S is the CAFE standard, and Q_i is the quantity of each model type i sold by the firm. Under the CAFE standard, a firm's MPG is defined as a harmonic average,

$$(2) \qquad MPG = \sum_{i=1}^{T} Q_i \Big/ \sum_{i=1}^{T} (Q_i/MPG_1)$$

where MPG_i is the mileage for each type of car sold by the relevant firm.

In this model, the firm faces total cost

$$(3) \quad TC = \sum C_i(Q_i, MPG_i) + F .$$

where C_i represents the costs of one model and i is an index of models. Here the cost for MPG_i is net of consumer demand for MPG. Thus, we assume that a firm will invest in fuel efficiency without CAFE standards as long as they it finds it profitable to do so, that is, consumers are willing to pay for fuel economy increases. Under this assumption, the free market net[8] marginal cost of fuel economy is 0, as the marginal cost of fuel economy will equal the marginal returns of fuel economy to the consumer.

Let us define the cost function for any vehicle type i as

$$(4) \qquad TC_i = C_i(Q_i) + Q_i D_i(MPG_i),$$

where D_i represents the cost of fuel economy. Inserting the impact of fuel economy standards, total cost becomes

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[7] While statute sets the CAFE fine at $55 per vehicle-mpg, firms that view the statute as binding may have a higher cost of compliance.

[8] All of the costs of fuel efficiency used in this section, and applied to subsequent sections, refer to *net* costs, that is, the costs of fuel efficiency minus the benefits. Thus, these represent economic rather than engineering costs. I ask the careful reader not to confuse these two concepts.

$$(5)\ TC = \sum_{i=1}^{T}\left(C(Q_i) + Q_i D_i(MPG_i)\right)$$
$$+\left(\lambda\sum_{i=1}^{T}Q_i\right)\left(S - \left(\sum_{i=1}^{T}Q_i \Big/ \sum(Q_i/MPG_i)\right)\right)$$

Minimizing total costs with respect to MPG_i yields

$$(6)\qquad dTC/dMPG_i = Q_i(dD_i/dMPG_i) - \lambda MPG^2 Q_i/MPG_i^2 = 0.$$

If the constraint is binding, MPG=S, and

$$(7)\qquad dD_i/dMPG_i = \lambda S^2/MPG_i^2.$$

Given this and MPG_i, a firm has marginal cost of production in type i of

(8)
$$dTC/dQ_i = dC/dQ_i + D_i(MPG_i) + \lambda\Big[(S - MPG) - \sum Q_i\Big((1/\sum(MPG_i)$$
$$- \left(\sum Q_i/(\sum(Q_i/MPG_i))^2\right)(1/MPG_i))\Big)\Big]$$
$$= dC/dQ_i + D_i(MPG_i) + \lambda\left[S - 2MPG + (MPG^2/MPG_i)\right]$$

In equilibrium, $S = MPG$, which implies

$$(9)\qquad dTC/dQ_i = dC/dQ_i + D_i(MPG_i) + \lambda S((S/MPG_i) - 1).$$

It is necessary to employ empirical estimates for the D_i function, which represents the cost of fuel economy to vehicle producers. The 1999 Sierra Research report[9] is used for this purpose. The Sierra report estimates the cost of additional fuel economy improvements in the year 2010. The report has a series of estimates of how much money – in excess of returns to the consumer – would be required to increase fuel economy to a certain level. Initially, for both cars and trucks, I estimated a function

$$(10)\qquad dD/dMPG = a\Delta MPG + b(\Delta MPG)^2,$$

[9] See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle%5Ftechnology%5Fold /study2/Final_report/Final_Report.htm. The Sierra Research report relies on estimates of the costs and fuel economy benefits of different technologies based on confidential data supplied by different OEMs and suppliers, from technical papers, and the engineering expertise of Sierra Research employees. At current U.S. gasoline prices, Sierra estimated that nearly all technologies that would be available by 2010 would cost consumers more than the discounted value of future fuel savings and would, therefore, increase the cost of transportation to consumers. I have used the Sierra data to estimate the costs of the 3.0 MPG long-term mandatory CAFE increases.

where ΔMPG equals the change in MPG above the unconstrained market level. I expected both coefficients a and b to be positive. Consistent with the discussion above, in this model, D=0 at the pre-CAFE equilibrium level (ΔMPG=0), as firms should invest in fuel economy up to the point where consumers are willing to pay for it. In both car and truck estimates, however, the coefficient b was slightly negative and insignificant. I therefore re-estimated the equations, setting the relevant b's to 0. I obtained an a=24.0 for cars and 65.6 for trucks. This implies (by integration) the total cost of increasing fuel economy (net of the benefits to consumers) is $12(\Delta MPG)^2$ for cars and 32.8 $(\Delta MPG)^2$ for trucks.

It should be noted that the long-term model implicitly assumes that the vehicle manufacturers have perfect foresight with respect to the demand for fuel economy several years into the future. Given this perfect foresight, they can reach all of the CAFE mandated increases in fuel economy through technology forcing, without the need to resort to far more expensive short-run mix-shifting. Given the uncertainties inherent in the market for energy, which is crucial to the demand for fuel economy, the perfect foresight assumption would appear to result in a conservative estimate of the long-run cost of CAFE standards.

F. The Gasoline Consumption Model

Once the relevant market equilibrium has been calculated, the impact of that market equilibrium on gasoline consumption must be estimated. Two important factors must be considered here. First, CAFE standards put some or most new car buyers in more fuel-efficient vehicles. This lowers their marginal cost of driving, and causes them to drive more, a phenomena that is referred to as the "rebound effect." A recent study, whose results I employ, finds that for every 10 percent that fuel economy is increased, driving increases 2 percent.[10]

In addition, several studies imply that changing conditions in the new car market changes the actions of market participants in the used car market. Higher prices in new car markets makes used cars more attractive, reducing the scrappage rates of such cars. Here I adopt the empirical estimates I used in my previous studies. As in my previous work, a (real) discount rate of 4 percent is used.

G. Pollution Impacts

CAFE standards have important consequences for emissions of traditional pollutants, volatile organic compounds, oxides of nitrogen, and carbon monoxide (NOx, VOC, and CO respectively) from automobiles. These traditional pollutants are regulated by the EPA on a per mile basis. Thus, CAFE does nothing to change the grams/mile emissions. However, if CAFE standards increase miles driven, say via the rebound effect for mileage, they can be expected to increase emissions of traditional pollutants.

To model pollution emissions, one must know the emissions per mile by model year and vintage. The difficulty here is that while regulators set the standards at one level, emissions over

[10] See Greene *et. al.*, "Fuel Economy Rebound Effect for U.S. Household Vehicles," Energy Journal 20 (1999) 1-31.

time are generally larger as on-board emission systems deteriorate and automobile users fail to maintain and repair them. Data on emission rates by model year and vintage were obtained from Air Improvement Resources, Inc.

Unlike the rest of the model, I use year 2004 pollution characteristics for the base year, and years 1990-2003 for the stockage years. This is because these levels are set by government regulation, and we can have some confidence at this point in time that this will be the actual emissions from 2004 vehicles.

III. Results of the Short-Run Model Assuming the Current CAFE Standard is Not Binding

The model was run to induce a 1.0 MPG increase in the fuel economy average for both cars and trucks, above the actual 1999 level, from GM, Ford, and Chrysler. The results, in terms of price and output effects, are contained in Table Two.

Shadow taxes needed to induce a 1.0 MPG change in U.S. firms' average fuel efficiency range from a low of $1173 per MPG for Ford cars to a high of $2959 for Chrysler trucks. (See Table Three.) Raising the three firms' MPG by 1.0 MPG results in a "market substitution" effect from the other, non-constrained, firms. For example, because CAFE standards reduce luxury car sales from the three constrained firms, they increase profit opportunities in that sector for unconstrained firms. The net result, across the entire market, is that industry car MPG increases only 0.460 miles per gallon, not 1.0 mpg, while industry truck MPG increases 0.854. (See Table Four.)

Table Five presents the welfare effects. GM profits fall $409 million, Ford profits fall $1.094 billion, and Chrysler (domestic) profits fall $0.843 billion. Non-constrained firms' profits rise $3.638 billion. Changes in consumer welfare, which occur in a multi-product market, are calculated along the lines of Braeutigam and Noll.[11] The net change in consumer welfare estimate is a decline of $13.505 billion. The net domestic loss to society is $15.851 billion. The largest welfare effects in this model occur in the truck sector.

The impact of a higher short-run CAFE standard on pollution is presented in Table Six. Short-run increases in CAFE can be expected to reduce pollution because they reduce the number of new vehicles on the road. However, this impact may be offset by reductions in the turnover of existing vehicles, which are generally more polluting.[12] Emissions of VOCs decline approximately 1.0 percent in total, with over half of the decrease in the current fleet (model year, or MY) VOC pollution offset by increases in VOC emissions from the stock of vehicles on the road. Emissions of oxides of nitrogen decrease about 0.4 percent, with almost 84 percent of the new vehicle fleet reductions being offset by increases in pollution from the existing fleet. For carbon monoxide, emissions actually increase by 0.11 percent, as the impact of reduced turnover is greater in magnitude than the effect on the current fleet.

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[11] Braeutigam and Noll, "The Regulation of Surface Freight Transportation: The Welfare Effects Revisited," The Review of Economics and Statistics, 66(1):80-87 (1984).

[12] See, e.g., Howard Gruenspecht, "Differentiated Regulation: The Case of Auto Emissions Standards," American Economic Review 72:2 (1982) 328-31.

Table Seven presents the results of the gasoline model. New vehicle fleet gasoline consumption declines by 3.870 billion gallons. This is offset somewhat by an increase of 496 million gallons from the increased retention of older vehicles. The net reduction in gasoline consumption is 3.374 billion, implying an average cost per gasoline saved of $4.70.

The model does not explicitly generate a marginal cost per gallon saved. To generate such a figure, I ran the model 30 times, for MPG increases of 0.05 MPG at a time, up to an MPG increase of 1.5. I then ran a regression of total cost on gallons saved, gallons saved squared, and gallons saved cubed (costs in billion dollars, gallons saved in billions). (No constant is used, as total costs are zero if gallons saved are zero.) The results of this regression are reported in Table Eight. Taking the relevant derivatives, and solving for the amount of gasoline saved with a CAFE increase of 1.0 MPG yields a marginal cost per gallon saved of $4.37

In the short-run a gasoline tax of 13.5 cents per gallon would also reduce gasoline consumption by 3.374 billion gallons per year, for a total welfare loss imposed on domestic and auto consumers and producers of just $228 million per year[13] vs. the $15.9 billion in total societal losses imposed by the 1.0 MPG increase in the CAFE standard. In other words, the 1.0 MPG short-run increase in the CAFE mandate imposes a hidden tax that is 70 times more expensive to society than the welfare losses imposed by a 13.5 cent per gallon increase in the gasoline tax.[14]

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[13] See, e.g., Dahl and Sterner, "Analyzing Gasoline Demand Elasticities: A Survey," Energy Economics 13:3 (1991), page 203-10. Using the Dahl and Sterner results, I will employ a short-run elasticity of demand for gasoline of –0.26, and a longer run (five year) elasticity of demand of –0.49. I will also assume a base gasoline consumption in the U.S. of 120 billion gallons at an initial price of $1.25 per gallon, and that the demand curve for gasoline is linear in shape. Using these assumptions, it is straightforward to determine the gasoline tax needed to reach the desired level of gasoline savings. Economic theory indicates that the total loss to society from such a tax equals one-half the tax times the reduction in the number of gallons of gasoline consumption, while the marginal loss equals the level of the relevant tax.

[14] I note here that the comparison is between a one year increase of 1.0 MPG in CAFE standards occurring in the short run (say in one year) and a one year increase in the gas tax, also occurring in the same year.

IV. Results of the Long-Run Model Where the Current CAFE Standard is Non-Binding

Table Nine begins the presentation of the results of raising the CAFE standard by 3.0 MPG in the long-run. Here the relevant welfare changes are smaller than in the short-run model, as the availability of relatively less expensive technology reduces the cost to society of higher standards

Table Ten presents the shadow taxes required by firm. Since all three firms meet the standards in large part by technology forcing, and are assumed to have the same technology available to them, all three have similar shadow tax values. Taxes on cars range from $66 to $70 per MPG, while taxes on trucks, where technology increases are more expensive, range from $181 to $184 per MPG.

Welfare effects are presented in Table Eleven. U.S. manufacturers between them would lose about $633 million, while U.S. consumers would lose approximately $1.596 billion. Total losses to society therefore amount to $2.2 billion.

Pollution impacts are presented in Table Twelve. Emissions of all three traditional pollutants rise between 1.64 and 1.84 percent. This increase is due in large part to the rebound effect, which causes more driving and more pollution. (The stockage effect here is small, because changes in price in the new car market are fairly small compared to the short run model.)

Impacts on gasoline consumption are reported in Table Thirteen. In this model, gasoline consumption declines by 5.242 billion gallons or 7.21 percent. The average cost to society of gasoline savings is 43 cents per gallon. A gasoline tax increase of 11 cents per gallon would save the same amount of fuel at a cost to society of $292 million per year vs. the $2.2 billion in welfare losses imposed by the 3.0 MPG increase in the CAFE standard. In other words, the 3.0 MPG increase in the CAFE standard imposes a hidden tax amounting to 7.6 times the explicit tax increase necessary to save the same amount of fuel.[15]

Once again, the model does not explicitly generate a marginal cost per gallon saved. To generate such a figure, I ran the model 30 times, for MPG increases of 0.10 MPG at a time, for MPG increases ranging from 1.1 MPG to 4.0 MPG. As before, I then ran a regression of total cost on gallons saved, gallons saved squared, and gallons saved cubed (costs in billion dollars, gallons saved in billions). The results of this regression are reported in Table Fourteen. Taking the relevant derivatives, and solving for the amount of gasoline saved with a CAFE increase of 3.0 MPG yields a marginal cost per gallon saved of $0.92.

The $0.92 cents per gallon marginal cost of increasing CAFE standards by 3.0 MPG in the long-run compares with benefits of $0.26 per gallon, based on the NRC study. Thus, in the long-term the marginal cost of a 3.0 MPG CAFE increase is 3.5 times the marginal benefit.

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[15] Here the comparison is between the gasoline savings of a one year CAFE standard increase of 3.0 MPG announced credibly several years in advance so that new technologies could be introduced, and an increase in the gasoline tax years in advance that has long-run impacts in the same year as the hypothetical CAFE standard increase.

All of the results of Sections III and IV assume the current CAFE standard is not binding at today's standard, but would be binding for any increases. The NRC study, cited above, however, concludes that the existing standards are, in fact, binding and this is consistent with my discussions with GM engineers and economists. I next turn to the case of binding current constraints.

V. The Effect of Raising CAFE Standards Assuming the Standards are Already Binding

A. Modeling Approach

It is conceptually possible to calculate the impact of increasing CAFE standards given that they are already binding. This is an important consideration. It is a well-known result of public finance economics that the losses due to taxation are a function of the taxes squared, rather than simply a linear function of the taxes. If CAFE standards were already binding in MY 1999, it implies that the approach used above underestimates the true loss to the economy of raising CAFE standards.

To make this estimation, I took the following steps. First, I assumed that U.S. firms in MY 1999 engaged in mix-shifting, but not technology forcing as a result of CAFE standards. Second, I obtained input ratios by car type for General Motors (GM) cars (with a Chevrolet Malibu having an input ratio of 1.0). I assume that the marginal costs of production for cars are a linear function of these input ratios.

Third, I assumed that marketing and other costs (including goodwill) constitute a constant fraction R of marginal costs. (Recall that because we are using a competitive model, price equals (total) marginal cost.) In this context, assume that the shadow CAFE tax per MPG on vehicles is L. Also assume that the PT equals the pass-through rate, the rate at which changes in taxes are passed through to the final consumer. This implies the equation

$$(1+R)MC_i + PT*L\,(S((S/MPG_i)-1)) = P_i, \tag{11}$$

where P_i equals price of car i, MC_i equals marginal cost of car i, S is the implicit CAFE standard (here it would be the fleet MPG that actually occurred in MY 1999), MPG_i is the miles per gallon achieved by car i, and $L(S(S/MPG_i)-1)$ is the formula for per-car MPG, derived from CAFE harmonic averaging. Because I only have data on GM models (and only sufficient data on GM car models) I estimate the value of L using least squares across GM car models.

Fourth, the implicit tax L calculated here applies directly only to GM cars. I assumed that Ford and Chrysler have similar CAFE taxes on their cars. Since they currently have CAFE levels roughly equivalent to GM's, their implicit taxes may be similar to GM's. (In fact, Ford and Chrysler had slightly lower fleet MPGs than GM in MY 1999.) I also assume that the CAFE tax on trucks is equal to the tax on cars. Because there is substantial evidence that U.S. manufacturers have had more difficulty reaching their CAFE standards for trucks rather than cars, this assumption serves to underestimate the relevant loss to society.

Fifth, given an estimated CAFE shadow tax L, I ran the 1999 model (the one presented above) "backwards," setting the CAFE tax at –L, generating a new equilibrium in prices and quantities.

Sixth, the supply curves calculated for the initial model will have the relevant values subtracted from its intercept terms, to recalibrate the model for the unconstrained scenario.

At this point I have a new "initial" no-CAFE or free market equilibrium with demand and supply curves. The model can then be run for firms to reach a particular CAFE standard. Changes in welfare from this equilibrium to the higher CAFE standard equilibrium can then be calculated.

B. Calculating the Pass-Through Rate and the Level of the GM Shadow Tax

An additional problem comes from the multi-product nature of the market. This implies that taxes on one type of vehicle will impact prices of other types of vehicle. Given this, it takes some work to determine the pass-through rates for each type of vehicles, as presented below.

Let demand be characterized by

(12) D: $P = A - BQ$, P,Q, A, are N x 1 vectors, B an N x N matrix.

This implies

(13) $Q = B^{-1}(A-P)$;

"Fringe" supply (here foreign firms) is such that

(14) $P = K + LQ_F$; where Q_F is fringe supply, K an N x vector, L an N x N matrix,

implying

(15) $Q_F = L^{-1}(P-K)$

Residual demand is

(16) $Q_R = Q - Q_F = B^{-1}(A-P) - L^{-1}(P-K) = P(-L^{-1} - B^{-1}) + H_1$, H_1 a vector of constants.

Facing a vector of taxes T, the U.S. three firms have supply relationship

(17) $MC = P = Z + T + YQ_s$, Z an N x 1 vector, Y an N x N matrix;

$$Q_s = Y^{-1}(P-Z-T) = Y^{-1}P - Y^{-1}T - H_2,$$

H_2 a vector of constants.

Putting supply and demand together yields,

(18)
$$Y^{-1}P - Y^{-1}T - H_2, = P(-L^{-1}-B^{-1}) + H_1,$$
$$P(Y^{-1}+L^{-1}+B^{-1}) = Y^{-1}T + H_2 + H_1;$$
$$P = (Y^{-1}+L^{-1}+B^{-1})^{-1}Y^{-1}T + H_3,$$

H_3 a vector of constants.

Let T = tF, where t is a scalar (here the shadow CAFE tax), and F is a vector of CAFE functional forms based on type MPG. As before,

(19)
$$F_i = S*((S/MPG_i)-1)),$$

where MPG_i is the fuel efficiency of type i. This implies

(20)
$$dP/dt = (Y^{-1}+L^{-1}+B^{-1})^{-1}Y^{-1}F.$$

This function dP/dt is the vector of explanatory variables by type to be used to estimate the level of t faced by GM in 1999. In equation (11) above, it is equal to $PT*(S((S/MPG_i)-1))$.

For the model of this report, the results of the impact of a CAFE tax by vehicle type are presented in Table Fifteen. For every dollar of CAFE shadow tax, dP/dt represents the pass-through rate. For example, every dollar of CAFE tax reduces the price of small cars by about $0.84, and increases the price of luxury cars by about $0.88.

Table Sixteen presents the estimation results for the level of the CAFE tax in MY 1999. The dependent variable is the price in thousand dollars of GM cars. The two independent variables are the input ratios and the coefficient on the CAFE tax, as deduced in Table Sixteen. The model is run with and without a constant term. However, the estimated constant term in Model One has a very low t-statistic. Model Two, which is run without a constant, has large t-statistics and a high R-square (0.950). The estimated shadow tax from this estimation is $1652/MPG, and this is the level used in the simulations of Part C below.[16]

[16] The resulting changes in MPG because of this negative tax of $1652 per MPG are -1.05, -1.42, and –0.55 MPG for GM, Ford, and Chrysler cars, and –0.59, -0.50, and –0.40 MPG for GM, Ford, and Chrysler trucks.

C. Welfare Implications of Raising CAFE Standards Given that Standards are Already Binding

1. Short Run

Tables Seventeen and Eighteen summarize the welfare changes as a result of increasing the short-run CAFE standard 1.0 MPG above the 1999 level, assuming that a short-run tax of $1652 was binding in MY 1999. As expected, the economic harms are much greater than the previous models, which assumed the standards were just non-binding in MY 1999. The changes in this section are calculated from two baselines, the first from the actual MY 1999 equilibrium, and the second from the equilibrium that would have occurred in MY 1999 had their been no CAFE standard (the "no-CAFE equilibrium").

The total losses of a 1.0 MPG short-run increase in the CAFE standard from the MY 1999 actual market equilibrium are $33.9 billion. Consumer losses relative to actual CAFE constrained equilibrium are $23.2 billion. With respect to the MY 1999 equilibrium VOC emissions fall 2.83 percent, NOx emissions fall 1.2 percent, while CO emissions remain essentially unchanged. These impacts are largely the result of fewer new cars on the road. Gasoline consumption falls 5.8 billion gallons, amounting to 8 percent of consumption. The average cost of reducing a gasoline externality is $5.85.

With respect to the no-CAFE equilibrium, the total loss in economic welfare from an increase in CAFE 1.0 MPG above 1999 levels is approximately $39.5 billion. Losses to consumers relative to the free market equilibrium are $24.1 billion With respect to the no-CAFE equilibrium, VOC emissions decline 1.6 percent above the level in the free market equilibrium, while NOx emissions fall 0.4 percent. Carbon monoxide emissions rise 0.57 percent due to the impact on the used car market. Gasoline consumption falls 5.6 billion gallons, amounting to 7.8 percent of consumption. The average cost of reducing a gallon of gasoline externality is $7.01. The inferred marginal cost (in both scenarios) of reducing a gasoline externality is estimated to be $4.10 per gasoline externality at an MPG increase of 1.0.)

2. Long Run

Tables Twenty and Twenty-One present the welfare changes as a result of raising the long-run CAFE standard 3.0 MPG above the 1999 level, again assuming a short-run tax of $1652 was binding in MY 1999. Once again, harm to the economy is greater than that in the previous long-term model.

Total losses to society from the MY 1999 equilibrium of raising the long-run CAFE standard 3.0 MPG are $2.965 billion. Emissions of VOCs, NOx, and, carbon monoxide rise between 1.64 to 1.86 percent from the MY 1999 equilibrium. Consumption of gasoline is reduced 5.1 billion gallons or 7.14 percent from the MY 1999 equilibrium. The average cost of reducing a gasoline externality is $0.58 from the MY 1999 equilibrium.

Total losses to society from the no-CAFE equilibrium of raising the long-run CAFE standard 3.0 MPG are $3.026 billion. Emissions of VOCs, NOx, and, carbon monoxide rise from 2.07 to 2.25 percent from the no-CAFE equilibrium. Gasoline consumption falls 6.4 billion gallons, or 9.82 percent from the no-CAFE equilibrium. The average cost of reducing a gasoline externality from the no-CAFE equilibrium is $0.47. The marginal cost of reducing a gasoline consumption externality (in both scenarios) is $1.06.

A gasoline tax increase of 11 cents per gallon would achieve the 5.091 billion gallon reduction relative to a binding 1999 CAFE standard, while an increase of 14 cents per gallon would be required to achieve a reduction of 6.403 billion gallons relative to the no-CAFE equilibrium. In the first instance, the $2.965 billion in CAFE costs compares to costs of $275 million from the 11 cent per gallon increase in the gasoline tax. This is a ratio of 11 to 1. In the second instance (the no-CAFE equilibrium), the $3.026 billion in CAFE costs compare to $436 million in costs associated with a 14 cent per gallon increase in the gasoline tax. This is a ratio of seven to one.

VI. Cost-Benefit Analysis

The results of all four models are summarized in Table Twenty-Three. Because there is widespread agreement that the current CAFE standard is binding for both cars and trucks, the most relevant scenarios for public policy analyses seem to be those which compares the 1.0 MPG short-run and 3.0 MPG long-run mandatory CAFE increases to the constrained model year 1999 equilibrium. There are two fundamental issues: whether the mandatory CAFE increases are cost-effective and whether the incremental or marginal benefits associated with those mandates exceed the marginal welfare costs imposed on the nation's consumers and producers.

In the short-run, a period of one to three years in which auto manufacturers are locked in to existing technologies and thus must meet any mandatory CAFE increases largely by adjustments in the mix of products sold, a 1.0 MPG increase in both car and truck CAFE standards above existing levels would impose consumer welfare losses amounting to $23 billion per year and domestic producer welfare losses of $11 billion per year, for a total loss to society of $34 billion. Gasoline consumption would decline by 5.8 billion gallons per year, for an average social welfare loss or cost of $5.85 per gallon of fuel conserved.

For CAFE standards to constitute cost-effective policy, the welfare costs of imposing higher CAFE standards should be compared to the welfare costs of an increase in the gasoline tax that would save the same amount of gasoline. Under consensus estimates of gasoline demand price elasticities, a gasoline tax of 23 cents per gallon would achieve the same reduction of 5.8 billion gallons per year over the relevant time frame. Social welfare losses associated with the gasoline tax increase amount to $670 million per year vs. the $34 billion costs of the 1.0 MPG increase in CAFE. In other words, the CAFE increase imposes a hidden tax 50 times higher than the explicit tax required to save the same amount of gasoline.

Alternatively, from a cost-benefit perspective, the marginal costs of increasing CAFE by more than the 1.0 MPG amount to $4.10 per gallon. This compares with marginal benefits from reduced externalities of $0.26 per gallon, if one accepts the NRC study. This is a cost-benefit ratio of roughly 16 to one. In the short run, CAFE is neither cost-effective nor cost-beneficial.

In the long run, a period over which auto manufacturers are able to fully utilize new technologies in order to comply with increased CAFE mandates, a 3.0 MPG increase above existing levels in both car and truck CAFE standards decreases social welfare by $3.026 billion per year.

Once again, the most relevant scenario is the one that compare a mandated CAFE increase to a binding CAFE constraint in 1999. In that scenario, gasoline consumption falls by 5.091 billion gallons per year, for an average cost of $0.58 per gallon. Using estimates for the long-run gasoline demand price elasticity, this same reduction in gasoline consumption could be achieved by a gasoline tax increase of 11 cents per gallon. The gasoline tax would impose social costs of $275 million, compared to $2.9645 billion from higher CAFE standards. In other words, the 3.0 MPG increase in the CAFE mandate would cost society 11 times more than a 11 cent per gallon gasoline tax increase saving the same amount of fuel.

The marginal cost of mandating the long-run 3.0 MPG CAFE increase is $1.06 per gallon and increases rapidly beyond that point. This compares with a marginal external cost for gasoline consumption of $0.26, according to the NRC study. Thus, it is clear that in the long run, a 3.0 MPG CAFE increase is neither cost-effective, nor cost-beneficial.

It should also be noted that in the long-run model, the marginal cost of moving from the unconstrained or no-CAFE equilibrium to the MY 1999 CAFE-constrained equilibrium amounts to $0.13 cents per gallon, below the $0.26 per gallon estimate of the marginal benefits of reducing the gasoline consumption externality inferred from the NRC study. I must state, however, that I am skeptical of the NRC externality cost estimate of $0.26 per gallon.[17] The

[17] The NRC divides the estimate into three components: $0.02 cents per gallon for increased automotive emissions of criteria pollutants, $0.12 cents per gallon for adverse global climate effects, and $0.12 per gallon for oil import effects. My results suggest that mandatory CAFE increases will increase, not reduce automotive emissions. The $0.12 per gallon estimate for global warming is two to ten times the upper and lower bound found in other economic estimates. See, for example, Toman and Shogren, "How Much Climate Change is Too Much:

NRC estimate also excludes the offsetting externality costs of the CAFE mandate – including the increased vehicle emissions documented in this study.

VII. Conclusion

Mandatory increases in CAFE standards above current levels are neither cost-effective nor cost-beneficial. In the short run, a one mile per gallon increase in the CAFE mandate would impose social costs of $34 billion per year and reduce gasoline consumption by 5.8 billion gallons per year. This amounts to 50 times the cost of a gas tax increase that would save the save amount of fuel. The short-term marginal costs of the 1.0 mpg CAFE increase would exceed the marginal benefits associated with reduced gasoline consumption externalities by a factor of 16 to one and those costs rise rapidly with further short-term increases in the CAFE standard.

In the long run, increasing the CAFE standard by more than 3.0 MPG would impose additional costs of $3 billion per year and reduce gasoline consumption by 5.1 billion gallons per year. This amounts to 11 times the cost of a gas tax increase that would save the save amount of fuel. The long-term marginal costs of the 3.0 MPG mandate would exceed the additional benefits of avoided gasoline consumption externalities by a factor of over 4 to one.

An Economic Perspective," *Climate Change Issues Brief* No. 25, Resources for the Future (September 2000), page 12. The $0.12 per gallon estimate for oil import effects ignores the benefits from specialization according to comparative advantage and falsely assumes that CAFE changes can have a material influence on worldwide energy supply and demand. See, e.g., Douglas R. Bohi and Michael A. Toman, *The Economics of Energy Security* (1996). Bohi and Toman conclude that there is no discernible oil import or energy security premium. In addition, I note that the gains to society from reducing the consumption of gasoline may be reduced or eliminated because gasoline is already a highly taxed good. For the extent of those taxes, see http://www.energy.ca.gov/fuels/gasoline/gas_taxes_by_state.html.

Table One
Initial Conditions – Prices and Quantities

Class	Initial Totals by Class			Initial Quantities by Firms (millions of units)			
	Prices ($000)	Quantity (million)	MPG	GM	Ford	Chrys.	Forgn.
1	14.336	2.057	33.53	0.589	0.313	0.096	1.059
2	18.508	2.921	27.26	1.255	0.640	0.395	0.631
3	21.710	1.840	26.86	0.267	0.363	0.243	0.968
4	21.607	0.506	26.03	0.104	0.214	0.004	0.184
5	30.365	1.102	24.44	0.240	0.117	0.000	0.746
6	17.345	0.970	22.68	0.223	0.400	0.134	0.213
7	23.424	1.455	18.83	0.576	0.513	0.356	0.000
8	26.284	1.169	20.24	0.323	0.320	0.154	0.372
9	31.296	1.459	18.30	0.390	0.304	0.486	0.279
10	25.157	0.964	23.49	0.184	0.255	0.387	0.207
11	20.611	0.336	18.90	0.191	0.092	0.053	0.000

Class	Initial MPG by Firms (miles per gallon)			
	GM	Ford	Chrys.	Forgn.
1	32.52	33.61	31.92	34.26
2	27.15	26.15	27.29	28.71
3	26.05	24.65	25.46	28.46
4	24.84	26.10	22.62	26.75
5	23.80	22.78	-	24.94
6	24.56	22.61	19.25	23.59
7	19.34	18.43	17.60	-
8	21.36	19.78	20.85	23.17
9	16.91	16.36	18.53	20.20
10	23.72	22.44	23.70	24.46
11	19.78	17.77	18.04	-

Table Two
Price and Output Effects of Short-Run CAFE Increase of 1.0 MPG
For Both Cars and Trucks

Class	Totals by Class		Change from Initial	
	Prices ($000)	Quantity (million)	Prices ($000)	Quantity (million)
1	13.269	2.531	-1.067	0.474
2	19.133	2.595	0.624	-0.326
3	22.662	1.619	0.952	-0.221
4	22.836	0.459	1.229	-0.047
5	32.473	1.069	2.108	-0.034
6	16.281	1.267	-1.066	0.297
7	27.444	1.066	4.020	-0.379
8	27.175	1.267	0.891	0.064
9	36.527	1.066	5.231	-0.383
10	22.825	1.234	-2.332	0.278
11	23.280	0.227	2.669	-0.108

Class	Output by Firms (millions of units)				Change of Output by Firms (millions of units)			
	GM	Ford	Chrys.	Forgn.	GM	Ford	Chrys.	Forgn.
1	0.920	0.518	0.184	0.909	0.331	0.205	0.088	-0.151
2	1.025	0.556	0.336	0.677	-0.229	-0.084	-0.059	0.046
3	0.187	0.263	0.112	1.057	-0.080	-0.099	-0.130	0.085
4	0.053	0.201	0.000	0.206	-0.051	-0.014	-0.004	0.022
5	0.136	0.080	0.000	0.852	-0.103	-0.037	0.000	0.106
6	0.415	0.617	0.046	0.188	0.192	0.217	-0.087	-0.025
7	0.529	0.397	0.140	0.079	-0.048	-0.116	-0.216	0.000
8	0.371	0.291	0.173	0.398	0.048	-0.029	0.019	0.027
9	0.169	0.111	0.422	0.373	-0.221	-0.193	-0.064	0.094
10	0.249	0.316	0.579	0.170	0.065	0.061	0.189	-0.037
11	0.174	0.034	0.019	0.000	-0.016	-0.058	-0.034	0.000

Table Three
Shadow Taxes By Firm
Short-Run Model

	Shadow Taxes by Firm ($/MPG)		
	GM	Ford	Chrysler
Cars	1488	1173	2301
Trucks	2786	2959	3159

Table Four
Change in Firm MPGs
Short-Run Model

	Change in MPG by Firm				
	GM	Ford	Chrysler	Foreign	Total
Cars	1.000	1.000	1.000	-0.344	0.460
Trucks	1.000	1.000	1.000	-0.287	0.854

Table Five
Welfare Effects
Short-Run Model

	GM	Ford	Chrysler	Foreign	U.S total
Change in Producers Surplus ($ billion)	-0.409	-1.094	-0.843	3.638	-2.347
Change in Consumer Surplus ($ billion)	-13.505		**Total U.S. Change in. Surplus ($ billion)**	-15.851	

Table Six
The Impact of Standards on Pollution Emissions
Short-Run Model

	Pollution Impacts (all in million kilograms)		
	VOC	**NOX**	**CO**
Original MY Emissions	638.962	487.739	5,288.892
Induced change from reduced vehicle sales	-15.156	-12.146	-130.061
Change in Stockage Emissions	8.882	10.152	135.932
Total Change	-6.273	-1.994	5.871
Percent Change	-0.982%	-0.409%	0.111%

Table Seven
Impact of Higher Standards on Gasoline Consumption
Short-Run Model

MY Pre-CAFE Gas. Cons. (billion gall.)	72.695	**Domestic Average Cost of Gasoline Externality Saved**	$4.70
Change in MY Gas Cons. (billion gall.)	-3.870		
Change in Stockage Consumption (billion gall.)	0.496		
Net change in Consumption (billion gall.)	-3.374	**Domestic Marginal Cost of Gasoline Externality Saved (inferred)**	$4.37
Percentage Change in Consumption	-4.578%		

Table Eight
Regression Results to Estimate Marginal Cost of Gasoline Savings
Short-Run Model

Variable	Coefficient	T-statistic
Gallons Saved	5.288	68.32
(Gallons Saved)^2	-0.227	-6.61
(Gallons Saved)^3	0.0181	5.03
	Number of Obs: 30	R-square: 0.99

Table Nine
Price and Output Effects of Long-Run CAFE Increase of
3.0 MPG For Both Cars and Trucks

Class	Totals by Class		Change from Initial	
	Prices ($000)	Quantity (million)	Prices ($000)	Quantity (million)
1	14.279	2.584	-0.057	0.027
2	18.568	2.893	-0.060	-0.028
3	21.783	1.827	0.073	-0.013
4	21.706	0.503	0.099	-0.003
5	30.496	1.102	0.131	0.000
6	17.292	0.990	-0.053	0.020
7	23.798	1.421	0.374	-0.034
8	26.389	1.172	0.105	0.003
9	31.746	1.429	0.450	-0.030
10	25.024	0.982	-0.133	0.018
11	20.896	0.347	0.285	0.011

Table Nine (continued)

Class	Output by Firms (millions of units)				Change of Output by Firms (millions of units)			
	GM	Ford	Chrys.	Forgn.	GM	Ford	Chrys.	Forgn.
1	0.610	0.333	0.099	1.042	0.021	0.020	0.003	-0.017
2	1.233	0.629	0.392	0.640	-0.022	-0.011	-0.003	0.008
3	0.260	0.351	0.235	0.981	-0.008	-0.012	-0.007	0.013
4	0.100	0.212	0.003	0.187	-0.004	-0.002	0.000	0.003
5	0.231	0.113	0.000	0.759	-0.009	-0.004	0.000	0.013
6	0.242	0.417	0.121	0.210	0.019	0.016	-0.013	-0.003
7	0.572	0.503	0.337	0.000	-0.004	0.010	-0.020	0.000
8	0.326	0.314	0.155	0.378	-0.003	-0.006	0.001	0.006
9	0.366	0.285	0.483	0.295	-0.024	-0.019	-0.003	0.016
10	0.190	0.258	0.402	0.203	0.005	0.003	0.015	-0.004
11	0.189	0.086	0.050	0.000	-0.002	-0.006	-0.003	0.000

Table Ten
Shadow Taxes By Firm
Long-Run Model

	Shadow Taxes by Firm ($000/MPG)		
	GM	Ford	Chrysler
Cars	0.068	0.066	0.070
Trucks	0.181	0.183	0.184

Table Eleven
Welfare Impacts of Long-Run CAFE Increase of 3.0 MPG
for Both Cars and Trucks

	GM	Ford	Chrysler	Foreign	U.S total
Change in Producers Surplus ($ billion)	-0.219	-0.265	-0.149	0.296	-0.633
Change in Consumer Surplus ($ billion)	-1.596		**Total U.S. Change in. Surplus ($ billion)**	-2.230	

Table Twelve
The Impact of Standards on Pollution Emissions
Long-Run Model

	Pollution Impacts (all in million kilograms)		
	VOC	**NOX**	**CO**
Original MY Emissions	638.962	487.739	5,288.892
CAFE – induced change in MY Emission	9.307	7.387	79.297
Change in Stockage Emissions	1.167	1.33	17.931
Total Change	10.474	8.720	97.228
Percent Change	1.64%	1.79%	1.84%

Table Thirteen
Impact of Higher Standards on Gasoline Consumption
Long-Run Model

MY Pre-CAFE Gas. Cons. (billion gall.)	72.695	**Domestic Average Cost of Gasoline Externality Saved**	$0.43
Change in MY Gas Cons. (billion gall.)	-5.299		
Change in Stockage Consumption (billion gall.)	0.057		
Net change in Consumption (billion gall.)	5.242	**Domestic Marginal Cost of Gasoline Externality Saved (inferred)**	$0.92
Percentage Change in Consumption	7.21%		

Table Fourteen
Regression Results to Estimate Marginal Cost of Gasoline Savings
Long-Run Model

Variable	Coefficient	T-statistic
Gallons Saved	-6.90	31.68
(Gallons Saved)^2	7.02	758.07
(Gallons Saved)^3	0.23	246.71
	Number of Obs: 30	R-square:0.963

Table Fifteen
Pass-Through Rates by Car Type

Type – Description	MPG	F	dP/dt
1- small car	32.524	-4.158	-0.839
2 – midsize car	27.152	0.486	0.040
3 – large car	26.046	1.680	0.228
4 – sports car	24.837	3.107	0.783
5 – luxury car	23.796	4.451	0.876
6 – small truck	24.558	-3.727	-1.168
7 – large truck	19.339	0.658	0.246
8 – small suv	21.357	-1.292	-0.300
9 - large suv	16.912	3.619	1.171
10 – minivan	23.715	-3.150	-1.253
11 – van	19.777	0.201	0.007

Table Sixteen
Estimating the 1999 CAFE tax
(T-Statistics in Parentheses)

	Model One	Model Two
Constant	0.725 (0.39)	
Input Ratio	15.271 (1.48)	15.835 (49.36)
CAFE Tax	1.986 (1.12)	1.652 (2.32)
R-square	0.951	0.950
Number of Observations	25	25

Table Seventeen
Results of CAFE Previously Binding Model
Welfare Effects
Short-Run Model - 1.0 MPG Increase

	Change from MY 1999 Equilibrium	Change from No-CAFE Equilibrium
Changes in Producer Surplus ($ billion)		
General Motors	-4.165	-6.297
Ford	-4.055	-6.245
Chrysler	-2.441	-2.893
Foreign Firms	6.647	5.984
U.S. Firms Total	-10.661	-15.435
Change in Consumer Surplus ($ billion)	-23.217	-24.055
Change in U.S. Total Surplus ($ billion)	-33.879	-39.490

Table Eighteen
Results of CAFE Previously Binding Model
Pollution and Gasoline Consumption Effects
Short-Run Model - 1.0 MPG Increase

	Change from MY 1999 Equilibrium	Change from No-CAFE Equilibrium
% Change in VOC Emissions	-2.829%	-1.621%
% Change in NOx Emissions	-1.208%	-0.427%
% Change in CO Emissions	0.021%	0.565%
Change in Gasoline Consumption (billion gallons)	-5.785 (-7.959%)	-5.633 (-7.777%)
Average cost of reducing Gasoline Externality	$5.85	$7.01
Marginal cost of reducing Gasoline Externality (inferred)	$4.10	

Table Nineteen
Regression Results to Estimate Marginal Cost of Gasoline Savings
Short-Run Model, CAFE Previously Binding Model

Variable	Coefficient	T-statistic
Gallons Saved	12.519	14.76
(Gallons Saved)^2	-1.408	-5.40
(Gallons Saved)^3	0.0782	4.11
	Number of Obs: 30	R-square: 0.975

Table Twenty
Results of CAFE Previously Binding Model
Welfare Effects
Long-Run Model - 3.0 MPG Increase

	Change from MY 1999 Equilibrium	Change from No-CAFE Equilibrium
Changes in Producer Surplus ($ billion)		
General Motors	-0.433	-0.470
Ford	-0.455	-0.501
Chrysler	-0.236	-0.244
Foreign Firms	0.260	0.213
U.S. Firms Total	-1.124	-1.215
Change in Consumer Surplus ($ billion)	-1.841	-1.811
Change in U.S. Total Surplus ($ billion)	-2.965	-3.026

Table Twenty-One
Results of CAFE Previously Binding Model
Pollution and Gasoline Consumption Effects
Long-Run Model - 3.0 MPG Increase

	Change from MY 1999 Equilibrium	Change from No-CAFE Equilibrium
% Change in VOC Emissions	1.64%	2.07%
% Change in NOx Emissions	1.80%	2.21%
% Change in CO Emissions	1.86%	2.25%
Change in Gasoline Consumption (billion gallons)	-5.091 (-7.15%)	-6.403 (-8.82%)
Average cost of reducing Gasoline Externality	$0.58	$0.47
Marginal cost of reducing Gasoline Externality (inferred)	$1.06	

Table Twenty-Two
Regression Results to Estimate Marginal Cost of Gasoline Savings
Long-Run Model, CAFE Previously Binding Model

Variable	Coefficient	T-statistic
Gallons Saved	0.047	-149.54
$(\text{Gallons Saved})^2$	0.065	599.63
$(\text{Gallons Saved})^3$	0.0025	270.06
	Number of Obs: 30	R-square: 0.997

Table Twenty-Three
Summary of Results
Four Different Scenarios

	Short-Run 1.0 MPG Increase from Current Levels		Long-Run 3.0 MPG Increase from Current Levels	
	CAFE Not Binding	**CAFE Already Binding**	**CAFE Not Binding**	**CAFE Already Binding**
Gasoline Saved (gallons billion)	3.870	5.785	5.242	5.091
Cost to Society ($ billion)	$15.851	$33.879	$2.230	$2.965
Average Cost/Gallon	$4.70	$5.85	$0.43	$0.58
Marginal Cost of Gallon Saved	$4.37	$4.10	$0.92	$1.08
Tax need for equivalent savings	$0.135 per gallon	$0.231 per gallon	$0.111 per gallon	$0.108 per gallon
Cost to Society of Equivalent tax ($ billion)	$0.228	$0.670	$0.292	$0.275
Ratio of CAFE costs to costs of a tax increase	70	50	7.6	11

Table Twenty-Four
Initial Conditions – Demand Elasticities

Class	Parameters Used in CAFE Simulation										
	Demand Elasticity Table										
	1	2	3	4	5	6	7	8	9	10	11
(1) Small Car	-2.808	0.423	0.063	0.018	0.000	0.036	0.027	0.009	0.009	0.009	0.000
(2) Medium Car	0.684	-3.528	1.107	0.027	0.018	0.018	0.018	0.036	0.045	0.054	0.009
(3) Large Cars	0.270	1.926	-4.500	0.027	0.216	0.009	0.054	0.018	0.063	0.054	0.009
(4) Sport Car	0.549	0.423	0.324	-2.250	0.009	0.090	0.198	0.045	0.108	0.018	0.000
(5) Luxury Car	0.045	0.405	1.062	0.009	-1.737	0.000	0.027	0.045	0.189	0.072	0.009
(6) Small Truck	0.162	0.099	0.000	0.009	0.000	-2.988	0.702	0.045	0.054	0.009	0.009
(7) Large Truck	0.063	0.072	0.018	0.009	0.000	0.234	-1.548	0.027	0.090	0.018	0.036
(8) Small SUV	0.216	0.279	0.099	0.027	0.009	0.090	0.351	-3.645	0.747	0.108	0.072
(9) Large SUV	0.117	0.243	0.171	0.018	0.018	0.054	0.387	0.414	-2.043	0.234	0.108
(10) Minivan	0.081	0.171	0.063	0.000	0.009	0.009	0.045	0.027	0.135	-2.286	0.180
(11) Van	0.027	0.036	0.009	0.009	0.000	0.009	0.054	0.036	0.072	0.387	-2.385

Attachment 6:

"Analysis of the Relationship between Passenger Vehicle Weight and the Risk of Traffic Fatality and Injury", Exponent Failure Analysis Associates, Inc.
(July 17, 2001)

Analysis of the Relationship Between Passenger Vehicle Weight and the Risk of Traffic Fatality and Injury

April 11, 2001*

Prepared for
Robert C. Lange
Director, NAO Engineering
General Motors Corporation

Prepared by
Rose M. Ray, Ph.D.
Principal Scientist, Data Analysis

Alan Donelson, Ph.D.
Principal Scientist, Data Analysis

Karuna Ramachandran, Ph.D.
Senior Scientist, Data Analysis

Allise Wachs, Ph.D.
Managing Scientist, Data Analysis

SF30223

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Appendix A: Models of the Risk of Driver Injury and Fatality in Two Vehicle Crashes

Appendix B: Models of the Risk of Driver Injury and Fatality of Single Vehicle Crashes

Appendix C: Projections of the Change in Injuries and Fatalities Associated with Decreases Passenger Vehicle Weight

Appendix D: Theory and Methodology of Crash Scenario Analysis

July 17, 2001

Executive Summary

General Motors Corporation (GM) contracted Exponent Failure Analysis Associates, Inc. to revisit the relationship between vehicle mass and collision fatality risk in conjunction with the National Academy of Sciences panel studying the U.S. Corporate Average Fuel Economy (CAFE) system. The Exponent study extends and updates prior work to assess the role of mass (weight) and safety that was performed by various researchers, particularly NHTSA. The Exponent study is confined to modern vehicles with current level architectures and technology. The purpose of Exponent's study is to use existing data to build mathematical models of the motor vehicle collision experience in the United States, to use the models to assess the effects of a new technology (air bags) on the vehicle mass – fatality risk relationship, and to forecast the motor vehicle safety effects of various vehicle fleet mass reduction schemes that might be proposed to increase fleet wide fuel economy in pursuit of more stringent CAFE requirements. In this study, safety performance is measured by the change in the number of driver fatal and serious injuries that would be projected to occur with a proposed mass reduction scheme.

The study examines collision performance of 1985-1998 model year vehicles in three states over the period 1986-1998 calendar years. The three states are: Florida, Maryland and North Carolina. For each state, four analytical models were developed: three separate models using Multiple Logistic Regression, and a fourth mechanism, "Scenario Analysis" – a method that models the simultaneous combinations of several crash related fact circumstances rather than the traditional method of model regression for the individual factors. Separate models were constructed for two vehicle and single vehicle crashes. Four models were run for two vehicle crashes and four models for single vehicle crashes in each of the three states.

The models were constructed based on current fleet experience; they were then run to estimate the change in risk outcome if the fleet mass distribution were changed to reflect various proposals for fleet-wide mass reductions. The results of these modified models (with a lower mass fleet) were then applied to calculate the national projections for fatalities and for injuries (based on NASS/GES crash involvement data).

Risk was projected for six unique fleet mass reduction proposals:

1. 100 lb. reduction to all passenger cars
2. 100 lb. reduction to all passenger cars, vans and SUVs.
3. An average of 100 lb. reduction for all passenger cars but mass was reduced only from mid-size and full-size (i.e., heavier) passenger cars.
4. An average of 100 lb. reduction for all passenger cars, vans and SUVs but mass was reduced only from heavy passenger cars, vans and SUVs.
5. A 10% proportional mass reduction across all passenger vehicles.
6. A 20% proportional reduction across all passenger vehicles.

For two vehicle crashes, each of the seventy-two modeled fleet mass reduction scenarios predicted an increase in driver fatalities. This is an important observation because some CAFE advocates had proposed that overall fleet safety would be improved if all of the mass reduction were to be taken from heavy vehicles only. Such an approach does not improve societal safety; it degrades societal safety, as do all other hypothesized fleet mass reduction scenarios studied. There is no identified fleet mass reduction scenario in which the safety effect is neutral or beneficial.

The results for single vehicle crashes were equivocal with no consistent pattern

Several specific questions were also addressed regarding the crash involvement rates and pedestrian safety tradeoffs consequent to a lighter fleet. In discussions with the NAS panel – one member suggested that lighter, smaller vehicles are safer for society than a heavier fleet due to superior collision avoidance capability and lower risk of pedestrian fatality and injury rates.

Data from NASS/GES was examined to address these claims. The incidence of collisions does not decrease with decreasing vehicle size and mass. Therefore, the increased driver fatalities modeled for the six fleet mass reduction proposals will not be offset by reduced crash involvement rates in smaller lighter vehicles (Figure 15). Similarly, pedestrian involvement and fatality rates are not positively correlated with vehicle mass and size. Therefore, the increased driver fatalities and injuries projected for a lighter fleet will not be offset with fewer pedestrian fatalities (Figure 16). Thus neither of the potential benefits hypothesized with a lighter fleet is evidenced in real world performance.

Motor vehicle safety degrades with decreasing vehicle mass. The hypothesis that improved crash avoidance and reduced pedestrian involvement would result from lighter vehicles are shown by research to be false. In conclusion, proposed CAFE increases that produce consequent vehicle mass reductions will further degrade the safety performance of the motor vehicle fleet. As stated earlier, there is no identified fleet mass reduction scenario in which the safety effect is neutral or beneficial.

July 17, 2001

Scope of Work

General Motors contracted Exponent Failure Analysis Associates, Inc. to assess the risk of injury for crash involved occupants of light trucks and passenger cars as a function of vehicle size mass, and the availability of airbags. The scope of the study included the following tasks:

- Evaluate factors related to the risk of fatality or injury to crash involved occupants.
- Estimate the effect of vehicle size (weight and wheelbase) and the availability of airbags on the risk of fatality and injury to crash involved drivers, with appropriate control for other factors related to the risk of fatality and injury.
- Evaluate whether the relationship between vehicle weight and the risk of fatality and injury is attenuated in airbag-equipped vehicles as compared to vehicles without airbags.
- Characterize trends in traffic fatalities and describe the relationship of these to trends in vehicle design and crash factors.
- Estimate the change in traffic fatalities and injuries to be expected with a change in the weight of vehicles in the passenger vehicle fleet.

Background

Charles Kahane, Susan Partyka and Ellen Hertz at NHTSA, Leonard Evans at GM and many other researchers in traffic safety, have studied the risk of injury and fatality to drivers as a function of passenger vehicle weight. In empirical studies both vehicle weight and vehicle wheelbase are inversely correlated to the risk of driver injury in two vehicle crashes. The relationship of injury risk to wheelbase may *appear* to be stronger than the relationship between mass and driver fatality risk[1], however, this should not be interpreted to mean that wheelbase better explains fatality risk than mass. A proper assessment accounts for the fact that a unit change in wheelbase coincides with a steep change in mass; hence, we cannot conclude that reduced risk in driver fatality results from larger wheelbases because wheelbase is highly correlated with mass.

Evans[2] separated the effects of wheelbase and mass by considering fatalities in two car crashes where both cars had the same wheelbase, but different mass. His results indicate that on average the driver fatality risk in the lighter car is 1.45 (plus or minus .09) times higher than the risk in the heavier car with the same wheelbase. A similar analysis was performed for two car

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[1] Evans, L., Frick, M.C. Car Size or Car Mass: Which Has Greater Influence on Fatality Risk? *American Journal of Public Health*. August 1992, Vol. 82, No. 8, 1105-1112.

[2] Ibid.

crashes where the masses of the cars were within 20 kg of each other, but wheelbase differed. The results reveal that a larger wheelbase did not reduce the driver fatality risk. Thus, the empirical evidence suggests that mass is the main causative factor in driver fatality risk reduction.

NHTSA studies used various types of multiple logistic regression to model the relationship between vehicle weight and injury risk while controlling for various driver and environmental confounding factors. The research described here expands upon this body of research. In particular, vehicles equipped with airbags are included in the present study. The study addressed whether or not the relationship between vehicle size and the risk of occupant injury in airbag equipped vehicles is similar to the relationship between vehicle size and the risk of occupant injury for vehicles not equipped with airbags.

At the request of NHTSA, the National Research Board, acting through the Transportation Research Board (TRB) convened a panel of scientists to review the NHTSA studies of the relationship between vehicle weight and injury risk. Issues raised by the Transportation Research Board (TRB) evaluation of the NHTSA studies included:

- Need to include confidence intervals or uncertainty bounds for the estimated risks of injury for each model studied.
- Need for a sensitivity analysis to evaluate the importance of the exact specification of the statistical model used.
- The difficulty of adequately controlling for confounding factors such as driver risk taking or aggressiveness, seat belt use, type and severity of accident.
- The difficulty of choosing an adequate measure of exposure.
- The need to measure the risk of crash involvement as well as the risk of injury to crash involved occupants.
- The desire to estimate the effects of vehicle downsizing upon the risk of injury to pedestrians and to occupants of other vehicles.
- An across the board reduction of 100 lbs per vehicle may not be an adequate measure of the way in which the CAFE standards would change the weight of the vehicle fleet.
- The completeness and accuracy of the databases of traffic accident information that are available for study.
- The potential for offsetting effects of improved occupant protection.

This study attempts to deal with these issues.

Data from three state databases as well as from the Fatality Analysis Reporting System (FARS) and the National Automobile Sampling System General Estimates System (NASS-GES), and two methods of statistical analysis, logistic regression and crash scenario analysis, are included in this study. A discussion of the theory and method of crash scenario analysis is included in appendix D. The statistical methods used permit estimation of confidence intervals as well as examination of the expected effect of more than one proposed rule for reducing passenger vehicle weight. A meta-analysis that combines the results of these statistical analyses avoids the problem of reliance upon a single model or database. Valid and robust statistical inference is

based upon consistency of results arising from different sources of data and application of different statistical methods.

The analyses presented here are based upon the risk of injury or fatality to crash involved drivers. Thus the measure of exposure chosen is the crash involved driver, and the focus of this study is the relationship between vehicle mass and crashworthiness. The relationship between vehicle mass and the risk of crash involvement, and the risk of injury to non-occupants are additional aspects of the relationship between vehicle size and the risk of injury. An initial investigation of these issues is included in the discussion section of this report.

Data Sources

Computerized databases of police reported traffic crashes from the states of Florida, North Carolina and Maryland were used for the primary data analyses. These traffic crash databases include Vehicle Identification Number (VIN). The VIN can be decoded to identify the make and model year of the vehicle as well as vehicle weight, wheelbase and the type of occupant protection system available in the vehicle. This information is available for the subject vehicles and for other vehicles in collision with the subject vehicles. This information is essential for the study of the relationships between vehicle mass, airbag availability and risk of driver injury and fatality. These databases also contain information on:

- accident circumstances, (e.g. rural vs. urban, posted speed limit).
- type of accident (e.g. single vehicle accident collision with a pole, rollover, head-on, sideswipe, etc.).
- direction of impact (front, right, left, rear, rollover, other).
- driver behavior (e.g. alcohol use, risky or reckless driving).
- occupants (e.g. seating position, seat belt use, level of injury).

This information is needed for the statistical control of potentially confounding factors.

Data from FARS, and NASS-GES are used to examine historical trends in traffic fatality and injury and as additional validation of the statistical models developed for the state traffic accident databases.

Methodology

Statistical models of the relationship between vehicle weight and wheelbase and the risk of fatal, or fatal and incapacitating injury to the driver were constructed. All models included a control for vehicle type, accident type and driver factors that are related to the risk of injury or fatality and that may confound the relationship between vehicle weight and injury risk. A term for the effect of the presence of an airbag and a term for the possible differential effect of vehicle weight in airbag-equipped vehicles was included in all of the models. Two types of models were used: multiple logistic regression and scenario risk.

Passenger vehicles (cars, vans, SUVs and pickup trucks) model years 1985 and later were chosen as the population of vehicles under study. No restriction on model year or vehicle type was made for the other vehicle in the two vehicle crashes

Analyses were performed for two vehicle crashes and for single vehicle crashes. In the databases used in this study, more than 90% of the passenger vehicles involved in traffic crashes were involved in either single vehicle or in two vehicle collisions. Approximately 30% of the passenger vehicles were involved in single vehicle crashes and more than 60% were involved in two vehicle crashes.

The results of each of the models of injury and fatality were used to estimate the expected change in injury or fatality risk that would be expected should there be a change to the typical mass of the passenger vehicle fleet.

National estimates, based upon 1998 NASS/GES data were used to estimate the change in the annual number of driver fatalities and the annual number of fatal or incapacitating injuries to drivers that would be expected to accompany a hypothesized change in the average mass of the vehicles in the current passenger fleet.

Six scenarios for downsizing were considered: 1) 100 lb reduction for all passenger cars, 2) 100 lb reduction for all passenger cars, vans and SUVs 3) 100 lb average reduction for all passenger cars, but the entire reduction from medium and large passenger cars, 4) average 100 lb reduction for passenger cars, vans and SUVs, but the entire reduction to be taken from medium and large vehicles 5) a 10% reduction for all passenger vehicles (passenger cars, vans, SUVs and pickups) and 6) a 20% reduction for all passenger vehicles.

Multiple Logistic Regression

Multiple Logistic regression is a generalization of the multiple regression method. This technique was developed to provide a statistically rigorous methodology for analysis of data that is naturally binary (e.g., injured or not injured), or ordered categorical (e.g. no injury, minor injury, severe injury, fatal injury), rather than continuous. This method permits analysis at the level of crash and, therefore, can describe *interactions* between factors related to the risk of injury.

Briefly, logistic regression describes the proportion of events as a function of specific predictive factors. In order to avoid the problem of outcome values outside the possible range for proportions (0 to 1), the logistic regression is performed on the natural logarithm of the odds, where odds are defined as the probability that an event occurs divided by the probability that the event does not occur. This transformation prevents out-of-range estimates either below 0 or greater than 1.

The effect of the predictive factors on the risk of injury or fatality is described as additive on the log of the odds. This means that the logistic equation is a suitable descriptive model when the factors have a multiplicative effect on the risk of injury. For example, if the odds of injury are 2:1 for unbelted drivers vs. belted drivers, and the odds of injury are 3:1 for drivers in a left side impact vs. rear impact, then a multiplicative model implies that the odds of injury are (2:1) x (3:1) or 6:1 for (1) unbelted drivers in left side impacts versus (2) belted drivers in rear impacts.

To the extent that the odds of injury for unbelted drivers in left side impacts are different[3] from the odds of injury for unbelted drivers times the odds of driver injury for left side impacts, there is said to be *interaction* between failure to wear the seat belt and left side impact in their effect on driver injury risk. The interaction can be explicitly included in the model by adding interaction factors. In this example, one might add to the logistic model a factor for "unbelted drivers in left side impacts".

A term for the possible interaction effect of vehicle weight and availability of an airbag was included in the logistic models used in the analyses presented in this report. This term allows for the separate estimates of the effect of vehicle weight upon risk of driver injury, for airbag equipped vehicles and for vehicles not equipped with airbags.

Crash Scenario Analysis

Crash scenario analysis is a method designed to deal with the complexity of motor vehicle accidents and their consequences (Donelson et al. 1996)[4]. As events, motor vehicle accidents have both a *causal* and a *temporal* structure. This is fully appreciated in the discipline of accident reconstruction. Traditional approaches to the statistical analysis of traffic injury risk do not take into account the structure of motor vehicle accidents. The structure of such events is defined by causal and temporal connections among contributing factors related to the driver, driving environment, vehicle, and other circumstances immediately related to the outcome of injury (including physical interactions of the driver with the immediate, *at-crash* environment). Because we applied crash scenario analysis extensively in this research, and because this method may not be familiar to many readers of this report, we discuss this method in some detail in this report.

As findings from multidisciplinary accident investigations (MDAI) show, outcomes of motor vehicle accidents result from interactions among and, ultimately, the combined influence of several or more *pre-crash* and *at-crash* factors. The inherent complexity of motor vehicle accidents often defeats traditional approaches to multiple regression analysis. Traditional multiple regression may be difficult to appropriately implement as a result of the existence of complex factor interactions. If it is not possible to properly account for interactions, results may be misleading.

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[3] Either higher (positive interaction) or lower (negative interaction).

[4] Donelson. A.C., Ramachandran, K and Davis, M.S., *Vehicle Rollover: Assessing the Relative Importance of Risk Factors with Crash Scenario Analysis,* Safety Engineering and Risk Analysis (SERA), ed. F.J. Mints, SERA-vol6, pp.7-14, New York, New York: American Society of Mechanical Engineers.

The usual approach has been to treat contributing factors as discrete, independent variables: Rural vs. urban roadway, frontal vs. rear impact, older vs. younger occupant, younger vs. older driver, and so on. The problem is that, at the level of crash, the risk of injury or fatality is not a simple function of separate, independent factors. Rather, combinations of factors influence the likelihood of injury or fatality as an outcome of motor vehicle accidents.

In some cases selected risk factors (like "risky driving") may not have played any part in the outcome of crash, even though the risk factor was reported "present" by investigators. Of course, the data analyst will have no way to know this. What seemed needed, therefore, was a method that could better take into account the inherent complexity of crash events and both the interactions and non-interactions of (potentially) contributing factors.

Therefore, rather than treat many "causal factors" as discrete variables, the method of crash scenario analysis defines combinations of risk factors as unique "crash scenarios". We generally define a "crash scenario" as a combination of selected pre-crash and at-crash factors that may increase or decrease the chance of a particular outcome of a motor vehicle accident. Several criteria guide the selection of elements that comprise "crash scenarios": their relevance to the outcome variable chosen for investigation, their frequency in motor vehicle accidents, and their apparent strength of association with the outcome variable.

The influence of combinations of risk factors may be greater or less than the contributions or each of the individual factors. For example, consider the risk of fatal or incapacitating injuries to a driver involved in a two vehicle crash. Consider the following example using data for two vehicle crashes in Maryland during1984-98 and passenger vehicles of model years 1985 and later. In a one factor at a time analysis we find:

Figure 1

Factor	Percent Fatal or Incapacitating Injury			
	High Risk Level of Factor	Low Risk Level of Factor	Relative Risk High Level of Factor vs Low Level of Factor	Relative Risk Low Level of Factor vs High Level of Factor
Older Driver vs Younger Driver	6.54%	5.76%	1.14	.88
Unbelted Vs Belts	12.32%	5.49%	2.24	.45
Airbag not Available vs Airbag Available	6.04%	4.83%	1.25	.80
Not Risky Driving vs Risky Driving[5]	5.84%	5.53%	1.06	.95

Using the single factor at a time multiplicative model, for an older driver, unbelted, in an airbag equipped vehicle, not noted as risky driving we would get a relative risk (RR) of:

(RR older) x (RR unbelted) x (RR airbag) x (RR risky driving) =

(1.14) x (2.24) x (0.80) x (1.06) = 2.15

This represents a 115[6]% elevation in risk.

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[5] Note that in this particular example, the injury rate for drivers noted as having risky driving is lower than the injury rate for drivers not noted as having risky driving. In single vehicle accidents drivers noted as having risky driving have a higher injury rate. Curiously, in this set of two vehicle accidents, the injury rate is higher if the driver of the *other* vehicle is noted as having risky driving.

[6] A relative risk of 1.0 represents equal risk, a relative risk of 2 represents a doubling of risk of a 100% increase in risk.

In contrast, direct calculation of the injury rates for these combinations of factors shows the following:

Figure 2

Factor Combinations				
Older vs Younger Driver	Unbelted vs Belted	No Airbag vs Airbag Equipped	Not noted as risky driving vs risky driving noted	Percent Fatal or Incapacitating Injury
older	unbelted	airbag	risky driving *not* noted	5.05%
younger	belted	no airbag	risky driving noted	4.45%

And direct calculation of the relative risk results in:

RR=(5.05/4.45) =1.14, that is, an increase in risk of 14%.

This is an example of a "four-factor" interaction, the influence of the combination of the four factors is different than would be calculated in a one factor at a time multiplicative model.

Projection of Change in Risk

Each of the statistical models of injury and fatality risk produces results in a regression equation that describes the expected change in risk associated with a change in the weight of the subject vehicle. For the two vehicle analyses, a factor for the ratio of the weight of the subject vehicle to the weight of the other vehicle in the crash is also included in the predictive equations.

The projections of the change in risk are made by applying the regression equation to a hypothetical population of traffic accidents involving the same vehicles and the same accident circumstances with the exception that the weight of passenger cars (or passenger cars, vans and SUVs) has been reduced by some amount. In two vehicle analyses, it is assumed that the weights of the other passenger cars (or passenger cars, vans and SUVs) the collision are also reduced in accordance with the structured mass reduction proposals studied. Thus the change in risk described here is the change that is to be expected if the entire population of passenger cars and light trucks were to be downsized. No change in the average weight of pickup trucks or of medium and heavy trucks is assumed in these four scenarios. Two additional scenarios were also considered: 10%, and a 20% proportional reduction in the weight of all passenger vehicles including pickups. In each of the six structured proposals, all other accident and driver factors are assumed to remain unchanged.

Estimates were made for two vehicle accidents. The change in risk is the difference between the percent of crash involved drivers reported as injured or killed in the traffic accident database, and the percent of crash involved drivers projected to be injured or killed after the hypothetical downsizing. The NASS-GES was used to estimate the annual number of drivers in two vehicle crashes for passenger cars (or passenger cars, vans and SUVs) in 1998. These estimates were multiplied by the projected change in risk to estimate annual change in the number of driver fatalities (fatalities and incapacitating injuries) that would be expected with each of the hypothesized downsizing scenarios. The upper and lower 95% confidence bounds for the change in risk were used to calculate upper and lower 95% confidence bounds for the expected change in the annual number of driver fatalities and injuries.

Meta Analysis

The objective of a meta analysis is to determine whether our conclusions are largely dependent on a distinct model specification. Ideally, the conclusions are robust against a particular model specification.

In order to check whether a conclusion is sensitive to changes in the model specifications, four different models were developed. If a conclusion changes depending on which model formulation is selected, we should not be as confident in our interpretation. Furthermore, if only one model is tested, we do not even know how sensitive the result is to that particular model specification.

It is also possible for conclusions to depend heavily on a particular data set. Certainly, it would be undesirable for the interpretation to be sensitive to the data used, so three different state data bases were used with each model to determine whether the conclusions were also robust against a particular data set.

The meta analysis performed here does not rely upon any mathematical combination of results from the various analyses performed, it is simply a critical review of the results of the various analyses and an evaluation of the consistency, or lack thereof, in the implications of the results of the statistical models.

A primary goal of these analyses is to gain an understanding of the likely effect of a hypothesized downsizing of the passenger vehicle fleet upon the risk of driver injury and fatality. The expected change in the annual number of driver injuries and fatalities and the 95% confidence interval of that estimate was used as the yardstick to evaluate the robustness of the models constructed here.

The sensitivity of the analysis to the exact specifications of the statistical models was evaluated through comparison of the results of the 4 models created for each state database. The sensitivity of the results to the accuracy of the reported information in the traffic records databases was evaluated through comparison of the projections based upon data from different states. The consistency of the odds ratio for a change of 100 lbs vehicle weight was also examined to evaluate the sensitivity of the estimates of the effect of vehicle weight upon risk of injury.

Results

Factors Related to the Risk of Fatal or Incapacitating Injury

In addition to vehicle weight and presence of driver airbag, factors consistently found to be related to the risk of fatal (or fatal and incapacitating injury) to crash involved drivers include: driver belt use, driver alcohol use, ejection, gender, age 65 and over, speed limit 55 and over, direction of impact and vehicle type. For single vehicle crashes, rollover and object in collision are consistent injury risk factors. For two vehicle crashes, the type of crash (front to front, sideswipe, T-bone, etc.), the type and weight of the other vehicle in the collision and the ratio of the weights of the two vehicles are risk factors for driver injury.

Models of Two Vehicle Crashes

This research, as well as previous research[7], reveals that in two vehicle crashes, the risk of driver injury or fatality decreases as vehicle weight increases; the ratio of the weight of the subject vehicle to the weight of the other vehicle in the crash is the best predictor of driver injury risk. Leonard Evans elucidated the physical basis for this relationship[8]

In two vehicle accidents, the scenario risk factor includes the contributions of:

- Driver alcohol use
- Vehicle damage
- Rural roadway
- Male driver
- Risky Driving
- Driver age 65 and older
- Unbelted driver
- Ejected driver
- Speed limit 55 mph or higher
- Crash type

as well as the combinations of these factors in their effect upon the risk of driver fatality and injury.

The fact that the scenario risk variable consolidates the combined influence of several injury and fatality risk factors results in a relative risk attributable to scenario risk that is substantially greater than the relative risk associated with any of the individual risk factors.

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[7] *Causal influence of car mass and size on driver fatality risk,* preprint, Leonard Evans, Vehicle Analysis and Dynamics Laboratory, GM Research & Development Center

[8] Ibid.

For two vehicle accidents, three logistic models with individual risk factors:

- A: Two Vehicle Accidents including Vehicle Characteristics; Crash Type; Driver Belt Use and Air Bag; Vehicle Damage.
- B: Two Vehicle Accidents Including Vehicle Characteristics; Crash Type; Driver Belt Use and Air Bag.
- C: Two Vehicle Accidents including Vehicle Characteristics; Crash Type; Driver Belt Use, Ejection and Air Bag; Vehicle Damage; Driver Characteristics; Environmental Characteristics

and one scenario risk model:

- D: Two Vehicle Accidents including Accident Scenario Risk; Vehicle Characteristics; Driver Air Bag

were calculated for each of the three databases of state police reported traffic accidents, for a total of 12 models of the risk of fatal or incapacitating injury to drivers in two vehicle accidents.

An additional 12 models of the risk of driver fatality were also constructed.

Factors for the weight, size and vehicle type for the other vehicle in the collision were included in all of the models. The results of these models including the relative risk associated with each factor are tabulated in Appendix A. As an illustration, the relative risks for each risk factor the 2-vehicle model D for the state of Maryland are displayed below:

Figure 3

Scenario Analysis Results:

Maryland, 1984-1998

Fatal or Incapacitating Injury to Drivers

Model D: Two Vehicle Accidents including Accident Scenario Risk; Vehicle Characteristics, Airbag

Description of Model Variables Used	Relative Risk		
		95% Confidence Interval	
	Estimate	Lower Bound	Upper Bound
Scenario Risk[9]:	23.765	22.741	24.835
No Driver's Side Air Bag vs Air Bag Present for Subject Vehicle	1.599	1.399	1.828
Ratio: Vehicle Weight for Subject Vehicle divided by Vehicle Weight of the Other Vehicle	0.618	0.574	0.666
Wheelbase for Subject Vehicle	0.993	0.990	0.995
Vehicle Weight (per 100 pounds) in the Absence of Driver's Side Air Bag for Subject Vehicle	0.991	0.987	0.996

- [9] Variables included in the scenario risk are: driver alcohol use, vehicle damage, rural roadway, male driver, risky driving, driver age 65 and older, unbelted driver, ejected driver, speed limit 55 mph or higher, and crash type.

Figure 3 (Continued)

Scenario Analysis Results (continued):

Maryland, 1984-1998

Fatal or Incapacitating Injury to Drivers

Model D: Two Vehicle Accidents including Accident Scenario Risk; Vehicle Characteristics, Airbag

Description of Model Variables Used	Relative Risk (Odds Ratio)	95% Confidence Interval	
	Estimate	Lower Bound	Upper Bound
Subject Vehicle:			
Other Vehicle Type vs. Passenger Cars	0.792	0.705	0.890
Pickup vs. Passenger Cars	0.907	0.855	0.963
Sport Utility Vehicle vs. Passenger Cars	0.851	0.792	0.914
Van vs. Passenger Cars	0.965	0.896	1.038
Other Vehicle:			
Other Vehicle Type vs. Passenger Cars	1.307	1.202	1.420
Pickup vs. Passenger Cars	1.237	1.180	1.297
Sport Utility Vehicle vs. Passenger Cars	1.175	1.106	1.249
Van vs. Passenger Cars	1.182	1.110	1.258
Medium/Heavy Truck vs. Passenger Cars	1.147	1.075	1.223
Motorcycle vs. Passenger Cars	0.719	0.499	1.035

In this example, the relative risk for an increase in the ratio of the weight of the subject vehicle to the weight of the other vehicle in the collision is .618. The relative risk for a decrease in the ratio of the weight of the subject vehicle to the other vehicle in the collision is 1/.618, or 1.618. Applying this factor to a decrease in relative weight, we find that the risk of fatal or incapacitating injury to drivers in two vehicle crashes increases by 5% for every 10% decrease in the ratio of the weight of the subject vehicle to the weight of the other vehicle in the crash.

The relative risk of injury to the driver of a pickup truck is .907 as compared to the risk of injury to the driver of a passenger car in the same accident circumstances; this difference is statistically significant as can be seen from the fact that both the upper and lower 95% confidence bound of the relative risk estimate are less than 1.0. In contrast the relative risk of injury to the driver of a van as compared to the driver of a passenger car is .965, but the upper bound of the 95% confidence interval is 1.038, indicating that risk to van drivers is not statistically significantly different from the risk to passenger car drivers.

The relative risk associated with other factors in the model is interpreted in the same way as these two illustrations.

Models of Single Vehicle Crashes

In single vehicle accidents, the scenario risk factor includes the contributions of:

- Driver alcohol use
- Vehicle damage
- Rural roadway
- Male driver
- Risky Driving
- Driver age 65 and older
- Unbelted driver
- Ejected driver
- Fixed object struck
- Speed limit 55 mph or higher
- Impact type

as well as the interaction of these factors in their effect upon the risk of driver fatality and injury. Consequently, the relative risk attributable to scenario risk is substantially greater than the relative risk associated with any of the individual risk factors.

For single vehicle accidents, three logistic models with individual risk factors:

- E: Single Vehicle Accidents including Vehicle Characteristics; Impact Type; Driver Belt Use and Air Bag; Vehicle Damage.

- F: Single Vehicle Accidents Including Vehicle Characteristics; Impact Type; Driver Belt Use and Air Bag.

- G: Single Vehicle Accidents including: Vehicle Characteristics, Impact Type, Driver Belt Use, Ejection, Air Bag Availability, Vehicle Damage, Driver Characteristics, and Environmental Factors.

and one scenario risk model:

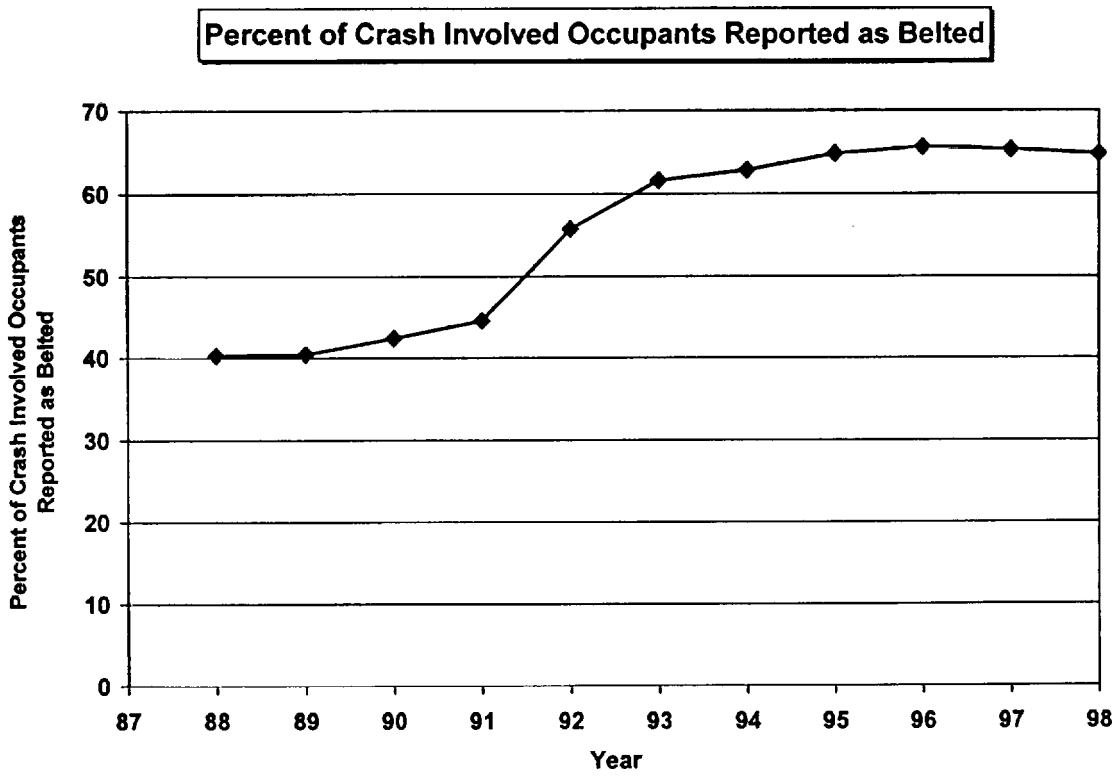
- H: Single Vehicle Accidents including Accident Scenario Risk; Vehicle Characteristics; Driver Air Bag

were calculated for each of the three databases of state police reported traffic accidents, for a total of 12 models of the risk of fatal or incapacitating injury to drivers in single vehicle accidents. The results of these models as well as the 12 models of fatal risk are displayed in Appendix B. The relative risk associated with each factor and the 95% confidence bounds for the relative risk are included in the tables.

Trends in Factors Related to the Risk of Fatal or Incapacitating Injury

Data from NASS/GES and from the state traffic records databases were used to study changes over time in injury and fatality risk factors. The most striking change is the increase in reported seat belt use. This change is paralleled by a decrease in the rate of fatal and incapacitating injuries to crash involved drivers.

Figure 4



Source: NASS/GES 1988-1998.

The increase over time in the relative proportions of SUVs, vans and pickup trucks is a second factor associated with the decrease in the risk of injury to all crash involved occupants of passenger vehicles.

Figure 5

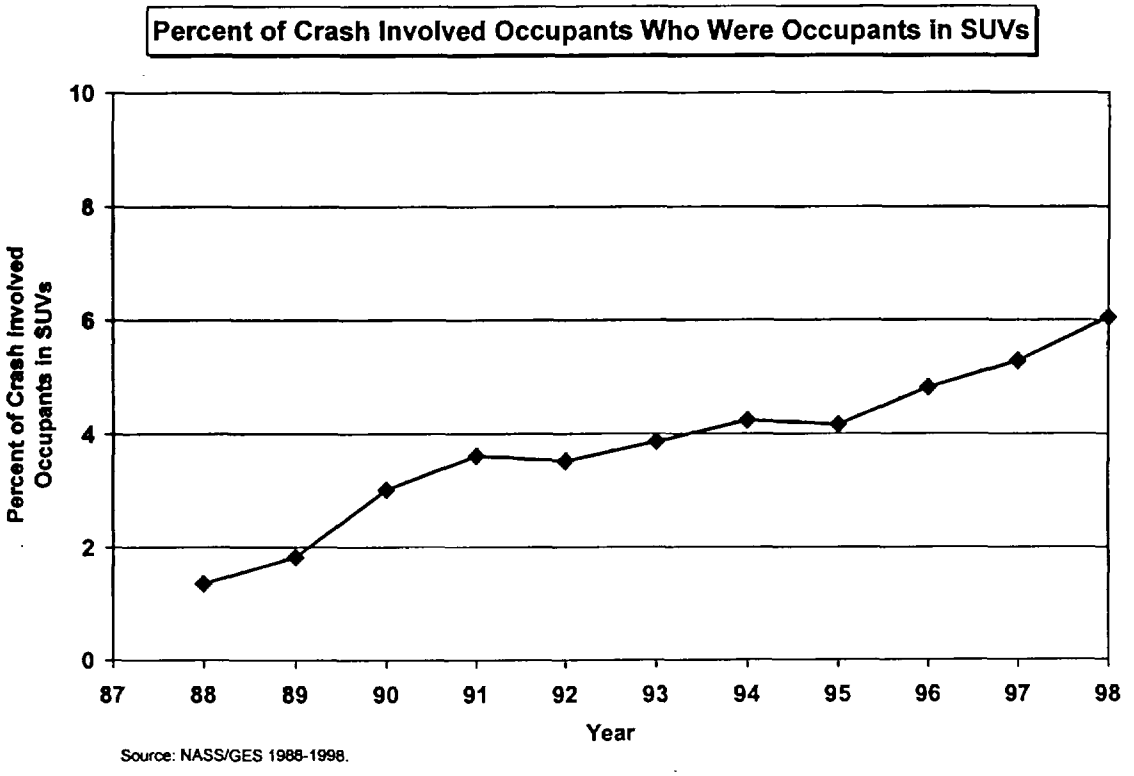
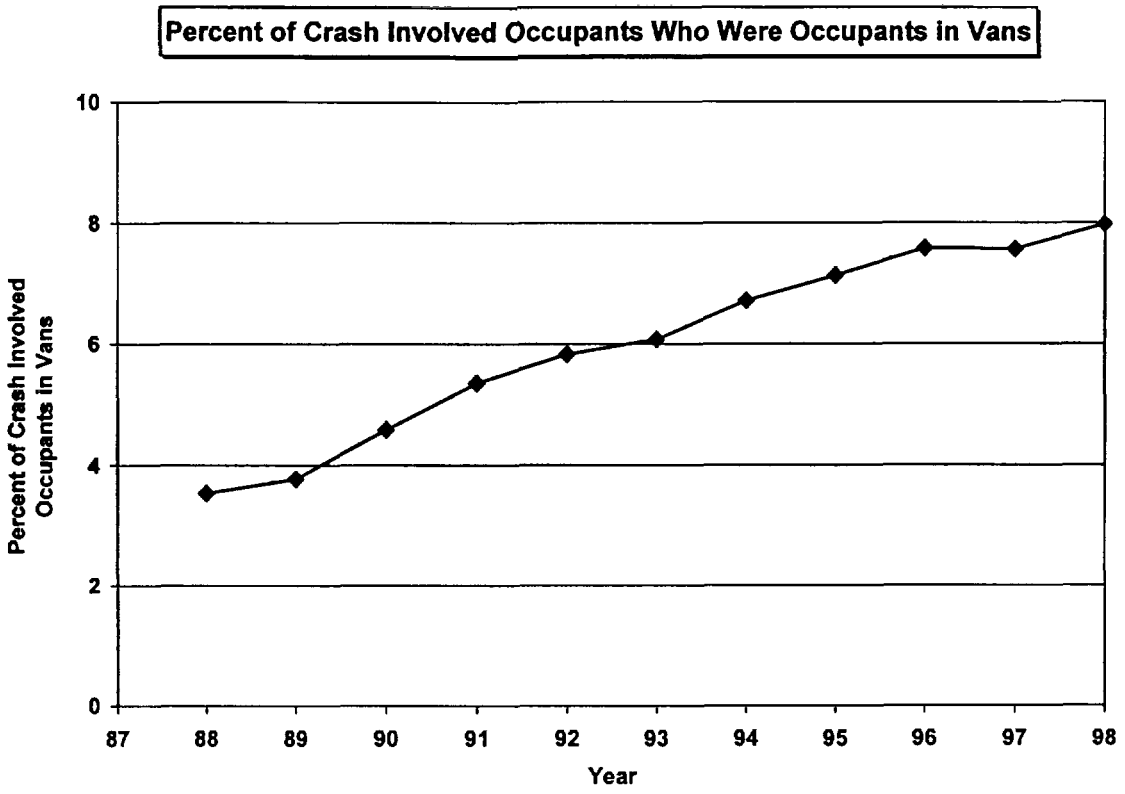


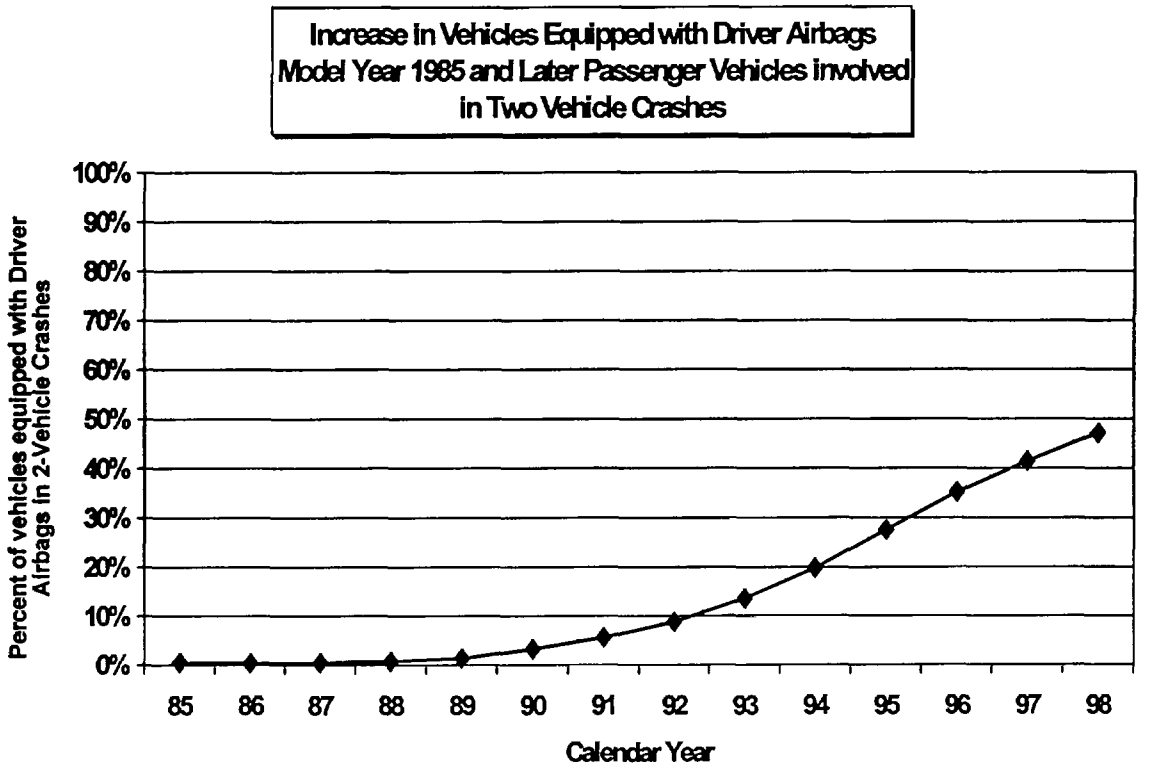
Figure 6



Source: NASS/GES 1988-1998.

The proportion of model year 85 and later passenger vehicles equipped with driver airbag has also increased over time.

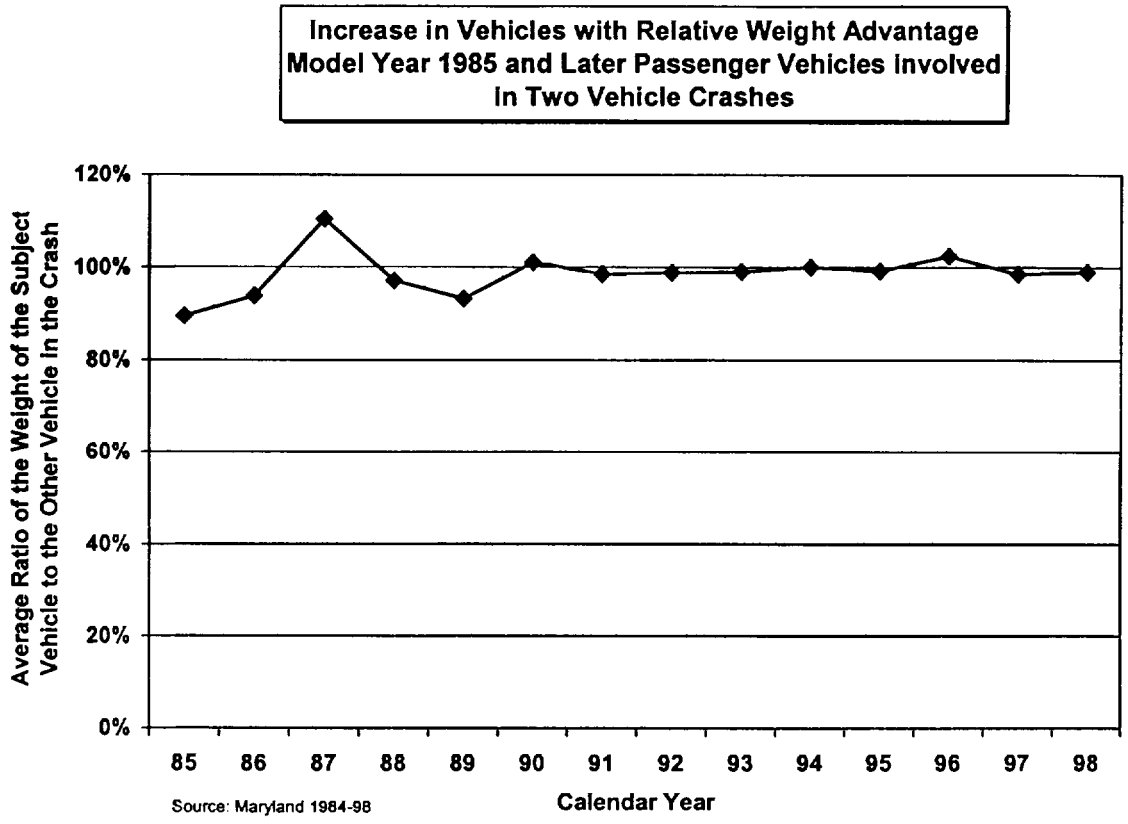
Figure 7



Source: Maryland 1984-

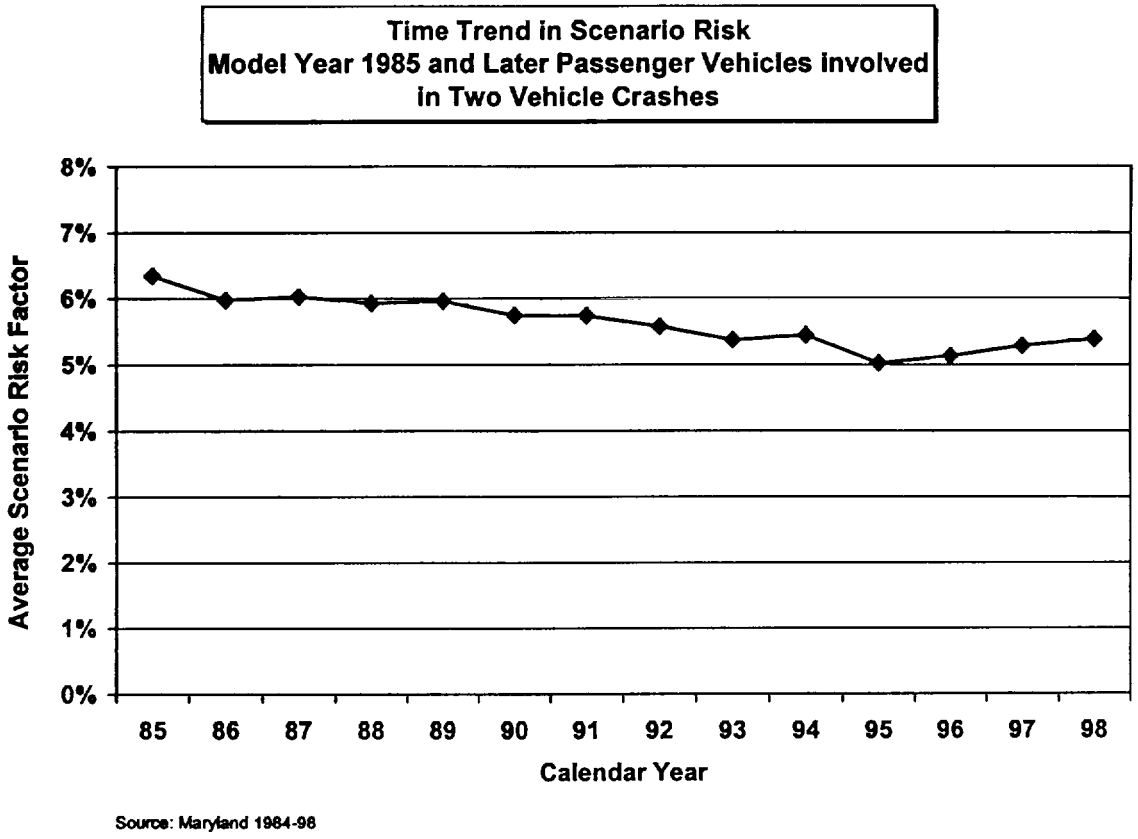
For passenger vehicles of model year 85 and later, the proportion of two vehicle crashes for which the subject vehicle has the relative weight disadvantage decreased between 1985 and 1990, and has held steady through 1998.

Figure 8



The change in injury risk associated with changes in driver and accident type variables may be summarized by the change over time in the scenario risk factor. This factor summarizes the combined influence of: driver alcohol use, vehicle damage level, rural roadway, male driver, risky driving, driver age 65 and older, unbelted driver, ejected driver, speed limit 55 mph or higher, and crash type, as well as the interactions of these factors.

Figure 9



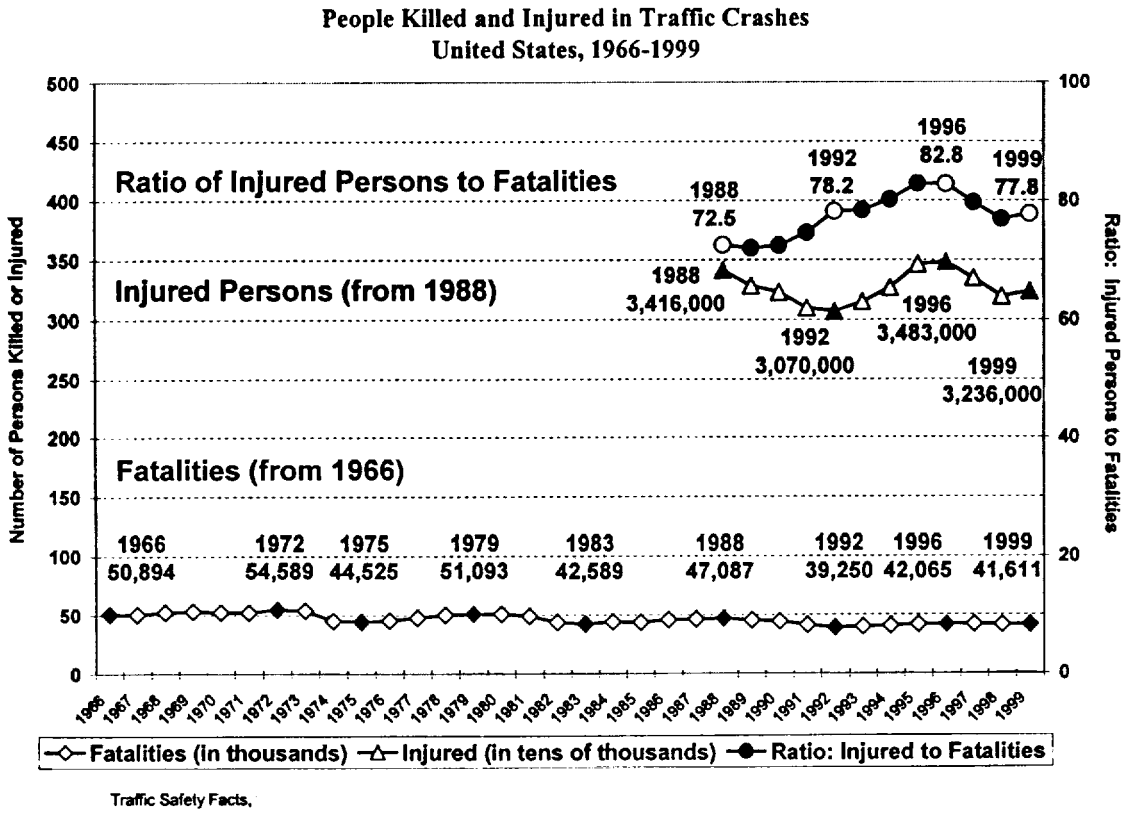
In Maryland two-vehicle crashes, the risk of fatal and incapacitating injury attributable to the driver and accident type factors as summarized in scenario risk has decreased from an approximately 6.5% risk to a 5.5% risk of driver injury. This decrease is statistically significant[10].

[10] Significance probability, $p<.0001$;

Characterization of Trends in Traffic Fatalities

The number of traffic fatalities decreased from almost 51, 000 in 1966 to a low of 39,250 in 1992 and is currently about 42,000 annually. This decrease in the number of fatalities exists despite the increase in population, in vehicles on the road and in annual passenger miles driven.

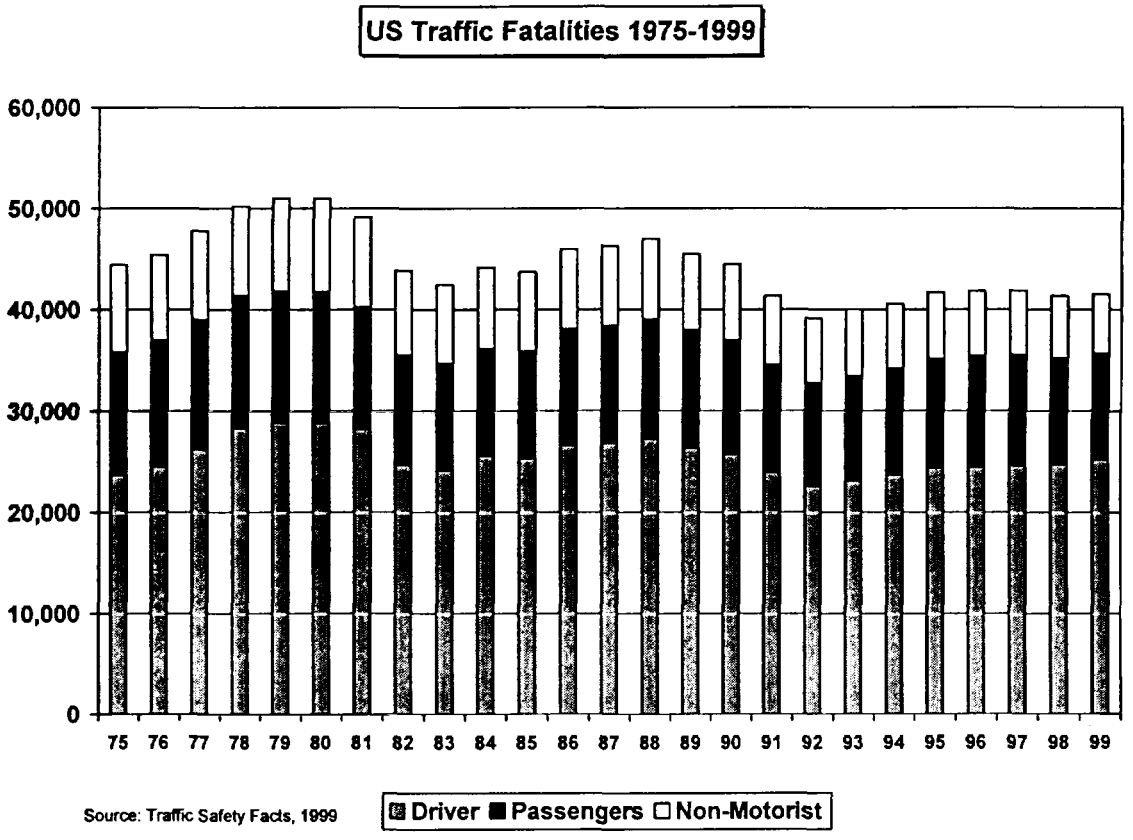
Figure 10



The influence of the increase in seat belt usage between 1988 and 1996 is reflected in the increase in the ratio non-fatal traffic injuries to traffic fatalities. This indicates that occupant protection measures have reduced the severity of some traffic injuries from fatal to non-fatal.

The proportion of traffic fatalities for drivers as compared to other vehicle occupants and non-motorists has not changed a great deal over the period 1975-1999.

Figure 11



Therefore, it is reasonable to assume that the trends in fatality and injury risk factors for drivers and other occupants are similar to the trends in injury and fatality risk factors that were discovered in this study of drivers.

Using the data from the single vehicle crash and two vehicle crash studies for the state of Maryland for crashes occurring in the period 1985-1998, and for model year 1985 and later passenger vehicles, we find the following factors contributing to the change in risk of fatal & incapacitating injury:

Figure 12

	% Change in Risk of Fatal and Incapacitating Injury Attributable to Factors For the period 1985-1998	
Factor	**In Single Vehicle Crashes**	**In two Vehicle Crashes**
Increase in Seat Belt use	50% decrease	41% decrease
Increase in Vehicles Equipped with Driver Airbags	14% decrease	20% decrease
Change in Average Weight of Passenger Vehicles	2% decrease	na
Change in Ratio of Weight of Subject Vehicle to the Other Vehicle in the Collision	na	4% decrease
Change in Scenario Risk	30% decrease	10% decrease

These estimates are based upon the estimates of relative risk produced by the logistic models and the change in the average value of the factor between 1985 and 1998[11].

As can be seen from the above table, the increase in seat belt use is the largest contributor to the reduction in injuries to crash involved drivers. This is true both in single vehicle and in two vehicle crashes. The increase in the availability of airbags is also a major contributor to the decrease in the risk of injury. Increases in passenger vehicle weight have contributed to the reduction in injuries to drivers in two vehicle crashes but have had minimal effect in single vehicle crashes. In Maryland, there was a large decrease in the riskiness of the accident scenario in single vehicle accidents. As was noted earlier, the scenario risk factor is a composite of factors related to the risk of injury and fatality. Seat belt use was one of the factors included in the scenario risk factors. Thus it appears that the decrease in the fatal and incapacitating injury rates, is more than explained through the increase in reported seat belt use for drivers. The fact that the decrease in incapacitating and fatal injury rates attributable to scenario risk is less than the decrease attributable to increase in seat belt use alone indicates that the risk of injury and fatality is increasing in some other aspects of the crash situations.

Projected Impact of Reduction of Passenger Vehicle Size

The projected change in the annual number of fatal and incapacitating injuries to drivers of passenger vehicles involved in two vehicle crashes, was calculated for each of the 12 statistical models, and six passenger vehicle fleet weight reduction scenarios. These results are listed in Appendix C.

Following the work of Kahane, an average reduction of 100 lbs per vehicle was chosen to illustrate the effect of vehicle mass reductions. In two vehicle crashes, the effect of a change in vehicle weight is expressed through the change in the ratio of the weights of the two vehicles in collision. This means, that a weight reduction of 200 lbs does not produce exactly twice the projected increase in injuries and fatalities as does a 100 lb decrease. Each version of a reduction in mass of passenger cars is projected to result in an increase in driver fatalities. The largest increases in fatalities and injuries are projected for CAFE scenarios, which require an across the board reduction of 100 lb for all passenger vehicles. A larger increase in injuries and fatalities is expected if weight reductions are required for vans and SUVs, than if reductions are required only for cars.

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[11] The estimates for the all factors other than increase in seat belt use are based upon the logistic model, which incorporates the scenario risk factor (model D for the two-vehicle crashes and model F for the single vehicle crashes). Due to the fact that seat belt use is one of the factors included in the scenario risk, these models could not be used to calculate the change in injury rates attributable to increase in seat belt use. The calculations of the change in injury rate attributable to increase in seat belt use were based upon the logistic regression model, which did not include factors for vehicle damage (model B for the two-vehicle crashes and model F for the single vehicle crashes).

If the average weight reduction is accomplished by making a larger reduction for heavier cars, SUVs and vans, then the projected increase in injuries and fatalities is smaller than if a 100 lb reduction is taken across the board.

For an across the board decrease of 100 lbs for passenger cars only, projected annual increases in driver fatalities range from 82 to 105 for models based upon Florida data, from 59 to 90 for models based upon Maryland data and from 47 to 74 for models based upon North Carolina data.

Annual increases in fatal and incapacitating injuries range from 267 to 310 for models based upon Florida data, from 205 to 259 for models based upon Maryland, and from 61 to 85 for models based upon North Carolina data.

In the models of two-vehicle collision described here, the influence of vehicle weight is through the ratio of the weights of the two vehicles in the collision. Thus if the weight of the passenger car fleet were to be simultaneously proportionally downsized, with no need for phasing in of the new vehicles[12], the risk of injury to occupants in collision of two passenger vehicle would remain unchanged. However, the risk of injury and fatality to the occupants of this downsized fleet is still expected to increase because the fleet of medium and heavy trucks will not be reduced in weight.

Examples of the projections of increased injury and fatality for the two proportional downsizing scenarios are seen in the following charts.

[12] In these extreme hypothetical scenarios, all passenger vehicles, currently in use, are taken out of service and are instantaneously replaced by new passenger vehicles either 10% or 20% lower in weight.

Figure 13

CAFÉ Scenarios: 10% and 20% Reduction of Entire Passenger Vehicle Fleet

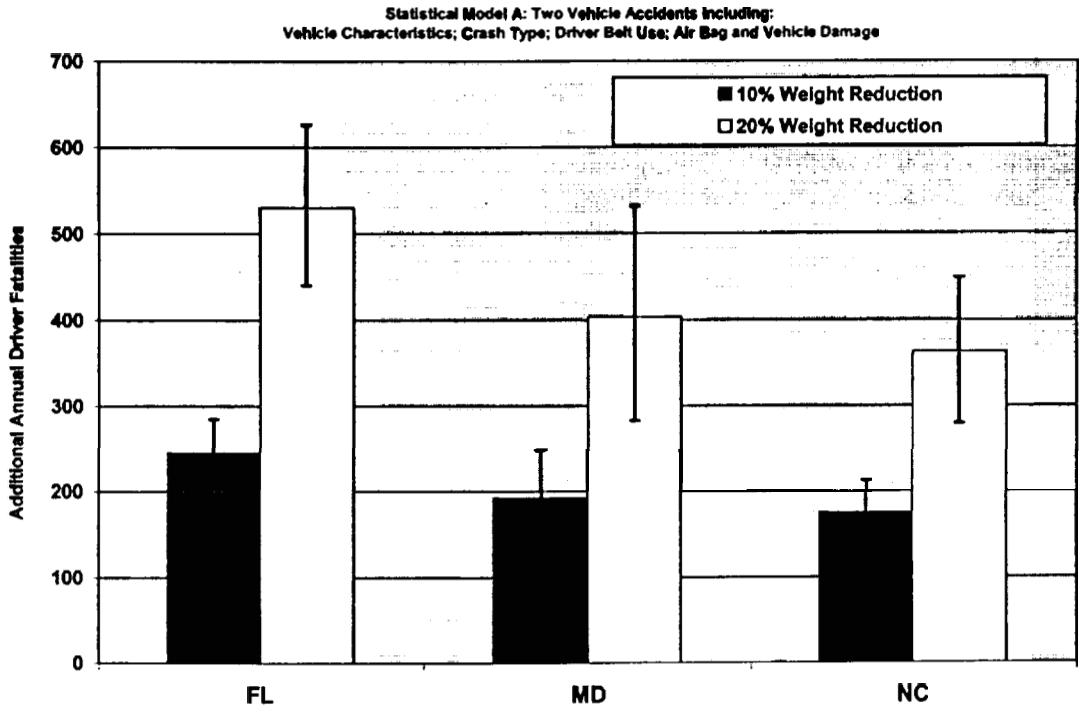
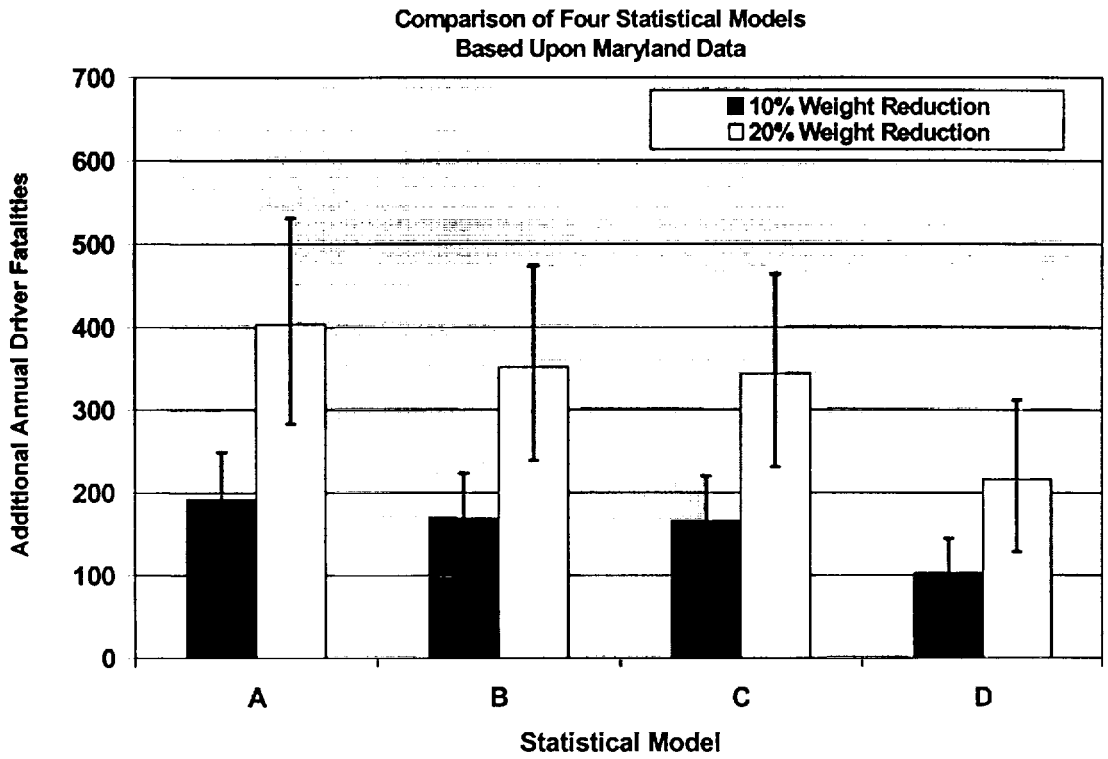


Figure 14

CAFÉ Scenarios: 10% and 20% Reduction of Entire Passenger Vehicle Fleet



As is seen from these charts and the more detailed presentation in appendix C, a 10% reduction in the weight of the entire passenger car fleet is expected to result in 100 to 200 additional fatalities per year, and a 20% proportional reduction in the weight of the passenger vehicle fleet is expected to result in an additional 200 to 400 fatalities per year. Even ignoring the additional fatalities, which would result form the phase in of the smaller vehicles, hundreds of additional fatalities would be expected each year.

In all cases, projections based upon data from North Carolina are markedly lower than the projections based upon data from Maryland or Florida. This may result from the fact that North Carolina projections are based on a population of crashes from a state with an aggressive seat belt use law enforcement program. National projections from the North Carolina models are

describing the situation, which would ensue if the entire population of the United States had seat belt use rates like those in North Carolina.[13]

The results from Florida and Maryland are similar to each other.

Meta Analysis and Discussion

Two Vehicle Crashes

For two-vehicle crashes, the results of all analyses are consistent: Decreases in the weight of the passenger car fleet can be expected to result in increases in driver fatalities and injuries. Projections from every model evaluated, and in every state database used, indicate a statistically significant increase in risk of fatality and incapacitating injury with a decrease in vehicle weight.

Changes in the predictions based upon variations in the specification of the statistical models are not very large. This indicates that the logistic modeling methodology is not sensitive to small changes in the specification of the model.

The pattern of results from state to state is consistent. In particular, reductions in the weight of passenger vehicles that have the effect of increasing disparities in weight within the fleet, are projected to produce more injuries and fatalities than changes in the weight of the passenger vehicle fleet that are accomplished through a method that tends to reduce disparities weight within the fleet.

Single Vehicle Crashes

The statistical models of single vehicle crashes, studied here, did not produce a consistent relationship between vehicle weight and the risk of fatal or incapacitating injury. In most of the analyses, the change in risk with the change in vehicle weight was small. These small changes were not consistently either positive or negative. These results are in contrast to the studies of FARS data performed by Leonard Evans, in which he found an increase in injury risk associated with a decrease in mass in in single vehicle accidents[14].

The single vehicle crashes studied here, consist of a wide range of accident types ranging from sideswipes with parked cars to high speed off road rollovers. It may be necessary to stratify

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[13] Thanks to Anne Ginn of General Motors for pointing this out.

[14] Car Size and Safety, a review focused on identifying causative factors, Proceedings of the 14th Enhanced Safety Vehicle Conference, Munich, Germany, 23-26, May 1994, US Government Printing Office: Vol 1, pp721-733, 1995.

single vehicle crashes into sub-classes of accidents that are more similar to one another before the effect of vehicle weight on the risk of injury in single vehicle crashes can be characterized. Initial investigations along these lines indicate that the risk of driver injury decreases with increasing vehicle weight in single vehicle frontal collisions.

Risk of Crash Involvement

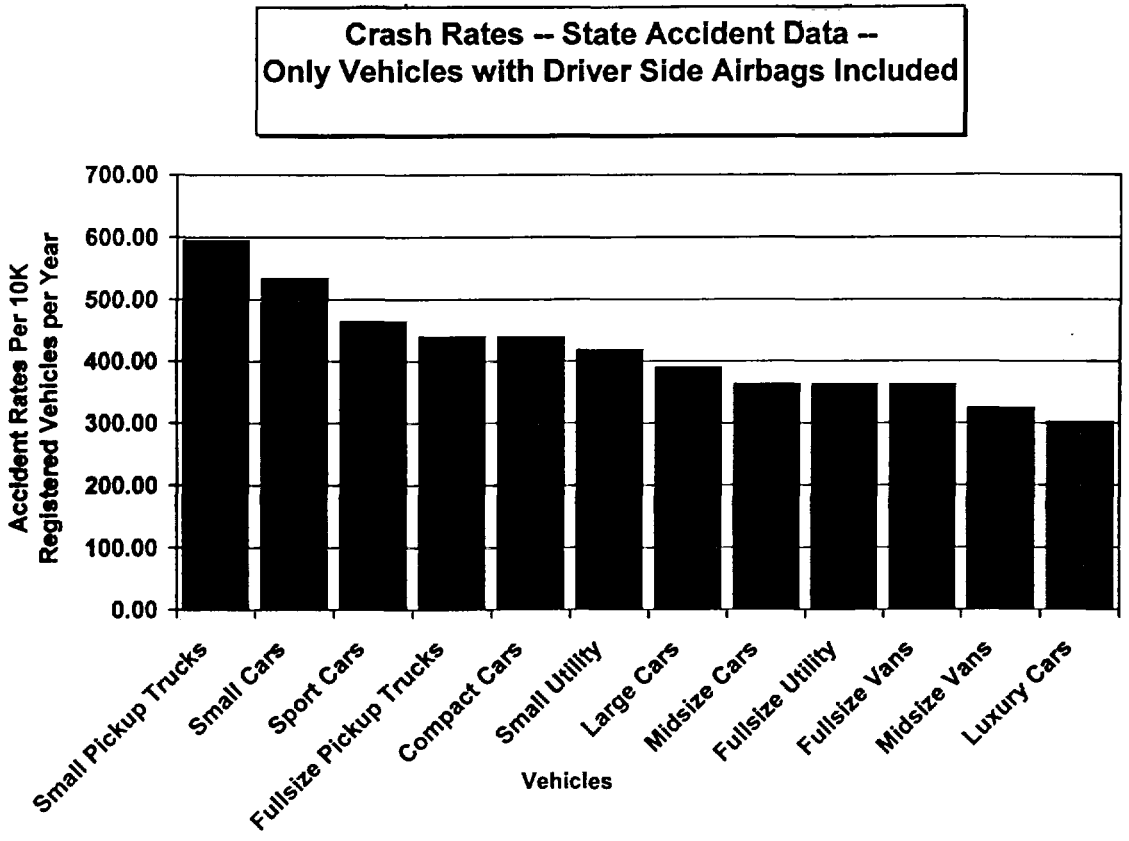
If the risk of involvement in traffic crashes is related to the mass of the passenger vehicles involved, then a the increased injury risk for crash involved occupants of the downsized vehicles would be mitigated if decreasing the size of passenger vehicle reduces the crash rate, and exacerbated if decreasing the mass of vehicles increases the rate of crash involvement.

A preliminary investigation of this issue was made by comparing the average rate of police reported traffic accidents per 10,000 registered vehicles per year for passenger vehicles of different size classes. As part of a previous study commissioned by General Motors, Exponent calculated the rate of police reported traffic accidents per 10,000 registered vehicle per year for passenger vehicle model years 1990-1997. The rates presented here are based upon the combined results for seven states: Alabama, Arkansas, Florida, Maryland, N. Carolina, New York, and Pennsylvania. Crash rates were calculated for each of thirteen classes of vehicles. Only vehicles with driver airbags were included.

As can be seen from the following chart, smaller vehicles frequently have higher crash rates than larger vehicles of the same type. For example small passenger cars have higher crash involvement rates than compact passenger cars, which have higher crash involvement rate than large or mid-size passenger cars. The relationship between crash involvement rate and passenger car size is not monotonic here. Large passenger cars have higher crash involvement rates than midsize passenger cars. This may be related to the relatively small number of vehicles in the large car group.

In addition, small pickups have higher crash involvement rates than full-sized pickups, small utility vehicles have higher crash involvement rates than full-sized utility vehicles, but full-sized vans have higher crash involvement rates than small vans.

Figure 15



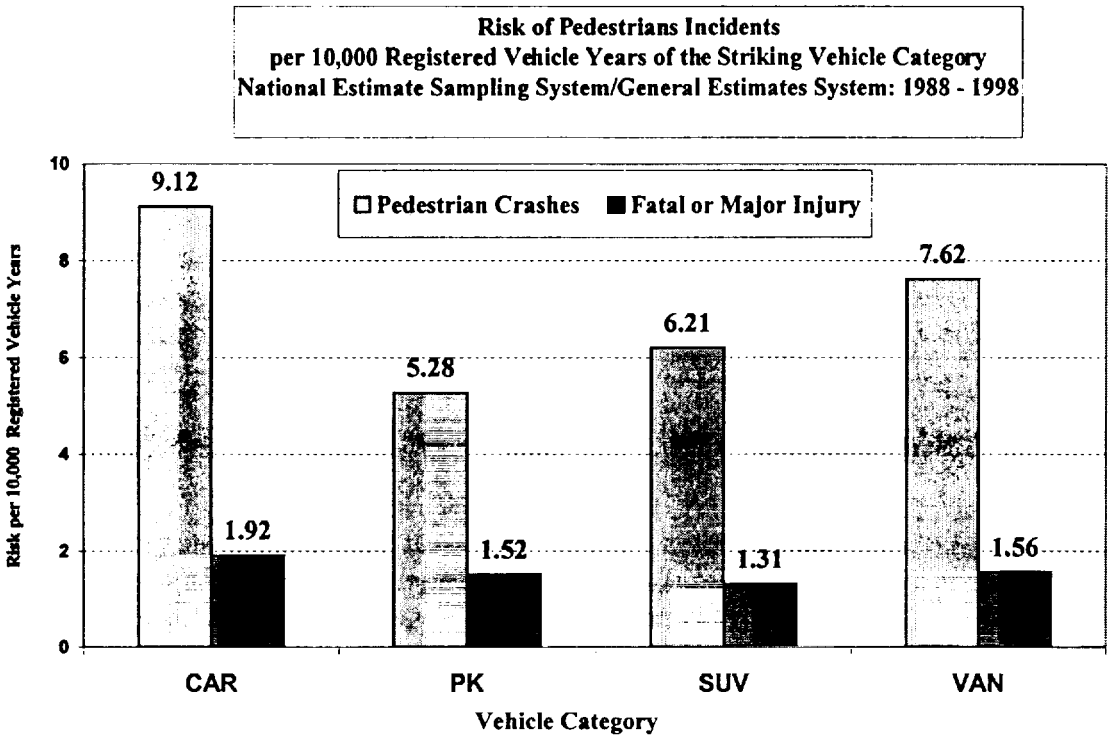
Risk of Injury and Fatality to non-Occupants

The risk of injury to pedestrians and pedicyclists may also be considered in the equation linking public safety and proposed changes to regulations concerning the weight of passenger vehicles.

Data from the NASS/GES system was used in combination with vehicle registration data to calculate the rate of cashes involving pedestrians for four broad classes of passenger vehicles: passenger cars, pickups, vans and SUVs Rates of collision and injury collisions were calculated.

As is seen in the following chart, the risk of pedestrian incident and of pedestrian fatal or incapacitating injury incident per year of use of the vehicle is higher for passenger cars than for pickups, SUVs or vans. The assertion that smaller vehicles may have a lower risk of pedestrian incident is not born out by this data.

Figure 16


Risk of Pedestrians Incidents
per 10,000 Registered Vehicle Years of the Striking Vehicle Category
National Estimate Sampling System/General Estimates System: 1988 - 1998
Pedestrian Crashes
Fatal or Major Injury
Risk per 10,000 Registered Vehicle Years
10
8
6
4
2
0
9.12
1.92
5.28
1.52
6.21
1.31
7.62
1.56
CAR
PK
SUV
VAN
Vehicle Category

Conclusions

1. Projections based upon several methods of analysis, and using different sources of data are consistent.

2. Each of the six scenarios for reduction in average mass of the passenger vehicle fleet that were considered here result in an increase in risk of injury and fatality to crash involved occupants. Scenarios based upon reducing weight by a fixed number of pounds per vehicle increase the risk of injury as a result of a increase in the disparities of weights between passenger vehicles in the fleet. Mass reduction scenarios based upon proportional reductions of weight in the entire passenger vehicle fleet produce increases in expected numbers of injuries and fatalities due to collision with medium and heavy vehicles.

3. The risk of fatality and injury to crash involved drivers has decreased over the last 10 years.

4. The largest factor contributing to this decrease in risk is improvement in occupant protection, particularly the increase in seat belt use and the introduction of airbags. Increase in seat belt usage in the 1985 through 1998 time period can be attributed with decrease of fatal and incapacitating injuries of about 50% in single vehicle crashes and 41% in two vehicle crashes. The increase in driver air bags can be attributed with a decrease in fatal and incapacitating injuries of about 14% in single vehicle crashes and 20% in two vehicle crashes

5. Increases in passenger vehicle weight have also contributed to the reduction in injury and fatality risk.

Attachment 7:

Letter from R.C. Lange, Executive Director, Vehicle Integration, General Motors, and the NAS Panel on CAFE, Fleet Safety and Vehicle Mass, (March 20, 2001)

General Motors
North America Product Development
Vehicle Integration
Robert C. Lange, Executive Director
Safety Integration

March 20, 2001

Dr. David L. Greene
Center for Transportation Analysis
Oak Ridge National Laboratory
National Transportation Research Center
2360 Cherahala Blvd.
Knoxville, TN 37932

Dear David:

Reference: CAFE, Fleet Safety and Vehicle Mass

It was a pleasure meeting you on March 1, 2001 and I greatly appreciated our discussion. It is crucial that public policy debates regarding motor vehicle safety receive the full attention of all interested parties and I believe our discussion promoted that end. I believe at the end of my presentation, we agreed motor vehicle safety is a significant factor in the evaluation of the nation's current Corporate Average Fuel Economy policy.

Historically, CAFE standards have had an impact on manufacturers' decisions to produce vehicles with less mass (weight). This down weighting of the fleet has decreased motor vehicle safety from levels that could have been achieved with a heavier vehicle fleet. Moreover, a change to CAFE to raise the standard, will promote further mass reductions and consequently negatively impact motor vehicle safety by increasing the probability of injury and death in motor vehicle collisions. Such a policy outcome is ill advised from the standpoint of overall societal good and is absolutely unacceptable to motor vehicle safety researchers and public health advocates. There is no circumstance in which the social calculus of improved fuel economy (with whatever measure of societal "goodness" one chooses) can balance a degradation in the safety performance of the motor vehicle fleet. Desired energy or environmental objectives can and must be promoted without the loss in motor vehicle safety that would result as a necessary outcome consequent to increases in CAFE.

During our discussion that day, the hypothesis was raised that reducing the weight of every vehicle in the U.S. fleet by the same proportion would not reduce motor vehicle safety. The hypothesis was offered in the context of multiple vehicle crashes and assumed away all single vehicle crashes. Please recall, single vehicle crashes have greater risk in lighter vehicles as compared to heavier vehicles (in the light duty-passenger car and light-duty truck fleet). A fleet-wide decrease in vehicle mass due to CAFE demands, even achieved over a lengthy period – twenty or more years – will result in more death and injury as compared to a baseline fleet not mass reduced due to CAFE.

General Motors Corporation *Mail Code 480-111-N65* *30200 Mound Road* *Warren, MI 48090*
Phone 810-986-8764 *Fax 810-986-8353*

We discussed a related proposition – that a fleet wide proportional mass reduction (i.e., each vehicle mass reduced a specific proportional amount – say 5%) would yield a fleet wide velocity change profile identical to that which would have obtained absent the proportional mass reduction. This proposition is a hollow palliative and of no meaningful consequence. The relevant points are simply:

1. a lower mass fleet is less safe than one unchanged in mass from the current level, and
2. the lower mass vehicles placed into the normal stream of commerce during the transition from the current mass profile state, to some future proportionally mass reduced profile state are all less safe in collisions with current design level vehicles than they otherwise would be absent the mass reduction.

Further, the hypothesized technological solutions CAFE advocates promote as an antidote to mass reduction for improved CAFE, is a fiction. New safety technologies will be developed and broadly applied across the entire fleet, not uniquely applied to the lightest vehicles in an effort to make up the safety disadvantage inherent to such lighter vehicles.

Additionally, consider Dr. Leonard Evans comments.[1] on the potential exposure to the occupant population if the mass of all vehicles were to be reduced in the same proportion.

> "...replacing a fleet of identical mass cars with another fleet in which every car was 10 percent lighter would increase casualties by 10 percent. Although this result is simple and relatively reliable it cannot be generalized in any simple way to actual fleets that contain a wide mix of car sizes.
>
> "Klein, Hertz and Borener [1993] applied logit analysis to two-car crashes in Texas and Maryland to estimate the change in casualties that resulted from the reduction in the average mass of a car from 3700 pound in 1970 to 2700 pounds in 1982. In their calculations, they reduced the masses of all cars by the same proportion to achieve this 1000-pound reduction, so that the same relative mix of cars by mass was maintained. They find that such a change in the average mass of cars in the fleet would increase casualties by 14.3 percent (based on Texas data) and by 4.3 percent (based on Maryland data)."[2]

In the same paper, Dr. Evans continued, "...averaged over the mix of cars into which any particular car might crash, Evans and Frick [1993b] concluded that replacing any car in the fleet by a lighter one always led to a net increase in fatality risk."[3]

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[1] Leonard Evans, "Small Cars, Big Cars": What Is the Safety Difference?" Chance, 1994.
[2] Leonard Evans, "Car size and safety: a review focused on identifying causative factors." Paper presented to 14th Enhanced Safety of Vehicles Conference, Munich, Germany, May 1994.
[3] Leonard Evans, "Car size and safety: a review focused on identifying causative factors." Paper presented to 14th Enhanced Safety of Vehicles Conference, Munich, Germany, May 1994.

John Graham has reported similar conclusions. "The negative relationship between weight and occupant fatality risk is one of the most secure findings in the safety literature."[4] In response to those who have challenged his research, Dr. Graham said in a letter to Sen. John Ashcroft in June 2000,

> "...we estimated the CAFE regulation (from 1975 to 1985) was responsible for about half of the 1,000-pound decline in the average weight of new passenger cars, which resulted, once the entire fleet was regulated, in 2,200 to 3,900 additional fatalities to motorists per year in the USA. To the best of my knowledge, these findings have never been disputed in the peer-reviewed scientific literature."[5]

Single vehicle crashes cannot be eliminated from consideration when evaluating the risk to occupants of a fleet of lighter weight vehicles. Dr. Evans addressed this occupant risk in single vehicle crashes and its relationship to mass: "Risks in single-car crashes, two-car crashes, and crashes between cars and other vehicles all increase with decreasing car mass."[6]

In "Car size and safety," Dr. Evans again stated that less mass has a negative impact on occupants in multiple <u>and</u> single vehicle crashes.

> "... As 70% of car-occupant deaths occur in crashes involving only one car, and lighter/smaller cars increase driver risk in all of these, a smaller/lighter fleet leads to increased casualties regardless of any interactive effect in the two-car crash component. Because mass is a dominant causal factor in crashes that account for over 50% of car-occupant fatalities, mass reductions (even if size remained unchanged) would lead to casualty increases. Any measure that reduces the mass of cars, even if car size remains unchanged, will increase car-occupant fatalities."[7]

On March 1, the Panel also discussed the merits of NHTSA's research on the net safety impact of down-weighting cars, vans, SUVs, and other light trucks. NHTSA reported that reducing passenger car weight by 100 pounds would increase the risk of injury and death for passenger car occupants; however, NHTSA estimated that reducing light truck weight by 100 pounds might have a negative or positive net impact on safety.[8] NHTSA's reports also stated that the net impact on occupant injuries and fatalities from a 100-pound weight reduction for light trucks was not statistically significant.

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[4] Robert W. Crandall and John D. Graham, "The Effect of Fuel Economy Standards on Automobile Safety." <u>The Journal of Law and Economics</u>. April 1989.

[5] John D. Graham, Harvard Center for Risk Analysis. Letter to Senator John Ashcroft, Committee on Commerce, Science and Transportation. June 13, 2000.

[6] Leonard Evans, "Car Size or Car Mass: Which Has Greater Influence on Fatality Risk?" <u>American Journal of Public Health</u>, August, 1992.

[7] Leonard Evans, "Car size and safety: a review focused on identifying causative factors." Paper presented to 14th Enhanced Safety of Vehicles Conference, Munich, Germany, May 1994.

[8] Charles L. Kahane, "Relationship of Vehicle Weight to Fatality and Injury Risk in Model Year 1985 – 93 Passenger Cars and Light Trucks." NHTSA Report Number DOT HS 808 569, April 1997.

In 1997, Olga Pendleton and Ronald Hocking, Pen-Hock Statistical Consultants, published a report that analyzed NHTSA's studies on vehicle size and weight.[9] Following are several excerpts from the Pen-Hock report:

> "The fatality and injury rates from both the Kahane and Partyka NHTSA reports contain large uncertainties and are not based on scientifically supported statistical methodologies."
>
> "There is no scientific support for the ad-hoc methods used in the Kahane study."
>
> "The statement in the press release (and executive summary) neglect to mention that the -40 estimate for light trucks was found to be statistically insignificant....."This means that the effect is negligible and could well be zero or even positive (i.e., a reduction in light truck weight could increase fatalities)."
>
> "The moderate-to-critical [injury] estimates of 1,823 and -601 were obtained from the Partyka report. The logic used to obtain the injury crash rates of 1.6 and 1.3, respectively, which led to these estimates may be flawed."

While Dr. Kahane's report is of use in considering the safety effects of mass reductions in the motor vehicle fleet, there are methodological questions that preclude its use as a definitive assessment. The body of work from Evans and Graham provide a better balanced, comprehensive overview of the issue.

I have attached copies of the referenced Evans and Dr. Graham publications and a copy of the Pen-Hock report.

I look forward to the opportunity for additional exchanges with you to address CAFE's impact of safety. Please let me know if you have any questions.

Sincerely,

Robert C. Lange

cc: D. Minano
C. Sloane
T. Stephens

[9] Olga Pendleton and Ronald R. Hocking, "A Review and Assessment of NHTSA's Vehicle Size and Weight Safety Studies." Pen-Hock Statistical Consultants, October 1997.

Attachment 8:

GM Comments on Executive Order 13045
Regarding Disproportionate Impact
Of CAFE on Children

Regarding Executive Order 13045 and the disproportionate effect on children, NHTSA stated in the Request for Comments (Federal Register 67 at 5774) "[t]his request for comments and any subsequent proposal does not have a disproportionate effect on children". We disagree.

New CAFE standards, if so aggressive as to cause the elimination of entire classes of vehicles, or so as to force mass reductions significant enough to adversely affect collision performance in the real world, will certainly have the potential to disproportionately adversely affect the safety of child occupants. Several classes of vehicles – full size SUVs, mini-vans and to a lesser extent mid-size and small SUVs are the transport mode of choice for families. GM market data shows that among households with children aged 15 and younger owning SUVs and mini-vans, between 68% and 86% of those vehicles are used to "carpool" children once or more weekly.

Any CAFE standard that would eliminate full size SUVs or mini-vans, or that so significantly impacts the vehicle mass of these types as to degrade safety performance of the class, or force restrictions on to new vehicle volumes of such types will consequently force those households affected by the loss of choice, to transfer that child specific "carpool" function to other types of vehicles. The expected resultant level of crashworthiness protection provided to the effected child population will degrade because the most likely substitute vehicle types, mid-size and large passenger cars do not and can not provide the same level of crashworthiness protection as do full-size SUVs and mini-vans. The overall fatality rate for modern vehicle architectures with current technology content is 0.76 fatal vehicles per 10,000 registered vehicle years for mini-vans, 0.94 for full-size SUVs as compared to 1.15 for mid-size cars, 1.16 for large cars, and 1.67 for small cars.

A too aggressive CAFE standard clearly has the potential to drive large market distortions between what consumers need to satisfy their functional requirements and what manufacturers could affordably offer into the marketplace. Also, a too aggressive CAFE standard offers the potential to eliminate whole classes of vehicles.

Unfortunately the vehicle types that serve primarily as child conveyances, full-size SUVs and mini-vans, are the types most vulnerable to elimination from the marketplace due to CAFE. This is so, for it is those same vehicle types that inherently exhibit above average fuel consumption due to the embedded architectural features necessary to provide the intended functionality that enables their use for "carpooling" and other similar activities demanding of a high interior volume to footprint ratio. Any manifestation of new registration limits on these classes of vehicles of vehicles will adversely affect child passenger safety, for the alternative vehicle choices generally provide a level of crashworthiness protective capacity lower than that provided by the vehicles of choice for child passenger conveyance, full-size SUVs and mini-vans.