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Review of the August 2004 Proposed CARB Regulations to Control Greenhouse Gas Emissions from Motor Vehicles: Cost Effectiveness for the Vehicle Owner or Operator

Appendix C to the Comments of The Alliance of Automobile Manufacturers

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prepared by:

Sierra Research, Inc.
1801 J Street
Sacramento, California 95814
(916) 444-6666

At the request of the Alliance of Automobile Manufacturers, we have performed a detailed review of the assumptions and analyses supporting the proposed regulations, in order to determine whether the proposed standards meet the requirement of cost-effectiveness as defined by the CARB staff. This work included estimation of some of the changes in technology and some of the associated costs of the proposed standards, using some of the same assumptions as the CARB staff, combined with an independent review of some of critical engineering and economic elements in the ISOR materials.

Organization of the Report

Immediately following this introduction, Section 3 provides a summary of the CARB staff analysis that supports the proposed standards and identifies problems with certain assumptions and calculations used in that analysis. Section 4 summarizes the problems with CARB's analysis that have been identified by Sierra and that could be assessed in the time permitted in order to prepare comments for the current rulemaking. A series of attachments and electronic files (the latter filed with this report at CARB and available upon request from Sierra) provide more detailed analyses.

3.0 The CARB Staff Analysis

The Initial Statement of Reasons (ISOR) for the proposed regulation includes sections related to the following subject areas:

- The environmental and human health impacts of climate change;
- The feasibility and cost of technologies to reduce greenhouse gas emissions from motor vehicles;
- Estimates of the emissions reductions and net lifetime costs of various combinations of technologies;
- The procedure used for developing the proposed standards; and
- The estimated environmental and economic impact of the proposed standards.

Environmental and Health Effects

Although the section of the August 6 ISOR dealing with the environmental and human health impacts of climate change is designed to create the impression that the regulation of greenhouse gas emissions from vehicles sold in California will be beneficial, there has been no attempt to quantify the benefits. Neither is there any analysis showing that the proposed regulations would actually result in a net reduction in greenhouse gas emissions on a global basis. (This is a significant issue given the flexibility manufacturers have under the federal CAFE standards to offset the sale of vehicles with higher fuel economy in California with the sale of vehicles with lower fuel economy in other states.) This issue is being addressed in more detail in other studies.

Baseline Emissions Estimates

The ISOR materials characterize methane from motor vehicles as "negligible" and nitrous oxide emissions from motor vehicles as "decreasing . . . due to increasingly stringent NOx control technologies." There is no suggestion in the report that specific control measures for either of these two compounds need to be pursued; however, the report says that including methane and nitrous oxide in the calculation of total greenhouse gas emissions "may encourage more development work." CARB's analysis assumes baseline emissions of methane and nitrous oxide are 0.005 and 0.006 g/mi, respectively. Multiplied by their respective global warming potential (GWP), the CO_2-equivalent emissions are 0.12 g/mi for methane and 1.78 g/mi for nitrous oxide. (For comparison purposes, the CO_2 emissions of a passenger car achieving the 27.5 mpg CAFE standard are 322.5 g/mi.)

HFC-134a emissions from air conditioning systems are identified as a significant source of greenhouse gas emissions that could be further controlled. The "direct" emissions of HFC-134a (i.e., releases to the atmosphere from leaks, accidents, servicing, and dismantling) are estimated to average 85 grams per year (which is equivalent to 110,500 grams of CO_2). Table 4 summarizes the staff's estimates of baseline emissions for a passenger car that just meets the 27.5 mpg CAFE standard.

Table 4
Baseline Greenhouse Gas Emissions from Passenger Cars

Source	Emissions	CO_2-Equivalent Emissions	Percent of Total CO_2-Equivalent
Exhaust CO_2 during CAFE Testing	322.48 g/mi	322.48 g/mi	92.46%
Exhaust Methane	0.005 g/mi	0.12 g/mi	0.03%
Exhaust Nitrous Oxide	0.006 g/mi	1.78 g/mi	0.51%
Direct HFC-134a Emissions	0.007 g/mi	9.00 g/mi	2.58%
"Indirect" AC Emissions (CO_2)	15.40 g/mi	15.40 g/mi	4.42%
TOTAL	-	348.78 g/mi	100.00%

Emissions Control Technology Analysis

The technology assessment contained in the August 6 ISOR is a slightly revised version of the assessment contained in a draft report published on April 1, 2004, and relies heavily on an interim draft report published by the Northeast States Center for a Clean Air Future (NESCCAF). The potential for reducing exhaust CO_2 emissions is addressed in two ways: (1) reducing emissions during the CAFE test procedure; and (2) reducing emissions through reduced air conditioning compressor load. The CAFE-related technologies described in the ISOR include the following:

- Variable valve lift and timing;
- Turbocharging with engine resizing;
- Cylinder deactivation;
- Increased number of transmission gears;
- Automatically shifted manual transmissions;
- Electric power steering;
- Higher efficiency alternators;
- Gasoline direct injection;
- Hybrid drivetrains;
- Engine friction reduction;
- Reduced aerodynamic drag; and
- Lower rolling resistance tires.

Although there is a general discussion of the way in which each of the above-listed technologies can reduce CO_2 emissions, there is no reference to any literature describing the magnitude of the CO_2 emission reductions that are achievable. This may result from the fact that the relevant literature addresses the technological issue in its most commonly understood form, by describing potential effects on fuel economy or fuel consumption, not as methods to reduce CO_2. There is also no reference to the CO_2 reduction potential associated with weight reduction. In fact, two tables from the NESCCAF report (II-8 and III-1) summarizing the CO_2 reduction potential of various technologies were modified to delete estimates for weight reduction before they were reproduced in the August 6 ISOR. The ISOR points out that CARB "will not rely on weight reductions in setting its climate change emission standards," but also states that "manufacturers would still have the option of lowering weight to improve CO_2 emission performance.". One effect of this omission is to deprive CARB of any quantitative estimate by the CARB staff of the likely weight reductions for some vehicle models in California if the proposed rules take effect, or likely changes in the overall weight of the California new-vehicle fleet if CO_2 emissions are to be controlled.

Table 5 summarizes the estimates contained in the ISOR for the effect of individual technologies. Some of the estimates were prepared by AVL under contract to NESCCAF. Others, however, and in particular the "advanced hybrid" estimate, were the sole product of the CARB staff and apparently differed from the estimates prepared by AVL. Based on explanations provided by AVL during previous CARB workshops, the estimates shown in Table 5 have not consistently been adjusted to a "constant performance" basis. (However, the effect of combinations of technologies described later includes adjustments to maintain constant performance.) It should be noted that the effect of the variable displacement air conditioning compressor is apparently based on operation with the air conditioner turned on. There is proportionally less benefit when accounting for the fraction of time the air conditioner is used.

The CO_2 emissions emitted as a result of the power required to run the air conditioning compressor are referred to in the ISOR as "indirect" CO_2 emissions. The ISOR says that variable displacement compressors can be used in conjunction with "better control systems and condensers and evaporators with improved heat transfer" to reduce the CO_2 emissions associated with running the compressor by 50%. This conclusion appears to be based on the assumption that the engine load requirements for "externally controlled VDCs are lower than those of fixed displacement compressors," which are used by most vehicles produced for sale in the U.S. It was also assumed that the amount of outside air would be reduced, although the amount was not quantified. The ISOR says that the net effect of these changes will be reductions in CO_2 emissions ranging from 1.9-2.5% depending on the vehicle category. Large cars were projected to achieve a 2.3% reduction. That reduction is based on an assumed 29% AC utilization factor in the state of California. The ISOR also states that indirect emissions can be reduced by elimination of "air reheat." Because this requires automated climate controls, it was not assumed in CARB's feasibility analysis. The analysis also did not quantify the potential benefits of revising glass angles, increased cabin insulation, and changing vehicle color.

Table 5 CARB Staff Estimates of CO_2 Reductions Achievable in "Large Cars" and Associated Fuel Economy Changes	CO_2 Change	MPG Change
Coupled Cam Phasers (CCP)	-4%	+4.2%
Dual Cam Phasers (DCP)	-4%	+4.2%
Discrete Variable Valve Lift (DVVL)	-4%	+4.2%
Continuously Variable Valve Lift (CVVL)	-6%	+6.4%
Turbocharging (with engine resize) (Turbo)	-8%	+8.7%
Cylinder Deactivation (Deact)	-6%	+6.4%
5-Speed Automatic Transmission (A5)	-1%	+1.0%
6-Speed Automatic Transmission (A6)	-3%	+3.1%
Automatically Shifted Manual Transmission (AMT)	-7%	+7.5%
Electric Power Steering (EPS)	-1%	+1%
Higher Efficiency Alternator (ImpAlt)	-1%	+1%
Gasoline Direct Injection-Stoichiometric (GDI-S)	-1%	+1%
Variable Displacement AC Compressor (VDC)	-9%	+9.9%
Aggressive Shift Logic, Improved Torque Converter + Reduced Aero Drag, Rolling Resistance, Engine Friction	-5%	+5.3%
Camless Valve Actuation (i.e., VVLT)	-16%	+19.0%
Mild Hybrid (42-volt, 10 kW) (ISG)	-6%	+6.4%
Advanced Hybrid	-54%	+117.4%

"Direct" AC emissions (i.e., emissions of the refrigerant itself) are estimated at 6 g/mi CO_2-equivalent from "regular" leakage; 2 g/mi from "irregular" emissions (service and accidents), and 0.5 g/mi from eventual scrappage. The ISOR estimates that leakage emissions can be reduced by 50% through "upgrades to a few key components (e.g., compressor shaft seal)"; however, there is no testing or other documentation referenced to support this estimate.

Replacement of HFC-134a with HFC-152a in a system with 50% leakage reduction is estimated to reduce total CO_2-equivalent emissions by 94%, primarily due to the 91% lower GWP of HFC-152a.

Individual Technology Costs

The costs of the various design changes assumed by the CARB staff are shown in Table 6. These estimates were usually based on the cost estimates contained in the NESCCAF report. Those estimates were based primarily on vendor prices or other sources (the specific sources of which are undocumented) estimated by Martec, Inc., a NESCCAF contractor, that were multiplied by a factor of 1.4 to translate them to a retail price

Table 6
CARB Staff Estimates of Retail Price Increase
For Various Technologies Applied to a "Large" Car
and Associated Fuel Economy Changes

	Price	MPG Change
Coupled Cam Phasers (CCP)	$161	+4.2%
Dual Cam Phasers (DCP)	$196	+4.2%
Discrete Variable Valve Lift (DVVL) (with DCP)	$357	+4.2%
Continuously Variable Valve Lift (with DCP)	$581	+6.4%
Turbocharging (with engine resize)	-$210	+8.7%
Cylinder Deactivation (Deact)	$113	+6.4%
5-Speed Automatic Transmission (A5)	$140	+1.0%
6-Speed Automatic Transmission (A6)	$105	+3.1%
Automatically Shifted Manual Transmission (AMT)	$0	+7.5%
Electric Power Steering (EPS)	$39	+1%
Higher Efficiency Alternator (ImpAlt)	$56	+1%
Gasoline Direct Injection-Stoichiometric (GDI-S)	$259	+1%
Modified AC Compressor and HFC-152a refrigerant	$88	+9.9%
Aggressive Shift Logic, Improved Torque Converter + Reduced Aero Drag, Rolling Resistance, Engine Friction	$125-145	+5.3%
Camless Valve Actuation (i.e., VVLT)	$637	+19.0%
Mild Hybrid (42-volt, 10 kW, motor assist) (ISG)	$1107	+6.4%
Advanced Hybrid	$4009	+117.4%

equivalent (RPE) basis. However, CARB staff discounted some of Martec's cost estimates by 30% to account for "unforeseen innovations in design and manufacturing" that the ISOR says will occur based on previous experience. CARB also reduced Martec's cost estimate for replacing overhead valve engines with dual overhead cam engines by $250 for V-6 engines and $300 for V-8 engines to back out the cost premium for an aluminum block. On an RPE basis, the cost of the conversion was reduced by $350 for V-6 engines and $420 for V-8 engines, cutting in half Martec's estimate for the cost premium of a dual overhead cam (DOHC) engine compared to an overhead valve (OHV) engine. How CARB determined the cost premium for an aluminum block was not explained.

CARB's estimated cost premium for DOHC engines has a substantial effect on the cost estimates for adding fuel economy improvement technology to light-duty trucks because CARB's analysis assumes that all future truck engines use technology that requires DOHC engines to meet the proposed greenhouse gas emissions standards. In fact, all trucks not in the "large" category are assumed to use DOHC engines under the 2009 baseline forecast CARB has used.

As shown in Table 6, the RPE for turbocharging is -$210; the claimed cost savings is based on the assumption that V-6 engines can be replaced with less expensive inline engines when turbocharging is used to achieve constant performance. There are other downward adjustments to the RPE costs for other technologies that CARB also assigns when turbocharging is assumed. These adjustments are not described in the ISOR; however, they can be seen in the spreadsheets that CARB used to construct the values reported.

2009 Baseline Forecast

Before using combinations of the technologies listed in Table 6 to determine the "maximum feasible" level of exhaust CO_2 reductions, an estimate was made by the CARB staff (and/or the NESCCAF contractors or staff) to predict how CO_2 emissions will change by 2009 in the absence of a CARB regulation. The 2009 "future baseline" was constructed assuming the same reduction in 0-60 mph acceleration times that were used in the NESCCAF report. CARB followed the assumption in the NESCCAF interim draft report that there would be no significant increase in weight for light-duty trucks, despite a clear trend. The rationale for ignoring the weight trend for trucks is that changes in federal CAFE standards will stop that trend. (Implicit in CARB's analysis is the assumption that manufacturers will respond to increased CAFE requirements by <u>reducing vehicle weight</u> from what it otherwise would have been, which underscores the importance of the CARB staff's error in failing to consider weight reduction as a consequence of the proposed rule.) The forecast also assumes increased use of variable valve lift and timing and transmissions with a greater number of gears. (As discussed below, these future baseline assumptions predict that manufacturers will deliberately switch to more expensive transmissions and engine technology, instead of using less expensive alternatives that would simultaneously improve fuel economy.)

The 2009 baseline technology assumptions are said to be based on "market research" by one of the NESCCAF contractors. According to the NESCCAF report, Martec, Inc. "conducted detailed market research into Original Equipment Manufacturer (OEM) product plans and developed a database of estimated 2009 vehicle platforms under baseline conditions." (Based on our private communications with OEMs representing well over 50% of total vehicle sales, there was no such disclosure of product plans to Martec. To the contrary, it appears that Martec may have contacted and attempted to interview the engineering or product staffs for some OEMs, but did not receive any concrete information.) The technology combinations assumed to be representative of the projected 2009 baseline are shown in Table 7.

Table 7

CARB's Projected 2009 Baseline Assumptions

Vehicle Category	Technology	CO_2 Change*	Cost Change
Small Cars	DVVL, DCP, A5	-2.6%	+$308
Large Cars	DVVL, DCP, A6	-6.6%	+$427
Minivans	DVVL, CCP, A5	-6.4%	+$315
Small Trucks	DVVL, DCP, A6	-9.0%	+$427
Large Trucks	CCP, A6	-5.5%	+$126

*Relative to the 2002 baseline.

To put the significance of these technology assumptions into context, consider that Table 6 shows that automatically shifted manual transmissions can be used to increase the fuel economy of a large car by 7.5% (a 7% CO_2 reduction) at zero cost. The projected 2009 baseline instead assumes that manufacturers will spend $427 to reduce CO_2 by only 6.6%. As described below, the relatively low cost estimates that CARB has made for achieving further reductions in fuel consumption and CO_2 emissions result from undoing the technology changes that are in the projected baseline.

Emission Reduction and Cost Estimates for Combinations of Technology

The ISOR includes tables showing the effect of various technology combinations on the cost and greenhouse gas emissions of future vehicles. The combinations were apparently suggested in consultation with AVL and represent technologies that are compatible on an engineering basis. Most of the emissions reductions were based on the use of AVL's vehicle simulation model (called "CRUISE"); however, the final estimates include the use of multiplicative and subtractive adjustment factors to account for certain technologies.

To achieve reductions in CO_2 emissions beyond the projected 2009 baseline case, CARB concludes that the optimum package of "near-term" design changes for "large cars" consists of (using the abbreviations shown in Tables 5 and 6 above) GDI-S, DCP, Turbo, AMT, EPS, ImpAlt, VDC, and a package of miscellaneous improvements consisting of aggressive shift logic, reduced aerodynamic drag, tires with lower rolling resistance, and reduced engine friction. This package is projected to achieve a 22.1% reduction in CO_2 emissions compared to the projected 2009 baseline while simultaneously reducing the price of the car by $65.

It is not possible to determine how this price reduction was calculated from the ISOR; however, spreadsheets obtained from CARB make it possible to duplicate most of the numbers. As shown in Table 7, the projected 2009 baseline vehicle is assumed to be equipped with discrete variable valve lift, dual cam phasers, and a 6-speed automatic transmission. Those technologies are estimated to increase the cost over the 2002 baseline by $427 while reducing CO_2 emissions by just 6.6%. Under the proposed near-term standards, CARB assumes that the 6-speed automatic transmission is replaced by an automatically shifted manual transmission that costs $105 less. The V-6 engine with DVVL is also assumed to be replaced by an inline 5-cylinder turbocharged GDI-S engine that costs almost $300 less.[1] Offsetting this cost savings is $87.50 for an alternative air conditioning system, $39 for electric power steering, $56 for an improved alternator, and $145 for the miscellaneous upgrades (reduced aero drag, etc.). CARB reports that the net effect is a $65 cost reduction. (Using CARB's numbers, we independently calculated a $58 reduction, which is the number used in the draft version of the ISOR published on June 14.)

Based on the analysis described above, the CARB staff is claiming that, in the absence of a regulation, manufacturers will incorporate design changes into large cars that will increase their price by $427 and reduce their fuel consumption by 6.6%. But under the proposed regulation, manufacturers will be able to make design changes costing only $362 that provide an additional reduction in fuel consumption of 22.1%. In constructing the final cost estimates, the CARB staff estimates that an average price increase of $219 will be associated with meeting the near-term standards for large cars. This is based on the assumption that half of the vehicles will use the above-described technology combination that saves $65 and the other half will use a combination of technologies that does not include turbocharging and costs $504. (The alternative technology combination benefits from the assumed use of the transmission that saves $105, but not from the savings assumed from resizing the engine.) No rationale is stated for why the option that saves money would not be universally used.

Table 8 summarizes the technology combinations and incremental costs (over the projected 2009 baseline) that CARB assumes will be used to comply with the proposed standards. It should be noted that the extent to which the technologies are required for compliance depends on each individual manufacturer's baseline fuel economy.

There are several curious aspects of the combinations listed in Table 8. First, as noted above, the CARB staff has constructed average cost estimates that do not rely on the lowest cost technology combinations. In addition, there are several technology combinations included in the average that appear unrealistic in terms of emissions compliance and technological readiness. These are shown in **bold** font in the table. For example, it is assumed that the use of a Diesel engine (HSDI) is feasible in small trucks despite any demonstration that emissions control technology is available to achieve the applicable NOx emissions standard with a Diesel engine. Other questionable technologies are electro-hydraulic continuously variable valve actuation (CVAeh) and gasoline homogeneous charge compression ignition (gHCCI). Both of these technologies are at a relatively early stage of development and it is not clear that they can be cost-effectively employed in the mid-term. The ISOR materials and related documents from the CARB

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[1] The total cost savings associated with the assumed ability to convert from Vee to inline engines through the use of turbocharging cannot be accurately determined from tables in the ISOR. The backup spreadsheets show that turbocharging combined with engine resizing is assumed to reduce the cost of several other technologies in addition to the basic engine itself.

staff provide no evidence or reasoned analysis to support an assumption that those technologies can be employed in a cost-effective manner during the forecasted period.

Table 8
Summary of Technology Combinations Assumed by CARB Staff

	Vehicle Class	Technologies	RPE	Avg. RPE
Near-Term	Small Car	DVVL, DCP, ATM, EPS, ImpAlt	-$149	$382
	Small Car	GDI-S, DCP, Turbo, AMT, EPS, ImpAlt	$812	
	Large Car	GDI-S, Deact, DCP, AMT, EPS, ImpAlt	$504	
	Large Car	GDI-S, DCP, Turbo, AMT, EPS, ImpAlt	-$65	
	Minivan	CVVL, CCP, AMT, EPS, ImpAlt	$696	$358
	Minivan	GDI-S, DCP, Turbo, AMT, EPS, ImpAlt	$572	
	Small Truck	Deact, DVVL, CCP, AMT, EPS, ImpAlt	$244	
	Small Truck	GDI-S, DCP, Turbo, AMT, EPS, ImpAlt	-$77	
	Large Truck	Deact, DVVL, CCP, A6, EHPS, ImpAlt	$663	
	Large Truck	Deact, DVVL, CCP, AMT, EHPS, ImpAlt	$551	
Mid-Term	Small Car	CVVL, DCP, AMT, ISG-SS, EPS, ImpAlt	$1071	$1,204
	Small Car	GHCCI, DVVL, ICP, AMT, ISG, EPS, eACC	$1459	
	Large Car	CVAeh, GDI-S, AMT, EPS, ImpAlt	$761	
	Large Car	GHCCI, DVVL, ICP, AMT, ISG, EPS, eACC	$1575	
	Large Car	GDI-S, DCP, Turbo, A6, ISG, EPS, eACC	$975	
	Minivan	CVAeh, GDI-S, AMT, EPS, ImpAlt	$1099	$1,326
	Minivan	GDI-S, CCP, AMT, ISG, Deact, EPS, eACC	$1589	
	Small Truck	Deact, DVVL, CCP, A6, ISG, EPS, eACC	$1470	
	Small Truck	CVAeh, GDI-S, AMT, EHPS, ImpAlt	$742	
	Small Truck	HSDI, AMT, EPS, ImpAlt	$1141	
	Large Truck	CVAeh, GDI-S, AMT, EHPS, ImpAlt	$1495	
	Large Truck	Deact, DVVL, CCP, A6, ISG, EPS, eACC	$1759	

Adverse Attribute Impacts

With the exception of an assumed $50 cost for exhaust system modifications to deal with the increased noise of cylinder deactivation technology, there has been no concrete recognition of how the effects of the technologies assumed in CARB's analysis will affect noise, vibration, and harshness (NVH) or driveability, or how adverse impacts on these attributes will be mitigated. This is a significant issue with respect to several of the technologies. For example, significant benefits are assigned to the use of automatically shifted manual transmissions (AMTs). However, NESCCAF subcontractor AVL has advised that its modeling of AMT did <u>not</u> address the driveability problem associated with a loss of torque transmission during gear changes with this technology. As stated in an appendix to the NESCCAF report prepared by AVL, "In practice there is still a loss of torque during the shift when compared to the automatic transmission" and "the U.S. market does not like the effect of the torque loss during the shift on driveability." To address this problem, AVL indicated that AMTs may require "electric motors to augment the torque applied to the driveline during shifts. In this form, the shift behavior is more like that of an automatic transmission." However, the increased cost and complexity associated with electric motor augmentation to address the driveability problem was not considered in the NESCCAF study.

Standards Setting Process

According to the ISOR, the standards are based on what can be achieved by applying cost-effective technologies to "the manufacturer with the highest average weight vehicles to ensure all manufacturers can comply with the standards." The ISOR says that the process involved starting with the achievable exhaust CO_2 emissions demonstrated in the NESCCAF study (using modeling results for the technology combinations shown in Table 8) and then adjusting this value to account for "the CO_2 equivalent reductions achievable from improved mobile air conditioning systems." For example, if a large passenger car was estimated to be able to achieve 245 g/mi CO_2 exhaust emissions in the near-term, the next step was to subtract 11.1 g/mi from 245, reducing the standard to 234. The value of 11.1 g/mi is the estimated reduction in direct and indirect emissions from the air conditioning system that can be achieved by using a variable displacement air conditioning compressor and leak reduction technology. A vehicle using this technology is given a "credit" of 11.1 g/mi, which is subtracted from the exhaust CO_2 emissions. (For the mid-term standards, the air conditioning adjustment increases to 16.6 g/mi, which is the reduction associated with a variable displacement compressor, leak reduction technology, and replacement of HFC-134a refrigerant with HFC-152a.)

Following the air conditioning adjustment, the next step in determining the standard was described as "include vehicle emissions of CH_4 and N_2O." This would involve adding 1.9 g/mi to the standard. Each vehicle is assumed to emit 1.9 g/mi CO_2-equivalent of methane and nitrous oxide unless the manufacturer submits test data showing a lower emission rate.

The next step in the process was described as "derive the regression lines for setting the near and mid term climate change emissions standards." This apparently involved plotting the "Maximum Feasible" CO_2-equivalent emissions vs. test weight for the example vehicles used in the NESCCAF study and drawing a line through the near-term and mid-term data points. Table 9 shows the "Maximum Feasible" CO_2 levels for the five different vehicle categories, as shown in Tables 6.1-2 and 6.1-3 of the ISOR. (The values reflect the air conditioning adjustment and the adjustment for methane and nitrous oxide described above.) The test weight for each vehicle is based on the values plotted in Figures 6.1-1 and 6.1-2 of the ISOR. (The values for the minivan are not plotted, so the test weight used for the minivan is unknown.)

Table 9
"Maximum Feasible" CO_2 Levels Reported by CARB

Vehicle Category	Test Weight	Near-Term (g/mi CO_2)	Mid-Term (g/mi CO_2)
Small Car	3000	209	190
Large Car	3625	241	210
Minivan	Not plotted	283	265
Small Truck	4250	303	284
Large Truck	5500	387	354

The proposed standards are points on the graphs where the lines connecting the near-term and mid-term maximum feasible CO_2 levels intersect the test weight of the manufacturer with the "heaviest fleet" (considering only the top six manufacturers by sales volume). Based on an analysis of California-specific registrations, General Motors was determined to be the manufacturer with the "heaviest overall average test weight." The average test weight of GM's cars and LDT1s was calculated to be 3,470 pounds. The weight of GM's LDT2s was calculated to be 5,113 pounds. Where these values intersect the "regression lines" determines the level of the proposed standards.

It should be noted that the technique described above for determining the appropriate value of the standards renders meaningless the weight adjustment that was supposed to have been made to the projected 2009 baseline for small cars. Even if the weight adjustment were used to plot the points used to draw the line showing the relationship between CO_2 and weight for the PC/LDT1 vehicles, by using the <u>current</u> weight of GM's vehicles to find the point on the line associated with the proposed standards, no credit was given for the effect that projected weight increases would have in the future. (In addition, CARB did not account for the weight of GM's Medium-Duty Passenger Vehicles [e.g., Hummer] that are required to comply with the proposed standards.)

A four-year phase-in period is proposed for both the near-term and mid-term standards. In 2009, the standard is set at a level that CARB says is "20% of the way from the highest 2002 baseline CO_2 level of any of the major manufacturers (323 g/mi CO_2 equivalent/mi for PC/LDT1, 439 g/mi CO_2 equivalent/mi for LDT2) to the near-term standard." Table 10 shows the proposed standards and the equivalent fuel economy levels. The 20/40/70/100 phase-in for the mid-term standards is calculated based on the difference between the final near-term standards and the final mid-term standards.

Table 10

Proposed "Climate Change Emission Standards"

		---- Passenger Cars/LDT1 ----		-------- LDT2/MDPV --------	
	Year	Equivalent CO_2	Fuel Economy*	Equivalent CO_2	Fuel Economy*
Near-Term	2009	323 g/mi	27.6 mpg	439 g/mi	20.3 mpg
	2010	301 g/mi	29.7 mpg	420 g/mi	21.2 mpg
	2011	267 g/mi	33.5 mpg	390 g/mi	22.9 mpg
	2012	233 g/mi	38.4 mpg	361 g/mi	24.7 mpg
Mid-Term	2013	227 g/mi	39.4 mpg	355 g/mi	25.1 mpg
	2014	222 g/mi	40.3 mpg	350 g/mi	25.5 mpg
	2015	213 g/mi	42.0 mpg	341 g/mi	26.2 mpg
	2016	205 g/mi	43.7 mpg	332 g/mi	26.8 mpg

* Assuming use of conventional, HFC-134a air conditioning systems and baseline methane/N_2O emissions

<u>Alternative Compliance Methods</u> - Although AB 1493 requires CARB to adopt regulations that allow manufacturers to use "alternative" compliance methods, the ISOR describes restrictions on the allowable alternatives that would eliminate all alternatives except for emissions reductions from vehicles subject to the statute in California.

Estimated Cost of Compliance

According to the ISOR, the ultimate (year 2016) cost increase associated with the proposed standards is $626 for passenger cars and LDT1s and $955 for LDT2/MDPV. These were reported to be the average costs for the six largest manufacturers. These costs were based on assumptions regarding the fraction of each manufacturer's production that would require the most effective combinations of technology available in the "mid-term." However, the assumed technology use fractions were obviously inconsistent with the assumptions used to set the standards. For example, the PC/LDT1 standards are based on mid-term technology being applied to 100% of GM vehicles, but the cost estimate is based on the assumption that GM will be required to apply mid-term technology to only 34% of its 2016 model year PC/LDT1 vehicles. Similar underestimates of required technology use were made for other manufacturers. When these discrepancies were pointed out by Sierra, CARB staff agreed that an error had been made. Revised estimates of cost were subsequently provided in the form of revised version of selected tables and text from the August 6th version of the ISOR.

Based on the revised CARB staff estimates, the cost increase associated with the proposed 2016 standards is $1,064 for passenger cars and LDT1s and $1,029 for LDT2/MDPV. Costs of the 2012 standards, originally estimated at $292 for PC/LDT1 and $308 for LDT2/MDPV, were increased to $367 for PC/LDT1 and reduced to $277 for LDT2/MDPV.

The ISOR says that vehicle owners will realize a net savings as a result of the improved fuel economy. The money saved as the result of improved fuel economy is projected to exceed the cost of the design changes required to meet the proposed standards by a wide margin. Although no estimates of the per-vehicle fuel cost savings appear in the ISOR, Sierra was provided Excel files showing the calculations used to determine fuel cost savings. For passenger cars, the spreadsheets are set up to sum fuel costs over a 16-year period and convert them to an NPV using a discount rate of 5%. For light-duty trucks, fuel cost savings are summed over a 19-year period and converted to an NPV using a 5% discount rate. Table 11 summarizes the technology cost estimates and fuel savings estimated by CARB staff. Lifetime reductions in total gasoline consumption and CO_2 emissions were estimated in the CARB spreadsheets based on an assumed 202,329 lifetime average mileage for passenger cars and 223,969 lifetime average mileage for light-duty trucks. The spreadsheet calculations do not account for any increase in automobile travel induced by lower fuel costs (i.e., a "rebound effect").

Table 11
CARB Estimates of Cost and Fuel Savings
for the Proposed 2016 Standards

Standards	Increased Vehicle Price	Gallons of Gasoline Saved	Present Value of Gasoline Savings
2012 PC/LDT1: 233 g/mi	$367	1,630	$1,980
2016 PC/LDT1: 205 g/mi	$1,064	2,283	$2,773
2012 LDT2/MDPV: 361 g/mi	$277	1,881	$2,215
2016 LDT2/MDPV: 332 g/mi	$1,029	2,624	$3,090

Projected Effect on Vehicle Sales and the State's Economy

According to the August 6 ISOR, "The economic impact analysis is based on the staff assessment that the reduced vehicle operating cost resulting from the regulation will be sufficiently attractive to new car buyers to compensate for the vehicle price increase, which results in vehicle sales that are unchanged from the levels that would have been the case without the regulation." However, there was also an analysis described using a model called "CARBITS" that supposedly accounted for the combined effect on sales of a vehicle price increase and an operating cost reduction. The computer program or programs was not provided by CARB and access to it has thus far been refused by the apparent source of the model at the University of California at Davis. Some materials related to the program, including an executable version of one or more of the models included in CARBITS, have been provided by CARB and are being evaluated by National Economic Research Associates. According to the ISOR, the CARBITS model predicts that new car sales will increase slightly in the short term and decline slightly beginning in 2013. Using the EMFAC model, the CARB staff concludes that there will be no significant effect on ozone precursors.

The ISOR also discusses the results of modeling of the entire state economy (using the "EDRAM" model) to account for the net effect of the increased vehicle costs and the operating cost reductions. The lifetime operating cost reductions are based on CARB's estimates that passenger cars accumulate a total of 202,000 miles over a 16-year lifetime and LDT1 and LDT2 vehicles accumulate 219,000 miles and 224,000 miles, respectively.[1] Based on the assumed net savings to California motorists, the ISOR projects that the money saved will be spent in other areas and result in a net increase of 3,000 jobs in 2010, 55,000 jobs in 2020, and 83,000 jobs in 2030. The conclusion stated in the ISOR is "The proposed climate change regulation has a net positive impact on the State's economy."

Analysis of the "Rebound Effect"

A 1999 paper by Greene, et al, from Oak Ridge National Laboratory[2] describes the body of research that supports the existence of a "rebound effect" when automotive fuel economy increases. The rebound effect is basically an extension of the "Law of Demand"—when the cost of something decreases (in this case vehicle travel), there is a natural tendency for consumers to demand more of it. As Greene explains, numerous researchers have documented that a rebound effect exists for increasing automotive fuel economy and Greene concludes that the long-term effect is 20%. In other words, a 100% improvement in fuel economy induces a 20% increase in vehicle travel. In its recent rulemaking regarding light-duty truck fuel economy standards,[3] the National Highway Traffic Safety Administration (NHTSA) also addressed the rebound effect and concluded that the magnitude of the effect was the same as Greene had estimated.

Clearly, the rebound effect would make it difficult for CARB to justify adopting regulations that would have the effect of increasing vehicle travel with the attendant increase in ozone precursor emissions. However, the ISOR claims that the rebound effect will not be significant in California because of "higher income and worse traffic congestion." The stated rationale is that "people value their time highly enough that a few pennies in operating cost savings per mile is not going to encourage them to drive more." The ISOR also contains the statement that "people already drive all they need."

The ISOR says that CARB and the California Energy Commission funded the University of California, Irvine (UCI) to estimate how a regulation resulting in reduced vehicle operation cost (i.e., higher fuel economy, a term that is never used in the ISOR) would affect vehicle miles traveled. According to the ISOR, the UCI study found "when California household income and transportation conditions are accounted for, the rebound estimate is very small." The increase in VMT associated with a 25% reduction in consumption was estimated to be 0.32% in year 2020. Based on the literature, the expected effect would have been 2.5% to 5.0%. As documented in reports prepared by

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[1] The problems with these estimates are described in detail below and in Attachment C-3.

[2] David L. Greene, et al, "Fuel Economy Rebound Effect for U.S. Household Vehicles," The Energy Journal, Vol. 20, No. 3, 1999.

[3] Light Truck Average Fuel Economy Standards, Model Years 2005-2007 (Docket No.: NHTSA-2002-11419 or 68 FR 16867; April 7, 2003).

NERA and Robert Crawford, the results of the UCI study are inaccurate because of mistakes made in formulating the models used in the study—when those mistakes are corrected, the magnitude of the rebound effect calculated using the UCI methodology is essentially the same as that found elsewhere in the literature. The ISOR also states that the travel demand models used by the Southern California Association of Governments and the Bay Area Metropolitan Transportation Commission show no significant rebound effect. The following section of this report contains an explanation of why travel demand models are not capable of estimating the rebound effect.

4.0 Critique of CARB's Analysis

As mentioned in the Summary section, there are a number of problems with the CARB staff analysis that lead to an underestimate of the cost of compliance and an overestimate of the reductions in fuel consumption, fuel cost, and CO_2 emissions associated with the proposed regulations. Three of those problems are (1) insufficient engineering resources to make the required design changes by 2016; (2) the assumption that design changes necessary for compliance will be deployed nationwide; and (3) the failure of CARB staff to account for the effect of MDPVs on the cost of compliance with the standards proposed for light-duty trucks. The other problems we have identified are as follows:

1. The price of passenger cars in the 2009 baseline (no regulation) case is inflated by unrealistic assumptions about expensive technology changes that will be made in the absence of a regulation.
2. CARB vehicle cost estimates are based on an unrealistic 40% markup factor to vendor-supplied parts prices, which is less than half of the markup required to account for manufacturer costs for research, development, engineering, warranty, overhead, sales and marketing, profit, and dealer margin.
3. CARB failed to account for the integration costs of certain vendor-supplied components that cannot merely be added without other design changes.
4. Cost estimates for technology changes provided by a contractor were arbitrarily discounted by 30% to account for "unforeseen innovations in design and manufacturing."
5. Credit was claimed for significant reductions in aerodynamic drag and rolling resistance despite evidence that customers will not accept such changes and despite the fact that customers do not routinely use OEM replacement tires.
6. CARB assumed that technologies that simultaneously <u>reduce</u> vehicle price and <u>improve</u> fuel economy will be used <u>only if a regulation is adopted</u>.
7. CARB failed to account for California's average 8% sales tax in doing its calculations of net lifetime costs of technology changes.
8. The fuel economy benefits of automatic transmission improvements were inadvertently assigned to both manual transmissions and automatic transmissions.
9. Fuel cost savings are estimated using a single set of driving cycles, and without considering the impact of the relevant technologies based on driving patterns that more accurately represent the way that typical Californians drive.
10. Fuel cost savings were based on inflated estimates of vehicle service life resulting from an obvious mathematical error in CARB's analysis of odometer data from the State's vehicle inspection and maintenance program.
11. The present value of fuel cost savings is based on the unrealistic combination of a 5% discount rate and a 16-19 year payback period, which substantially overstates the value to new vehicle purchasers.
12. The fuel savings calculated for light-duty trucks is substantially overstated by CARB's failure to account for the fuel economy improvement required under the

2007 federal standards and by CARB's failure to account for the effect of minivans on baseline fuel economy.

13. Estimated fuel cost savings ignore the "rebound effect," which is the well-documented increase in travel associated with reductions in vehicle fuel cost.

The following subsections address each of these problems. Detailed analyses of some of the issues are provided in the attachments to this report.

Cost of the 2009 Baseline Car Fleet Has Been Exaggerated

For passenger cars, the NESCCAF/CARB analysis is based on the simplifying assumption that all small cars will use 5-speed automatic transmissions by 2009 and all large cars will use 6-speed automatic transmissions. It is also assumed that all passenger cars will use overhead cam engines with "discrete variable valve lift" (DVVL) and cam phasers. This is projected to result in an average price increase of $308 for small cars and $427 for large cars. Sierra's conferences with large volume manufacturers indicate that these assumptions are incorrect. Changes in engine and transmission technology will not be this dramatic. Our independent analysis, presented in detail in Attachment C-1, shows that such radical changes are not required to maintain compliance with the CAFE standards. Based on information available at the time this report was prepared, Sierra estimates a price increase of $239 for the average 2009 model year passenger car. In contrast, our analysis indicates that NESCCAF/CARB analysis has understated the cost increase required by 2009 for light-duty trucks to comply with the recently adopted increase in CAFE standards.

The significance of CARB's 2009 baseline cost estimates is related more to the assumptions regarding technology change rather than to the increase in price itself. As explained in more detail below, CARB's analysis assumes that manufacturers will make technology changes that are not cost-effective compared to other available technologies. The cost of the proposed standards is then minimized by assuming that greenhouse gas regulations will force manufacturers to reverse technology changes planned for 2009 and use more cost-effective technology.

The 40% Markup Factor is Far Too Low

The CARB report cites an Argonne National Laboratory ("ANL") report and an EPA report to support the staff's estimate that a 1.4 multiplier is appropriate for marking up manufacturing costs to the retail level. In fact, the ANL report estimates the overall multiplier to range from 2.0 to 2.05 based on two different cost breakdowns and profit assumptions. ANL then estimates that the multiplier for components purchased from vendors ranges from 1.50 to 1.56 based on the assumption that vendors bear the costs of "Warranty," "R&D/Engineering," and "Depreciation and Amortization." However, OEMs usually have warranty, R&D, and engineering costs associated with components purchased from vendors. The multipliers developed by ANL may not be unreasonable for their intended purpose in that they were being used to estimate the retail price equivalent of electric and hybrid/electric vehicles. Components such as the battery used in an electric vehicle are likely to be fully developed by a vendor and failures in customer service may be more readily assigned to the battery manufacturer. However, most vendor-supplied components are designed by the OEM, not the vendor, and the OEM has full responsibility for warranty costs as long as the vendor has manufactured the component to the OEM's specifications. In fact, the NESCCAF report specifically states (see page II-17) the following:

> *Additional manufacturer-level costs that were not captured in this analysis but that could be associated with the use of new technologies include:*
>
> - *Engineering costs, including advanced R&D, vehicle design and development engineering for integrating new technologies and software development;*
> - *Warranty and possible recall costs;*
> - *Factory capital costs associated with vehicle-level technology changes;*
> - *Manufacturing costs for powertrain or vehicle assembly.*

Based on the above, more typical vendor-supplied components would have a multiplier of 1.83 using the ANL cost breakdown. It must be noted, however, that many of the cost estimates made by Martec do not include the cost of integrating the component into the vehicle. For components that simply replace other components (e.g., a more efficient alternator), the 1.83 markup factor may be appropriate because there are no significant integration costs. For other components (e.g., cam phasers), however, significant changes to the engine are required to integrate the component. In cases like that, the 2.05 markup factor is more appropriate. The 1.4 multiplier used in the NESCCAF/CARB analysis has therefore understated the cost of compliance by 32%. Additional analysis of this issue is provided in Attachment C-1.

Integration Costs Have Not Been Accounted For

As noted above, many of the technology changes must be integrated into the vehicle in a systematic way, and this integration requirement is generally much more complex than the introduction of new hardware or systems that are normally studied by the CARB staff, such as the after treatment of exhaust emissions of precursor or criteria pollutants or the control of fuel evaporative emissions. In the case of systems like cylinder deactivation, variable valve timing, and variable valve lift, significant changes to the basic engine are required. Martec's analysis did not address the cost of such changes. Such costs are a significant event in a fresh engine design and can be substantial when adapting such technology to an existing engine. We have partially accounted for such cost by applying the more reasonable 2.05 multiplier indicated above to the vendor prices for the additional components. In the case of technologies that adversely affect NVH, additional integration costs are required to mitigate the NVH impacts. Based on the industry's current experience, an integration cost of $220 or more is required to integrate cylinder deactivation into an existing vehicle platform.

A 30% Discount for "Unforeseen Innovations" is Not Justified

CARB staff discounted some of Martec's cost estimates by 30% to account for "unforeseen innovations in design and manufacturing" that the ISOR says will occur based on previous experience. This discount was applied to Martec's estimates for the following technologies:

- Cylinder deactivation;
- Electro-hydraulic camless valve actuation;
- Homogeneous charge compression ignition (HCCI) engines;
- Turbocharging;
- 42-volt hybrid systems; and
- Electric power steering.

Some of these technologies, e.g., electric power steering, have been in mass production for several years. They rely on technologies that are decades old and have little potential for "unforeseen innovations." Other technologies, e.g., electro-hydraulic camless valve actuation, have been under development for a number of years and, while simple in concept, have been prevented from reaching mass production due to significant practical problems. Martec's cost estimates for such technologies are based on information obtained from companies who hope to become <u>vendors</u> of the technology. As a result, their estimates are likely to be somewhat optimistic in the first place. There is no basis for CARB staff to arbitrarily assume that actual costs will be 30% lower, and indeed this would be directly contrary to the advice long given by CARB to the air districts when estimating compliance costs.[1] While CARB claims such reductions are based on the agency's experience, the actual experience of the agency in projecting the cost of new technologies is not consistent with the assumption being made. When CARB adopted its Zero Emission Vehicle mandate in 1990, the staff projected that innovations would result in the cost premium for full-function electric vehicles declining to $1,350 in approximately one decade. In fact, no significant change in the cost premium for electric propulsion systems occurred and, based on the conclusions reached by a panel of experts commissioned by CARB, the cost premium for full-function electric vehicles remains in excess of $10,000. Without the 30% cost reduction assumed by CARB, the cost of the technologies increase by 43%.

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[1] Catherine Witherspoon, et al., "Cost-Effectiveness, District Options for Satisfying the Requirements of the California Clean Air Act," California Air Resources Board, Office of Air Quality Planning and Liason, September 1990.

Significant Reductions in Aero and Rolling Resistance are Not Plausible

CARB assumed an 8-10% reduction in aerodynamic drag would be achieved, leading to 1.5-2.0% reductions in CO_2 emissions. There is no evidence that supports that assumption, owing to market-driven styling limitations on reductions in aerodynamic drag. The new Chrysler 300 sedan is a case in point. Its 0.35 drag coefficient is significantly higher than the vehicle it replaces. As reported in the June 2004 edition of *Car & Driver*, "The 300 also represents a return to chiseled three-box proportions after a long run of smooth, cab-forward designs." The commercial success this vehicle is achieving indicates that styling to minimize drag coefficient is contrary to what the market wants. Based on conferences with other OEMs, similar trends toward more classic, chiseled styling are apparent at other companies and similar effects on drag coefficient are expected.

In the case of reduced rolling resistance, CARB assumed a 2% reduction in CO_2 could be achieved through a 10% reduction in rolling resistance. As shown in Attachment C-7, our analysis indicates that (1) the rate of progress in reducing rolling resistance has slowed; and (2) new federal safety standards may limit the extent to which future reductions occur. In addition, CARB's analysis is implicitly based on the assumption that changes in OEM tire rolling resistance will generate benefits over the full life of the vehicle. However, motorists cannot be expected to purchase OEM replacement tires. The NESCCAF/CARB estimates of the benefits of aerodynamic drag and rolling resistance reductions have inflated the fuel economy improvement potential of the technology combinations evaluated by about 4%.

Assuming "Credit" for Certain Cost-Reduction Technologies is Unrealistic

CARB's estimates of compliance costs are significantly affected by the assumptions made regarding the cost and effectiveness of two specific technologies: turbocharging and automated manual transmissions. Compared to the baseline, no-regulation case, CARB assumes that these technologies simultaneously reduce cost and improve fuel economy. On its face, this assumption is irrational. If technologies were really available that simultaneously reduce cost and improve fuel economy, manufacturers would voluntary use them.

Attachment C-5 provides a detailed analysis of why the assumed benefits of turbocharging are not available. Although not mentioned in either the NESCCAF report or the ISOR materials, we have confirmed through personal communications with AVL that the fuel economy improvement assigned to turbocharging assumes the use of <u>premium fuel</u>. The $0.20 per gallon cost penalty for premium fuel completely eliminates the fuel cost savings assumed by CARB. As shown in Attachment C-1, our independent analysis concludes that there is zero fuel economy improvement resulting from the use of turbocharging when regular grade fuel is assumed. In addition, the cost savings that CARB assigned to replacing V6 engines with less expensive inline engines failed to account for the value customers assign to V6 engines. This is also addressed in Attachment C-5.

In the case of automated manual transmissions, CARB's analysis assumes these transmissions cost less than the 5- and 6-speed automatic transmissions assumed to be used in the baseline case while simultaneously providing a fuel economy benefit. As is the case with the turbocharging assumption, manufacturers would voluntarily apply such technology if this were the fact. Here the problem is that manufacturing capacity for such transmissions does not exist and CARB failed to account for the cost of developing such capacity. It should also be noted that Martec specifically stated that its cost estimate for automated manual transmissions covered "piece cost only" and that "US manual transmission capacity does not exist." When the costs of developing the necessary production capacity and retiring existing transmission facilities are considered, it is clear that AMTs cannot be produced for zero incremental cost, as assumed in CARB's analysis. Our independent analysis of some AMT costs, which accounts for the engineering and capital investments ignored in the NESCCAF/CARB analysis, indicates that there is an average $577 price premium relative to conventional 4-speed automatic transmissions.

Sales Tax Should Be Accounted For

CARB's analysis of the consumer benefit of improved fuel economy does not account for sales tax. This has a significant effect on the results. Our independent analysis accounts for an 8% tax on the price increase associated with the technology changes needed to comply with the proposed standards.

Manual Transmissions Were Not Properly Accounted For

The NESCCAF/CARB analysis ascribes significant fuel economy improvements to changes in transmission technology. However, all of the technologies evaluated were automatic transmissions. No technology changes affecting manual transmissions were considered. However, the fuel economy benefits for the automatic transmission technologies were assigned to all vehicles. Since 13% of passenger cars are sold with manual transmissions, the benefits of the automatic transmission technology changes have been overestimated by 15%.[1] Sierra's analysis, described in Attachment C-1, properly accounts for the fraction of manual transmission vehicles in the fleet and assigns the benefits of automatic transmission technology only to that fraction of the fleet equipped with automatic transmissions.

The AVL Results Do Not Represent Actual Driving Conditions

The fuel economy modeling of various technologies by AVL used a single set of driving cycles in order to compare on a relative basis the various technologies and combinations

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[1] By applying benefits to 100% of passenger vehicles instead of 87%, the benefits are exaggerated by a factor of 100/87=1.15.

of technologies that NESCCAF chose for its interim report. The ISOR materials then use the AVL results from the interim NESCCAF report for a different purpose—to estimate the overall fuel economy levels that those technologies would achieve in typical or average driving in California, if the proposed regulation is implemented. That was not the purpose of the AVL simulations.

The use of AVL's results from simulated driving with a single set of driving cycles to predict fuel savings on an aggregate basis is not appropriate. The ISOR materials contain no evidence that the fuel economy levels determined from the CAFE test procedure, which contains the driving cycles used by AVL, would reflect the level that motorists achieve under average driving conditions in California, and indeed that is not the purpose of the CAFE test procedures.[1] Based on data gathered in a series of studies from 1997-2000 sponsored by the California Department of Transportation and CARB, many of the technologies that the CARB staff has identified to meet the proposed standards and many alternative technologies will provide fuel economy improvements that are substantially overstated by reliance on a single set of driving cycles like the CAFE test procedures. Sierra's analysis, detailed in Attachment C-1, indicates that for the average California driver, the benefits attributed in the ISOR materials to the proposed standards are inflated by approximately 20 percent.

CARB Staff Overstated Average Vehicle Life

CARB staff's estimates of the benefits of the fuel savings associated with the proposed standards are based on average lifetime vehicle mileages that were erroneously calculated. The staff's estimates of 202,329 lifetime mileage for passenger cars and 223,969 lifetime average mileage for light-duty trucks are based on an obvious mathematical error. The staff failed to recognize that vehicles with higher than average mileage accumulation rates tend to be retired from customer service at an earlier age. Attachment C-3 provides a detailed analysis of this issue and presents data supporting our estimate that the true lifetime average mileage accumulation rate is approximately 155,000 miles for both passenger cars and light-duty trucks. The erroneous lifetime mileage estimates used by the staff inflate the fuel savings by 30-44%.

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[1] The CAFE test procedures provide the basis for determining compliance with federal fuel economy standards, and their results permit consumers to make relative comparisons between different vehicles in the marketplace. In 1984, EPA revised the fuel economy labeling program to provide for adjustments to both the City and Highway values achieved on the CAFE test procedure. The annual report on the CAFE program published by NHTSA also explains the difference between CAFE calculations, the EPA fuel economy values and on-road values. The data in Appendix C-2 indicate that the benefits to be obtained in California will fit the pattern that has been well established at the federal level for many years – that is, the fuel economy achieved by motorists is generally lower than the level on the unadjusted CAFE test procedure.

The Value of Improved Fuel Economy Has Been Overstated

In addition to overestimating the lifetime mileage of vehicles that would be subject to the proposed standards, the CARB staff has assumed that new vehicle purchasers will value the future savings associated with improved fuel economy using a discount rate of only 5%. The discount rate is essentially the opportunity cost of capital. A 5% discount rate implies that the average new car buyer is willing to spend or borrow money in order to obtain a 5% return over time. Current unsubsidized new car loan rates have averaged somewhat over 8% over a recent five-year period. Even if consumers valued fuel economy savings over the 16-19 year period assumed by CARB, no rational consumer would borrow money at 8% in order to obtain a return on investment of 5%. The implied discount rate new car buyers assign to fuel economy improvement is likely to be substantially in excess of 8%. For purposes of this review, Sierra uses an extremely conservative 8% discount rate.

Use of the Wrong Baseline Exaggerates Fuel Savings for Light Trucks

Excel files provided by CARB staff make it clear that the fuel savings assumed for the proposed LDT2 standards are relative to the 2002 baseline. CARB failed to account for the improved fuel economy required to comply with more stringent federal CAFE standards applicable to 2007 and subsequent model years. In addition, CARB excluded minivans from the baseline fuel economy/carbon dioxide calculations. These errors alone result in CARB overestimating the fuel savings due to the LDT2 standards by 45%.

The Rebound Effect Has Been Ignored

As mentioned above, separate analyses prepared by Robert Crawford and NERA demonstrate fundamental problems with the UCI analysis of the rebound effect that CARB relies on. As described below, CARB's analysis based on the use of transportation demand models is also flawed.

In section 12.3.C. of the ISOR, CARB staff presents what is purported to be an analysis of the VMT rebound effect in Southern California that was performed using the Southern California Association of Government's (SCAG) travel demand model for southern California. The results of this analysis in terms of changes in VMT and emissions are presented in Table 12.3-3 of the ISOR. Based on the results, CARB staff claims that the elasticity or VMT rebound with respect to changes in fuel cost is about -0.04. However, CARB staff's decision to use SCAG's travel demand model to assess the travel-inducing effect of reduced vehicle operating expenses is inherently flawed as the model is wholly unsuitable for estimating the VMT rebound effect.

Transportation planners are focused on forecasting traffic flows and identifying potential deficiencies in their local transportation system. While the transportation system may include other modes of travel such as walking, bikes, or railroads, the models are typically used for evaluating the effects of roadway and transit service improvements. For this reason, operating expenses are used only to address shifts between automobiles and transit operations (i.e., mode split). The effect of operating expenses on the VMT by motorists who do not shift modes is not accounted for by the model.

Discussions with Hong Kim on SCAG's modeling staff[1] confirmed that the SCAG transportation demand model referenced by CARB staff in the ISOR does not account for the effect of changes in the cost of gasoline on the number of trips that people make (i.e., their demand for travel). Instead it accounts only for the effect of gasoline price changes on people's decisions to either drive alone, take a bus, or participate in a carpool (e.g., as the cost of driving increases, some people will choose to ride a bus in order to conserve expenses). The point is that the model structure assumes that people's decision to travel is unaffected by the price of fuel. The model will predict that people are taking the same number of trips if gasoline is $2, $5, $10 a gallon. The only role that gasoline price has in the model is related to the driving mode that people choose to get from point A to point B. SCAG's model design inherently assumes that people's response to gasoline price changes is completely inelastic with regard to their demand for travel (in both the short-term and the long-term). This is not a realistic view of how people make travel decisions.

Since SCAG's model accounts only for the effect of fuel price and vehicle operating expenses on travel in a very indirect manner (by shifting person trips from single occupant vehicles to transit and carpools), the response to changes in operating expenses is limited to at most a second-order effect. As a result, the analysis presented in Section 12.3.C is meaningless with respect to the estimation of the magnitude of a VMT rebound effect in California, as are the conclusions drawn by CARB staff from the results of the analysis.

The fact that the Bay Area Metropolitan Transportation Commission (MTC) travel demand model forecasted a similar response is hardly surprising. Metropolitan Planning Organizations (MPOs) in general are focused on identifying congestion deficiencies in their networks, not evaluating the long-term response of travel demand to changes in fuel price and vehicle operating expenses. As a result, they employ similar four-step models (i.e., trip generation, trip distribution, mode choice, and assignment) that are also unable to estimate the magnitude of the VMT rebound effect.

Attachment C-4 presents our independent analysis showing that the rebound effect in California is approximately 16% (i.e., -0.16), which is consistent with the literature for the nationwide rebound effect. A separate analysis by NERA reaches the conclusion that the rebound effect is 17%. By ignoring the rebound effect, CARB has overstated the fuel savings by approximately 17%.

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[1] Telephone conversation between Bob Dulla and Hong Kim, September 13, 2004.

Net Effect of the Errors in the ISOR Materials

The errors outlined above do not include several major simplifying assumptions in the CARB staff analysis, which, as indicated at the beginning of this report, are unsupported in the ISOR materials. Those include (1) the assumption that there are sufficient economic and engineering resources to make the required design changes by 2016; (2) the assumption that design changes necessary for compliance will be deployed nationwide; and (3) the assumption that MDPVs will have no significant effect on the cost of compliance with the standards proposed for light-duty trucks. Accepting those assumptions for purposes of this analysis, which CARB's process of delaying information and analyses has required, we conclude that an average per-vehicle cost of compliance should be estimated at $4,573 for vehicles that the proposed rules would classify in the PC/LDT1 category, compared to the $1,064 estimate in the ISOR materials. The average compliance costs in the LDT2/MDPV category defined by CARB, accepting the same three assumptions, would be $1,308, compared to the ISOR materials' estimate of $1,029.

Ignoring the rebound effect, gasoline savings estimated on the same basis would be 1,605 gallons for PC/LDT1s (compared with 2,283 estimated based on the ISOR materials) and 774 gallons for LDT2/MDPVs (compared with 2,644 based on the ISOR materials). Accounting for a 17% rebound effect, the gasoline savings decrease to 1,403 gallons for PC/LDT1s and 655 gallons for LDT/MDPVs.

Ignoring the rebound effect, Sierra's NPV estimates for the fuel savings that result from the proposed regulations are $1,810 for PCs/LDT1s and $872 for LDT2/MDPVs. With the rebound effect, the NPV of the fuel savings decreases to $1,582 for PCs/LDT1s and $738 for LDT2/MDPVs. Using CARB's assumptions, the NPV of the fuel savings would be $2,773 for PC/LDT1 and $3,090 for LDT2.

The net effect of the specific errors identified in the above analysis is that the actual cost of the proposed standards will exceed an optimistic estimate of the present value of the fuel savings for an average California driver by a factor of approximately 200%. Few, if any, customers would be more willing to pay the increased cost of the proposed standards, if their alternative was the current program in which the national government sets standards relating to fuel consumption. The results of the proposed regulation can therefore be expected to include reduction in new vehicle sales, longer retention of older vehicles on the road, and an increase in ozone precursor emissions. The magnitude of this effect is quantified in a joint report by NERA and Sierra being provided under separate cover.

Attachment C-1

Forecasting the 2009 No-Regulation Baseline and the Effects of Fuel Economy Improvement Technology

Consistent with the approach used by NESCCAF, CARB staff characterized the baseline fleet and potential technology changes to it by addressing five different types of vehicles: (1) small cars; (2) large cars; (3) minivans; (4) small trucks; and (5) larger trucks. This classification scheme, like the classification scheme used in the federal Fuel Economy Guide, fails to distinguish between cars and light-duty trucks with fundamentally different characteristics. The vehicles that fall into the "minivan" category are reasonably similar in most of their characteristics affecting fuel economy and greenhouse gas emissions; however, the other four categories contain vehicles with substantial differences. For example, the "small car" category contains high-performance sports sedans, convertibles, and "economy" cars. It is therefore necessary to consider the extent to which certain technology changes conflict with the maintenance of vehicle characteristics that are critical to market success.

As explained in detail below, our vehicle simulation modeling of technology changes required to comply with the proposed greenhouse gas emissions standards is based on four different types of vehicles (a mid-size sedan, a minivan, a large pickup, and a mid-size SUV), each using multiple types of engines and transmissions. However, we have extrapolated the results of our detailed modeling to a more detailed breakdown of the fleet using a classification scheme that divided passenger cars into 13 different categories and light trucks into 12 different categories. The overall objective of the classification scheme was to preserve the size class distinctions used in the Fuel Economy Guide published by the federal government while recognizing some of the important distinctions between vehicles that are ignored in the Fuel Economy Guide.

This attachment also describes our cost estimates for most of the technology changes manufacturers would need to make if they are to comply with the proposed standards without restricting model availability or substantially downgrading the performance of passenger cars and light-duty trucks.

Passenger Car Categories

Table 1 presents the classification scheme used for passenger cars. By comparing our classification scheme with vehicle categories used in the federal Fuel Economy Guide, an obvious difference is that we distinguish between sports cars, coupes and convertibles, and sedans. In contrast, the federal scheme categorizes vehicles based only on the number of seats and the interior volume. This leads to the following vehicles being put in the same category:

Table 1
Passenger Car Categories

This Analysis	EPA Class	Examples
Mini Cars	Mini-Compact	Mini Cooper
Subcompact Sedans/Wagons	Subcompact, Small Wagon	Volkswagen Beetle
Compact Sedans/Wagons	Compact, Small Wagon	Chevrolet Cavalier
Mid-Size Sedans/Wagons	Mid-Size Sedan, Mid-Size Wagon	Chrysler Sebring
Large Sedans/Wagons	Large Sedan, Large Wagon	Ford Crown Victoria
Small Coupes/Convertibles	Mini-Compact	Mitsubishi Eclipse Spyder
Mid-Size Coupes/Convertibles	Subcompact, Compact	Toyota Celica GT
Large Coupes/Convertibles	Mid-Size or Large Sedan	Chevrolet Monte Carlo
Small Sports/Luxury Sedans	Subcompact, Compact	BMW 330
Mid-Size Sports/Luxury Sedans	Mid-Size Sedan	Cadillac CTS
Large Sports/Luxury Sedans	Large Sedan	Mercedes S500
Sports/GT Cars	Two-Seater, Mini-Compact, Subcompact	Mazda Miata
High Performance Sports/GT Cars	Two-Seater, Mini-Compact, Subcompact	Chevrolet Corvette

- Mercedes SL55 AMG and Honda Insight are both considered "two-seaters;"
- Ferrari 456 GT and Ford Escort are both considered "subcompacts;"
- Mini Cooper and Porsche Turbo are both considered "minicompacts;" and
- BMW M5 and Chevrolet Cavalier are both considered "compacts."

Obviously, these vehicle groupings are inconsistent with the market segment in which they actually compete. This leads to absurd conclusions about the fuel economy improvement that could be achieved if all vehicles had fuel economy ratings equivalent to what could be achieved by a "typical" vehicle using an optimum combination of technologies. Assuming that a high-performance sports car could remain commercially viable when redesigned to achieve the same fuel economy as a low-performance economy car is unreasonable.

As described below, the definitions of the passenger car categories we have used to represent the fleet were created to account for characteristics that could significantly affect fuel economy, including power-to-weight ratio and styling features.

Mini-Cars are passenger cars not covered by another class definition that have an interior volume the same as those in the EPA "mini-compact" category. Although numerous car models are classified as mini-compacts by EPA, our classification scheme moves most of these models into other categories (e.g., sports/GT, small coupes/convertibles). Under our classification scheme, mini-cars are sedan-type vehicles smaller than subcompacts, such as the Mini Cooper, and two-passenger vehicles, like the Honda Insight, that do not meet our definition of "sports car" (see below).

Subcompact Sedans/Wagons - Sedans are passenger cars that provide similar accommodations in front and rear seats and that have a cargo compartment of lower average height than the greenhouse (the area surrounded by windows). Station wagons are sedans with a greenhouse extended to the rear of the vehicle to facilitate larger cargo volume or a third row of seating. Subcompact Sedans/Wagons are sedans, other than sports/luxury sedans, that have interior volumes the same as those in the EPA "sub-compact" category and station wagon derivatives of such vehicles.

Compact Sedans/Wagons are sedans, other than sports/luxury sedans, that have interior volumes the same as those in the EPA "compact" category and station wagon derivatives of such vehicles.

Mid-Size Sedans/Wagons are sedans, other than sports/luxury sedans, that have interior volumes the same as those in the EPA "mid-size" category and station wagons that have interior volumes the same as those in the EPA "mid-size" category.

Large Sedans/Wagons are sedans, other than sports/luxury sedans, that have interior volumes the same as those in the EPA "large" category and station wagons that have interior volumes the same as those in the EPA "large" category.

Small Coupes/Convertibles - Coupes are two-door, fixed roof or "T-top" configuration passenger cars, other than sports cars or sports/GT cars, with two- or "2+2" passenger seating or otherwise more limited rear seating and cargo space than typical of sedans with equivalent overall passenger compartment volume. Convertibles are passenger cars, other than sports cars or sports/GT cars, with fold-away or completely stowable tops. Small Coupes/Convertibles are coupes and convertibles with interior volumes the same as those in the EPA "mini-compact" category.

Mid-Size Coupes/Convertibles are coupes and convertibles with interior volumes the same as those in the EPA "sub-compact" and "compact" categories.

Large Coupes/Convertibles are coupes and convertibles with interior volumes the same as those in the EPA "mid-size" and "large" categories.

Small Sports/Luxury Sedans/Wagons - Sports sedans/wagons are sedans and wagons with relatively high power-to-weight ratios (no more than 16 pounds curb weight per horsepower) and that are usually designed for cornering and braking performance superior to that typical of conventional sedans. Sports sedans/wagons may also incorporate luxury features. Luxury sedans/wagons are sedans and wagons, other than sports sedans and wagons, that incorporate numerous luxury features (such as power-assisted seats, steering, windows, and door locks; standard leather upholstery; automated climate control; and numerous decorative items [e.g., metallic paint, wood-trimmed interiors, aluminum wheels, etc.]) as standard equipment and that have no more than 19 pounds curb weight per horsepower. Luxury sedans/wagons usually incorporate suspension systems designed to maximize ride quality when driven sedately. Small Sports/Luxury Sedans/Wagons are sports sedans/luxury sedans with interior volumes the same as those in the EPA "sub-compact" and "compact" categories.

Mid-Size Sports/Luxury Sedans/Wagons are sports sedans/luxury sedans with interior volumes the same as those in the EPA "mid-size" category.

Large Sports/Luxury Sedans/Wagons are sports sedans/luxury sedans with interior volumes the same as those in the EPA "large" category.

Sports/GT Cars are small, two- or "2+2" passenger coupes and convertibles designed for cornering and braking performance superior to that typical of conventional sedans and that have more than 13 pounds curb weight per horsepower. Interior volumes for these vehicles are generally in the EPA size class for two-seaters, mini-compacts, or subcompacts.

High Performance Sports/GT Cars are sports/GT cars with no more than 13 pounds curb weight per horsepower.

Truck Categories

The biggest problem with the EPA classification scheme for trucks was the total lack of distinction between different size SUVs. To account for the significant differences that exist, we classify SUVs as small, medium, or larger based on the product of their length, width, and height. In contrast, we eliminate the distinction between passenger and cargo vans within the EPA classification scheme and we eliminate the distinction between 2-wheel drive and 4-wheel drive minivans. We classify all vans as either small or large based on the product of length, width, and height because there are relatively few 4-wheel drive vans and relatively few differences between small passenger and cargo vans and minivans. EPA classifies pickup trucks as small or standard based on their gross vehicle weight. We classify pickup trucks as small or larger based on the product of their length, width, and height. Table 2 compares the truck category definitions used in this analysis to the EPA categories; descriptions of each category follow.

Small 2WD Pickup Trucks are 2-wheel-drive light-duty trucks with an uncovered cargo bed and for which the product of length, height, and width is ≤550 cubic feet.

Table 2
Light-Truck Categories

This Analysis	Typical EPA Class	Examples
Minivan	Passenger Van, Cargo Van, Minivan 2WD, Minivan 4WD	Chrysler Voyager
Large Van	Passenger Van, Cargo Van	Chevrolet G1500
Small Pickup 2WD	Small Pickup 2WD	Toyota Tacoma
Small Pickup 4WD	Small Pickup 4WD	Ford Ranger
Large Pickup 2WD	Standard Pickup 2WD	Ford F150
Large Pickup 4WD	Standard Pickup 4WD	Dodge Ram 1500
Small SUV 2WD	SUV 2WD	Toyota RAV4
Small SUV 4WD	SUV 4WD	Jeep Wrangler
Mid-Size SUV 2WD	SUV 2WD	Nissan Pathfinder
Mid-Size SUV 4WD	SUV 4WD	Ford Explorer
Large SUV 2WD	SUV 2WD	Ford Expedition
Large SUV 4WD	SUV 4WD	Chevrolet Suburban

Small 4WD Pickup Trucks are 4-wheel-drive light-duty trucks with an uncovered cargo bed and for which the product of length, height, and width is ≤550 cubic feet.

Large 2WD Pickup Trucks are 2-wheel-drive light-duty trucks with an uncovered cargo bed and for which the product of length, height, and width is >550 cubic feet.

Large 4WD Pickup Trucks are 4-wheel-drive light-duty trucks with an uncovered cargo bed and for which the product of length, height, and width is >550 cubic feet.

Small Vans are light-duty trucks with a fully enclosed passenger and cargo space that are designed to maximize interior volume per unit of length through the use of relatively tall roofs and engines installed transversely or recessed into the passenger/cargo compartment and for which the product of length, height, and width is ≤680 cubic feet.

Large Vans are light-duty trucks with a fully enclosed passenger and cargo space that are designed to maximize interior volume per unit of length through the use of relatively tall roofs and engines installed transversely or recessed into the passenger/cargo compartment and for which the product of length, height, and width is >680 cubic feet.

Small 2WD Sport/Utility Vehicles are light-duty trucks, other than pickup trucks and vans, incorporating relatively high ground clearance and 2-wheel drive, and for which the product of length, height, and width is ≤450 cubic feet.

Small 4WD Sport/Utility Vehicles are light-duty trucks, other than pickup trucks and vans, incorporating relatively high ground clearance and 4-wheel drive, and for which the product of length, height, and width is ≤450 cubic feet.

Mid-Size 2WD Sport/Utility Vehicles are light-duty trucks, other than pickup trucks and vans, incorporating relatively high ground clearance and 2-wheel drive, and for which the product of length, height, and width is >450 cubic feet and ≤600 cubic feet.

Mid-Size 4WD Sport/Utility Vehicles are light-duty trucks, other than pickup trucks and vans, incorporating relatively high ground clearance and 4-wheel drive, and for which the product of length, height, and width is >450 cubic feet and ≤600 cubic feet.

Large 2WD Sport/Utility Vehicles are light-duty trucks, other than pickup trucks and vans, incorporating relatively high ground clearance and 2-wheel drive, and for which the product of length, height, and width is >600 cubic feet.

Large 4WD Sport/Utility Vehicles are light-duty trucks, other than pickup trucks and vans, incorporating relatively high ground clearance and 4-wheel drive, and for which the product of length, height, and width is >600 cubic feet.

Characteristics of the 2003 Baseline Fleet

Sales-weighted average vehicle statistics for each of the baseline car and truck categories described above were obtained for approximately 823 different test vehicles. Fuel economy (unadjusted) for each 2003 model was obtained from U.S. EPA.[1] Sales volumes were obtained from U.S. EPA for the most recent model year available, which was model year 2002. These sales were assigned to the same or equivalent 2003 model. Most vehicle specifications were obtained from EPA. Information unavailable from EPA (e.g., height, length, width, drag coefficient, frontal area) was obtained from manufacturer websites, other internet sites (e.g., new-cars.com), or directly from participating vehicle manufacturers.

Information on frontal area and aerodynamic drag coefficient (C_d) was available for about 75% of all passenger car and truck models. When data were missing, frontal area was calculated using a regression based on the height and width of vehicles with a known frontal area. The missing C_d values could then be calculated from the frontal area, TRLHP, equivalent test weight (curb weight + 300 lb.), and estimated coefficient of rolling friction.

The rolling friction coefficient was calculated with the TRLHP, frontal area, C_d, and weight by averaging only the vehicles with complete data. The rolling friction coefficient used is .0113 for cars and minivans and .0114 for pickups and SUVs. By virtue of the way it was calculated, this rolling friction coefficient includes brake drag and other driveline losses.

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[1] http://www.fueleconomy.gov/feg/download.shtml

Table 3 contains a summary of sales-weighted average characteristics of the 2003 baseline fleet obtained from the above-described approach. The sales-weighted fuel economy estimates for the passenger car and truck fleets shown in Table 3 match the values published by EPA when rounded to the nearest 0.1 mpg, which were 29.0 mpg for cars and 20.8 mpg for light-duty trucks. It should be noted, however, that the values published by EPA may not be precisely the same as the "official" 2003 model year CAFE values from NHTSA that were not available at the time our analysis was done (July 2004). In addition to the difference in sales data, it is not clear that EPA accounted for the credits for alternative fuel vehicles that NHTSA applies when calculating official CAFE results.

Characteristics of the Future Baseline Fleet

Before projecting the benefits of fuel economy improvement technologies, some adjustments to the baseline were made to account for recent trends of improved acceleration performance and higher weight.

The NESCCAF report on which CARB staff relies examines historical trends when considering how vehicle weight can be expected to change in the future. Based on data for 1993-2003 model year vehicles reported by U.S. EPA, NESCCAF concludes that the annual weight changes have been 42 lbs/year for large trucks, 25 lbs/year for small trucks, 32 lbs/year for minivans, 0 lbs/year for large cars, and 22 lbs/year for small cars. The cumulative change from 2003 to 2009 would therefore range from 192-252 pounds for light-duty trucks and from 0-132 pounds for passenger cars. However, rather than assume current trends continue, NESCCAF assumes no further increases in the weight of light-duty trucks will occur because the CAFE standards for trucks will increase from the current 20.7 mpg standard to a standard of 21.0 miles mpg for model year (MY) 2005, 21.6 mpg for MY 2006, and 22.2 mpg for MY 2007.

Our analysis adjusts curb weight only to account for safety equipment even though other weight trends are apparent. Based on estimates by member companies of the Alliance, we assume a 105-pound increase for the average passenger car and a 70-pound increase for light-duty trucks. These are extremely conservative forecasts given historical trends.

Table 3
Characteristics of the 2003 U.S. Light-Duty Vehicle Fleet

Automobiles

No.	Name	Test Vehs.	Auto Sales	%LDV Sales	Unadj. Fuel Econ. (mpg) City	Unadj. Fuel Econ. (mpg) Hwy	Unadj. Fuel Econ. (mpg) Wtd	Curb Wt (lb)	Frontal Area (ft²)	Aero Drag	Roll Frict.	Axle Ratio	# Cyl	Power (hp)	Disp (cid)	%2V	%Auto Trans	%Auto 5-Spd
1	MINI	4	0.16%	0.08%	33.14	48.27	38.58	2,434	21.27	0.333	0.0113	4.14	3.83	107.0	91.6	0.0%	0.0%	0.0%
2	SCSW	18	5.54%	2.72%	26.79	40.68	31.65	2,738	21.34	0.326	0.0114	3.81	4.07	142.3	131.2	8.7%	79.1%	2.7%
3	CSW	130	31.56%	15.51%	28.12	41.92	33.01	2,757	22.18	0.347	0.0112	3.71	4.41	137.4	124.9	28.6%	80.7%	12.1%
4	MSW	68	30.66%	15.06%	23.80	37.64	28.53	3,209	23.36	0.318	0.0111	3.59	4.93	166.2	164.8	32.3%	96.7%	16.9%
5	LSW	10	8.24%	4.05%	22.05	37.03	26.96	3,527	24.95	0.398	0.0100	3.13	6.27	201.9	217.3	72.3%	100.0%	0.0%
6	SCC	14	0.87%	0.43%	20.48	32.35	24.53	3,608	21.97	0.366	0.0104	3.53	6.72	239.8	200.5	4.9%	83.4%	67.8%
7	MCC	40	4.24%	2.08%	23.65	37.02	28.24	3,066	22.00	0.334	0.0110	3.66	5.18	203.1	171.3	33.4%	71.7%	9.9%
8	LCC	2	0.90%	0.44%	22.34	38.87	27.62	3,340	23.57	0.505	0.0089	2.86	6.00	191.4	221.4	100.0%	100.0%	0.0%
9	SSL	38	1.75%	0.86%	20.50	33.12	24.74	3,432	22.38	0.310	0.0115	3.49	6.09	236.7	188.0	0.0%	71.5%	71.4%
10	MSL	48	8.78%	4.31%	21.57	34.86	26.04	3,446	23.21	0.305	0.0130	3.83	6.20	234.0	202.6	3.1%	91.3%	59.1%
11	LSL	19	4.42%	2.17%	19.82	33.51	24.29	3,903	25.09	0.311	0.0107	3.26	7.25	262.1	255.8	24.8%	99.6%	24.1%
12	SC	17	0.50%	0.25%	23.32	35.72	27.63	2,792	20.48	0.356	0.0153	3.95	4.65	183.5	134.4	0.0%	31.8%	23.1%
13	HPSC	41	2.37%	1.16%	20.19	32.32	24.35	3,223	21.99	0.340	0.0144	3.35	7.13	295.3	258.2	44.8%	39.6%	19.3%
All Autos		449	100%	49.13%	24.32	38.19	29.07	3,117	22.93	0.336	0.0113	3.60	5.15	175.6	165.5	30.2%	87.2%	18.2%

Light Trucks

No.	Name	Test Vehs.	Auto Sales	%LDV Sales	Unadj. Fuel Econ. (mpg) City	Unadj. Fuel Econ. (mpg) Hwy	Unadj. Fuel Econ. (mpg) Wtd	Curb Wt (lb)	Frontal Area (ft²)	Aero Drag	Roll Frict.	Axle Ratio	# Cyl	Power (hp)	Disp (cid)	%2V	%Auto Trans	%Auto 5-Spd
1	SVAN	25	10.81%	5.50%	19.77	30.65	23.53	4,092	31.30	0.344	0.0103	3.65	5.97	202.9	214.5	61.4%	100.0%	26.3%
2	LVAN	25	1.38%	0.70%	15.89	22.81	18.40	4,829	39.65	0.391	0.0110	3.53	7.03	221.2	291.6	99.3%	100.0%	0.0%
3	S2P	29	5.70%	2.90%	20.78	29.88	24.08	3,127	25.90	0.458	0.0098	3.70	5.08	155.4	180.2	58.5%	74.0%	25.5%
4	S4P	18	2.82%	1.43%	17.53	24.75	20.18	3,715	26.07	0.504	0.0121	3.88	5.81	189.1	227.4	70.8%	79.7%	27.0%
5	L2P	34	12.71%	6.47%	16.43	24.21	19.21	4,305	33.30	0.452	0.0105	3.46	7.09	236.2	284.0	93.4%	93.4%	14.2%
6	L4P	32	9.98%	5.07%	15.48	22.74	17.98	4,727	33.00	0.454	0.0124	3.62	7.56	258.0	309.1	94.1%	96.9%	4.1%
7	S2SU	14	3.06%	1.56%	22.80	33.38	26.59	3,066	25.43	0.402	0.0109	3.04	4.10	158.9	139.9	0.0%	88.3%	0.0%
8	S4SU	17	2.46%	1.25%	21.66	30.18	24.84	3,157	26.57	0.440	0.0150	3.75	4.83	166.8	169.9	30.5%	71.1%	0.0%
9	M2SU	63	14.21%	7.23%	19.23	28.67	22.66	3,879	30.21	0.399	0.0112	3.79	5.72	208.9	216.1	41.2%	92.0%	22.1%
10	M4SU	75	26.28%	13.37%	18.00	26.75	21.11	4,153	30.18	0.407	0.0118	3.79	5.94	217.9	225.2	43.8%	95.5%	33.4%
11	L2SU	17	3.68%	1.87%	15.17	22.74	17.85	5,051	34.31	0.414	0.0097	3.64	7.91	269.2	308.6	77.7%	100.0%	0.0%
12	L4SU	25	6.91%	3.52%	15.29	23.13	18.04	5,135	35.37	0.402	0.0118	3.88	7.42	275.9	297.5	58.7%	100.0%	23.2%
All Trucks		374	100%	50.87%	17.77	26.36	20.82	4,166	31.03	0.415	0.0114	3.69	6.27	219.8	241.1	59.6%	93.4%	19.5%

We used a slightly different approach to that used by NESCCAF to project future changes in performance. The NESCCAF forecast assumes 0-60 mph acceleration times will continue dropping by 0.15-0.22 seconds per year for light-duty trucks and 0.11-0.14 seconds per year for passenger cars. The cumulative change from 2003 to 2009 would therefore range from 0.90-1.32 seconds for light-duty trucks and from 0.66-0.84 seconds for passenger cars. Our independent analysis of the EPA data indicates slightly different 0-60 mph acceleration trends; however, we developed a projected 2009 baseline from power-to-weight ratio trends rather than 0-60 times because we believe these trends are significantly more accurate.[2] Our analysis of the EPA data shows that the power-to-weight ratio of midsize cars is increasing by 0.000945 hp/lb per year. The corresponding increases for small vans, midsize SUVs, and large pickups are 0.000802, 0.00519, and 0.001108 hp/lb, respectively.

Projected to 2009, the increase in power to weight ratio would be as follows:

- Midsize pass cars increase by 0.0057 hp/lb.
- Midsize SUVs increase by 0.0031 hp/lb.
- Small vans increase by 0.0048 hp/lb.
- Large pickups increase by 0.0066 hp/lb.

To simplify the analysis, we initially projected the 2009 baseline based on the assumption that the performance increase would be equivalent to a horsepower-to-weight ratio increase by 0.005 for all categories of passenger cars and light-duty trucks. Next, using our vehicle simulation model (VEHSIM),[3] adjustments in the forecasted power to weight ratio were made to account for performance increases associated with increasing use of 5-speed automatic transmissions. (In other words, improved acceleration resulting from increasing use of 5-speed transmissions was substituted for the increase in power to weight ratio.) To reflect current trends and to simplify our modeling of future technologies, our 2009 baseline forecast assumes the uniform use of 5-speed transmissions with the fraction of automatic transmissions unchanged from the 2003 baseline. We also assume increased utilization of overhead cam engines, albeit at a more moderate amount than assumed in CARB's analysis. The assumed changes in overhead cam (OHC) and overhead valve (OHV) fractions are shown in Table 4. The more comprehensive specifications for the 2009 projected baseline vehicles are shown in Table 5.

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[2] EPA's estimates of 0-60 mph acceleration times are based on a relatively simplistic algorithm that does not consider significant factors affecting 0-60 mph, such as gear ratios.

[3] Sierra's vehicle simulation model is similar to the CRUISE model used by AVL. It was originally developed by General Motors Corporation, became public domain under a U.S. Department of Transportation funded project, and has subsequently been enhanced by Sierra Research to incorporate routines to simulate cold start and warmup and to make it more computationally efficient. A detailed description of VEHSIM is contained in Attachment C-6.

Table 4
Overhead Cam Engine Use
2003 vs. Projected 2009

Vehicle Category	2003	2009
Passenger Cars	70%	85%
Vans	35%	70%
Pickup Trucks	15%	50%
Sport Utility Vehicles	56%	70%

Following the above-described adjustments, VEHSIM was used to see how the 2009 projected baseline fuel economy compares to the fuel economy level needed to achieve compliance with the federal CAFE standards. Four different types of vehicles were used to represent the fleet:

- Mid-size sedan;
- Minivan;
- Large pickup truck; and
- Mid-size SUV

To account for simulation error, VEHSIM was used to model each type of vehicle for both the 2003 baseline and the 2009 projected baseline.

For the 2003 baseline case, each type of vehicle was modeled with two different types of engines (OHC and OHV) and three different types of transmissions (5-speed manual, 4-speed automatic, and 5-speed automatic). The specifications for the baseline versions of these vehicles and their 2003 baseline fuel economy levels are shown in the highlighted rows of Table 3 above.

The VEHSIM modeling done for the baseline cases used "blended" engine maps, which were originally created during Sierra's 1999 study for the Canadian government. The maps were constructed by averaging engine maps provided to Sierra by several high volume manufacturers. Separate maps were created to represent OHC and OHV engines. None of the engines represented in the baseline engine maps used cylinder deactivation, cam phasers, or variable valve lift. All of the maps were for regular fuel (87 R+M/2) engines. All maps were adjusted to reflect an assumed 2% reduction in engine friction, which was forecasted to occur in the Canadian study through the use of lower viscosity lubricants and other miscellaneous changes. (Such changes in lubricants did occur.) The maps were adjusted to match the displacement of the vehicles being simulated using a "resize" routine built into the VEHSIM model. Transmission gear ratios were set to represent the actual gearing of high volume models. Shift logic was configured to represent typical current shift logic provided to Sierra by high volume automobile manufacturers. Table 6 shows how the model predicted the fuel economy of the 2003 baseline vehicles.

Table 5
Characteristics of the 2009 Projected U.S. Light-Duty Vehicle Fleet

Automobiles

No.	Name	Auto Sales	%LDV Sales	Unadj. Fuel Econ. (mpg)			*Curb Wt (lb)*	Frontal Area (ft²)	Aero Drag	Roll Frict.	Axle Ratio	# Cyl	*Power (hp)*	*Disp (cid)*	*%2V*	%Auto Trans	*%Auto 5-Spd*
				City	Hwy	Wtd											
1	MINI	0.16%	0.08%	33.14	48.27	38.58	2,514	21.27	0.333	0.0113	4.14	3.83	123.1	n.c.	0.0	0.0%	100.0%
2	SCSW	5.54%	2.72%	26.79	40.68	31.65	2,828	21.34	0.326	0.0114	3.81	4.07	161.1	n.c.	4.3%	79.1%	100.0%
3	CSW	31.56%	15.51%	28.12	41.92	33.01	2,847	22.18	0.347	0.0112	3.71	4.41	156.1	n.c.	14.2%	80.7%	100.0%
4	MSW	30.66%	15.06%	23.80	37.64	28.53	3,314	23.36	0.318	0.0111	3.59	4.93	188.2	166.4	16.1%	96.7%	100.0%
5	LSW	8.24%	4.05%	22.05	37.03	26.96	3,642	24.95	0.398	0.0100	3.13	6.27	226.7	n.c.	35.9%	100.0%	100.0%
6	SCC	0.87%	0.43%	20.48	32.35	24.53	3,727	21.97	0.366	0.0104	3.53	6.72	266.3	n.c.	2.4%	83.4%	100.0%
7	MCC	4.24%	2.08%	23.65	37.02	28.24	3,166	22.00	0.334	0.0110	3.66	5.18	225.6	n.c.	16.6%	71.7%	100.0%
8	LCC	0.90%	0.44%	22.34	38.87	27.62	3,449	23.57	0.505	0.0089	2.86	6.00	214.9	n.c.	49.7%	100.0%	100.0%
9	SSL	1.75%	0.86%	20.50	33.12	24.74	3,545	22.38	0.310	0.0115	3.49	6.09	262.2	n.c.	0.0%	71.5%	100.0%
10	MSL	8.78%	4.31%	21.57	34.86	26.04	3,559	23.21	0.305	0.0130	3.83	6.20	259.5	n.c.	1.5%	91.3%	100.0%
11	LSL	4.42%	2.17%	19.82	33.51	24.29	4,031	25.09	0.311	0.0107	3.26	7.25	290.9	n.c.	12.3%	99.6%	100.0%
12	SC	0.50%	0.25%	23.32	35.72	27.63	2,883	20.48	0.356	0.0153	3.95	4.65	203.9	n.c.	0.0%	31.8%	100.0%
13	HPSC	2.37%	1.16%	20.19	32.32	24.35	3,329	21.99	0.340	0.0144	3.35	7.13	321.6	n.c.	22.3%	39.6%	100.0%
All Autos		100%	49.13%	24.32	38.19	29.07	3,219	22.93	0.336	0.0113	3.60	5.15	197.5	n.c.	15.0%	87.2%	100.0%

Light Trucks

No.	Name	Auto Sales	%LDV Sales	*Unadj. Fuel Econ. (mpg)*			*Curb Wt (lb)*	Frontal Area (ft²)	Aero Drag	Roll Frict.	Axle Ratio	# Cyl	*Power (hp)*	*Disp (cid)*	*%2V*	%Auto Trans	*%Auto 5-Spd*
				City	*Hwy*	*Wtd*											
1	SVAN	10.81%	5.50%	21.21	32.87	25.24	4,166	31.30	0.344	0.0103	3.65	5.97	227.3	217.2	28.0%	100.0%	100.0%
2	LVAN	1.38%	0.70%	17.04	24.46	19.74	4,916	39.65	0.391	0.0110	3.53	7.03	249.8	n.c.	45.3%	100.0%	100.0%
3	S2P	5.70%	2.90%	22.28	32.05	25.82	3,183	25.90	0.458	0.0098	3.70	5.08	174.1	n.c.	34.4%	74.0%	100.0%
4	S4P	2.82%	1.43%	18.80	26.54	21.64	3,782	26.07	0.504	0.0121	3.88	5.81	211.4	n.c.	41.6%	79.7%	100.0%
5	L2P	12.71%	6.47%	17.62	25.97	20.60	4,382	33.30	0.452	0.0105	3.46	7.09	262.3	272.9	54.8%	93.4%	100.0%
6	L4P	9.98%	5.07%	16.61	24.39	19.28	4,812	33.00	0.454	0.0124	3.62	7.56	286.7	n.c.	55.2%	96.9%	100.0%
7	S2SU	3.06%	1.56%	24.45	35.80	28.52	3,121	25.43	0.402	0.0109	3.04	4.10	177.3	n.c.	0.0%	88.3%	100.0%
8	S4SU	2.46%	1.25%	23.23	32.37	26.64	3,214	26.57	0.440	0.0150	3.75	4.83	185.8	n.c.	20.7%	71.1%	100.0%
9	M2SU	14.21%	7.23%	20.63	30.75	24.30	3,949	30.21	0.399	0.0112	3.79	5.72	232.4	220.5	28.0%	92.0%	100.0%
10	M4SU	26.28%	13.37%	19.31	28.69	22.64	4,228	30.18	0.407	0.0118	3.79	5.94	243.0	n.c.	29.7%	95.5%	100.0%
11	L2SU	3.68%	1.87%	16.27	24.39	19.14	5,142	34.31	0.414	0.0097	3.64	7.91	299.7	n.c.	52.8%	100.0%	100.0%
12	L4SU	6.91%	3.52%	16.39	24.80	19.35	5,228	35.37	0.402	0.0118	3.88	7.42	307.0	n.c.	39.8%	100.0%	100.0%
All Trucks		100%	50.87%	19.06	28.27	22.33	4,241	31.03	0.415	0.0114	3.69	6.27	245.0	n.c.	36.2%	93.4%	100.0%

n.c = not calculated

Table 6 VEHSIM Modeling Results for Composite 2003 Baseline Vehicles	Reported by EPA	Modeled by VEHSIM	VEHSIM Error
Mid-Size Sedan	28.53	29.67	+4.0%
Minivan	23.53	22.86	-2.9%
Large 2WD Pickup	19.21	18.70	-2.7%
Mid-Size SUV	22.66	22.85	+0.9%
Average Error			-0.2%

Given the wide range of vehicles represented by the simulations, the agreement between the EPA-reported CAFE test results and the VEHSIM model is excellent. The minor simulation error shown in the table was used to establish category-specific correction factors applied to all modeling of future cases.

Table 7 shows how the VEHSIM modeling of the projected 2009 baseline vehicles compares to the 2003 baseline. The "target" fuel economy values shown in the table are the levels required to maintain CAFE compliance. In the case of the mid-size sedan, the target level is equal to the 2003 baseline because the CAFE standards are unchanged and the same modest degree of fleetwide compliance margin is assumed. In the case of the three light-duty truck categories, the target fuel economy levels reflect an upward adjustment of the 2003 baseline to account for the recently adopted 2007 LDT CAFE standard of 22.2 mpg. (The 2003 fuel economy level for each category was increased by the ratio of the 2007 standard and the 2003 standard, i.e., 22.2/20.7.)

Table 7 2003 vs. 2009 Projected Baseline Fuel Economy	2003 (mpg)	2009 Projected	2009 Target	Improvement Required
Mid-Size Sedan	28.53	28.38	28.53	+0.5%
Minivan	23.53	23.49	25.24	+7.4%
Large Pickup	19.21	19.51	20.60	+5.6%
Mid-Size SUV	22.66	21.81	24.30	+11.4%

As shown in the table, the increased use of 5-speed automatic transmissions and OHC engines assumed in the 2009 projected baseline almost provides a sufficient fuel economy benefit to offset the adverse fuel economy effect associated with the forecasted increase in vehicle weight and performance of passenger cars. Light-duty trucks will require additional technology changes, primarily due to the 7.2% higher CAFE standard they will be required to meet beginning in 2007.

Estimates of Costs and Benefits for Individual Technologies

Technology Costs – In 1999, Sierra performed a detailed evaluation of the potential for reducing greenhouse gases from motor vehicles for the Canadian government.[4] Estimates of retail price equivalent (RPE) for design changes to improve vehicle fuel economy were developed using information obtained from participating manufacturers, component vendors, and Harbour and Associates, an internationally recognized manufacturing and management consulting firm. As described in the above referenced report, our technology cost estimates were constructed using a bottom-up approach that accounted for all of the individual elements of cost and translated them into RPE using a consistent set of assumptions regarding capital costs, overhead rates, corporate profit, and dealer markup.

Harbour and Associates has recently provided Sierra with an updated version of the prior study that reflects current manufacturing costs and updated projections of the frequency with which major automotive subsystems are being redesigned. The technologies for which Harbour provided updated cost information included:

- OHV engines;
- OHC engines;
- Variable valve lift and timing systems;
- 4-speed automatic transmissions;
- 5-speed automatic transmissions;
- 6-speed automatic transmissions;
- 6-speed automated manual transmissions;
- Conventional steel bodies and closures;
- Ultralight steel bodies and closures; and
- Aluminum bodies and closures.

Harbour did not have detailed cost studies available from which reliable information could be provided regarding the cost of hybrid systems or various technologies considered by NESCCAF and CARB that have never been mass produced (e.g., electro-hydraulic camless valve actuation). In cases where cost estimates developed using information provided by Harbour could be compared to the cost information provided by Martec, the principal discrepancies were as follows:

- Martec's estimate for the cost premium associated with OHC vs. OHV engines was significantly higher; and
- Martec's estimate for the cost of 6-speed automatic and 6-speed automated manual transmissions was significantly lower.

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[4] T.C. Austin, et al., "Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles," Report No. SR99-07-01, prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Sierra Research, Inc., July 8, 1999.

As a consultant to manufacturers who produce the vast majority of all engines and transmissions used in passenger cars and light-duty trucks, we believe Harbour's knowledge of the costs involved in manufacturing these components is unparalleled. We have therefore relied on Harbour's estimates for the cost of engines and transmissions.[5] We have also relied on Harbour's estimates for the cost of continuously variable valve lift and timing systems because Martec did not provide a cost estimate for the specific type of system on which our fuel economy projections are based. Since Martec did not provide cost estimates for lightweight bodies and closures, we also relied on input from Harbour for determining those costs. Harbour's cost estimates for the use of ultralight steels in bodies and closures were also used to estimate the cost of applying ultralight steel to suspension systems.

For all other items, Martec's estimates of the cost of vendor-supplied components were considered reasonable, with one exception. For the reasons described in detail in another attachment (Attachment C-5), the ability to simultaneously reduce costs and improve fuel economy with the use of turbocharging is not feasible. In addition, the manner in which NESCCAF and CARB estimated RPE from Martec's cost estimates is not reasonable.

Markup Factor - CARB cites an Argonne National Laboratory report and an EPA report to support the staff's estimate that a 1.4 multiplier is appropriate for marking up manufacturing costs to the retail level. In fact, the ANL report estimates the overall multiplier to range from 2.0 to 2.05 based on two different cost breakdowns and profit assumptions. ANL then estimates that the multiplier for components purchased from vendors ranges from 1.50 to 1.56 based on the assumption that vendors bear the costs of "Warranty," "R&D/Engineering," and "Depreciation and Amortization." However, OEMs usually have warranty, R&D, and engineering costs associated with components purchased from vendors.

The multipliers developed by ANL may not be unreasonable for their intended purpose in that they were being used to estimate the retail price equivalent of electric and hybrid/electric vehicles. Components such as the battery used in an electric vehicle are likely to be fully developed by a vendor and failures in customer service may be more readily assigned to the battery manufacturer. However, most vendor-supplied components are designed by the OEM, not the vendor, and the OEM has full responsibility for warranty costs as long as the vendor has manufactured the component to the OEM's specifications. In fact, the NESCCAF report specifically states (see page II-17) the following:

> *Additional manufacturer-level costs that were not captured in this analysis but that could be associated with the use of new technologies include:*
>
> - *Engineering costs, including advanced R&D, vehicle design and development*

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[5] It should also be noted that Martec specifically stated that its cost estimate for automated manual transmissions covered "piece cost only" and that "US manual transmission capacity does not exist." When the costs of developing the necessary production capacity and retiring existing transmission facilities are considered, it is clear that AMTs cannot be produced for zero incremental cost, as assumed in CARB's analysis.

- *engineering for integrating new technologies and software development;*
- *Warranty and possible recall costs;*
- *Factory capital costs associated with vehicle-level technology changes;*
- *Manufacturing costs for powertrain or vehicle assembly.*

Based on the above, more typical vendor-supplied components would have a multiplier of 1.83 using the ANL cost breakdown. It must be noted, however, that the cost estimates made by Martec do not include the cost of integrating the component into the vehicle. For components that simply replace other components (e.g., a more efficient alternator), the 1.83 markup factor may be appropriate because there are no significant integration costs. However, for most other components (e.g., cam phasers) significant changes to the engine are required to integrate the component. As a result, the 2.05 markup factor is more appropriate.

The referenced EPA report says, "In regulatory development, EPA uses a retail price equivalent (RPE) markup factor of 1.26 to adjust a manufacturing price increase to a retail price increase. This factor accounts for manufacturer overhead and profit." There is no justification for the factor contained in the referenced report and it is obviously insufficient to cover the other elements of cost considered by ANL (i.e., dealer markup, warranty, R&D, engineering). Other reports published by EPA make it clear that the source of the 1.26 markup factor is a report prepared by an EPA contractor almost 20 years ago.[6] That report makes it quite clear that the 1.26 markup factor is intended to cover pension obligations and health insurance costs, which have increased substantially since the collection of the data on which the 1985 report was based. In addition, it is clear from the 1985 report that the 1.26 markup factor is based on a corporate profit rate of only 3.8% and a dealership profit rate of only 2%. These profit levels appear to reflect a downturn in the automotive business at the time the data were collected. The assumed corporate profit rate is insufficient to attract investors.

Because the 2.05 multiplier cited by ANL is consistent (although slightly lower) than estimates provided to Sierra by vehicle manufacturers, it has been used to adjust all of Martec's cost estimates to a RPE basis. In the case of cylinder deactivation systems, additional costs were added to account for the cost of mitigating adverse NVH impacts.

"Unforeseen Innovations" – CARB staff discounted some of Martec's cost estimates by 30% to account for "unforeseen innovations in design and manufacturing" that the ISOR says will occur based on previous experience. This discount was applied to Martec's estimates for the following technologies:

- Cylinder deactivation;
- Electro-hydraulic camless valve actuation;
- Homogeneous charge compression ignition (HCCI) engines;
- Turbocharging;

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[6] "Update of EPA's Motor Vehicle Emission Control Equipment Retail Price Equivalent (RPE) Calculation Formula," Jack Faucett Associates for U.S. EPA, Report No. JACKFAU-85-322-3. September 4, 1985.

- 42-volt hybrid systems; and
- Electric power steering.

Some of these technologies, e.g., electric power steering, have been in mass production for several years. They rely on technologies that are decades old and have little potential for "unforeseen innovations." Other technologies, e.g., electro-hydraulic camless valve actuation, have been under development for a number of years and, while simple in concept, have been prevented from reaching mass production due to significant practical problems. Martec's cost estimates for such technologies are based on information obtained from companies who hope to become vendors of the technology. As a result, their estimates are likely to be somewhat optimistic in the first place. There is no basis for CARB staff to arbitrarily assume that actual costs will be 30% lower. While CARB claims such reductions are based on the agency's experience, the actual experience of the agency in projecting the cost of new technologies is not consistent with the assumption being made. When CARB adopted its Zero Emission Vehicle mandate in 1990, the staff projected that innovations would result in the cost premium for full-function electric vehicles declining to $1,350 in approximately one decade. In fact, no significant change in the cost premium for electric propulsion systems occurred and, based on the conclusions reached by a panel of experts commissioned by CARB, the cost premium for full-function electric vehicles remains in excess of $10,000.

Comparison of CARB and Sierra Cost Estimates – Table 8 shows how the cost estimates we developed compare to those used by CARB for selected technologies. It should be noted that these estimates are based on the optimistic assumption that engineering resources sufficient to make the required design changes in time to comply with the proposed 2016 standards will be available. A shortage of such resources could present a prohibitive barrier to implementation of these technology packages by 2016. Individual manufacturers may also have unique circumstances that prohibit achievement of the indicated levels of potential improvement.

Values shown in italics are based on vendor prices reported by NESCCAF subcontractors (Martec and Meszler) marked up to RPE using a more appropriate 2.05 factor vs. the 1.4 factor used by NESCCAF and CARB. The value shown for cylinder deactivation is also based on NESCCAF contractor vendor prices but it includes $220 for integration costs that were not accounted for.

Technology Benefits - Table 9 shows Sierra's estimates of the fuel consumption benefits and of most of the technologies considered in the CARB analysis. In this table, costs are incremental to the 2009 projected baseline, which assumes 100% use of 5-speed transmissions. All of the results shown in the table are on a constant performance basis. In other words, engine resizing was assumed for any technologies that simultaneously improve fuel economy and performance (e.g., weight reduction and additional transmission gears).

Table 8
CARB Staff Estimates of Retail Price Increase For Various Technologies Applied to a "Large" Car Compared to Sierra Estimates

	CARB	Sierra*
Discrete Variable Valve Lift (DVVL) (with DCP)	$357	*$523*
Continuously Variable Valve Lift (with DCP)	$581	$808
Turbocharging w/resize (CARB) and w/o resize (Sierra)	-$210	*$820*
Cylinder Deactivation (Deact)	$113	$456
5-Speed Automatic Transmission (A5) vs. 4-Speed	$140	$192
6-Speed Automatic Transmission (A6) vs. 4-Speed	$105	$624
Automatically Shifted Manual Transmission (AMT)	$0	$769
Electric Power Steering (EPS)	$39	*$82*
Higher Efficiency Alternator (ImpAlt)	$56	*$73*
Gasoline Direct Injection-Stoichiometric (GDI-S)	$259	*$337*
Modified AC Compressor and HFC-152a refrigerant	$88	*$128*
Aggressive Shift Logic, Improved Torque Converter + Reduced Aero Drag, Rolling Resistance, Engine Friction	$125-145	n.a.
Mild Hybrid (42-volt, 10 kW, motor assist) (ISG)	$1107	*$1886*

*Numbers in *italics* are based on costs reported by NESCCAF contractors.

Table 9
Benefits and Costs of Individual Technologies, Passenger Cars
(costs incremental to 2009 projected baseline)

	Fuel Cons/CO_2 Change			$/-1% CO_2
	CAFE	Average CA	Cost	(CAFE-based)
Reduced Aerodynamic Drag	0.0%	0.0%	n.a.	n.a.
Improved Tires	0.0%	0.0%	n.a.	n.a.
Light-Weight Steel Substitution	*-0.8%*	*-0.8%*	*$13*	*$15*
Lower Engine Friction/Parasitics	-0.5%*	-0.5%*	$14	$28
Aggressive Shift Logic (ASL)	-1.8%	-1.1%	$66	$37
Cylinder Deactivation (incl. mitigation)	-8.6%	-5.0%	$456	$53
Electric Power Steering	-1.5%	-1.1%	$82	$55
Ultra-Light Steel Body and Suspension	*-7.5%*	*-7.1%*	*$416*	*$56*
CVVL&T (like Valvetronic/VANOS)	*-12.6%*	*-7.4%*	*$808*	*$64*
DOHC V6 vs. OHV V6	*-8.7%*	*-7.4%*	*$622*	*$71*
Imp. Alternator/Charging	-1.0%*	-1.0%*	$73	$73
Automated Manual w/ASL	*-3.7%*	*-3.1%*	*$577*	*$154*
6-Speed Auto w/ASL	*-2.7%*	*-2.0%*	*$498*	*$184*
Aluminum Body vs. Ultralight Steel	*-5.9%*	*-5.7%*	*$1,596*	*$272*
42-volt Hybrid Motor Assist	*-6.0%*	*-2.0%*	*$1,886*	*$315*
Gasoline Direct Injection	-1.0%**	-1.0%**	$337	$337
Turbocharging, 87 octane	-0.3%	+2.1%	$820	$3,037

*Estimates based on consultation with vehicle manufacturers applied using multiplicative factor.
** GDI estimate is based on NESCCAF report.
Note: Estimates for technologies in *italics* include effects of engine downsizing for constant performance.

The results shown in Table 9 are rank ordered based on the ratio of technology cost to percent reduction in fuel consumption and CO_2. Except where noted, the fuel consumption/CO_2 results were generated using Sierra's VEHSIM model. The estimated CO_2 change under the column labeled "Actual CA" shows how the technology affects fuel consumption under driving patterns that are representative of how motorists actually drive in California. These results were obtained by substituting the driving cycles representing current California driving patterns for the driving cycles used for determining compliance with Corporate Average Fuel Economy standards. (A separate attachment, Attachment C-2, describes the driving cycles and how they were developed.) VEHSIM results for the "LA4" and "Highway" cycles used in the CAFE test procedures are also listed. As shown in the table, technologies that are designed to reduce throttling losses (e.g., cylinder deactivation) produce much larger benefits on the CAFE test procedures because of the relatively low loads and speeds associated with the LA4 and Highway driving cycles. (Modeling of the combinations of technologies necessary to meet the proposed standards indicates that fuel saving are about 20% less in average California driving than on the CAFE test procedures.)

Aerodynamic Drag and Rolling Resistance Reduction - Several technologies listed in Table 9 are worthy of comment because of their significance or because of how our estimates differ from those used by CARB. Note that we assign no benefits to aerodynamic drag improvements or lower rolling resistance tires. In contrast, CARB assumed an 8-10% reduction in aerodynamic drag would be achieved, leading to 1.5-2.0% reductions in CO_2 emissions. We conclude there are no significant benefits left to achieve on average due to the styling limitations imposed by further reductions in aerodynamic drag. The new Chrysler 300 sedan is a case in point. Its 0.35 drag coefficient is significantly higher than the vehicle it replaces. As reported in the June 2004 edition of *Car & Driver*, "The 300 also represents a return to chiseled three-box proportions after a long run of smooth, cab-forward designs." The commercial success this vehicle is achieving indicates that styling to minimize drag coefficient has already gone beyond what the market wants. Similar trends toward more classic, chiseled styling are apparent at other companies and the similar effects on drag coefficient are expected.

In the case of reduced rolling resistance, CARB assumed a 2% reduction in CO_2 could be achieved through a 10% reduction in rolling resistance. As shown in a separate attachment (Attachment C-7) addressing this issue, our analysis indicates that (1) the rate of progress in reducing rolling resistance has slowed; and (2) new federal safety standards may limit the extent to which future reductions occur. In addition, CARB's analysis is implicitly based on the assumption that changes in OEM tire rolling resistance will generate benefits over the full life of the vehicle. However, motorists cannot be expected to purchase OEM replacement tires.

Weight Reduction - Another significant deviation from CARB's analysis is that we show that redesigning bodies, closures, and suspensions with maximized use of ultralight steel will be competitive with other technologies considered by CARB. This conclusion is based on our review of the available technical literature.

Over the course of a number of years, an international consortium of sheet steel producers contracted with independent engineering firms for the design and development of lightweight vehicle bodies and body closures using high-strength steel as well as suspension systems using high-strength steel. The overall effort spanned seven years and was divided into four different program areas: Ultra Light Steel Auto Body (ULSAB); Ultra Light Steel Auto Suspension (ULSAS); Ultra Light Steel Auto Closures (ULSAC); and Ultra Light Steel Auto Body – Advanced Vehicle Concepts (ULSAB-AVC).

A variety of steels were considered for use, ranging from conventional mild steel (MS) with a yield strength of 140 MPa, to high-strength low-alloy (HSLA) steel with a yield strength of 350-490 MPa, and martensite steels with a yield strength of over 1,000 MPa.

In addition to the use of higher strength steels, the ULSAB program included evaluation of tubular hydroforming, hydromechanical sheet forming, use of steel-polypropylene-steel sandwich materials, and laser welding as the production techniques that could be used to minimize weight. As a result, the weight reduction achieved involves far more than material substitution and involves all new tooling.

Table 10 summarizes the results that have been published for the program. Links to the technical reports are at www.sierraresearch.com/lightweightsteel.

Table 10
Typical Midsize Passenger Sedan Mass Breakdown and Potential Savings with UltraLight Steel

Category	Baseline (lbs)	Category % Reduction	Total % Reduction	Savings (lbs)
Body in White	640	25%	5.0%	160
Drivetrain	576	n.a.		
Suspension	384	25%	3.0%	96
Interior	352	n.a.		
Trim/Hardware/Glass	224	n.a.		
Wheels and Tires	224	n.a.		
Fuel, Exhaust System, etc.	224	n.a.		
Body Closures	192	22%	1.3%	42
Fluids	160	n.a.		
Electrical	128	n.a.		
Steering and Brakes	96	n.a.		
TOTAL	3200		9.3%	298
Total With Compounding			11.7%	373

It should be noted that some of the potential benefits of ultralight steel are already being achieved and further weight reductions resulting from the use of this technology will be included in the 2009 baseline. Based on consultation with vehicle manufacturers, we estimate about two-thirds of the potential benefits will still be achievable post-2009. However, achievement of the benefits shown in Table 10 requires an all-new, ground up vehicle design. Insufficient lead time remains between now and 2016 to maximize the use of high-strength steels in all vehicle platforms without accelerated retirement of existing platforms. While we have accounted for the cost of early retirement, this adjustment does not reflect the lead time and resource obstacles that make clean sheet redesigns of all vehicle architectures unlikely.

For unibody vehicles, as was shown in Table 9, we estimate a 7.48% reduction in fuel consumption can be achieved at a cost of $416. As indicated in the row of Table 9 labeled "Aluminum Body vs. Ultralight Steel," further weight reductions would be possible with the use of aluminum; however, the cost premium is significant and the cost per percent reduction in CO_2 is relatively high. The weight reductions used in our VEHSIM modeling of this technology were based on our 1999 study for the Canadian government and information obtained from studies conducted by Harbour. Those studies indicate that the weight of a conventional steel body and closures can be reduced by 50% with the use of aluminum. On a constant performance basis, this allows another 5.87% reduction in fuel consumption for a unibody vehicle.

Cylinder Deactivation - Our modeling shows cylinder deactivation to be more effective than was estimated by AVL. The 8.6% reduction we estimate on a CAFE basis is consistent with data obtained from three different sources, which include whole vehicle tests and engine maps. It should be noted that we do not assume this technology is feasible for any vehicles with 4-cylinder engines because of noise, vibration, and harshness (NVH) issues. It should also be noted that the real world benefits of this technology are only about half of the CAFE benefits. Martec and Harbour estimates for the cost of the basic technology were reasonably consistent. We added additional costs to account for the mitigation measures necessary to prevent increased NVH.

Variable Valve Lift and Timing - Our modeling also shows significant benefits for continuously variable valve lift and timing (CVVL&T). The 12.64% reduction shown in Table 9 is based on our analysis of the BMW Valvetronic/VANOS system and literature showing the effect of CVVL&T on engine efficiency.[7] As described in Attachment C-6, the engine map we developed to represent CVVL&T enables us to match the actual CAFE values reported for the BMW 745i sedan that uses the system. The $808 cost estimate shown in the table is based on information provided by Harbour.

Automated Manual Transmission - We also show automated manual transmissions using "aggressive shift logic" (ASL) to be capable of providing a 3.74% reduction in fuel consumption relative to a 5-speed automatic. The higher benefit predicted by AVL must involve efficiency assumptions and/or shift logic assumptions that we cannot support. Unlike in CARB's analysis, we show a significant ($577) cost premium for AMT compared to a conventional 5-speed automatic. This cost, which includes $66 in adverse driveability impact for ASL, is based on Harbour's estimate of the Volkswagen Kassel transmission plant running at 100% of capacity. It also accounts for the cost associated with early retirement of existing transmissions manufacturing facilities, another cost that the NESCCAF CARB analysis completely ignores. Considering the cost factors that

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[7] D. Moro, et al., "Thermodynamic Analysis of Variable Valve Timing Influence on SI Engine Efficiency," SAE Paper No. 2001-01-0667, March 2001.

were ignored, CARB's use of a negative cost for this technology relative to a 5-speed automatic is not reasonable.

Replacement of OHV Engines with OHC Engines - We show the replacement of overhead valve (OHV) engines with dual overhead cam (DOHC) engines to be an effective strategy, assuming the DOHC engine is sized to provide the same 0-30 mph acceleration performance as the OHV engine. The $622 cost of this technique is based on detailed information obtained from Harbour.

Relatively Ineffective Technologies – The last three technologies listed in Table 9 are noteworthy because, although CARB assumed they would be used, our analysis indicates that they have very poor cost-effectiveness. Our modeling of motor-assisted hybrids produced results (-5.98% fuel consumption) that are consistent with AVLs; however, the ratio of cost to benefits is extremely high. The cost numbers shown in the table use Martec's estimates of manufacturing costs marked up to RPE using a 2.05 multiplier. (Harbour did not have its own cost information for this technology.) Note also that the "Actual CA" benefits of hybrid technology are less than half the benefits obtained on the CAFE test procedures.

When modeled assuming the use of 87 octane fuel and no conversion from V6 to inline 4-cylinder engines, turbocharging is another technology that produces an extremely high cost/benefit ratio. We show no significant fuel economy benefit for this technology on the CAFE test procedures and an <u>increase</u> in fuel consumption during actual California driving.

Finally, using Martec's estimate for cost and AVL's fuel estimated consumption benefits, GDI-S is the least cost effective of all of the technologies considered. (We did not have independent cost information or engine maps for GDI-S.) Why it was included in the analysis CARB is relying on is a mystery to us.

Alternative Air Conditioning Systems – As noted above, we have evaluated the cost-effectiveness of alternative air conditioning systems using cost estimates prepared by NESCCAF contractor Dan Mezsler. Mezsler estimated the manufacturing cost increase associated with a variable displacement compressor with "external control" at $40. He estimated the cost of converting from HFC-134a to HFC-152a at $22.50. Marked up to RPE, the cost of these changes would be $128. We have also used the NESCCAF estimates for the benefits of this technology change.[8]

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[8] It should be noted, however, that our simulation modeling of baseline A/C compressors indicates that the NESCCAF analysis may be overstating the fuel consumption associated with A/C system use. The baseline, fixed displacement compressor assumed in NESCCAF's analysis was estimated to consume 0.0017 gal/mi with a 29% "compressor on" fraction. Using our VEHSIM model to estimate the fuel consumption for current production compressors, consumption with a 29% "on" fraction ranged from 0.0009 to 0.0015 gal/mi as the ambient temperature varied from 25°C to 35°C. Assuming the average consumption over this temperature range is representative, the savings associated with a 50% reduction in compressor load would be about 30% less than CARB has estimated. Based on actual California driving patterns, the economic benefits of alternative compressors would be further reduced (because the energy required to run the A/C compressor per mile of travel goes down when vehicle speed goes up).

For passenger cars, CARB assumes an 8.1 g/mi reduction in indirect CO_2 emissions and a 8.5 g/mi CO_2-equivalent reduction in "direct" emissions for the alternative system. To put this reduction in perspective, 16.6 g/mi CO_2 is equivalent to 5.6% of the CO_2 emitted by a vehicle getting 30 mpg. At a cost of $128, the cost-effectiveness of alternative A/C systems would be $23 per 1% reduction in CO_2, which is less than the cost of almost all of the other technologies shown in Table 9 above. As a result, the use of alternative A/C systems is assumed to be one of the first technologies that would be used to comply with the proposed regulations. It should be noted, however, that our analysis did not address the vehicle service problems that might be associated with making another transition in A/C system refrigerant so soon after the replacement of Freon with HFC-134a. To the extent that the service industry cannot afford to simultaneously deal with Freon, HFC-134a, and HFC-152a, motorists may have reduced choices for where to obtain service. Our analysis is also based on the assumption that more expensive, secondary-loop systems are not necessary to deal with the increased flammability of HFC-152a.

Future Scenarios

The effect of combinations of technologies was evaluated using VEHSIM for each of the four vehicle categories selected for detailed modeling. The technology deployment sequence generally involved adding technologies in order of their cost effectiveness on an individual basis. Slight variations in that approach were used in cases where a more expensive technology was considered less risky. Table 11 shows the sequence of technology deployment that we determined to be most reasonable for the four vehicle categories considered. (Note that the technologies shown in the table do not include A/C system changes because they were not modeled using VEHSIM. Credit for alternative A/C systems is provided under the proposed regulations without the need for testing or modeling.)

Table 11
Technology Combinations
(shaded areas show technologies needed for federal CAFE compliance)

	Passenger Cars	Vans	Pickups	SUVs
1.	Minor Weight Red.	Minor Weight Red.	Minor Weight Red.	Minor Weight Red.
2.	Lower Fric/Parasitics	Aggressive Shift Logic	Aggressive Shift Logic	Aggressive Shift Logic
3.	Aggressive Shift Logic	Lower Fric/Parasitics	Lower Fric/Parasitics	Lower Fric/Parasitics
4.	Electric Power Steering	2V to 4V	Cyl. DeAct 2V >4 cyl	Cyl. DeAct 2V >4 cyl
5.	2V to 4V and CVVL&T	Electric Power Steering	4V CVVLT	Imp Alternator/Charging
6.	4V CVVL&T	All CVVL&T	Imp Alternator/Charging	4V CVVLT
7.	Imp Alternator/Charging	UltraLight Steel	Electro-Hydraulic PS	Electro-Hydraulic PS
8.	UltraLight Steel (ULS)	Imp Alternator/Charging	UltraLight Steel	UltraLight Steel
9.	Automated Manual Tran	Automated Manual Tran	Automated Manual Tran	Automated Manual Tran
10.	Aluminum replaces ULS	Aluminum replaces ULS	Aluminum replaces ULS	Aluminum replaces ULS
11.	42-Volt Hybrid	42-Volt Hybrid	42-Volt Hybrid	42-Volt Hybrid

The shaded cells at the top of each column in Table 11 show the technologies that were necessary to achieve the fuel economy improvement required to meet federal CAFE standards in 2009 baseline. In the case of passenger cars, increased use of OHC engines and 5-speed automatic transmissions assumed in the 2009 baseline was nearly sufficient to offset the weight and performance increase projected to occur by 2009. Only a minor amount of weight reduction is necessary to maintain the same CAFE compliance margin as existed in 2003. In the case of trucks, significant additional technology is required in the baseline (no CARB regulation case) because of the increased stringency of the 2007 federal CAFE standards.

Tables 12 and 13 show our modeling results for the combinations of technology needed to comply with the proposed 2016 standards. The tables show the effect on costs and CO_2 levels of the addition of alternative A/C systems using HFC-152a refrigerant.

Table 12
Fuel Economy and Costs of Passenger Car/LDT1 Technology Combinations Required to Comply With the Proposed 2016 Standard

Vehicle Category	2009 Baseline	Technology Combinations	
		1-10	1-11
Minicars	38.58	53.82	56.48
Subcompact Sedans/Wagons	31.65	44.15	46.34
Compact Sedans/Wagons	33.01	46.05	48.32
Midsize Sedans/Wagons	28.62	39.80	41.77
Large Sedans/Wagons	26.96	37.61	39.47
Small Coupes/Convertibles	24.53	34.22	35.91
Midsize Coupes/Convertibles	28.24	39.39	41.34
Large Coupes/Convertibles	27.62	38.54	40.44
Small Sports/Luxury Sedans	24.74	34.51	36.22
Midsize Sports/Luxury Sedans	26.04	36.33	38.12
Large Sports/Luxury Sedans	24.29	33.88	35.55
Sports Cars	27.63	38.55	40.45
High-Performance Sports Cars	24.35	33.97	35.65
All Passenger Cars	29.10	**40.56**	**42.56**
Small 2WD Pickups	25.82	30.55	32.91
Small 2WD SUVs	28.52	33.78	35.88
Small 4WD SUVs	26.64	31.56	33.52
All Cars and LDT1s	28.73	**39.31**	**41.34**
RPE Increase w/o A/C		**$3,484**	**$5,370**
RPE Increase for A/C		**$128**	**$128**
Total Price Increase		**$3,612**	**$5,498**
CO2 Equivalent g/mi, including A/C System Credit		**210.7**	**199.6**
Percentage of Each Combination Required		**49%**	**51%**
Composite CO2 g/mi		205	
Composite Costs		$4573	

Table 12 shows the modeling results for passenger cars and LDT1s. To comply with the proposed 205 g/mi standard for model year 2016, a 49:51 mixture of technology combinations through step 10 and step 11 of the 11 steps shown in Table 11 would be required. The price increment over the 2009 baseline for technologies through step 10 is $3,612. The price increment for technologies through step 11 is $5,498. An example of how these prices were calculated is shown below for passenger cars. Technology costs are multiplied by the fraction of the vehicles using the technologies.

Technology	Tech Cost * % Used	Average Cost/Vehicle
Lower Fric/Parasitics:	$14*100%=	$14
Aggressive Shift Logic:	$66*87%=	$57
Electric Power Steering:	$82*100%=	$82
2V to 4V and CVVL&T:	($622+$808)*15%=	$215
4V CVVL&T:	$808*85%=	$687
Imp Alternator/Charging:	$73*100%=	$73
UltraLight Steel (ULS):	$416*100%=	$416
Automated Manual Tran:	$577*87%=	$502
Aluminum replaces ULS:	$1596*100%=	$1596
Alternative A/C System:	$128*100%=	$128

TOTAL through technology 10.. $3770
Additional cost for technology 11.................................... $1886
TOTAL through technology 11.. $5656

Table 13
Fuel Economy and Costs of LDT2 Technology Combinations Required to Comply With the Proposed 2016 Standard

Vehicle Category	2009 Baseline	Technology Combinations	
		1-8	1-9
Minivans	25.33	30.85	n.a.
Large Vans	19.74	24.12	n.a.
Small 4WD Pickups	21.64	24.99	n.a.
Large 2WD Pickups	20.34	23.79	n.a.
Large 4WD Pickups	19.28	22.27	n.a.
Midsize 2WD SUVs	24.30	27.14	27.87
Midsize 4WD SUVs	22.64	25.29	25.97
Large 2WD SUVs	19.14	21.38	21.95
Large 4WD SUVs	19.35	21.61	22.19
RPE Increase w/o A/C		$945	$1,250
RPE Increase for A/C		$128	$128
Total Price Increase		$1,073	$1,378
CO2 Equivalent g/mi, including A/C System Credit		335.7	330.9
Percentage of Each Combination Required for SUVs		23%	77%
Composite CO2 g/mi		332	
Composite Costs		$1,308	

When LDT1s are included, the price through step 10 and through step 11 drops to $3,612 and $5,498, respectively. The price drop is primarily because of the more limited use, and therefore lower cost, of aluminum in trucks. (The use of aluminum in trucks with body-on-frame construction is much less than in unibody passenger cars.) The net price increase associated with a 49:51 mixture of these combinations is $4,573.

For light-duty trucks, the necessary mix of technology combinations required to achieve compliance is shown in Table 13. Vans and pickups use the eighth technology step. SUVs use a 23:77 mixture of steps 8 and 9. The average price increase to achieve the 332 g/mi standard is $1,308.

Table 14 shows how our estimates of lifetime gasoline savings for passenger cars, ignoring the rebound effect, compare to those made using CARB's methodology. As shown, we consider savings over a 13-year period and we account for vehicle scrappage. Average lifetime VMT is about 151,000 miles.

Table 14
Examples of Lifetime Cost Calculations for Passenger Cars Ignoring the Rebound Effect

Sierra's Technology Cost: $4,573 x 1.08 (sales tax) = $4,939
CARB's Technology Cost: $1,064
CAFE Baseline (CARB): 28.6 mpg; Average CA Driving Baseline (Sierra): 24.5 mpg
Future CAFE (CARB): 41.9 mpg; FutureAverage (Sierra): 33.1 mpg
Fuel Price: $1.74/gallon

Year	CARB VMT*	Sierra VMT**	CARB Base Cost	Sierra Base Cost	CARB NPV	Sierra NPV
0					-$1,064	-$4,939
1	16071	16071	$992	$1,150	-$764	-$4,664
2	15530	15096	$958	$1,080	-$488	-$4,424
3	15006	14364	$926	$1,028	-$234	-$4,213
4	14503	13728	$895	$982	-$1	-$4,026
5	14015	13051	$865	$934	$215	-$3,862
6	13545	12388	$836	$886	$413	-$3,718
7	13089	11697	$808	$837	$595	-$3,591
8	12649	10987	$781	$786	$763	-$3,482
9	12224	10236	$754	$733	$917	-$3,387
10	11815	9482	$729	$679	$1,059	-$3,306
11	11418	8709	$705	$623	$1,190	-$3,237
12	11036	7950	$681	$569	$1,310	-$3,178
13	10667	7193	$658	$515	$1,421	-$3,129
14	10310		$636		$1,523	
15	9966		$615		$1,617	
16	9633		$595		$1,703	
Total	201,477	150,953				

*CARB VMT ignores scrappage
** Sierra VMT includes effect of scrappage

We calculate baseline fuel costs and fuel savings based on actual California driving patterns, not CAFE test procedures. We calculate the net present value of fuel savings by summing fuel costs over a 13-year period using an 8% discount rate. We account for sales tax on new cars in comparing the fuel savings to the cost of the technology required to meet the standards.

In contrast, CARB's estimates are based on fuel economy measurements using CAFE test procedures over 16-year period, ignoring vehicle scrappage. Average lifetime VMT is almost 202,000 miles. (As explained in Attachment C-3, CARB's estimates of lifetime mileage are based on an obvious mathematical error in CARB's treatment of odometer data recorded in the State's motor vehicle inspection and maintenance program [i.e., "Smog Check"].) The NPV of the fuel savings is based on a discount rate of only 5%. Fuel savings are compared to the cost of the technology required to meet the standards without consideration of sales tax.

The VMT columns in Table 14 show the annual average mileage accumulation as a function of vehicle age. The values in the Sierra VMT column reflect the effect of scrappage and stop at age 13, which we believe to represent the average lifetime of vehicles in customer service.

The "base cost" columns in Table 14 show the annual fuel cost assumed for the no-regulation case. The values in the CARB Base Cost column start off lower because CARB does its calculations based on the assumption that motorists actually achieve the unadjusted CAFE levels in customer service. Sierra's base cost values start off higher because we account for the fact that fuel economy in average California driving is about 15% lower than CAFE. CARB's base cost values end up higher than Sierra's because CARB fails to account for scrappage.

The first value in the NPV columns is the cost of the technology required to meet the proposed standard. CARB's estimate is $1,064; our estimate is $4,573 before sales tax and $4,939 with the tax applied. The last value in the "NPV" columns is the net lifetime cost/savings. Based on CARB's assumptions, the savings is $1,703. Correcting the errors made by CARB, there is a net loss of $3,129.

Table 15 shows the same analysis accounting for a 17% rebound effect. The net cost increase associated with the proposed standards rises from $3,129 to $3,357.

The differences in fuel cost savings calculations are similar for light-duty trucks except that CARB sums fuel cost savings over a 19-year period while we continue to use a 13-year period. However, there is another problem with CARB's estimate of the fuel cost savings for light-duty trucks. The ISOR describes technology and cost changes that are expected to occur between 2002 and 2009. The 2009 baseline fuel consumption for minivans was projected to decrease by 6.4%, the fuel consumption for small trucks was projected to decrease by 9.0%, and the fuel consumption for large trucks was projected to decrease by 5.5%. The estimated reductions in fuel consumption by 2009 are consistent with the 7.2% increase in CAFE standards that was recently adopted by NHTSA. However, CARB's final calculation of the reduction in fuel consumption associated with the proposed standards failed to account for the fuel consumption reductions projected for

2009. LDT2 fuel consumption under the proposed standards was mistakenly compared to the 2002 baseline. As a result, the benefits of the proposed standards in terms of reduced fuel consumption and reduced fuel costs have been significantly overestimated.

Table 15
Example of Lifetime Cost Calculations for Passenger Cars Including a 17% Rebound Effect

Sierra's Technology Cost: $4,573 x 1.08 (sales tax) = $4,939
CARB's Technology Cost: $1,064
CAFE Baseline (CARB): 28.6 mpg; Average CA Driving Baseline (Sierra): 24.5 mpg
Future CAFE (CARB): 41.9 mpg; Future Real (Sierra): 33.1 mpg
Fuel Price: $1.74/gallon

Year	CARB VMT*	Sierra VMT**	CARB Base Cost	Sierra Base Cost	CARB NPV	Sierra NPV
0					-$1,064	-$4,939
1	16071	16071	$992	$1,150	-$764	-$4,698
2	15530	15096	$958	$1,080	-$488	-$4,489
3	15006	14364	$926	$1,028	-$234	-$4,304
4	14503	13728	$895	$982	-$1	-$4,141
5	14015	13051	$865	$934	$215	-$3,997
6	13545	12388	$836	$886	$413	-$3,871
7	13089	11697	$808	$837	$595	-$3,761
8	12649	10987	$781	$786	$763	-$3,665
9	12224	10236	$754	$733	$917	-$3,582
10	11815	9482	$729	$679	$1,059	-$3,511
11	11418	8709	$705	$623	$1,190	-$3,451
12	11036	7950	$681	$569	$1,310	-$3,399
13	10667	7193	$658	$515	$1,421	-$3,357
14	10310		$636		$1,523	
15	9966		$615		$1,617	
16	9633		$595		$1,703	
Total	201,477	150,953				

*CARB VMT ignores scrappage
** Sierra VMT includes effect of scrappage

The lifetime fuel cost calculations for LDT2s are shown in Tables 16 and 17. As noted above, the base fuel costs shown under the column "CARB Base Cost" are based on the fuel economy of model year 2002 LDT2s and fail to account for the improvement in fuel economy required under the 2007 federal CAFE standards. In contrast, Sierra's baseline fuel costs reflect the 7.2% increase in fuel economy required to comply with the federal CAFE standards. As with the tables for passenger cars and LDT1 trucks, Sierra's fuel cost estimates are based on average California driving patterns, while the fuel costs based on CARB's methodology are based on the inaccurate assumption that customer service fuel economy is equal to unadjusted CAFE fuel economy. By ignoring scrappage and summing VMT over a 19 year period, CARB's analysis accounts for fuel use for 227,423 miles. Sierra's analysis accounts for scrappage and sums costs over a 13 year period, which yields an average lifetime VMT of 152,863 (much closer to the true average).

Table 16
Example of Lifetime Cost Calculations for LDT2s
Including a 17% Rebound Effect
Sierra's Technology Cost: $1,308 x 1.08 (sales tax) = **$1,413**
CARB's Technology Cost: **$1,029**
CAFE Baseline (CARB): **20.1 mpg**; Average CA Driving Baseline (Sierra): **18.7 mpg**
Future CAFE (CARB): **26.2 mpg**; Future Real (Sierra): **20.7 mpg**
Fuel Price: **$1.74/gallon**

Year	CARB VMT*	Sierra VMT**	CARB Base Cost	Sierra Base Cost	CARB NPV	Sierra NPV
0					**-$1,029**	**-$1,413**
1	17009	17009	$1,493	$1,580	-$823	-$1,295
2	15745	15430	$1,382	$1,434	-$641	-$1,197
3	14847	14355	$1,304	$1,334	-$478	-$1,112
4	14135	13491	$1,241	$1,253	-$330	-$1,038
5	13538	12764	$1,189	$1,186	-$195	-$973
6	13023	12099	$1,143	$1,124	-$72	-$916
7	12567	11495	$1,103	$1,068	$42	-$866
8	12158	10887	$1,067	$1,012	$147	-$822
9	11787	10288	$1,035	$956	$243	-$784
10	11448	9669	$1,005	$898	$333	-$750
11	11134	9071	$978	$843	$416	-$721
12	10845	8471	$952	$787	$492	-$696
13	10574	7835	$928	$728	$564	**-$675**
14	10321		$906		$630	
15	10082		$885		$692	
16	9857		$865		$749	
17	9647		$847		$803	
18	9448		$829		$853	
19	9258		$813		**$899**	
Total	227423	152863				

*CARB VMT ignores scrappage
** Sierra VMT includes effect of scrappage

The first value in the NPV columns of Tables 16 and 17 is the cost of the technology required to meet the proposed standard. CARB's estimate is $1,029; our estimate is $1,308 before sales tax and $1,413 with the tax applied. The last value in the "NPV" columns is the net lifetime cost/savings. Based on CARB's assumptions, the savings is $899. Correcting the errors made by CARB, and accounting for the rebound effect, there is a net loss of $675. Ignoring the rebound effect, the net loss is $540, as shown in Table 17.

Table 17
Example of Lifetime Cost Calculations for LDT2s Ignoring the Rebound Effect

Sierra's Technology Cost: **$1,308 x 1.08 (sales tax) = $1,413**
CARB's Technology Cost: **$1,029**
CAFE Baseline (CARB): **20.1 mpg**; Average CA Driving Baseline (Sierra): **18.7 mpg**
Future CAFE (CARB): **26.2 mpg**; Future Real (Sierra): **20.7 mpg**
Fuel Price: **$1.74/gallon**

Year	CARB VMT*	Sierra VMT**	CARB Base Cost	Sierra Base Cost	CARB NPV	Sierra NPV
0					**-$1,029**	**-$1,413**
1	17009	17009	$1,493	$1,580	-$823	-$1,274
2	15745	15430	$1,382	$1,434	-$641	-$1,157
3	14847	14355	$1,304	$1,334	-$478	-$1,057
4	14135	13491	$1,241	$1,253	-$330	-$969
5	13538	12764	$1,189	$1,186	-$195	-$893
6	13023	12099	$1,143	$1,124	-$72	-$826
7	12567	11495	$1,103	$1,068	$42	-$766
8	12158	10887	$1,067	$1,012	$147	-$715
9	11787	10288	$1,035	$956	$243	-$669
10	11448	9669	$1,005	$898	$333	-$630
11	11134	9071	$978	$843	$416	-$596
12	10845	8471	$952	$787	$492	-$566
13	10574	7835	$928	$728	$564	-$540
14	10321		$906		$630	
15	10082		$885		$692	
16	9857		$865		$749	
17	9647		$847		$803	
18	9448		$829		$853	
19	9258		$813		$899	
Total	227423	152863				

*CARB VMT ignores scrappage
** Sierra VMT includes effect of scrappage

In summary, if one corrects the specific errors in the CARB staff analysis identified here, the average per-vehicle cost of technology required for passenger cars and LDT1s to comply with the proposed regulations is $4,573 (before adding sales tax) and the lifetime gasoline savings, accounting for the rebound effect, would average about 1,403 gallons. The NPV of the gasoline savings realized on these vehicles from compliance with the proposed regulation would average $1,582 (based on the $1.74/gallon fuel price assumed by CARB). When sales tax on the technology required for compliance is accounted for, the net effect of the proposed regulation would be to increase the lifetime cost of owning and operating a passenger car or LDT1 by $3,357 (as shown in Table 15 above). Further, even this large net cost is understated because of CARB's assumptions that design changes necessary for compliance will be deployed nationwide.

For larger trucks, correction of the specific errors made by the CARB staff causes the cost of the technology required to comply with the regulations to be $1,308 and the lifetime gasoline savings, accounting for the rebound effect, to become 655 gallons. The NPV of the gasoline savings is only $738. When sales tax on the vehicle price increase is accounted for, the net increase in cost for the LDT2 standards is $675. The actual cost increase will certainly be higher because CARB has ignored the impact of making MDPVs subject to the regulation.

Attachment C-2

California Driving Cycle Development

This attachment describes how new driving cycles (i.e., second-by-second vehicle speed vs. time) traces were developed from recent driving data collected in California to represent "real world" fuel economy and CO_2 emissions in both urban and non-urban areas of California. After presenting background information, the datasets and methodologies used to construct the new California cycles are described. Characteristics of these new cycles are compared to the current EPA City and Highway fuel economy cycles.

Background

Light-duty vehicle fuel economy and CO_2 emissions are routinely measured and reported using two driving cycles developed over thirty years ago by the U.S. Environmental Protection Agency (EPA) to represent the manner in which these vehicles are driven in both urban and non-urban areas as described below:

- Urban (City) Cycle – Urban or city fuel economy is measured using the driving cycle contained in the Federal Test Procedure (FTP) for light-duty vehicles[1], commonly referred to as the Urban Dynamometer Driving Schedule (UDDS) or the Los Angeles 4 (LA4) cycle. This cycle, which has been the standard cycle for light-duty vehicle emissions testing since model year 1972, was developed from vehicle speed measured over a road route intended to represent a typical commuting trip in the Los Angeles area in the 1960s. To ensure that all vehicles could be tested with this cycle on belt-driven chassis dynamometers in use at the time, the maximum acceleration (and deceleration) rate of the LA4 cycle was limited to 3.3 mph/sec. The cycle is 1371 seconds long with an average speed of 19.6 mph over a distance of 7.5 miles.

- Non-Urban (Highway) Cycle – Non-urban or rural fuel economy is measured using "Highway" driving cycle[2] developed by EPA in 1974. The Highway cycle was created in response to heightened interest in vehicle fuel economy as a result of the 1973 oil embargo. During the development of the Highway cycle, a policy decision was made by EPA to have the cycle represent operation in areas where the then new federal 55 mph speed limit was being strictly enforced. Thus the Highway cycle was developed with a maximum speed of 59.9 mph and is 765 seconds long with an average speed of 48.3 mph over 10.3 miles.

AVL's fuel economy simulations used the CAFE test procedure driving cycles, in order to permit comparisons between different technology packages. The CARB staff's benefit assessments in turn relied on portions of the AVL modeling, and on other predictions of fuel economy changes that apparently depended directly or indirectly on an assumption that the CAFE test procedures would adequately reflect the fuel economy changes that could be obtained for various technologies. Nevertheless, it has been well-understood since the late 1970s (at EPA, NHTSA and in Congress) that the fuel economy generally achieved in average driving conditions was below the value achieved on the CAFE test procedure. After several years of study, in April 1984, EPA issued final rules (49 *Fed Reg* 13832) that adopt "adjustment factors" from the values achieved on the CAFE test procedure. These "adjustment factors" are applied to the fuel economy labels affixed to new motor vehicles. In developing these factors, EPA examined data from DOE, various contractors and the auto industry based on travel characteristics, average miles traveled per day and technologies anticipated to be used by manufacturers. These factors adjust the "City" portion of the CAFE test downward by 10% and the "Highway" portion downward by 22%. Thus, EPA and other federal agencies involved with vehicle fuel economy have recognized for many years that adjustments to account for both driving patterns and how technologies perform under these conditions is critical to determining that information provided to consumers more accurately reflects the fuel economy they achieve in actual driving.

Because the CAFE driving cycles cannot properly be assumed to represent actual urban and non-urban driving patterns on California roads today, two new driving cycles were developed from driving data collected under a series of chase car studies[3,4,5,6,7] from 1997 through 2000 sponsored by the California Department of Transportation (Caltrans) and CARB. As described below, the new "Cal-Urban" and "Cal-Rural" cycles represent current California driving patterns, and thus provide a much more accurate picture of the actual effect of the technologies discussed by the CARB staff on fuel economy than the driving cycles that are either explicit or implicit in CARB's cost-effectiveness analysis.

Data Sources

Under the driving studies referenced above, instrumented "chase cars" were equipped with laser rangefinders mounted behind the front grill of each chase car. These laser rangefinders and an on-board data acquisition system were used to measure and record the speed-time profiles of randomly selected vehicles on a second-by-second basis while they were followed at a distance by the chase cars. (The following distance enabled the speed-time profile of randomly selected vehicles to be recorded without the drivers of the selected vehicles knowing they were being monitored.) These studies were performed in the Sacramento area, the San Francisco Bay area, the San Joaquin Valley and the South Coast (i.e., Los Angeles metropolitan area).

The studies employed either of the following two different types of chase car driving:

1. Route-Based Driving – Route-based studies consisted of driving on a representative set of actual road routes within each study area. The set of road routes were determined from trip-weighted random samples of origin to destination-based trips obtained from each study area's regional travel demand model. These route samples were also stratified by time of day (and directionally driven in each time period) based on time-of-day trip population weightings obtained from the travel models. Thus the road routes driven under these studies contained AM peak, PM peak and off-peak routes on a representative mixture of congested and uncongested roads in each study area. Under the route-based studies, 100 routes (across all three time periods) were generally driven from two to four times each.

2. Segment-Based Driving – Under segment-based studies, chase car driving was performed on individual road segments, rather than entire routes. (The original purpose of these studies differed from the route-based studies). In each area, Caltrans selected a representative set of road segments as defined in the Highway Performance Monitoring System (HPMS) database. HPMS road segments typically range from 0.25 miles to 2 miles in length. Similar to the route-base studies, each HPMS segment was sampled several times and under these studies, in both directions.

Data from a total of seven route- and segment-based driving listed below were employed in the development of new urban and rural cycles:

- 2000 Bay Area Route-Based Driving (BAR);
- 2000 Bay Area Segment-Based Driving (BAS);
- 2000 Sacramento Area Route-Based Driving (SAR);
- 1997 Sacramento Area Segment-Based Driving (SAS);
- 2000 Stanislaus County Route-Based Driving (STR);
- 1997 San Joaquin Valley Segment-Based Driving (SJS); and
- 2000 South Coast Route-Based Driving (SCR).

The resulting post-processed, quality-assured and validated datasets from each of these driving studies consisted of second-by-second measurements of the chase car speed and the "target" vehicle (i.e., the vehicle being randomly followed by the chase car) speed when a target was being followed and tracked by the laser. (During these studies, the chase car was usually, but not always "locked on" in pursuit of a target vehicle. For example, if a target vehicle being followed turned off the chase car's intended route, the chase car was instructed to flow with traffic until a new target vehicle could be randomly selected and followed and tracked with the laser.) The post-processed datasets thus also included a third second-by-second speed trace, referred to as the "composite" trace which was created by combining target vehicle speeds when a target was being followed with the chase car speeds when no target was available. (Since the chase car was instructed to flow with traffic during these generally short periods when a target vehicle was dropped until another target could be selected and followed, this substituted chase car speed in the composite trace was considered representative.)

These datasets contained driving in both urban and rural areas. In the post-processing that was performed under each of these studies, the type of roadway the vehicle was traveling on during each second was also recorded in the output dataset. (The technique for "locating" the roadway during each second of data collected used digitally marked flags in the raw data that were recorded by the chase car navigator using a hand-held switchbox. By flipping a switch the navigator "time stamped" points along road routes or segments that corresponded to the start and end of each type of roadway. During post-processing, these time-stamps were temporally merged with the types of roadway within each route or on each segment from Route/Segment definition tables to identify the type of road during each second of data collection.)

The roadway classification system used is the Functional Class scheme employed in HPMS. Table 1 shows this scheme.

Table 1
HPMS Functional Class Definitions

Code	Road Classification	Abbrev	Definition
		Rural Functional Classes	
01	Principal Arterial Interstate	R-PAI	Serves corridor movements having trip length and travel density characteristics of statewide or interstate travel
02	Other Principal Arterial	R-OPA	
06	Minor Arterial	R-MA	Links cities, larger towns and traffic generators
07	Major Collector	R-MJC	Provides service to county seats and larger towns not served by arterials
08	Minor Collector	R-MNC	Serves intracounty corridors and developed areas within a reasonable distance of a major collector road
09	Local	R-LOC	Provides access to adjacent land and service to short distance travel
		Urban Functional Classes	
11	Principal Arterial Interstate	U-PAI	Carries the major portion of trips entering or leaving urban areas as well as the majority of through trips bypassing the central city
12	Principal Arterial Other Freeway/Expressway	U-OFE	
14	Other Principal Arterial	U-OPA	
16	Minor Arterial	U-MA	Interconnect and expand the Principal Arterial system and provide services for moderate distance travel
17	Collector	U-COL	Provides land access and traffic circulation within urban neighborhoods, commercial and industrial areas
19	Local	U-LOC	Provides access to neighboring land or functionally classified roads

Note that the table categorized roadways into both rural and urban classes. Since the datasets contained the Functional Class designation for each second of data based on the post-processing as described in the preceding paragraph, it was easy to divide the driving data from all of these studies into both urban and rural groups for creating separate urban and rural (or non-urban) driving cycles.

Table 2 shows the number of second-by-second urban and rural driving data records contained in each of the chase car study datasets. As shown, the combined datasets contain over 380,000 rural records and over 1.4 million urban records, providing robust samples of actual driving patterns measured in both urban and rural areas for cycle development.

Table 2
Chase Car Driving Study Single-Second Record Counts by Area Type

Driving Study	Single-Second Data Records		
	Rural	Urban	Total
BAR	5,361	404,753	410,114
BAS	29,979	58,219	88,198
SAR	51,633	330,413	382,046
SAS	48,786	68,644	117,430
SJS	35,315	36,521	71,836
STR	210,349	317,402	527,751
SCR	0	187,725	187,725
Totals	381,423	1,430,677	1,812,100

Before beginning cycle development from the urban and rural datasets combined across all seven driving studies, the data in the combined urban or rural groups had to be examined to determine if it contained a representative mixture of interstate, principal and minor arterial and collector/local driving in California. This sample stratification issue and other initial processing steps prior to construction of the cycles are discussed in the following sub-section.

Sample Stratification and Initial Processing

Sample Stratification – To test (and re-weight as needed) the urban and rural driving datasets for representativeness by roadway type, statewide vehicle miles traveled (VMT) data broken down by HPMS functional class were obtained from the Federal Highway Administration (FHWA) at http://www.fhwa.dot.gov/policy/ohim/hs02/vm2.htm. The

HPMS database maintained by FHWA provides representative profiles of travel for each state in the U.S.

Table 3 shows annual VMT in California by rural and urban functional classes for 2002, the most recent year of available data. As shown in the table, urban VMT is roughly five times larger than rural VMT (321 billion vs. 64 billion, respectively). Within both the rural and urban area types, the first two functional classes (Interstate and Other Principal Arterials for rural and Interstate and Other Freeways for urban) encompass roughly 50% of the travel.

The VMT data in Table 3 include all vehicle types, including heavy-duty vehicles. These data were adjusted to represent only light-duty vehicles using separate HPMS-based summaries of national light-duty vehicle travel fractions obtained from FHWA and shown in Table 4.

Table 3
Travel in California by Functional Class
2002 Annual Vehicle Miles Traveled (millions)

Area Type	FC Code	Functional Class	VMT	% of Area Type	% of All
Rural	1	Interstate	17,733	27.7%	5.5%
	2	Other Principal Arterial	18,871	29.5%	5.9%
	6	Minor Arterial	10,618	16.6%	3.3%
	7	Major Collector	9,845	15.4%	3.1%
	8	Minor Collector	3,494	5.5%	1.1%
	9	Local	3,440	5.4%	1.1%
		Rural Total	64,001	100.0%	19.9%
Urban	11	Interstate	64,612	25.1%	20.1%
	12	Other Frwy & Exprwy	51,456	20.0%	16.0%
	14	Other Principal Arterial	55,072	21.4%	17.2%
	16	Minor Arterial	46,541	18.1%	14.5%
	17	Collector	15,483	6.0%	4.8%
	19	Local	23,777	9.3%	7.4%
		Urban Total	256,941	100.0%	80.1%
		Grand Total	320,942	n.a.	100.0%

Source: FHWA 2002 Highway Statistics, VM-2 Table (http://www.fhwa.dot.gov/policy/ohim/hs02/vm2.htm)

Table 4
U.S. Light-Duty Vehicle Travel Fractions

Area Type	FC Code	Functional Class	% LDV
Rural	1	Interstate	83.2%(1)
	2	Other Principal Arterial	84.3%(1)
	6	Minor Arterial	88.6%(1)
	7,8,9	Other Rural	89.6%(2)
Urban	11	Interstate	95.3%(1)
	12	Other Frwy & Exprwy	93.3%(1)
	14	Other Principal Arterial	87.4%(1)
	16	Minor Arterial	92.5%(1)
	17,19	Other Urban	95.4%(2)

Sources: (1) FHWA 1999 Highway Statistics, VM-4 Tables (http://www.fhwa.dot.gov/ohim/hs99/excel/vm4.xls)
(2) FHWA 2002 Highway Statistics, VM-1 Table (http://www.fhwa.dot.gov/policy/ohim/hs02/vm1.htm)

Table 5 shows the result of adjusting the California VMT for all vehicles shown in Table 3 with the light-duty vehicle fractions by area type and roadway category presented in Table 4.

Table 5
Light-Duty Travel in California by Functional Class
2002 Annual Vehicle Miles Traveled (millions)

Area Type	FC Code	Functional Class	VMT	% of Area Type	% of All
Rural	1	Interstate	14,754	26.8%	5.0%
	2	Other Principal Arterial	15,908	28.9%	5.4%
	6	Minor Arterial	9,408	17.1%	3.2%
	7	Major Collector	8,820	16.0%	3.0%
	8	Minor Collector	3,130	5.7%	1.1%
	9	Local	3,082	5.6%	1.1%
		Rural Total	55,102	100.0%	18.8%
Urban	11	Interstate	61,575	25.8%	21.0%
	12	Other Frwy & Exprwy	48,008	20.2%	16.4%
	14	Other Principal Arterial	48,133	20.2%	16.4%
	16	Minor Arterial	43,050	18.1%	14.7%
	17	Collector	14,764	6.2%	5.0%
	19	Local	22,673	9.5%	7.7%
		Urban Total	238,205	100.0%	81.2%
		Grand Total	293,307	n.a.	100.0%

As listed in Table 5, the travel (i.e., VMT) fractions for light-duty vehicle urban and rural urban driving in California are 81.2% and 18.8%, respectively. Within each area type (urban or rural) Table 5 also shows the percentages of light-duty travel by each functional class.

These HPMS-based rural and urban distributions by functional class are distance or VMT-based. The second-by-second driving records in the urban and rural datasets combined across all the chase car studies are time-based. Thus, the distributions in Table 5 were converted to a time-basis using the average travel speed of each functional class group determined from the chase car datasets.

Table 6 presents these calculations. Note that for each area type, the last two functional class categories were grouped together. (For example, Rural-Minor Collector and Rural-Local were combined into a single group, "R5".) This aggregation was done because of the relatively small frequencies in these categories and the similarity in driving patterns (i.e., low speeds and light congestion) that occurs on these types of roadways.

Table 6
Comparison of Time-Based Chase Car Driving and HPMS Travel Fractions by Functional Group

Area Type	FC Code	Functional Class	Group	Chase Car		HPMS	
				% Time by Area Type	Avg Spd (mph)	Time Factor	%Time by Area Type
Rural	1	Interstate	R1	25.4%	72.45	0.00370	19.4%
	2	Other Prin Art	R2	23.1%	56.54	0.00511	26.8%
	6	Minor Arterial	R3	18.1%	48.43	0.00353	18.5%
	7	Major Collector	R4	20.1%	43.07	0.00372	19.5%
	8	Minor Collector	R5	13.2%	37.38	0.00302	15.8%
	9	Local					
		Rural Total				0.01906	100.0%
Urban	11	Interstate	U1	14.8%	50.88	0.00508	15.6%
	12	Other Fwy/Expwy	U2	20.3%	50.59	0.00398	12.3%
	14	Other Prin Art	U3	30.3%	24.24	0.00834	25.7%
	16	Minor Arterial	U4	21.3%	25.74	0.00702	21.6%
	17	Collector	U5	13.4%	19.50	0.00806	24.8%
	19	Local					
		Urban Total				0.03248	100.0%

The first column labeled "% Time by Area Type" lists the time-based frequencies by functional group from the combined rural and urban chase car datasets. (These frequencies were calculated from the single-second record counts presented earlier in Table 2 broken down by functional class.) The average speed in each function group (using the composite trace in the chase car datasets) is shown in the next column. The final two columns show how the distance-based HPMS travel distributions were converted to a time basis for comparison to the chase car driving. The column named "Time Factor" contains the product of the HPMS VMT percentages by area type shown in Table 5 (expressed as fractions) and the average speed for each functional group. For example, the R1 value was calculated as follows:

$$\text{Time Factor (R1)} = 0.268 \div 72.45 \text{ mph} = 0.00370.$$

By dividing by the average speed of each functional group, each distance-based travel frequency was converted to a time basis. The final column in Table 6 presents the time-based HPMS frequencies, which were calculated by normalizing the time factor values in the preceding column by the total for each area type. For example, the R1 time frequency by area type was calculated as follows:

$$\text{Time Frequency (R1)} = 0.00370 \div 0.01906 = 0.194 = 19.4\%$$

As shown in Table 6, simply combining the rural and urban chase car data does not produce self-weighting datasets that properly represent the mixture of driving by functional class seen in the statewide HPMS data. Thus, the combined rural and urban chase car data were further divided into functional class groups (R1-R5 and U1-U5). The HPMS time-based travel frequencies shown in the rightmost column in Table 6, were then used as weighting factors and applied to the chase car data to properly represent the mixture of driving by functional class when creating a composite profiles of rural and urban driving patterns. These driving pattern profiles used in cycle development are called "SAFDs" and are explained below.

Driving Population SAFDs – In driving cycle development, detailed vehicle driving patterns that include accelerations, decelerations, idling and cruising events are best represented by producing joint speed and acceleration frequency distributions from measured second-by-second driving data. These Speed-Acceleration Frequency Distributions (referred to as SAFDs) provide a more detailed representation of the real word driving patterns that affect vehicle fuel economy and emissions than simple statistics like average speed or acceleration.

Thus, prior to constructing driving cycles, SAFDs were generated for the urban and rural driving populations the cycles were intended to represent. These "population" SAFDs were calculated by assigning the second-by-second speed and accelerations in each driving dataset into 861 (21 × 41) joint speed and acceleration bins. (They are subsequently referred to as population SAFDs so as to distinguish them from cycle

SAFDs that are generated from the second-by-second speeds in each driving cycle.) Separate SAFDs were computed for each of the five urban and rural driving groups (U1 through U5 and R1 through R5).

The weighting factors shown in Table 6 were then used to weight the frequencies in each separate SAFD to create composite urban and rural SAFDs which properly reflected the mixture of travel by roadway type (i.e., functional class) contained in HPMS. These weighting calculations are shown below:

$$SAFD_{Urban} = 0.156 \times SAFD_{U1} + 0.123 \times SAFD_{U2} + 0.257 \times SAFD_{U3} + 0.216 \times SAFD_{U4} + 0.248 \times SAFD_{U5}$$
$$SAFD_{Rural} = 0.194 \times SAFD_{R1} + 0.268 \times SAFD_{R2} + 0.185 \times SAFD_{R3} + 0.195 \times SAFD_{R4} + 0.158 \times SAFD_{R5}$$

Figure 1 and 2 show the resulting composite urban and rural driving population SAFDs. Summary statistics such as average and maximum speed and acceleration are shown below the SAFD in each of these figures. (A value of "0.000" is shown for cells that contained at least one record, but less than 0.0005% of the total records.)

As indicated in Figure 1, the average speed of all urban California driving is 30.8 mph, well above the 19.6 mph average speed of EPA's Urban (City) driving cycle. In addition, 17% of all urban driving occurs above the 56.7 mph maximum speed of the City cycle.

Figure 2 points out differences between the EPA Highway cycle and actual rural area driving in California. First, the average speed of rural driving is 52.5 mph, roughly 4 mph above the average speed of the Highway cycle. More noteworthy in its affect on fuel economy and CO_2 emissions, Figure 2 also shows that approximately 48% of rural area driving occurs in excess of the 59.9 mph maximum speed of the Highway cycle. This clearly indicates the Highway cycle does not represent the significant amount of high speed operation (i.e., above 55 mph) occurring in non-urban areas today after repeal of the federal 55 mph speed limit.

Both the urban and rural driving profiles reflected in the SAFDs and summary statistics in Figures 1 and 2 plainly show that current driving patterns are not accounted for in the EPA City and Highway cycles. This finding validates the reason for the development of new California urban and rural driving cycles in estimating the "real world" CO_2 and fuel economy impacts of CARB proposed regulations under AB1493.

Figure 1
California Urban Driving Population SAFD (%)

HPMS-Weighted California 1997-2000 Urban Area Driving (Composite Trace) SAFD (%)

ACCEL BIN (mph/s)	SPEED BIN (mph)																					
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	TOTALS
-20																						
-19																						
-18																						
-17				0.000			0.000	0.000				0.000			0.000							0.001
-16				0.000	0.000	0.000		0.000			0.000	0.000	0.000				0.000	0.000	0.000			0.001
-15				0.000	0.000	0.000				0.000				0.000	0.000					0.000		0.001
-14				0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000											0.001
-13				0.000	0.001	0.000	0.001		0.000	0.000	0.000	0.000	0.000		0.000		0.000				0.000	0.003
-12				0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000			0.000					0.000		0.000	0.006
-11			0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.000	0.000	0.000		0.000	0.000		0.000	0.000				0.011
-10			0.002	0.004	0.004	0.004	0.002	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000				0.000	0.000		0.021
-9			0.004	0.007	0.007	0.007	0.005	0.002	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000				0.000	0.036
-8		0.000	0.008	0.011	0.012	0.008	0.007	0.005	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000						0.068
-7		0.003	0.015	0.025	0.025	0.023	0.017	0.011	0.007	0.003	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000				0.133
-6	0.000	0.008	0.047	0.074	0.066	0.054	0.031	0.022	0.014	0.007	0.003	0.002	0.001	0.001	0.001	0.000	0.000	0.000				0.333
-5		0.043	0.210	0.243	0.238	0.162	0.110	0.063	0.030	0.015	0.010	0.006	0.004	0.002	0.001	0.001	0.001	0.000	0.000			1.162
-4	0.000	0.156	0.371	0.395	0.387	0.307	0.206	0.130	0.073	0.038	0.020	0.012	0.007	0.005	0.003	0.001	0.001	0.000	0.000			2.112
-3	0.001	0.489	0.507	0.545	0.587	0.510	0.395	0.274	0.175	0.098	0.053	0.034	0.021	0.013	0.009	0.004	0.001	0.000	0.000			3.717
-2	0.003	1.010	0.488	0.551	0.822	0.649	0.583	0.491	0.358	0.232	0.150	0.101	0.066	0.070	0.046	0.019	0.006	0.001				5.451
-1	0.004	1.281	0.453	0.538	0.617	0.848	0.966	1.092	1.044	0.837	0.837	0.563	0.660	0.781	0.635	0.276	0.083	0.007	0.001	0.000		11.282
0	10.862	2.237	0.862	1.098	1.080	2.610	3.044	3.337	3.214	2.843	2.213	2.022	2.398	3.603	3.269	1.442	0.227	0.036	0.002	0.000	0.000	46.930
1	0.216	1.209	0.545	0.753	1.032	1.410	1.568	1.588	1.413	1.073	0.788	0.696	0.793	0.835	0.620	0.251	0.052	0.007	0.000	0.000		14.849
2	0.105	1.023	0.760	1.041	1.046	0.994	0.817	0.638	0.416	0.246	0.155	0.112	0.093	0.066	0.035	0.010	0.003	0.001	0.000			7.581
3	0.032	0.766	0.597	0.761	0.843	0.459	0.267	0.148	0.070	0.037	0.019	0.012	0.008	0.006	0.003	0.001	0.000					3.829
4	0.012	0.433	0.305	0.273	0.241	0.136	0.065	0.035	0.016	0.007	0.003	0.003	0.002	0.002	0.000	0.000	0.000					1.533
5	0.004	0.255	0.158	0.102	0.068	0.035	0.019	0.010	0.005	0.002	0.001	0.001	0.001			0.000						0.856
6	0.002	0.074	0.048	0.023	0.014	0.008	0.004	0.002	0.001	0.000	0.000	0.000	0.000									0.176
7	0.002	0.032	0.013	0.008	0.004	0.003	0.001	0.001	0.000	0.000	0.000											0.068
8	0.001	0.017	0.006	0.003	0.002	0.001	0.000															0.031
9	0.000	0.003	0.003	0.002	0.001	0.001	0.000															0.017
10	0.000	0.008	0.002	0.001	0.000	0.001																0.012
11	0.000	0.004	0.001	0.000			0.000															0.006
12		0.001	0.000	0.000	0.000																	0.002
13																						
14																						
15																						
16																						
17																						
18																						
19																						
20																						
Totals	11.245	9.057	5.391	6.483	7.177	8.154	8.117	7.853	6.844	5.244	3.958	3.588	4.478	5.366	4.824	2.007	0.403	0.052	0.003	0.001	0.001	100.000

Summary Statistics

Avg Speed (mph)	30.79	Time at Idle (%)	11.245	Avg PKE (miles/hr2)	1805.923
Min Speed (mph)	0.00	Time at Cruise (%)	57.020	Avg Total Specific Power (mph2/sec)	13.736
Max Speed (mph)	108.46	Time in Accel (%)	16.292	Avg Non-Zero Specific Power (mph2/sec)	30.814
Avg Non-Idle Speed (mph)	34.07	Time in Decel (%)	15.444	Max Specific Power (mph2/sec)	392.188
Avg Cruise Speed (mph)	36.78	Avg Trip Length (miles)	2.047	Spec Pwr Freq (%): 0 mph2/sec	55.381
Avg Acceleration (mph/sec)	1.25	Avg Trip Time (min)	3.341	Spec Pwr Freq (%): >0-100 mph2/sec	43.555
Max Acceleration (mph/sec)	12.00	# Stops per Mile	1.196	Spec Pwr Freq (%): >100-200 mph2/sec	1.030
Avg Deceleration (mph/sec)	-1.41	# of 1-Sec Observations	1,403,569	Spec Pwr Freq (%): >200-300 mph2/sec	0.032
Max Deceleration (mph/sec)	-17.48	# of Trips	8,104	Spec Pwr Freq (%): >300 mph2/sec	0.001

Figure 2
California Rural Driving Population SAFD (%)

HPMS-Weighted California 1997-2000 Rural Area Driving (Composite Trace) SAFD (%)

ACCEL BIN (mph/s)	SPEED BIN (mph)																					TOTALS
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
-20																						
-19																						
-18																						
-17						0.000				0.000	0.000											0.001
-16																						
-15										0.000												0.000
-14				0.000		0.001		0.000				0.000										0.001
-13							0.001			0.000												0.001
-12				0.000	0.000	0.002	0.001	0.001	0.001		0.000				0.000							0.005
-11				0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.001				0.000							0.009
-10			0.001	0.002	0.001	0.002	0.002	0.002	0.000	0.001	0.001	0.000	0.001				0.000					0.013
-9			0.001	0.004	0.005	0.004	0.003	0.003	0.003	0.002	0.001	0.001	0.000		0.000		0.000					0.027
-8			0.006	0.004	0.005	0.005	0.005	0.005	0.004	0.003	0.002	0.001	0.001	0.000	0.000			0.000				0.042
-7		0.002	0.006	0.013	0.012	0.016	0.014	0.010	0.010	0.007	0.005	0.002	0.001	0.000	0.000	0.000						0.102
-6		0.002	0.020	0.036	0.040	0.038	0.033	0.027	0.022	0.013	0.006	0.005	0.002	0.001	0.001	0.001	0.000	0.000	0.000	0.000		0.251
-5		0.011	0.093	0.116	0.122	0.136	0.123	0.097	0.061	0.040	0.023	0.013	0.005	0.004	0.002	0.001	0.001	0.001	0.000			0.850
-4		0.049	0.144	0.143	0.160	0.154	0.153	0.149	0.112	0.084	0.056	0.027	0.015	0.008	0.005	0.004	0.002	0.002	0.000			1.287
-3	0.001	0.152	0.182	0.163	0.205	0.200	0.183	0.228	0.237	0.185	0.140	0.090	0.043	0.018	0.014	0.016	0.008	0.005	0.001	0.001	-	2.093
-2	0.001	0.301	0.136	0.128	0.137	0.168	0.185	0.222	0.291	0.329	0.315	0.239	0.151	0.089	0.071	0.072	0.038	0.015	0.003	0.001	0.000	2.894
-1	0.001	0.365	0.109	0.102	0.111	0.168	0.226	0.328	0.544	0.850	1.316	1.582	1.563	1.146	1.052	0.893	0.453	0.175	0.038	0.005	0.000	11.027
0	[illegible]	0.760	0.200	0.224	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.739	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.023	0.000	[illegible]
1	0.048	0.356	0.112	0.143	0.193	0.283	0.379	0.576	0.951	1.353	1.789	1.847	1.711	1.178	1.107	0.867	0.407	0.149	0.028	0.005	0.001	13.482
2	0.022	0.312	0.192	0.225	0.243	0.299	0.398	0.549	0.587	0.476	0.349	0.205	0.125	0.091	0.072	0.049	0.028	0.009	0.002		0.000	4.233
3	0.010	0.265	0.227	0.297	0.291	0.316	0.302	0.206	0.133	0.075	0.045	0.028	0.017	0.011	0.007	0.006	0.002					2.240
4	0.002	0.160	0.137	0.162	0.186	0.132	0.089	0.058	0.027	0.012	0.008	0.005	0.003	0.002	0.001							0.984
5	0.001	0.097	0.083	0.059	0.061	0.037	0.022	0.015	0.009	0.005	0.002	0.002	0.001									0.395
6	0.002	0.027	0.019	0.017	0.010	0.006	0.002	0.003	0.002	0.001	0.000											0.090
7		0.009	0.009	0.006	0.005	0.003	0.003	0.003	0.001	0.001												0.040
8	0.000	0.005	0.002	0.002	0.002	0.002	0.000															0.013
9		0.002	0.002	0.002	0.002	0.001																0.008
10		0.003	0.002	0.000	0.001	0.001																0.007
11		0.001		0.001	0.000	0.000																0.002
12		0.000	0.000	0.000																		0.001
13																						
14																						
15																						
16																						
17																						
18																						
19																						
20																						
Totals	2.066	2.877	1.684	1.874	2.125	2.518	2.363	3.529	4.707	6.179	9.227	12.285	13.983	10.426	10.515	8.074	3.644	1.201	0.206	0.035	0.002	100.000

Summary Statistics

Avg Speed (mph)	52.47	Time at Idle (%)	2.068	Avg PKE (miles/hr2)	1182.318
Min Speed (mph)	0.00	Time at Cruise (%)	71.626	Avg Total Specific Power (mph2/sec)	16.090
Max Speed (mph)	100.96	Time in Accel (%)	13.429	Avg Non-Zero Specific Power (mph2/sec)	36.100
Avg Non-Idle Speed (mph)	53.46	Time in Decel (%)	12.880	Max Specific Power (mph2/sec)	354.022
Avg Cruise Speed (mph)	55.92	Avg Trip Length (miles)	4.894	Spec Pwr Freq (%): 0 mph2/sec	55.450
Avg Acceleration (mph/sec)	0.90	Avg Trip Time (min)	5.103	Spec Pwr Freq (%): >0-100 mph2/sec	42.788
Max Acceleration (mph/sec)	11.76	# Stops per Mile	0.144	Spec Pwr Freq (%): >100-200 mph2/sec	1.693
Avg Deceleration (mph/sec)	-1.03	# of 1-Sec Observations	381,393	Spec Pwr Freq (%): >200-300 mph2/sec	0.067
Max Deceleration (mph/sec)	-17.13	# of Trips	1,434	Spec Pwr Freq (%): >300 mph2/sec	0.002

Driving Cycle Construction

Once representative urban and rural driving patterns were established from the population SAFDs presented in the preceding sub-section, a detailed methodology developed and applied by Sierra in previous cycle development efforts[3],[8] for CARB and EPA over the last decade was used to construct new real world California cycles under this effort. These steps are described below.

Candidate Cycle Construction - Given a set of driving data that may encompass many thousands of second-by-second speed measurements, it is not practical to develop a driving cycle for simulation modeling or emission testing purposes by simply stringing together all the data into a very long speed-time trace. To minimize cost, it is desirable to make driving cycles as short as possible while maintaining their representativeness of the entire driving data set from which they were created.

The EPA City cycle is 1371 seconds or nearly 23 minutes long; the Highway cycle is 765 seconds or just under 13 minutes long. For this effort, a "target" cycle length range of 10-20 minutes was established, roughly consistent with the lengths of the existing City and Highway cycles.

Microtrip Identification – A similar approach to that employed by Sierra in development of earlier driving cycles for CARB and EPA was used to construct driving cycles for this effort. Under this methodology, a computerized "trial-and-error" approach was used to select combinations of "microtrips" that best matched the population SAFD for each driving data set for which cycles were constructed. Under Sierra's prior cycle development efforts for CARB and EPA, microtrips were defined as segments of speed data that began and ended at rest with at least two consecutive seconds of zero speed. (The end of a microtrip was marked by one second of zero speed. Any additional seconds of zero speed were included as the beginning of the next microtrip.) For this effort, the definition of a microtrip as used in cycle construction differed slightly. Microtrips were defined as second-by-second driving data segments that started and ended at rest, or on high speed roadways (freeways and highways) were no more than 2 minutes (120 seconds) long.

Thus, the first element in cycle construction consisted of identifying the individual microtrips within each driving dataset (urban and rural) as described above. Totals of 3,077 and 15,645 rural and urban microtrips were identified in the driving datasets.

The number of possible combinations (without replacement) of microtrips chained or grafted together into a candidate driving cycle nominally 20 minutes in length is quite large (e.g., over 10^{32} based on an average microtrip time of 2 minutes). This is a prohibitively large number of combinations to individually evaluate, even with current computing technology. Thus, "intelligent" cycle construction logic had to be applied that did not examine every possible combination in trying to find microtrip combinations that closely matched the SAFD of the intended driving group.

Microtrip Chaining Constraints – Microtrips that always start and end at zero speed can easily be chained or grafted together. However, as explained earlier, not all microtrips as defined under this effort started or ended at rest and thus could not always be chained together if the starting and ending speeds (and accelerations) for particular microtrips were different. Consider two high-speed microtrips, one at a steady 55 mph speed and another at a steady 70 mph. If the 70 mph trip segment was chained onto the end of the 55 mph segment, the result would be an artificial acceleration of 15 mph/sec (70-55) at the chaining point that clearly does not represent actual driving patterns.

Thus, constraints were imposed that allowed only certain combinations of microtrips to be chained together in order to eliminate these speed/acceleration artifacts. Microtrips could be chained together only when the starting speed and acceleration of a "candidate" microtrip match the ending speed and acceleration of the "current" segment within tolerances of ±0.5 mph and ±0.5 mph/sec, respectively. These tight tolerances ensured that trip segments were chained only in "smooth" combinations in a manner that eliminated unrepresentative grafting artifacts.

Cycle Construction Logic - The "Hybrid Random/Best Incremental" cycle construction logic developed under earlier driving cycle work for CARB and EPA was used to generate a series of candidate driving cycles for each driving group from combinations of its individual microtrips.

Under this approach, a "seed" sample of microtrips for some subset of the desired cycle time (e.g., the first 4 minutes) was selected completely at random, without replacement. After the seed sample time was reached, subsequent microtrips were selected and successively built onto the seed sample by finding the microtrip that produced the best match of the cycle SAFD to the population SAFD for the driving group when added to the existing segments. This latter microtrip sampling phase is referred to as the "best incremental" phase because successive microtrips built on to the cycle after the random phase are selected by producing the best marginal improvement in matching the cycle's SAFD to that of the driving population.

During both sampling phases, the trip chaining constraints described earlier were used to identify a subset of "Matching Microtrips" whose starting speeds and accelerations matched the ending speeds and accelerations of the current microtrip within the listed tolerances. Only those segments that were contained in the Matching Microtrips subset were then considered for random or best incremental selection as described above. Note that identification of the Matching Microtrips subset was a dynamic process, performed before each new microtrip was added, and thus it produced a different subset of microtrips at each step.

Candidate Cycle Generation – A Sierra-proprietary Fortran program called *GenCycs* was executed to apply the Hybrid Random/Best Incremental cycle construction logic described earlier to iteratively "build" microtrips into a candidate driving cycle and repeatedly generate thousands of candidate cycles.

The *GenCycs* program was designed to input varying constraints (as a user input) on both the total cycle time and the seed time. (For urban candidate cycles, a best initial microtrip was also specified.)

GenCycs was also written to allow different methods of candidate cycle SAFD vs. population SAFD matching to be performed by the program as each cycle was generated:

- Total SAFD – optimize (i.e., minimize) the total difference between candidate cycle and population SAFD over the entire SAFD;
- Non-Idle SAFD – optimize the difference between candidate cycle and population SAFD over the non-idle portion of the SAFD;
- Non-Cruise SAFD – optimize the difference between candidate cycle and population SAFD over the non-cruise portion[1] of the SAFD;

These optimization strategies were developed over earlier cycle development studies performed by Sierra. For this effort, all urban and rural candidate cycles were generated using "Non-Cruise SAFD" optimization. This method was selected in conjunction with manual cycle editing procedures applied later in the process with the rationale that cycle editing would focus on and optimize representativeness for the cruise portion of the SAFD. (Cycle editing is discussed later in this sub-section.) Therefore, a non-cruise optimization strategy was selected during candidate cycle generation knowing that the cruise portion of the cycle would be optimized later.

Using the non-cruise optimization strategy and varying total cycle time and initial random time inputs, GenCycs runs were set up and executed to produce thousands of candidate urban and rural cycles with target cycle lengths between 10 and 20 minutes. In all, a total of 64,000 candidate urban and rural cycles were generated under this effort.

Selection of Best Cycles – Once the many thousands of candidate cycles were generated for each driving group (i.e., urban and rural), another Fortran program called *FindBest* was used to identify "short lists" of candidate cycles whose SAFDs best matched the population SAFD.

DiffSum Metric - A statistical metric labeled the "DiffSum" was computed within the *FindBest* program to quantify the match between each candidate cycle's SAFD and that of the population. The DiffSum is computed as the difference between the joint speed and acceleration frequency of the candidate cycle compared to that of the population, summed on an absolute basis (i.e., without regard to positive or negative bias) across each frequency bin of the SAFD. Mathematically, the DiffSum is expressed as follows:

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[1] The non-cruise portion of the SAFD under this optimization method was defined as the entire SAFD except that portion with accelerations or decelerations at or below 0.5 mph/sec (i.e., everything except the "Zero Accel" row in the tabular SAFD).

$$DiffSum = \sum_{a=-20}^{20} \sum_{s=0}^{20} |CycSAFD_{s,a} - PopSAFD_{s,a}|$$

where

CycSAFD = the cycle's joint speed-acceleration frequency at speed interval s and acceleration interval a; and

PopSAFD = the driving population's joint speed-acceleration frequency at speed interval s and acceleration interval a.

Candidate Cycle Short Lists – Using the same "Non-Cruise SAFD" optimization strategy employed in generating candidate cycles, the *FindBest* program sifted through the summary statistics generated for each candidate cycle and produced a short list of the 50 top-ranked candidate cycles for each driving group, sorted by Non-Cruise DiffSum.

In addition to the Total, Non-Idle and Non-Cruise DiffSums, cycle times, average and maximum speed and the number of microtrips are compiled for each cycle in these short lists.

Selection of Best Single Cycle – Once each "Best 50" candidate cycle short list was generated, the candidate cycle at the top of the list (lowest Non-Cruise DiffSum) was not always selected as the single best cycle. Average and maximum speed and cycle length (in minutes) were considered as secondary factors when the top ranked cycles all had nearly identical Non-Cruise DiffSums.

Table 7 lists the single best cycle selected from each short list and that cycle's Total and Non-Cruise DiffSums. Also shown are the cycle average and maximum speed (in mph) and time (in minutes).

Table 7
Summary of Selected Best Cycles (Prior to Editing)

Driving Group	Cycle ID	DiffSums		Speed (mph)		Cycle Time (minutes)
		Total	Non-Cruise	Avg	Max	
Urban	C15R02-00886	0.38266	0.14713	26.17	73.77	15.57
Rural	C15R07-00673	0.35750	0.14587	54.69	81.39	21.42

At this point in the cycle development process, these single best cycles are referred to as the *__unedited__* cycles. Cycle optimization edits were performed as described below to produce the *__final__* urban and rural driving cycles.

Cycle Optimization Editing – The final step in the cycle development process involved manually editing the computer-generated unedited cycles to improve their fit to the target SAFD. Using a procedure developed under previous work[8] for EPA, editing was limited to two types of operations: (1) segment addition, and (2) segment shortening. Each of these operations is described below.

Segment Addition – Segment addition consisted of inserting segments of actual speed-time trace from the entire data set for that driving group that began and ended with a speed within 0.5 mph of the speed at the insertion point. Segment addition was performed for the cycle's "cruise" SAFD bins (i.e., those along the "Zero Accel" row in the SAFD) that underrepresented the frequency of those bins compared to the population SAFD. The entire second-by-second data for each cycle's driving group were manually examined and pieces of actual speed-time trace from the master data set were identified and inserted into the cycle's trace using the criterion described above.

Note that in some instances, the inserted trace also contained some amount of operation at accel/decel rates outside the ±0.5 mph/sec range of the "cruise" bins in the SAFD. As long as the inserted trace began and ended within 0.5 mph of the speed at the insertion point and this amount of non-cruise operation was improving (rather than worsening) the representation of those affected non-cruise bins, it was considered acceptable.

Segment Shortening - Segment shortening involved removing portions of the speed-time trace between two cruise speeds that were within 0.5 mph. Segment shortening was applied for SAFD bins where the cycle overstated the frequency of operation in those bins compared to the population SAFD.

Resulting Driving Cycles

Using the methods detailed in the preceding sub-section, new driving cycles were developed to represent current real world urban and rural driving patterns based on actual driving data collected in California during several field studies conducted during 1997-2000. Tabular and graphical plots of these cycles and comparisons to the current EPA City and Highway cycles are also presented.

Figures 3 and 4 show the speed-time traces for the new California urban cycle (called Cal-Urban) and the EPA Urban (City) cycle respectively. Note that the Cal-Urban cycle has top speeds in excess of 70 mph and includes several acceleration-deceleration "hills" that reach the 40-50 mph range. By contrast, the EPA Urban cycle has a top speed of 56.7 mph, and with the exception of this hill of the cycle, has no other travel above about 35 mph. (Note that although the Cal-Urban cycle is shorter than the EPA Urban cycle, cycle length is not a factor in emissions or fuel economy measured over the cycle, which are expressed per mile of travel.)

Figures 5 and 6 provide a similar comparison of speed-time traces for the new California rural (Cal-Rural) and EPA Highway cycles, respectively. Like the urban

Figure 3
Cal-Urban Driving Cycle Speed-Time Trace

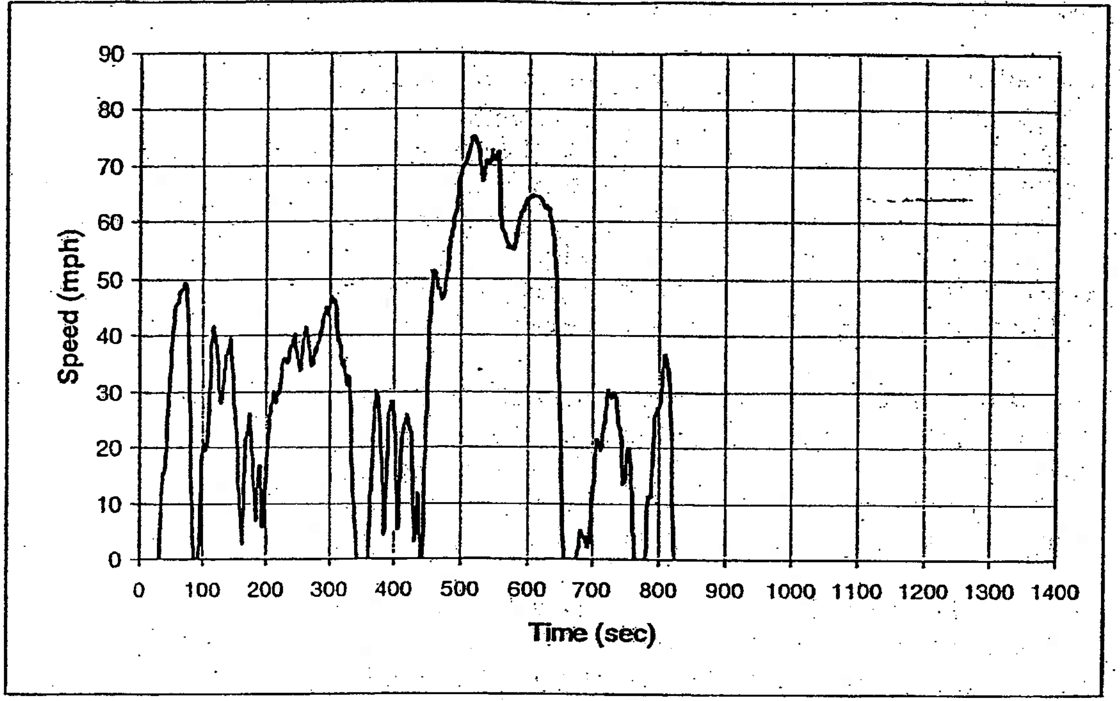


Figure 4
EPA Urban (City) Driving Cycle Speed-Time Trace

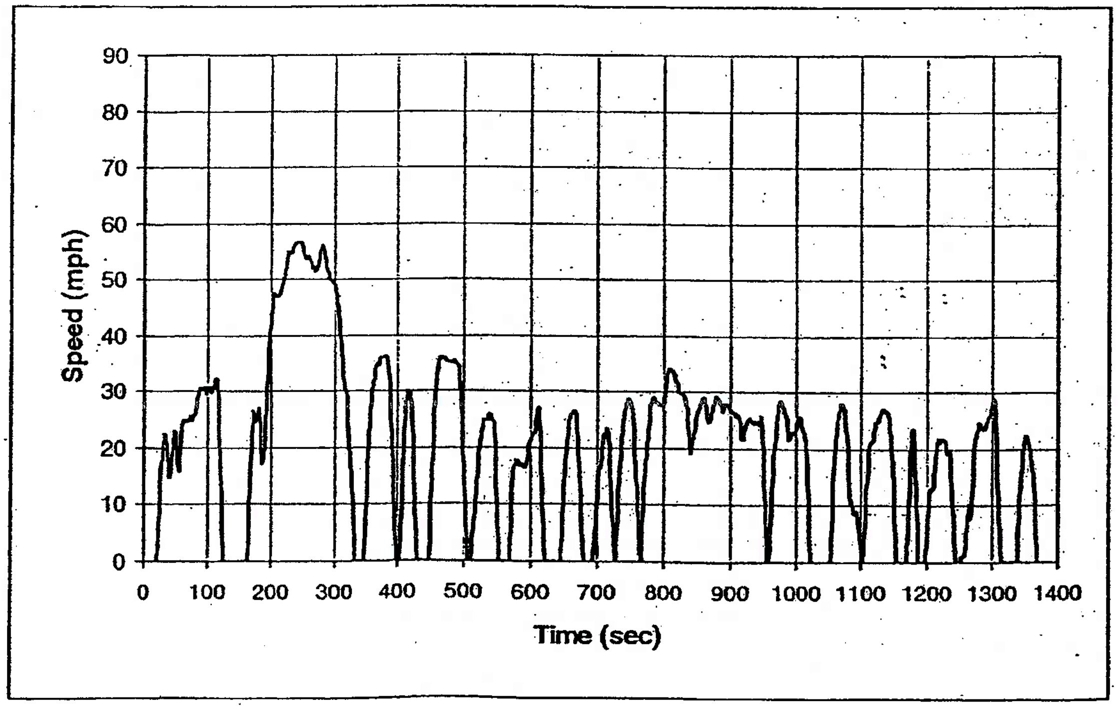


Figure 5
Cal-Rural Driving Cycle Speed-Time Trace

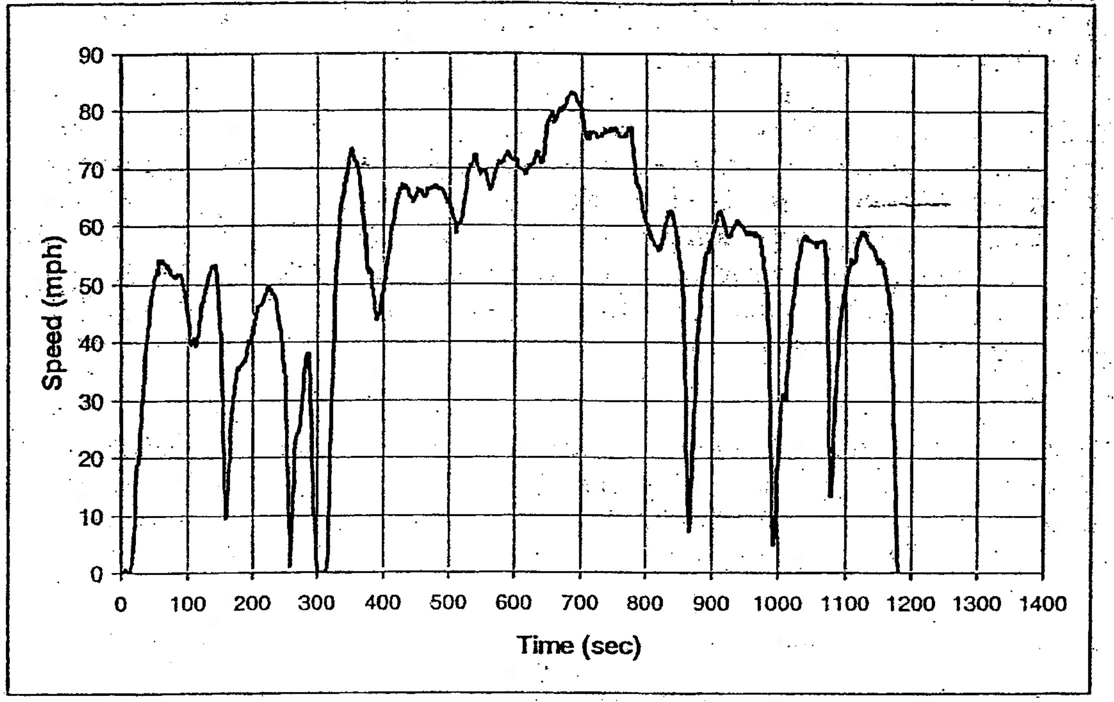
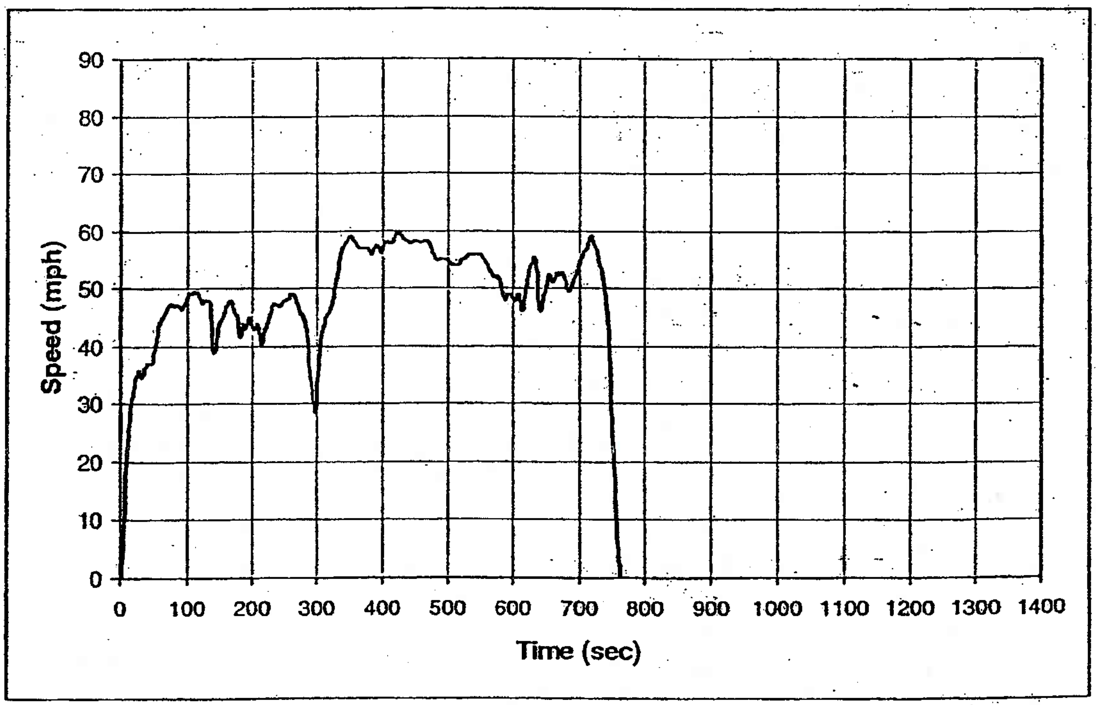


Figure 6
EPA Highway Driving Cycle Speed-Time Trace



comparison, the Cal-Rural cycle has more high speed travel than its counterpart, the EPA Highway cycle, and dramatically so. The maximum speed of the Cal-Rural cycle is over 80 mph and includes extended periods over 60 mph. By contrast, the EPA Highway cycle, constrained by the then 55 mph speed limit, never exceeds 60 mph.

Table 8 presents a comparison of key statistics for the EPA and new California cycles. As it shows, the average and maximum speeds of the new California cycles significantly exceed those of the EPA cycles. Table 8 also shows that the Cal-Urban cycle exhibits less idling and much higher maximum acceleration rates than the EPA Urban cycle. The Cal-Rural cycle also has a higher maximum acceleration rate than the EPA Highway cycle. (As noted earlier, maximum acceleration rates for the EPA cycles were limited by chassis dynamometer technology in use when these cycles were developed over thirty years ago.)

Another key metric shown in Table 8 is Average Positive Specific Power, defined as the positive kinetic energy per unit mass summed over each second of the cycle, divided by the total time of the cycle. As shown, both the Cal-Urban and Cal-Rural cycles have much higher average positive specific power than their EPA counterparts.

Table 8
Comparison of Driving Cycle Characteristics

Driving Cycle	Speed (mph)		Percent Idle	Max Accel (mph/s)	Avg Pos Spec Power (mph^2/s)	Distance (miles)	Time (min)
	Avg	Max					
EPA Urban (City)	19.6	56.7	19.0%	3.30	7.66	7.5	22.9
Cal-Urban	30.7	75.2	11.3%	5.81	14.64	7.0	13.7
EPA Highway	48.3	59.9	0.7%	3.20	7.62	10.3	12.8
Cal-Rural	52.7	83.2	2.0%	4.60	16.50	17.3	19.7

Table 8 shows that for both urban and rural driving, <u>the EPA cycles under-represent the amount of high speed and power that occurs in actual California driving</u>, clearly underscoring the need to use these new cycles to examine real world CO_2 and fuel economy impacts of CARB's proposed regulations.

References

1. R.E. Kruse and T.A. Huls, "Development of the Federal Urban Driving Schedule," Society of Automotive Engineers Paper No. 730553, May 1973.

2. T.C. Austin, et al., "Passenger Car Fuel Economy During Non-Urban Driving," SAE Paper No. 740592, August 1974.

3 T. R. Carlson, et al., “Average Speed Measurement in the SACOG Region,” prepared for the California Department of Transportation, Report No. SR97-09-01, September 12, 1997.

4. T.R. Carlson and R.G. Dulla, “Average Speed Measurement in the San Joaquin Valley Region,” Technical memorandum prepared for Dennis Azevedo, California Department of Transportation, March 17, 1998.

5. T.R. Carlson and R.G. Dulla, “Average Speed Baseline Measurement Chase Car Study – Field Study Documentation (Contract No. 72A0024),” Technical memorandum prepared for Vahid Nowshiravan, California Department of Transportation, August 23, 2000.

6. Sierra Research, Inc., “Task Order No. 2 SCF Improvement - Field Data Collection,” prepared for California Department of Transportation, Report No. SR02-07-04, July 18, 2002.

7. T. Carlson, et al., “Task Order No.7 SCF Improvement – Driving Data Collection, South Coast Air Basin,” prepared for California Department of Transportation, Report No. SR02-07-05, July 31, 2002.

8. T.R. Carlson and T.C. Austin, “Development of Speed Correction Cycles,” prepared for U.S. Environmental Protection Agency under Contract No. 68-C4-0056 Work Assignment No. 2-01, Report No. SR97-04-01, April 30, 1997.

Attachment C-3
Mileage Accrual and Full-Life Mileage of Vehicles

Summary

The carbon dioxide emission reduction and fuel cost savings that result from design changes to improve motor vehicle fuel economy are a function of average lifetime vehicle miles traveled (VMT). As a result, an overestimation of average lifetime VMT will result in an overestimation of both the emissions and fuel economy benefits of a regulation forcing the production and sale of vehicles with lower CO_2 emissions and higher fuel economy. Failure by CARB staff to properly account for lower accumulated mileage of the remaining fleet as higher mileage vehicles are retired from service has resulted in a substantial overestimate of the benefits of its proposal.

As described in more detail below, we can positively demonstrate that CARB's analytical technique for estimating lifetime average VMT is mathematically incorrect. In addition, we show, using data from the Bureau of Automotive Repair's random roadside test program, that average total mileage accumulation for older vehicles is much lower than predicted by CARB's methodology. Furthermore, final odometer readings from about 1,000 vehicles that were retired under CARB's pilot scrappage program indicate that most vehicles had a useful life in the range of 125,000 to 185,000 miles, and only 10% of scrapped vehicles had final odometer readings greater than 200,000 miles. This result further confirms the veracity of the methodology described herein and it contradicts CARB staff's calculation of typical full-life mileage (and benefits) on the order of 202,000 miles for passenger cars, 219,000 miles for LDT1 category vehicles, and 224,000 miles for LDT2 category vehicles.

As described in more detail below, a more accurate estimate of the lifetime average mileage of passenger cars and light duty trucks is 155,000 miles.

CARB Staff's Analysis of Mileage Accrual Rates and End of Life Mileage

CARB's June 14, 2004 draft staff proposal states that California-specific vehicle use data, including average annual vehicle use and vehicle lifetime, were obtained from the California Department of Motor Vehicles and ARB's EMFAC emission factor model and that version 2.2 (April 2003) of EMFAC was used to estimate the inventory for CO_2 and methane. However, the staff report does not provide specific details about the calculations that were performed to compute mileage accrual rates and average vehicle lifetime. Instead it refers to a "Technical Support Document,"[1] or TSD, that was issued by CARB staff subsequent to publication of staff's proposal. For details of the staff's

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[1] "Technical Support Document for Staff Proposal Regarding Production of Greenhouse Gas Emissions from Motor Vehicles, Climate Change Emissions Inventory", California Air Resources Board, August 6, 2004.

calculations, the referenced TSD refers in turn to CARB's EMFAC model and the Technical Support Documents for EMFAC ("EMFAC TSD") that are available on-line.[2] CARB's EMFAC[3] TSD does contain, in Section 7.1, a description of how mileage accrual rates were estimated from Smog Check data. The remainder of this section describes and discusses information contained in Section 7.1 of CARB's EMFAC TSD and related CARB documentation.

The EMFAC TSD describes CARB's estimation of average mileage accrual rates using Smog Check data (1991-1995). Briefly, CARB used three calendar year pairs, 91 & 93, 92 & 94, and 93 & 95, to determine mileage accumulation rates for cars and trucks (separately) and by region. In an attempt to account for odometer rollover, which reportedly occurred in approximately 13 percent of older vehicles, CARB staff allowed a cutoff of 100,000 miles between consecutive test year odometer readings. Data were sorted by vehicle identification number, and erroneous records were screened out. Age of the vehicle was assigned as the difference between second test date of the vehicle and model year. Miles traveled between smog checks were then determined and converted to average miles per year. In specified cases, air basin data were assigned for counties or air basins where insufficient data existed. Data for the analysis were only available to age 30, and EMFAC requires estimates up to age 45. Therefore, CARB staff used regression equations to fit and then "extend", i.e., extrapolate, the data to age 45.

Not all of the key intermediate calculations and results from CARB's analysis of mileage accumulation rate and median age are shown explicitly in the June 14, 2004 version of the draft staff report. However, some of the key data are shown in Appendix B of the April 1, 2004 staff report,[4] a copy of which is attached hereto. Briefly, those results represent a compilation of 21 EMFAC runs in which the annual mileage accrual of model year 2010 vehicles are allegedly computed. More specifically, per-vehicle mileage accrual was projected for model year 2010 vehicles in each calendar year from 2010 to 2030, and the values of annual mileage were summed by CARB staff to show "cumulative annual VMT (mi/yr/veh)" for light-duty autos (gasoline), light-duty trucks (LDT1) and light-duty trucks (LDT2). "Survival rates", i.e., the fraction of vehicles that continued to operate on the road in each successive year, were reported by CARB to be "from EMFAC model code, derived from DMV data".

The results of the computation described above are purported by CARB staff to show that the median vehicle age for cars, LDT1s and LDT2s are 16, 18 and 19 years, respectively, and that the corresponding median lifetime vehicle mileages are 202,329 for cars, 219,234 for LDT1s and 223,969 for LDT2s.

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[2] http://www.arb.ca.gov/msei/on-road/doctable_test.htm

[3] "On Road Emission Model Methodology Documentation," (http://www.arb.ca.gov/msei/on-road/doctable_test.htm), California Air Resources Board, "page updated April 6, 2004".

[4] "Draft Technology and Cost Assessment for Proposed Regulations to Reduce Vehicle Climate Change Emissions Pursuant to Assembly Bill 1493", CARB Mobile Source Control Division, release date April 1, 2004.

The EMFAC calculations performed by CARB staff have been confirmed by Sierra and numerically the results agree. However, as will be discussed in the next section, CARB staff's calculations of average accumulated mileage as a function of vehicle age are incorrect. CARB's analysis seriously overstates median lifetime vehicle mileage because it does not properly account for the fact that vehicles being retired from service tend to have higher total mileage accumulation than the remaining vehicles in the fleet. Instead, CARB's method assumes that average mileage accumulation for the model year fleet as a whole can be calculated by summing the annual mileage accumulation rates of on-road vehicles for each year without regard for the increasing fraction of high mileage vehicles that have retired from service and which are no longer accumulating miles. As shown below, this is mathematically incorrect.

Illustrative Example of Correct and Incorrect Methods for Calculating Mileage Accrual

This section will demonstrate through the use of a hypothetical example that CARB's interpretation of its EMFAC calculations pertaining to median lifetime vehicle mileage and the associated costs and benefits of controls, have been overestimated due to CARB staff's misinterpretation of the meaning of its calculated mileages and ages.

Stated most simply, the calculation of mileage accrual shown in CARB's documentation fails to account for the obvious fact that vehicles which accrue mileage at higher rates tend to be the ones that retire at a younger age, and the corollary of that fact which is that vehicles which remain on the road after the retirement of high mileage vehicles tend to be the ones which accumulate mileage at a lower rate. A simple hypothetical example illustrates the difference between CARB's incorrect interpretation of it's calculation and a calculation that properly accounts for the 'snapshot' data that are available for the on-road fleet using Smog Check odometer data.

Consider a hypothetical fleet that consists of just two vehicles of model year X, and the task at hand is to determine the average mileage for model year X vehicles at the end of useful life. Vehicle A is assumed to accrue miles at a rate of 40,000 per year, which would be on the higher end of normal use. Vehicle B is assumed to accrue miles at the rate of 10,000 per year.[5] It should be obvious that vehicle A will not last as many years as vehicle B. Assume that both vehicles provide service for 160,000 miles (an above average value for cars and trucks, as will be shown later) before being scrapped. For vehicle A, the annual odometer readings would be 40,000, 80,000, 120,000 and 160,000 miles and the end of useful life is reached after just four years. For vehicle B, annual odometer readings would be 10,000, 20,000... etc. up to 160,000 miles, which is reached after 16 years.

Now, consider an approach like the one used by CARB staff, of determining mileage at end of life that is based on adding successive annual mileage accruals of all on-road vehicles (e.g., based on Smog Check odometer readings in succeeding years) of model

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[5] This simple example ignores the fact, which is not critical to the point being made, that annual mileage accrual declines with age for most vehicles.

year X. Sampling the odometers from both on-road vehicles in each of the first four years, such an approach would find that the average annual mileage accrual per vehicle for the two-vehicle fleet in each year was 25,000 miles, i.e., (40,000+10,000)/2, which is, of course, correct. At the end of four years, the average odometer reading for the "fleet" is 100,000 miles. However, vehicle A retires after 4 years, and in years 5 through 16, the same approach of sampling on-road vehicles yields an average annual mileage accrual of 10,000 miles per on-road vehicle. Under CARB's approach, the average odometer reading at the end of year five is calculated by adding 10,000 miles to the 100,000 mile average calculated for the end of year 4 to arrive at a fleet average odometer mileage of 110,000 in year 5. This value is clearly wrong. The actual odometer of the one vehicle remaining on-road in the model year X fleet is 50,000 miles and the odometer of the vehicle that has already been retired from service is still 160,000 miles. Thus, the "true" odometer average for the model year at the end of five years is 105,000, not 110,000. CARB's technique for computing odometer readings for the hypothetical fleet yields successive annual odometer readings of 25,000, 50,000, 75,000, 100,000, 110,000, 120,000...220,000, which, recalling that both vehicles had an actual lifetime of 160,000 miles, is clearly incorrect and is much too high.

As shown in the above example, the problem with CARB's methodology arises as soon as high mileage vehicles start being scrapped and nothing is done to account for the fact that the average odometer reading of the vehicles remaining in service is lower. The true average of all vehicles of a particular model year can only be determined by keeping track of the odometer reading of vehicles being scrapped and assigning zero incremental mileage to those vehicles each year thereafter. A true average odometer for the two hypothetical model year X vehicles in year five would be calculated by first averaging together the mileage accruals for vehicles A and B in year 5, namely (0+10,000)/2 or 5000 miles, and adding this to the average odometer reading of 100,000 miles for the two vehicles in the prior year to arrive at an average 105,000 miles. Continuing on this process until the last vehicle (vehicle B) is retired in 16 years yields the correct average lifetime mileage for the two-vehicle fleet of 160,000 miles.

This simple hypothetical example demonstrates the potential for significant error to be introduced though the use of CARB's approach. However, the example also offers the insight that an odometer "snapshot" type approach that is different from CARB's but still uses Smog Check data or other periodic snapshot data from the on-road fleet can provide a better estimate of median lifetime vehicle mileage.

Going back to the example of the hypothetical, two-vehicle fleet, the average odometer reading of all vehicles remaining on the road at the end of year 4 is 100,000 miles. In year 5, the average odometer drops to 50,000 miles, which is less than half of the "true" average of 105,000 miles described above. However, at the end of 16 years, the average of all vehicles on the road is 160,000, which is equal to the true average.

It should be noted that the "snapshot" method provides the correct answer at the end of 16 years because all (both) vehicles were assumed to have the same lifetime mileage. When this assumption is not correct, neither the snapshot method nor CARB's method produces the correct average lifetime VMT.

Sierra has examined Smog Check data from enhanced areas for November 2003, using initial tests only (as determined by no other inspection in the previous two months). Vehicles accumulating miles at a rate greater than 50,000 miles per year or less than 250 miles per year were excluded, as were vehicles having more than 500,000 miles total (all of these were considered to be due to errors in odometer transcriptions or to rare and highly unrepresentative vehicle usage). Vehicle ages were computed for each model year and corrected to mid-model year for the purpose of comparing results by age. Results from this "snapshot" analysis are shown in Figures 1 and 2, for cars and trucks, respectively, along with the corresponding results from CARB's approach ~~of~~ ignoring the retired vehicles when calculating odometer values for the on-road fleet. Both figures show that CARB's approach to estimating mileage accumulation generally matches the snapshot data for the first 8-10 years. However, as an increasing fraction of the model year fleet is scrapped,[6] the CARB results, which show relatively little decrease in mileage accumulation rate with age, begin to diverge dramatically from average Smog Check odometer readings. While CARB continues to project high annual mileage accrual rates for vehicles over ten years in age, Smog Check data show a leveling off and then decline in annual mileage accrual for the aging on-road model year fleet, consistent with the expectation that vehicles with the greatest longevity in the on-road fleet tend to remain there, at least in part, because of their lower average rate of annual mileage accrual.[7]

The next two sections discuss corroborating evidence for this explanation from two of California's vehicle testing programs. Data from these two independent sources tend to agree and to confirm the validity of the "snapshot" data obtained from Smog Check program data.

Mileage Data From BAR's Random Roadside Testing Program

With the assistance of the California Highway Patrol, the California Bureau of Automotive Repair (BAR) periodically conducts random roadside emission tests of vehicles in which the majority of motorists participate.[8] CARB and BAR rely on these

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[6] CARB's vehicle retention data (described later) show that at an age of 9 years more than 20% of the original model year car fleet has been retired and is, therefore, no longer accruing miles.

[7] Absent more complete information on CARB's data and assumptions, it is not possible to verify the correction of CARB's odometer projections. However, if it is assumed that CARB's other calculations are correct and the only error is their failure to account for the differing mileage accrual rates of retired and remaining vehicles, it should be possible to correct CARB's estimate using their data on vehicle retention and calculating weighted average mileage accruals of the fleet with the inclusion of zero-mileage accruals by the retired vehicles. The resulting weighted average odometer values for the fleet are projected to closely match Smog Check and roadside pullover data for about the first 10 years, and then to gradually level off after another 10 years to a value that is within 10% of the average odometer reading from the scrappage program (described later).

[8] "Evaluation of the California Enhanced Vehicle Inspection and Maintenance (Smog Check) Program – Technical Support Document, Part 2, Draft Report to the Inspection and Maintenance Review Committee, submitted by CARB and Department of Consumer Affairs/Bureau of Automotive Repair, April 2004 (http://www.arb.ca.gov/msprog/smogcheck/jun04/tsd_part2.pdf).

Figure 1

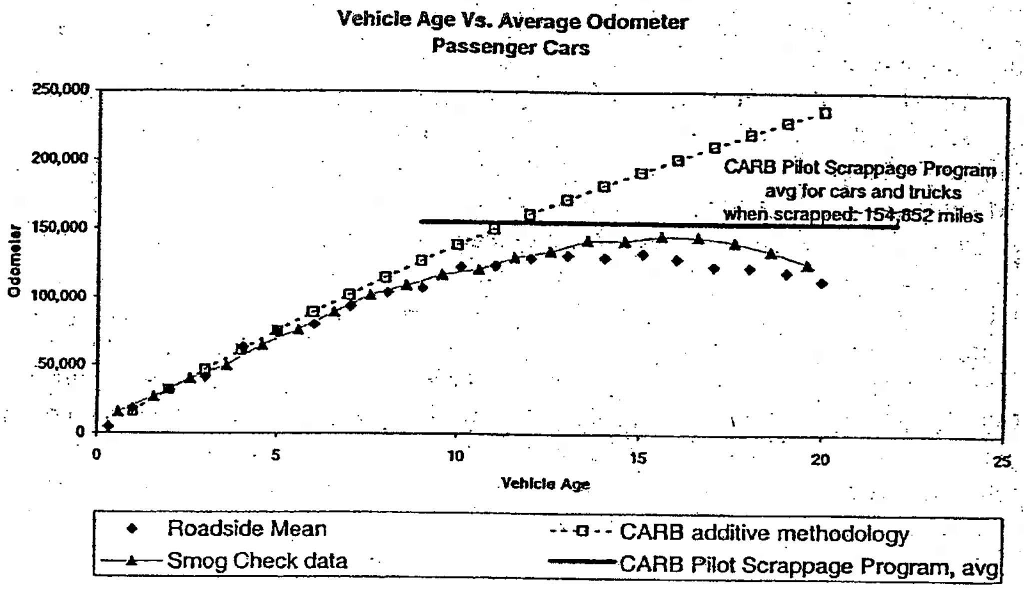
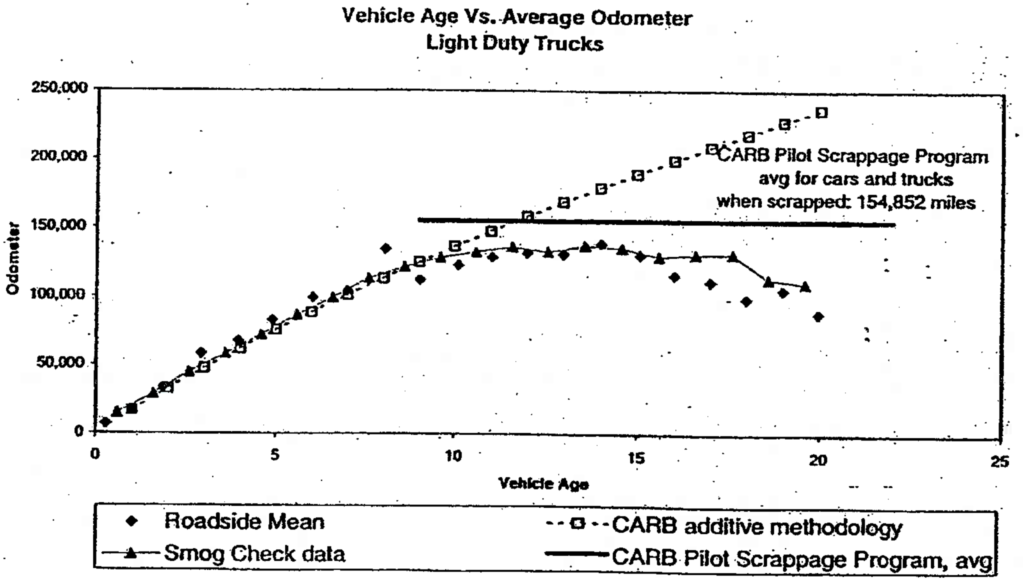


Figure 2



data for a variety of purposes, as alluded to by CARB in its recent testimony before the California Inspection and Maintenance (I/M) Review Committee[9]:

> *Whenever we're doing the studies we're often trying to look at whether or not there is any sort of external validation of the information we have collected, and one of the data sources that we have used is the roadside data analysis to try to see whether or not the roadside data analysis is giving us results that are typical, that are consistent. We try to do this in any different number of ways with any of the assumptions in the (EMFAC) model; it's always nice to have some sort of independent dataset to look at.*

The same random roadside data collected by BAR and the California Highway Patrol and relied upon by CARB for external validation of its model are used here as a check on the mileage accumulation data calculated from Smog Check data. Specifically, we examined the recent 2002 Roadside Data that were collected between January 2000 and October 2002 (most recent publicly available data) and that contain information, including odometer readings, on approximately 13,000 vehicles. As with the earlier described Smog Check data, vehicle age was corrected to mid-model year and vehicles accumulating miles at a rate greater than 50,000 or less than 250 miles per year were removed, as were vehicles having more than 500,000 miles. Results of this analysis are shown in the previous two figures. As both figures show, the roadside results are reasonably consistent with the Smog Check data and differ sharply from CARB's estimates.

Mileage Data From CARB's Pilot Scrappage Program

A final source of data that was used to investigate the end of life mileage of vehicles came from CARB's pilot vehicle scrappage program[10]. Although this study provided a more limited dataset than the other studies cited, it offered the advantage of focusing on high mileage vehicles at or near the end of useful life and it included odometer readings from vehicles at the time of scrappage. It thereby provides a direct check of the different methods for estimating end of life mileage of vehicles.

1,001 vehicles were voluntarily retired by their owners (for $500 cash remuneration) as part of CARB's voluntary accelerated vehicle retirement (VAVR) program.[11] Final

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[9] Testimony of CARB staff, at the Meeting of the California Inspection & Maintenance Review Committee, May 17, 2004 (www.imreview.ca.gov/meetings/transcripts/transcript_may1704.doc).

[10] "Operation of a Pilot Program for Voluntary Accelerated Retirement of Light-Duty Vehicles in the South Coast Air Basin: Volume 1 – Pilot Program Design, Data, and Analysis", Sierra Research Report No. SR01-05-02, prepared for CARB, May 23, 2001.

[11] This total excludes the twenty vehicles recruited from the "smog" program (which had a lower average mileage) and vehicles (of all makes) recruited for the Ford program which had different reimbursement and apparent odometer rollover artifacts; for example, all 32 VAVR vehicle makes had average mileage greater than 100,000 miles, whereas 9 out of 25 vehicle makes (36%) included in the Ford program had average odometer less than 100,000 miles.

odometer readings from these vehicles were first checked for reasonableness and adjusted (upward) as needed to obtain a conservative estimate of the true final mileage in consideration of odometer rollover. This was done by examining the final odometer reading and by comparing each final odometer reading against the corresponding odometer value (where available) that was recorded for each vehicle at the time of its most recent smog check. All odometer readings of less than 60,000 miles were assumed to be missing either 100,000 or 200,000 miles due to odometer rollover and were adjusted by the corresponding amounts. For the remainder of the odometer readings, the "final" reading was sometimes less than the odometer value recorded in the ~~earlier~~ Smog Check, indicating a transcription error or other error with one or both readings, or an 'error' due to omission of 100,000 miles or 200,000 miles from the final reading as a result of odometer rollover. In such cases, the incremental miles were added to the final reading. Discrepancies of up to about 10,000 miles between the final odometer reading and the last Smog Check's odometer reading were relatively few and, because of the relatively small difference, were ignored.

After adjusting conservatively for odometer rollover and any other identifiable artifacts for these voluntarily scrapped vehicles the average odometer reading, at time of scrappage, was 154,852 miles.[12] This average odometer reading, which is shown as a horizontal line in Figures 1 and 2, is seen to be well below the 200,000+ mile "typical" odometer reading computed (improperly) by CARB staff using its additive methodology. The average odometer reading from the scrappage program is, instead, much closer to the properly computed mileage values based upon snapshot data from the Smog Check and roadside pullover programs.

It is also instructive to compare ending odometer readings and age for the voluntarily scrapped vehicles, which is presented in Figure 3. As the figure shows, final odometer readings from the scrapped vehicles in CARB's pilot scrappage program did not vary significantly with vehicle age (rsquared = 0.00). Thus, for example, 10-year-old retiring vehicles had, on average, the same ending mileage as 20-year-old retiring vehicles. This implies that, in general, 20-year-old retiring vehicles had an average lifetime mileage accrual rate that was one-half that of 10-year old retiring vehicles.[13] As shown earlier, ARB's additive methodology for computing odometer readings ignores the different mileage accrual rates for vehicles that retire early and late and, as a result, substantially overstates both later life average mileage accrual rates and end of life odometer readings. By contrast, the alternative snapshot approaches of using Smog Check data or roadside pullover data to estimate mileage accrual provide a more accurate estimate of the decline

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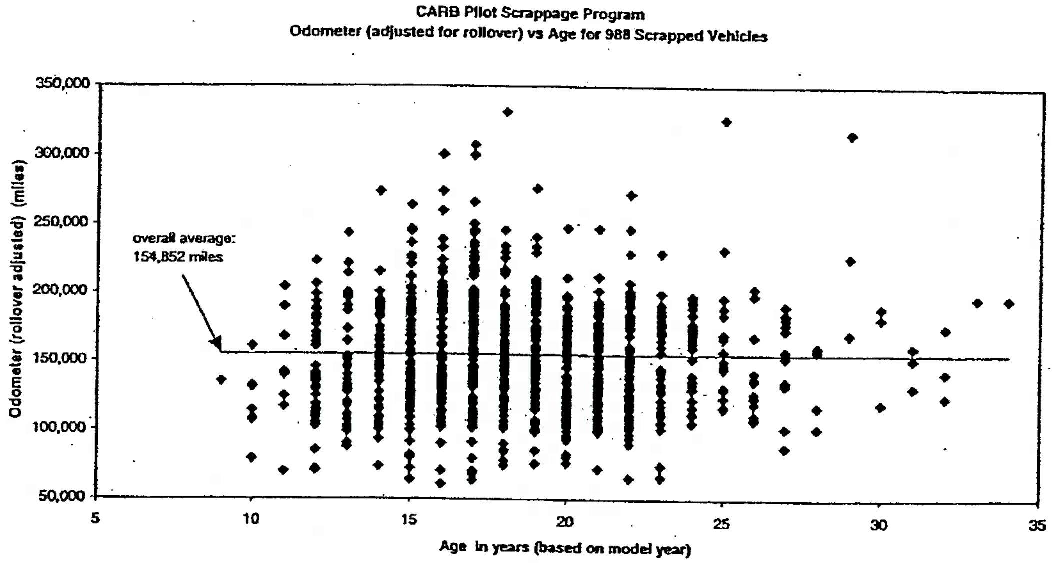
[12] Since it is not known whether the distinction between cars and trucks in the scrappage program was made rigorously, vehicles from both groups were included in the average. Futhermore, as there was no statistically significant relationship between age and mileage at time of scrappage for the subject vehicles, the average for all of the vehicles is plotted as a horizontal line in each figure. Vehicles obtained for the scrappage program ranged from model years 1965 to 1990.

[13] This implies that the 20-year retiring vehicles had either a markedly lower mileage accrual rate in the first ten years of their life than the 10-year retiring vehicles, or they had a similar mileage accrual rate to the ten year vehicles but an almost negligible mileage accrual rate in the ten years that ensued. Irrespective of which explanation is true, or whether it is a combination of the two explanations, the result is the same, *i.e.* CARB's additive methodology overstates the mileage of the total fleet after retirement of a significant number of high-mileage vehicles.

in mileage accrual of the remaining on-road fleet that occurs after a significant number of high mileage accrual rate vehicles have retired.

Finally, as reflected in Figure 3, only 10% of the scrapped vehicles had ending odometer readings of more than 200,000. If CARB's additive methodology were correct and the typical or median end of life odometer values were truly in excess of 200,000 miles as claimed, why is it that 90% of the scrapped vehicles in CARB's program had odometer readings less than 200,000 miles? While it may be conceivable that, absent the pilot scrappage program, some additional mileage could have been accumulated on these vehicles, the flat curve of ending mileage *vs.* age, together with the fact that every voluntarily retired vehicle was given up for an inducement of just $500, provides strong evidence that little useful vehicle life remained in these vehicles and only wildly optimistic or skewed estimates could conclude that substantial additional mileage could be accrued by most of them.

Figure 3



Attachment C-4
Evidence of the "Rebound Effect" in California

Summary

Analysis of California-specific data indicates that California motorists respond to changes in fuel price in essentially the same manner as motorists nationwide. In response to rising fuel prices, average mileage accumulation rates are lower than they would have been in the absence of a price increase. In response to falling fuel prices, average mileage accumulation rates increase. Since the literature indicates that motorists respond to changes in the cost of driving caused by changes in fuel economy in the same manner that they respond to changes in fuel price, increasing the fuel economy of new motor vehicles in California is expected to result in increased motor vehicle travel. Increased travel will result in increased emissions of ozone precursors and increased traffic congestion.

Introduction

The "rebound effect" is the term used to describe the increase in motor vehicle use associated with a reduction in the price of fuel or an increase in fuel economy. The rebound effect is essentially an extension of the "Law of Demand"—when the cost of something decreases (in this case vehicle travel), there is a natural tendency for consumers to demand more of it.

The existence of the rebound effect has significant implications regarding the net environmental impact of regulations requiring increased motor vehicle fuel economy or reduced motor vehicle greenhouse gas emissions (which are primarily associated with fuel combustion). In theory, reduced greenhouse gas emissions will contribute to lower ambient temperatures, which, in turn, will reduce the amount of ozone formed from precursor emissions (e.g., hydrocarbons and oxides of nitrogen). Lower ambient temperatures would also result in lower evaporative emissions of gasoline vapors from motor vehicle fuel systems and storage tanks. However, the rebound effect will result in an increase in precursor emissions due to the increase in vehicle travel. If the change in ambient temperature is negligible and the change in travel is significant, the net effect will be an increase in ozone levels.

Sierra participated in the preparation of another analysis being submitted on behalf of the Alliance that specifically addresses the potential change in ambient temperatures associated with reduced greenhouse gas emissions from motor vehicles and the associated change in ambient ozone concentrations. That analysis shows that the proposed regulation would have a negligible effect on ambient temperature and ozone concentration. In contrast to that negligible effect, previously published estimates of the rebound effect predict a 10% increase in motor vehicle travel would be associated with a doubling of motor vehicle fuel economy[1] (which is a rebound effect of –0.20). In addition to increasing exhaust emissions by 10%, the rebound effect would increase traffic congestion and consequences thereof. These estimates suggest that the net effect of regulations requiring increased fuel economy or reduced greenhouse gas emissions would be decidedly adverse.

Under Assembly Bill 1493 (Health and Safety Code section 43018.5), the California Air Resources Board (ARB) is charged with developing and adopting regulations that achieve "the maximum feasible and cost-effective reduction of greenhouse-gas emissions from motor vehicles." However, the statute directs the ARB to take environmental factors into account in determining whether such standards are feasible. At a September 18, 2003 workshop, Dr. Reza Mahdavi of the ARB Research Division made a presentation[2] entitled "Rebound Effect of California's Climate Change Regulations." The presentation suggests that rebound effect estimates from national data may not be accurate for California due to factors such as "higher income," "higher fuel prices," "travel condition," and "other socioeconomic characteristics." Subsequent estimates of the rebound effect using a model develop for CARB by UC Irvine and using the transportation demand model used by the Southern California Association of Governments have been used to support this earlier conclusion. However, as demonstrated elsewhere in the submissions being made by the Alliance, those models are not appropriate for estimating the rebound effect in California.

At the request of the Alliance of Automobile Manufacturers, Sierra Research has examined the extent to which the rebound effect occurs in California using California-specific data obtained from three different agencies: the California Department of Transportation (Caltrans), the California Bureau of Automotive Repair (BAR), and the California Energy Commission (CEC). A similar analysis conducted independently by NERA is being provided under separate cover.

Evidence of the "Rebound Effect" in National Data

As documented in a series of reports published by the U.S. Department of Transportation, annual vehicle miles traveled (VMT) by motor vehicles has been increasing faster than the number of vehicles has been increasing. Since 1987, annual VMT for all vehicles (including heavy trucks) has increased an average of 2.7% per year while vehicle registrations have increased by only 1.7% per year.[3] As a result, annual average VMT per vehicle is increasing. As described in more detail below, separate estimates for passenger vehicles indicate an even greater increase in annual average VMT over time. This increase is associated with a variety of factors, including changes in land use

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[1] David L. Greene, et al., "Fuel Economy Rebound Effect for U.S. Household Vehicles," The Energy Journal, Vol. 20, No. 3, 1999.

[2] ftp://ftp.arb.ca.gov/carbis/cc/091803workshop/rebound_mahdavi.pdf

[3] Highway Statistics 2002, Federal Highway Administration, U.S. Department of Transportation, http://www.fhwa.dot.gov/policy/ohim/hs02/

patterns and an increasing fraction of households in which more than one person commutes to work on a daily basis.

In addition to the long term trends in land use and percentage of two-income households, there have been changes in the fuel cost per mile of travel caused by variations in fuel price and motor vehicle fuel economy. Previous analyses of the effect of fuel costs have shown a "rebound effect" causing an increase in VMT when fuel costs are reduced. The existence of the rebound effect is not surprising because it is basically an extension of the "Law of Demand"—when the cost of something decreases (in this case vehicle travel), there is a natural tendency for consumers to demand more of it. As Greene has described in his previously referenced 1999 paper, numerous researchers have documented that a rebound effect exists for increasing automotive fuel economy. Greene concludes that the long-term effect is 20%. In other words, if increasing fuel economy reduces the cost of fuel by 10% per mile of travel, travel increases by 2%.

Although Greene's analysis is based on survey data, evidence of the rebound effect can also be seen in the historical relationship between fuel prices, fuel consumption, and mileage accumulation rates in the U.S. Figure 1 relates CPI-adjusted (1996 basis) fuel prices to VMT and fuel consumption for the U.S. fleet of passenger vehicles (including motorcycles, which have no significant effect on the average), both indexed to 1996. Based on the data collection techniques used by state transportation agencies, the term "passenger cars" includes most sport utility vehicles (SUVs), minivans, and small pickup trucks.[4] Only passenger cars were analyzed due to difficulties isolating like-categories of trucks with regard to the different metrics used in this portion of the analysis. Price data were taken from the Department of Energy website (http://www.eia.doe.gov/emeu/aer/txt/ptb0522.html). VMT and fuel economy data was downloaded from the Federal Highway Administration website (http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm).

Figure 1 shows a drop in VMT per vehicle associated with the gasoline price increase in 1974 following the Arab Oil Embargo. The figure also indicates that increased fuel prices during 1979 and the early 1980s are correlated with a significant flattening of the long-term trend in the annual VMT per vehicle. The dramatic drop in fuel consumption is due to the combined effects of the flattening of the VMT trend and the significant increase in the fuel economy of new cars that was occurring at the same point in time.[5]

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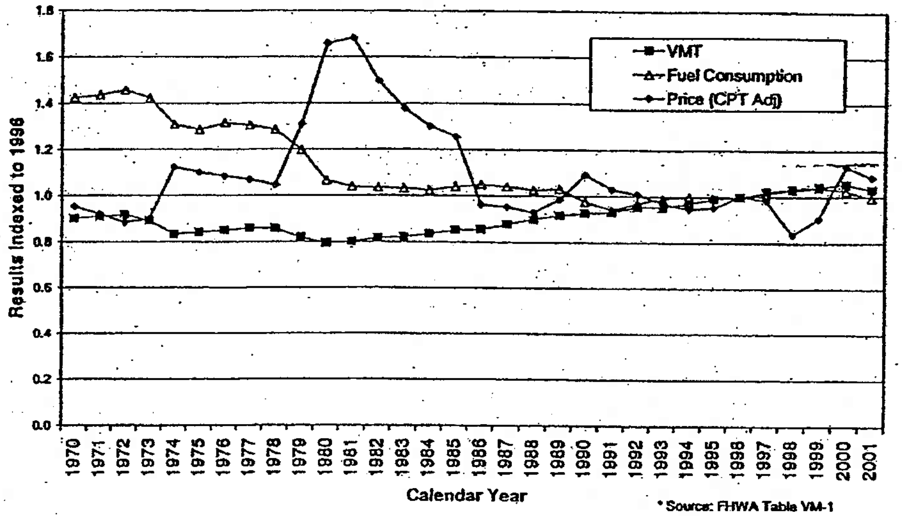
[4] "Passenger Cars" are often separated from other vehicles based on the wheelbase length detected by loop-detectors buried in the roadway. Vehicles with a wheelbase less that or equal to 10 feet are usually considered passenger vehicles.

[5] The average fuel economy of new passenger cars (as measured using a 55:45 weighting of the EPA "city" and "highway" driving cycles) increased from about 13 mpg in 1974 to more than twice that level by the time the Corporate Average Fuel Economy Standards were ramped up to 27.5 mpg in 1985.

Figure 1

CPI Adjusted Gasoline Price vs. U.S. Passenger Car & Motorcycle Per Vehicle VMT* and Consumption*



* Source: FHWA Table VM-1

Evidence of the "Rebound Effect" in California Data

Smog Check Data Analysis - Because California-specific data similar to that used in the national analysis were not readily available, a different analytical approach was required. The approach involved calculating mileage accumulation rates for vehicles from different periods of time in which there were significantly different fuel prices. By examining the change in both the fuel price and the mileage accumulation rates, a price elasticity can then be calculated. Odometer data recorded during the testing of vehicles under the California motor vehicle inspection and maintenance (I/M) program (called "Smog Check") and gasoline price data from the California Energy Commission web site (www.energy.ca.gov) were analyzed to determine whether the relationship between gasoline price changes and changes in the mileage accumulation rate in California is similar to the relationship observed in nationwide data.

Although the odometer reading of a vehicle at the time it is inspected under the Smog Check program does not provide information regarding the current mileage accumulation rate, vehicles undergoing change of ownership are often required to be inspected twice within a few months span of time. When a vehicle is sold just a few months after receiving a biennial inspection, the difference in odometer readings for these two tests can be used to calculate a current annual rate of mileage accumulation. This is the approach that was used to determine the average mileage accumulation rate at different points in time associated with different gasoline prices. For each period of interest, vehicles receiving two tests separated by 2 to 9 months were used to estimate annual average mileage accumulation rates.

The time periods selected for this analysis were June 1998 through March 1999, January 2000 through December 2000, and January through November 2003. The first time period was selected because prices during this time period were relatively low. (Prices were also relatively low prior to June 1998 but the data format used in California Smog Check program was not the same and expanding this period of time would have unnecessarily complicated the analysis.) Calendar year 2000 was selected next because a significant increase in gasoline prices occurred during that year. The first 11 months of 2003 were also analyzed because prices were still relatively high and this was the most recent data available for review. For each period of time, Sierra had millions of records previously obtained from BAR for the routine analysis of the Smog Check data that Sierra conducts for its clients.

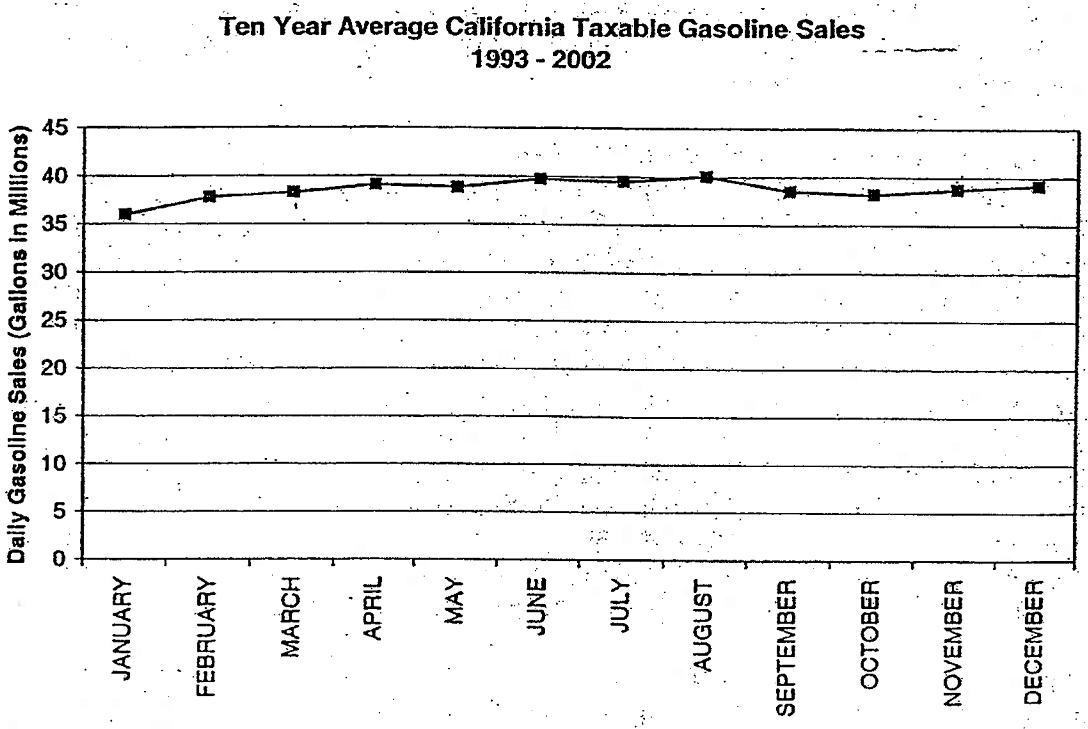
For each vehicle used in the analysis, fuel prices occurring between the change of ownership inspection and the previous inspection were averaged over that period of time. For example, the average annual mileage accumulation rate for vehicles tested twice during the first calendar quarter of 2000 was associated with the average fuel price during that same period of time. Not all model years were considered for each time period. Because of the relationship between vehicle age and mileage accumulation rate, the analysis was structured to ensure that vehicles in the three time periods were approximately the same age. For the June 1998 through March 1999 period of time, only 1991 through 1994 model years were considered. For vehicles tested in calendar year 2000, only 1993 through 1996 model years were utilized. For the January through November 2003 period, only 1996 through 1999 model years were considered. (Newer vehicles were not considered because California exempts the four newest model years from biennial emissions inspection and there were an insignificant number of newer vehicles for which two separate odometer readings were recorded several months apart.)

Comparing the three periods defined above, the average age of the vehicles in each were 6.5 years in 1998, 6.4 in 2000, and 6.3 in 2003. Because the 1998 data straddled a portion of 1999, the mileage accumulation rate for this year was adjusted upward to account for the slightly lower VMT associated the vehicles being slightly older in 1999. The adjustment was 1.125%, or 4.5 months/12months x 3%. The 3% represents the approximate mileage deterioration rates for vehicles in this age range and will be discussed in greater detail later.

In addition to the vehicle selection criteria described above, only vehicles weighing less than or equal to 8500 lbs GVWR were considered. Vehicles with extremely high or extremely low mileage accumulation rates were also excluded to minimize the use of data erroneously entered and to prevent other problems. Any vehicle accumulating miles at a rate lower than 3,000 miles per year was eliminated. Vehicles accumulating at a rate greater than 40,000 miles per year were removed because this rate of mileage accumulation was more likely due to decimal point errors during data entry.

Prior to comparing fuel prices to mileage accumulation, some seasonal corrections were made to the mileage accumulations so that natural seasonal variations in miles traveled were not mistakenly interpreted as being caused by fuel prices. To this end, taxable gasoline sales (assumed to be a reasonable surrogate for mileage miles traveled) were reviewed by month for the last ten years. The consumption shown in Figure 2 includes aviation fuel gasoline; however, aviation fuel represents only a small fraction of the gasoline sales. Sales shown in the figure have been "normalized" to account for the different number of days in each month. As shown in the figure, the highest gasoline sales occur during the summer months of June, July, and August.

Figure 2



VMT adjustment factors were developed from monthly average fuel sales shown in Figure 2. These factors were then averaged together over the period between the two test results for each vehicle. The mileage accumulation for each vehicle was then divided by this factor to arrive at a corrected mileage accumulation.

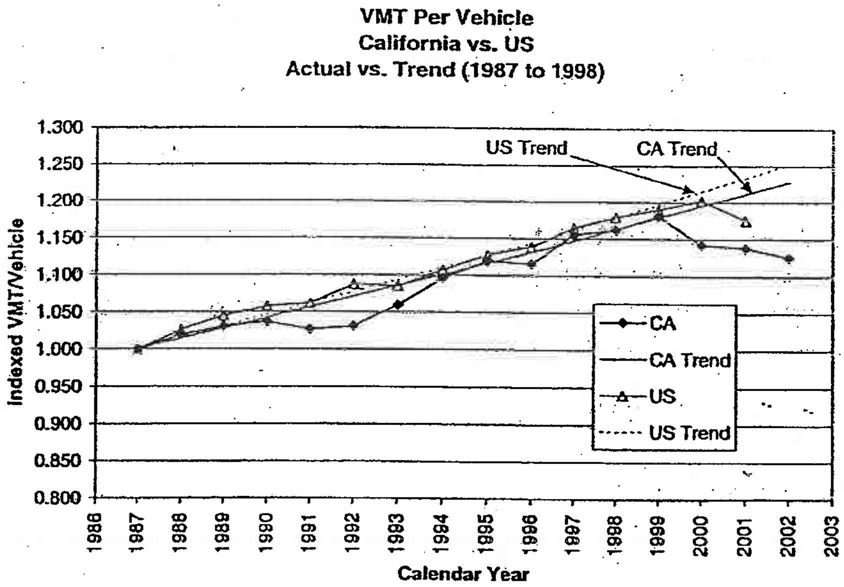
The last adjustment made to the data corrected for the expected reduction in mileage accumulation rate due to the aging of the vehicles. For example, if a vehicle ages one year, statistics show that the vehicle will likely be driven a certain amount less than it was the previous year due to the increasing age of the vehicle. For the vehicle ages considered for this analysis, which were five to eight years old, mileage accumulation decreases at a rate of approximately 3% per year. Rates calculated in this analysis were corrected accordingly.

As discussed previously, the intent of the analysis is to examine how changes in fuel price influence the mileage accumulation rate. This can be determined by knowing the annual VMT accumulation rate related to one price point and the annual VMT accumulation rate related to another price point. While actual VMT accumulation rate data related to an actual price point are easily calculated, the analysis is complicated by the fact that the VMT accumulation rate is increasing over time, independent of changes in fuel price.

The underlying change in VMT accumulation rate over time was determined from data obtained from Caltrans. In its "California Motor Vehicle Stock, Travel and Fuel Forecast,"[6] Caltrans estimates total VMT and the number of vehicles through the year 2025. After contacting the author of the Caltrans report, Sierra was provided the underlying data used to prepare the forecast.[7] These data were used to forecast VMT per vehicle in 2000 and 2003 absent the gasoline price surge first seen in 2000.

Figure 3 shows how the 1987-1999 annual VMT/year trend lines compare to year-to-year VMT data for both California vehicles and U.S. vehicles.[8] As shown in the figure, the California data and the U.S. data indicate similar VMT/vehicle growth rates. Prior to the significant price increase in calendar year 2000, the annual VMT growth rate in California was 1.38%/year. The U.S. average growth rate prior to 2000 was 1.51%/year. These growth rates are indicated in Figure 3 by the lines labeled "US Trend" and "CA Trend." Also shown in Figure 3 are the actual year-to-year variations in VMT. Both the California and U.S. data show a decrease in annual average VMT/vehicle once gasoline prices jumped in 2000. With both the California and US data showing similar annual VMT/vehicle growth trends through 1999, annual VMT/year was expected to continue increasing in 2000, 2001, and 2002, absent some other factor.

Figure 3



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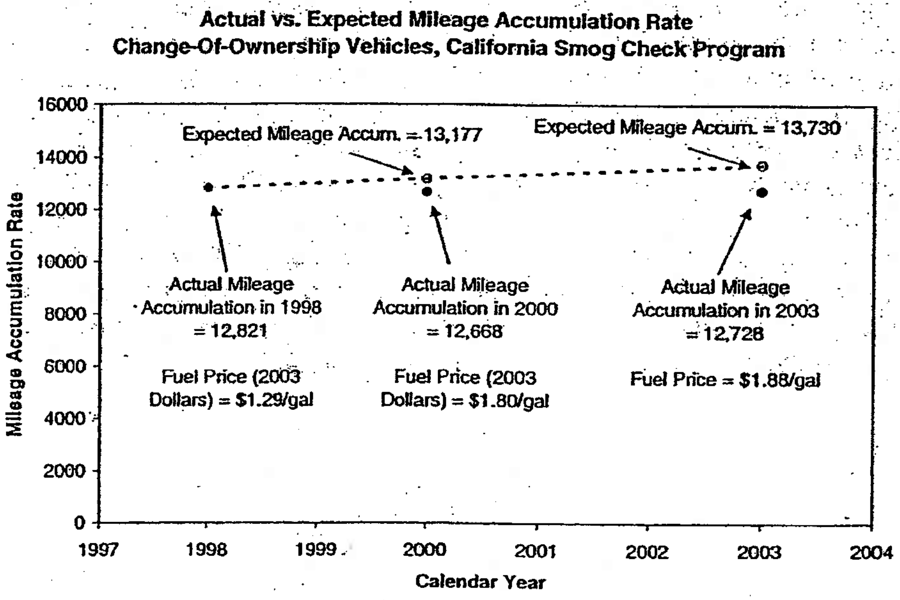
[6] California Motor Vehicle Stock, Travel and Fuel Forecast, California Department of Transportation, November, 2003.

[7] Personal communication with Luk Lee, Caltrans, April 2004.

[8] Data downloaded from Federal Highway Administration website. This data represented passenger cars and motorcycles (http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm).

Figure 4 shows the results of our analysis based on an underlying annual VMT/vehicle growth rate of 1.38%/year. The fuel price elasticity can be estimated by comparing the actual annual VMT/year to the expected annual VMT/year and then dividing the difference by the percent change in gasoline price.

Figure 4



In the absence of any rebound effect, the mileage accumulation rate in 2003 would have been 13,730 miles/year. Based on Smog Check data, the actual annual mileage accumulation rate was only 12,728 miles/year. The difference between the expected rate and the actual rate was as follows:

(12,728 - 13,730) / 13,730 = -7.30%

The fuel price changed as follows:

($1.88 - $1.29) / $1.29 = +45.7%

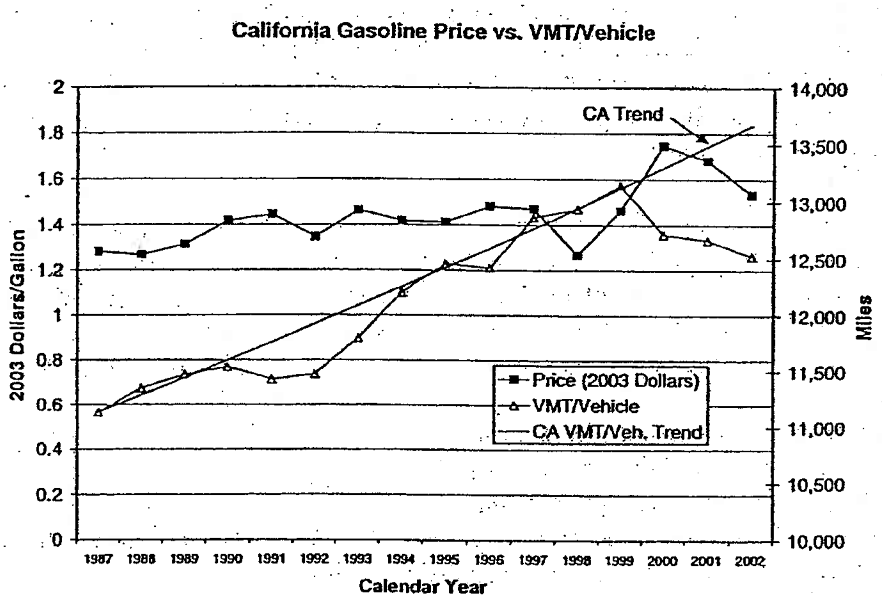
Since price elasticity is the proportional change in demand over the proportional change in price, it was calculated as follows:

-7.30 / 45.7 = -0.16

Thus, from this analysis, the mileage accumulation rate in California exhibits 16% elasticity with respect to fuel price. In other words, a 10% reduction in fuel cost would be expected to induce a 1.6% increase in VMT, which is similar to Greene's estimate of the rebound effect on a national basis. (Calculating the elasticity across the shorter, 1998 through 2000 timeframe results in an elasticity of –0.10, or 10%.)

Caltrans Data Analysis – The existence of a rebound effect in California can also be examined by using the aforementioned annual VMT/vehicle data from Caltrans directly, without the analysis of odometer data recorded in the Smog Check program. Figure 5 shows the annual VMT/year data obtained from Caltrans plotted with the annual average gasoline price data obtained from the Energy Comission. As shown in the figure, annual average VMT drops below the 1987-1999 trend line in response to the fuel price increases that occur post-1999.

Figure 5



The Relationship Between the Mileage Accumulation Rate and the Fuel Economy of California Vehicles

A separate analysis was performed to determine whether there is a relationship between motor vehicle fuel economy and the mileage accumulation rate for California vehicles. As in the analysis described above, mileage accumulation rates were derived from Smog Check data. Using Smog Check program data collected through November 2003, 1999 was the most recent full model year of inspection data available for study. Using biennial inspections for 1999 model year vehicles, the odometer reading at the time of the inspection in calendar year 2003 represents approximately five years of mileage accumulation.

Because of the possible relationship between mileage accumulation and vehicle size/functional class, the data were segregated into 12 different passenger car categories (e.g., subcompact sedans/wagons, compact sedans/wagons, etc.) and 7 different light-duty truck categories. Fuel economy data from the U.S. EPA website were used to assign fuel economy values to each 1999 model year vehicle in the dataset collected from January through November of 2003. In many cases, matching the EPA fuel economy data to the individual vehicles was time consuming when carlines would be identified by slightly different model names (e.g., Camaro vs. Z28) in each dataset, or when the datasets would break the vehicles down differently. For instance, a 1999 Chevrolet Prizm in the fuel economy dataset was identified separately based upon three different transmissions: a manual and two different automatics. Each configuration had a different fuel economy rating. In contrast, the California data had all three lumped together.

To address matching problems, the EPA and vehicle class data was averaged by make, model key word, and engine displacement. The model key word was used to simplify complicated names used by the manufacturers that use a different naming convention than that used in the California data. For instance, a Chevrolet C1500 pickup may have been called a "C1500 SILVERADO 2WD" in the EPA dataset or a "SILVERADO" in the California dataset. By using a model key word of "SILVERADO," a match could be made without an exact match.

In cases where vehicle models could not be matched with the EPA data, the vehicles were excluded from the analysis. After merging the two datasets, some additional records were eliminated for body type mismatches. For instance, if the EPA data identified that the vehicle should have been an SUV yet the Smog Check record indicated that the vehicle was a pickup, the record was assumed to be a mismatch and eliminated.

After merging the two datasets, the data were then analyzed to examine the relationship between fuel economy and the amount of miles that the vehicle was driven. Figure 6 shows passenger car results of this analysis. For each category, vehicles were binned based upon their EPA fuel economy rating. Within each fuel economy bin, the distribution of odometer readings was computed. For instance, if a class/fuel economy bin had 100 data points and all were ordered from the lowest odometer reading to the highest, the 10th percentile line shows the results for the 10th vehicle in that distribution. The lower 25% line shows the results for the 25th vehicle, and so on.

As shown in the figure above, mileage accumulation within each category tends to trend up as the fuel economy improves.

Figure 7 combines results from all passenger cars together to gain a better understanding of how the trend holds up overall.

Figure 6

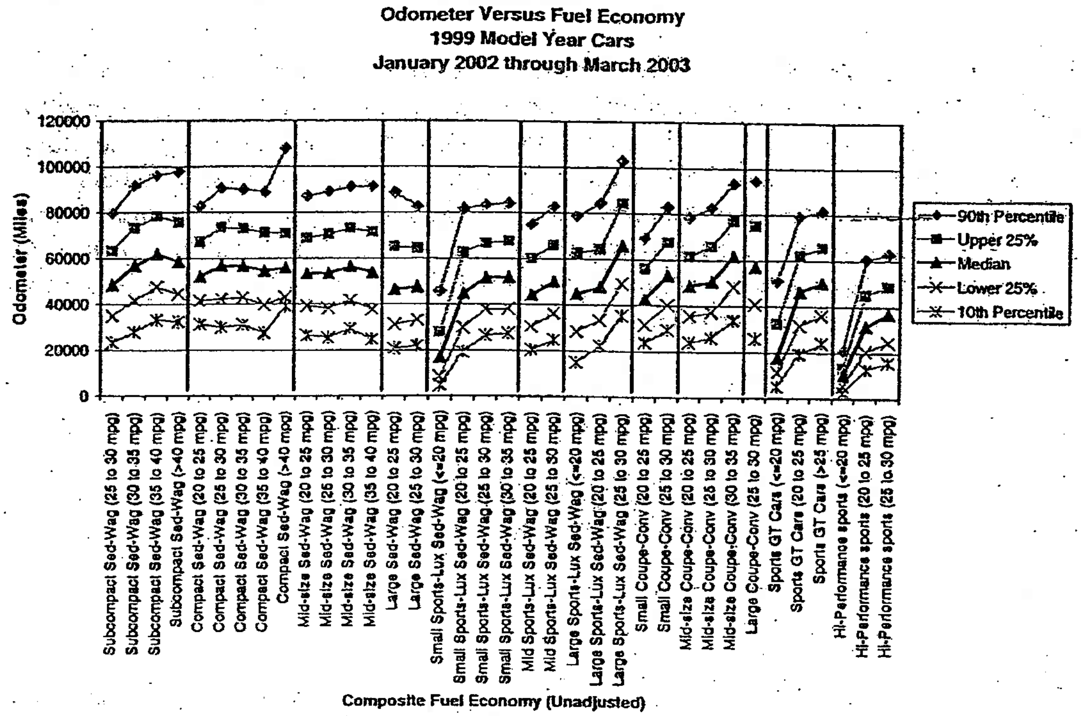
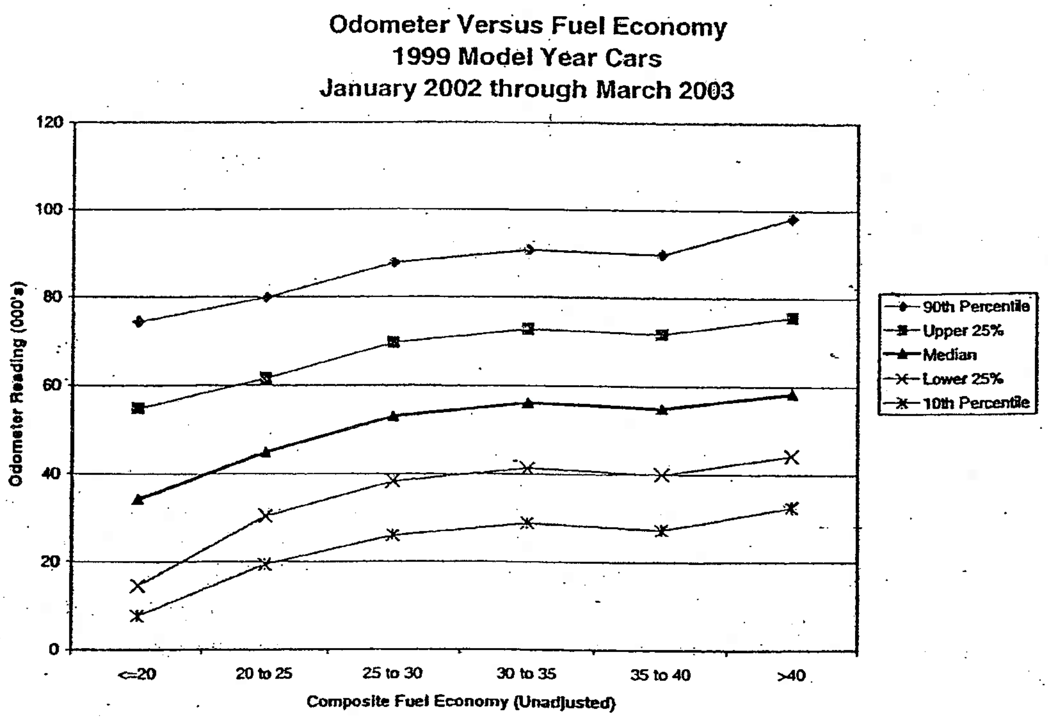

Odometer Versus Fuel Economy
1999 Model Year Cars
January 2002 through March 2003

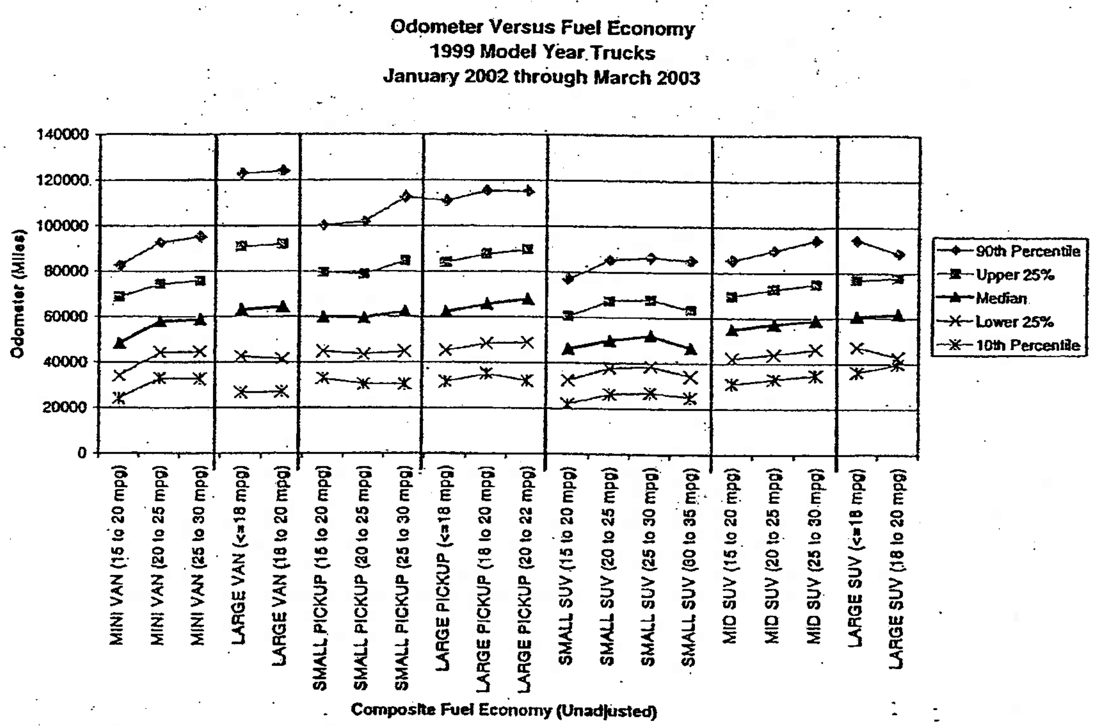
Figure 7


Odometer Versus Fuel Economy
1999 Model Year Cars
January 2002 through March 2003

As shown above, the mileage accumulation is significantly higher for vehicles with better fuel economies.

Figure 8 shows the results for trucks. Similar to the passenger car results, the truck results show that mileage accumulation is higher for vehicles with better fuel economy. In the case of trucks, however, results were not combined across classes because some classes had such dramatically higher mileage accumulation rates relative to others. For instance, combining large vans with small SUVs would make it appear that vehicles with poorer fuel economy were being driven more in spite of their fuel economy when, in fact, the mileage accumulation was being driven by the fundamentally different type of service and utility that the vehicles provide.

Figure 8



Conclusions

Analysis of California-specific data indicates that California motorists respond to changes in fuel price in essentially the same manner as motorists nationwide. Based on Greene's conclusion that "Consumer response to changes in fuel economy or fuel price per gallon appear to be equal and opposite in sign," it is apparent that regulations mandating the sale of vehicles with higher fuel economy will induce higher levels of travel than would otherwise occur.

Attachment C-5
Problems with CARB's Turbocharging Analysis

CARB's analysis assumes that turbocharging combined with engine downsizing makes it possible to simultaneously improve fuel economy while significantly reducing vehicle cost. The NESCCAF report on which CARB relies reached this conclusion. Testimony provided at CARB workshops by Honeywell made the same point. This conclusion stands in stark contrast to the relatively limited use of turbocharging in the current fleet. This attachment explains why the benefits of turbocharging assumed by CARB and NESCCAF are incorrect.

Turbocharging increases the maximum air consumption rate of the engine, allowing more fuel to be burned and higher power levels to be developed per unit of engine displacement. Although this technique is commonly used to increase vehicle performance, it can, in theory, alternatively be used to increase fuel economy if the engine size is reduced to maintain constant performance. The use of turbocharging in combination with engine downsizing offers the potential for improved fuel economy because a smaller engine requires a greater throttle opening to make equivalent power and there are lower throttling losses associated with greater throttle opening.

In practice, there are factors that limit the theoretical advantages of turbocharging. The primary factors are increased intake charge temperature, and increased knock tendency. Heating of the intake charge by the turbocharger and the higher cylinder temperatures associated with compressing a higher pressure intake charge both contribute to an increased tendency for the air-fuel mixture to auto-ignite. In a gasoline-fueled engine, this causes spark knock, which leads to overheating of the engine, noise, and excessive mechanical stress. Several techniques can be applied to eliminate spark knock, including the use of a higher octane fuel, reduced compression ratio, retarded spark timing, or some form of intake charge cooling. The use of higher octane fuel is effective, but expensive. There are also practical problems using gasoline with a R+M/2 octane in excess of 91 because of the limited availability of such fuels. Reduced compression ratio is highly effective and inexpensive. However, it also reduces the efficiency of the engine, defeating the advantage of turbocharging in the first place (at least the fuel economy advantage; turbocharged engines with reduced compression ratio can still achieve higher power per unit of displacement). Retarded spark timing also reduces the efficiency of the engine, but is generally less effective than reduced compression ratio. Intake charge cooling minimizes adverse effects on engine efficiency, but is more complicated and more expensive.

Considering only initial system cost, the most cost-effective form of intake charge cooling involves water injection at high boost pressure. This technique was applied on a commercial vehicle about 40 years ago when General Motors used water-alcohol injection on a turbocharged engine installed in one particular Oldsmobile model. The disadvantage of this technique is that it adds a maintenance requirement and requires an additional tank of liquid to be packaged onboard the vehicle. A less maintenance intensive, but more expensive, technique involves the use of an intercooler – a radiator-like device placed between the supercharger outlet and the intake manifold.

Estimates of the benefits of turbocharging presented at CARB's April 20, 2004 workshop ranged from 6-8% reductions in CO_2 emissions claimed by AVL to 15-21% reductions claimed by Honeywell.

Problems with Honeywell's Analysis

In his presentation at the workshop, Dr. S.M. Shahed from Honeywell claimed that current production vehicles using turbochargers have 5-12% lower CO_2 emissions than vehicles using non-turbocharged engines. He attributed 15-21% reductions to studies by "world class experts" and 5-18% reductions to what he referred to as "rough experiments" conducted by Honeywell. As described below, our analysis indicates that each of the three improvement ranges cited by Shahed misrepresent the true potential of turbocharging to improve fuel economy and provide corresponding reductions in CO_2 emissions.

Taking Shahed's claims in reverse order, the "rough experiments" cited by Shahed provided no information regarding whether the octane requirement of the engines was altered. In addition, EPA test data indicate that higher fuel economy and lower CO_2 emissions than reported by Shahed are possible without the use of turbochargers. Shahed's presentation at the April 20 workshop shows a picture of a Jeep Liberty SUV and lists the CO_2 emissions of the baseline 3.7 litre engine as 329 g/km City Cycle and 255 g/km Highway Cycle. With a turbocharged 2.4 litre engine, the CO_2 emissions are reported to drop to 311 City and 233 Highway, 5.5% and 8.6%, respectively. However, as shown in Table 1, EPA data for the 2003 model year Jeep Liberty with a 3.7 L engine shows fuel economy ratings equivalent to 283 g/km CO_2 City and 204 g/km Highway, which are lower than the values reported by Honeywell for the 2.4 L turbocharged vehicle.

Table 1
Effects of Turbocharging and Downsizing on Carbon Dioxide Emissions

	Source	City	Highway	55/45 Comp.
Jeep Liberty, 3.7 L Baseline	Honeywell	329 g/km	255 g/km	296 g/km
Jeep Liberty, 3.7 L Baseline	U.S. EPA	283 g/km	204 g/km	247 g/km
Jeep Liberty, 2.4 Turbo	Honeywell	311 g/km	233 g/km	276 g/km

The other vehicle shown in the materials presented by Shahed appears to be a Ford Escape/Mazda Tribute with a 3.0 L baseline engine. Shahed lists the baseline CO_2 emissions at 285 g/km City and 214 g/km Highway. With a 2.0 L turbocharged engine, the reported values are 233 g/km City and 190 g/km Highway, 18% lower and 11% lower, respectively. However, the EPA data for the 2003 3.0 L Escape/Tribute indicates fuel economy equivalent to CO_2 emissions of 260 g/km City and 172 g/km Highway. The 55/45 weighted average of the CO_2 reported by EPA is less than 3% higher than the turbocharged results reported by Shahed.

Our review of the literature cited by Shahed in support of the claimed 15-21% reductions indicated that those reductions were the net effect of multiple technology changes, not just turbocharging. The data reported in the literature included the effects of variable compression ratio, direct injection, and "Miller Cycle" engines. For that reason alone, the results are not representative of what can be accomplished for the cost associated with turbocharging. The literature cited by Shahed also fails to identify how the "baseline" engine configurations compare with other non-turbocharged engines. In addition, the literature cited is silent on the issue of whether the octane requirements of the baseline and modified engines were the same.

Shahed's claim that current production vehicles using turbochargers have 5-12% lower CO_2 emissions than vehicles using non-turbocharged engines also appears to misrepresent the effects of turbocharging. Shahed's claim was based on a series of graphs showing CO_2 emissions vs. horsepower for what he said were "hundreds of non-turbo vehicles" compared to "tens of turbocharged vehicles" in the European fleet. Regression lines for the turbocharged vehicles were shown to be 5-12% below the regression lines for the non-turbocharged vehicles. However, Shahed's analysis did not account for differences in weight between the turbocharged and non-turbocharged vehicles of equivalent power. Unless the weight of the turbocharged and the non-turbocharged vehicles happened to be the same, the differences in fuel economy and CO_2 emissions in Shahed's graphs could be significantly affected by differences in weight.

We conducted an analysis similar to the analysis described by Shahed by examining published EPA data on 2003 model year cars. As described in more detail below, we found no statistically significant effect of turbocharging on fuel economy after accounting for vehicle weight.

EPA's fuel economy database provides a listing and descriptions of all model year 2003 cars that were certified for sale in the U.S., including "city," "highway," and combined city/highway fuel economy in miles per gallon. Prior to analyzing the data, Diesel-powered vehicles, hybrid vehicles, and mechanically-supercharged vehicles were removed from the dataset. CO_2 emissions were calculated by inverting EPA's equation for fuel economy (mpg) as a function of CO_2, carbon monoxide (CO) and hydrocarbon (HC) emissions in grams per mile and assuming that the contribution of carbon from the CO and HC in vehicle exhaust is negligible compared to the amount of carbon in CO_2 emissions. Unadjusted, combined city/highway fuel economy values were used for the analysis.

Multiple linear regression was performed using the data analysis pack in Microsoft Excel 2000, with each vehicle model constituting one record. CO_2 emissions, calculated as described above, were treated as the independent variable and vehicle curb weight (lbs), vehicle rated power (horsepower), turbocharging and transmission type were the independent variables. Turbocharged models were represented by a value of "1" if the vehicle had a turbocharger and zero otherwise. Similarly, automatic transmissions (including continuously variable transmissions) were represented by a value of "1" and manual transmissions by zero.

There were 417 observations, i.e. vehicle models, in the data set, of which 68 (14%) were turbocharged. The full 4-parameter data analysis that included vehicle weight, horsepower, turbocharging and transmission type yielded an r-squared value of 0.760, i.e., more than ¾ of the variation in CO_2 emissions between vehicle models was explained by the resulting model. The resulting regression equation was:

$$CO_2 \text{ in g/mi} = 89.47 + 0.03599(\text{lbs}) + 0.603(\text{hp}) - 6.9(\text{turbo}) + 5.6(\text{auto})$$

However, the low t-value associated with the regression coefficient for the turbo factor indicated that, on a statistical basis, the turbo factor was indistinguishable from zero. Omitting the turbo factor resulted in a 3-parameter 'best fit' equation that had a nearly identical r-squared value of 0.758, but for which all coefficients in the regression equation, shown below, were statistically significant at the 90% confidence level:

$$CO_2 \text{ in g/mi} = 91.65 + 0.03497(\text{lbs}) + 0.602(\text{hp}) + 6.2(\text{auto})$$

Problems With AVL's Estimates

We also performed an engineering analysis of the effect of turbocharging on fuel economy and CO_2 emissions. VEHSIM modeling was performed to evaluate the potential benefits of achieving a 25% increase in Brake Mean Effective Pressure (BMEP) with turbocharging and then downsizing the engine by 20% to maintain constant performance. Simply downsizing the engine by 20% produces an estimated city/highway fuel economy benefit of 8.7%, which is in the same range as estimated by AVL. However, it is not possible to simply downsize the engine.

Even if an intercooler is used to reduce the increase in intake air temperature, the higher manifold pressure available with the turbocharger will lead to spark knock unless other changes are made. The two most common changes are increasing the vehicles octane specification and reducing the compression ratio. Spark retard and fuel-air mixture enrichment can also be employed to reduce the octane requirement; however, the mixture enrichment strategy is not feasible for vehicles required to meet the requirements of the Supplemental Federal Test Procedure (which requires a demonstration of effective emissions control at wide open throttle).

To the extent that higher fuel octane quality is specified to prevent spark knock in turbocharged engines, fuel costs increase by 10-13%. This increase exceeds the fuel cost savings associated with downsizing the engine. To the extent that lower compression ratio or spark retard is used to prevent spark knock, the theoretical benefits of engine downsizing are reduced or eliminated due to the associated reduction in engine efficiency. To make up for the octane requirement increase associated with a 25%

increase in BMEP, the compression ratio has to be reduced by about 1.5,[1] which reduces the efficiency of the engine by approximately 6%. (Based on personal communications with AVL, the 8% fuel economy benefit predicted by their model assumed the use of premium fuel.) Since the lower compression ratio also reduces peak power, the degree of downsizing possible while maintaining constant performance is also reduced. The turbo lag associated with acceleration from a standing start further limits the extent to which the engine can be downsized without degrading 0-30 mph acceleration. When all of these factors are accounted for, there is no fuel economy benefit associated with engine downsizing through the use of turbocharging unless higher octane fuel is used.[2] (Our simulation modeling of the effect of turbocharging without higher octane fuel shows an estimated 0.3% reduction in fuel consumption using the CAFE test procedures and a 2.1% increase in fuel consumption in actual California driving.)

Additional Considerations

For the reasons described above, the NESCCAF/CARB analysis of turbocharging has misrepresented the potential benefits. However, it also should be noted that the economic benefits assigned to the replacement of V-6 engines with inline 4 or 5 cylinder engines also fails to account for the premium that customers willingly pay for V-6 engines. As described below, customers willingly pay $1,300 for a V-6 engine of equivalent power to an inline 4-cylinder engine.

An evaluation was performed of option prices for light-duty, gasoline-powered vehicles to determine the value that consumers assign to added horsepower, V-6 (rather than 4-cylinder) engines, automatic transmissions and towing capacity. The evaluation used available option pricing data and other information from Edmunds.com and New-cars.com, and was restricted to major manufacturers and those models and "trim lines" for which the price of options could be reasonably identified. The analysis used multiple linear regression to compute the price change associated with each option.

The analysis determined the average price change per unit change in: 1) rated horsepower, 2) number of cylinders, 3) number of gears, 4) manual to automatic transmission, and 5) addition of a towing package. Results are summarized in the table below for both the full five-parameter model and a four-parameter model that excluded change in number of gears.

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[1] Estimate based on a representative boost tolerance of 0.65 psi per octane number.

[2] An analysis performed for the Canadian government in 1999 concluded that a 7% fuel economy benefit was feasible with turbocharging, but only for engines with relatively low volumetric efficiency. As pointed out in the 1999 study, our conclusion was that turbocharging would not be effective in improving the fuel economy of engines with 4-valve cylinder heads without the use of higher octane fuel.

Table 2
Computed Values of Consumer Options

Option	Value based upon 5-Parameter Model, r-squared = 0.695	Value based upon 4-Parameter Model, (r-squared=0.687
Horsepower	$17	$17
V-6 vs. I-4	$1,299	$1,299
Additional Transmission Gear	$132	NA (see text)
Automatic vs. Manual Transmission	$861	$748
Towing Package	$331	$331

Data and Analysis – To perform the analysis summarized above, a data set was compiled containing information on different pricing options that will permit computation of the average price for each option listed in the foregoing table. The listings of cars, trucks and SUVs at www.new-cars.com was used to identify makes and models of vehicles and, where appropriate, to obtain horsepower ratings. "Price with options" from www.edmunds.com was used as the source of information for all vehicle prices, and MSRP (manufacturer suggested retail prices) were used. The analysis was restricted to light-duty, gasoline-powered vehicles[3] manufactured by the five largest producers, namely: General Motors, Ford, Daimler-Chrysler (excluding Mercedes), Honda and Toyota[4]. The sample was restricted to those models and "trim lines" for which the price of the selected options was available explicitly or could be reasonably separated from the prices of other options[5].

For each vehicle included in the analysis, the dataset included the MSRP of the base unit (without the option), MSRP of the upgraded unit with the options, and the difference in the two MSPRs. If the upgrade was a different engine, the original and upgraded horsepower (and engine displacement) and the difference in horsepower were also recorded. In a similar fashion, the base number of cylinders, upgraded number of cylinders and difference in number of cylinders were recorded, as were the base and

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[3] Diesel vehicles and those identifiable as using alternative fuels were excluded. Flexible fuel vehicles where offered as an option were also excluded.

[4] The same data sources were also searched for vehicles manufactured by Nissan, the sixth largest manufacturer but none of those vehicle listings permitted the separation of costs by option, as described herein.

[5] Many models offer one engine size in a particular trim line and a larger, more powerful engine in a more expensive trim line of the same model. However, because the varying options offered as part of each trim line could not always be identified unambiguously from the available data, the dataset was generally limited to different options within trim lines. Data from a few models were, however, included across trim lines where it was reasonably possible, based on data contained in Edmund's "Editors' Reviews", to determine what features were included with each trim line and to estimate and adjust for the average incremental prices of those features.

upgraded numbers and differences of transmission speeds, and the transmission type (whether automatic or manual[6]). Finally, the cost of adding a towing package was included.

Several of the options of interest as shown in the foregoing table are closely interrelated. For example, number of cylinders is obviously related to horsepower, and the change between manual and automatic transmissions is often associated with a change in the number of gear speeds. Multiple linear regression was used to objectively separate and estimate each of these effects. Specifically, a 5-parameter model was constructed (and later 4-parameter model as well) to compute the difference in MSRP associated with the adding one horsepower, one cylinder, one gear change, automatic transmission and towing. For all computations, the regression constant was set to zero, consistent with the model design that there should be zero price change associated with no physical change. Multiple linear regressions were performed using Microsoft Excel 2000.

All of the dependent and independent variables used in the regression represented, for each model, simply the difference between the base values and the upgrade values, except for number of cycles. In that case, in order to provide an estimate that was most applicable for upgrading from a 4-cylinder engine to a more than 4-cylinder engine, the difference in number of cylinders was only entered when the base vehicle had a 4-cylinder engine and the upgraded vehicle a 4 or more cylinder engine; for all other vehicles the difference in cylinder change variable was entered as zero. Results from the 5-parameter model have already been summarized in Table 2.

Although the 5-parameter model explains almost 70% of the variance in price increase for the dataset, the estimated coefficient of $132 per additional gear has a computed t-statistic of only 1.52, indicating that the estimated coefficient is sufficiently uncertain that we cannot distinguish it from zero. Accordingly, a second model was constructed in which the variable for change in number gears was omitted. The coefficients for this 4-parameter model are likewise shown in Table 2. Most of the coefficients change little or not at all by the model change. However, the coefficient for automatic transmission, which is closely connected to number of gears, decreases when the variable for number of gears is omitted from the model.

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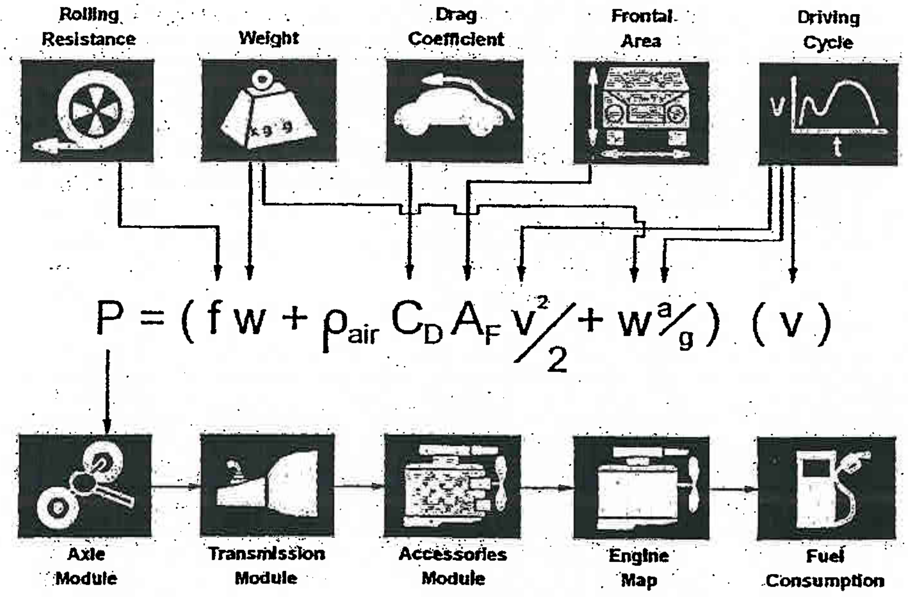
[6] The small number of vehicle models identified as having continuously variable transmissions were excluded from the database.

Attachment C-6
Description of Sierra's Vehicle Simulation Model

VEHSIM is an enhanced version of a fuel economy model originally developed by General Motors and subsequently modified by the U.S. Department of Transportation to estimate emissions, as has been described in previously published reports (Sierra Research, 1992). Figure 1 is a simplified representation of the way the model works.

Figure 1

VEHSIM Model Structure



Detailed specifications of the vehicle design and the driving conditions are inputs to the model. The user specifies vehicle weight, frontal area, drag coefficient, and other parameters affecting the power required to maintain the specified speed-time profile. The user also selects from a collection of "parts," which represent alternative choices in power train components. These parts represent the engine, engine accessories, transmission torque converter, transmission gear set, transmission shift logic, axle ratio, and tires.

Based on the specified vehicle design, the model calculates the instantaneous power at the drive wheels required to maintain the specified speed-time profile. Based on the tire size, axle ratio, and axle efficiency, the drive wheel power and speed is translated into the speed and power required at the output of the transmission. Based on the transmission gearing, shift logic, torque converter speed ratio, and efficiency, the power and speed at the input of the transmission is computed. Total engine load is determined by adding accessory losses to the required transmission input. Finally, the instantaneous fuel consumption rate is determined from the engine "map," which is a detailed tabulation of fuel consumption as a function of speed and load. The fuel consumption is computed 20 times a second by interpolation between the individual data points contained on the map. Fuel economy is calculated by integrating the instantaneous consumption over a specified driving cycle. To compute city/highway combined fuel economy, approximately 45,000 individual calculations are combined.

In addition to simulating fuel economy, VEHSIM can also be used to estimate the acceleration performance or top speed of a vehicle. Rather than having the model determine the engine speed and load required for a particular driving cycle, the user specifies a zero initial speed and wide-open-throttle. The model then determines the resultant speed-time profile as the vehicle accelerates to the maximum achievable speed.

Although the model is capable of simulating variations in roadway grade, wind speed, and surface conditions, simulations run during this study assumed zero wind speed, level terrain, and paved roads (which is consistent with the conditions simulated during official fuel economy tests). However, the model was also used to evaluate the effect of fuel efficiency improvement technologies on the ability of vehicles to maintain freeway cruising speeds on grades (i.e., "gradeability").

Because of the effect of transient operation and air-fuel ratio and exhaust stoichiometry, there are legitimate concerns about the use of steady-state engine maps to simulate vehicle emissions. However, such maps produce extremely accurate results for fuel consumption. The ability of the model to accurately estimate fuel efficiency from a steady-state engine map was verified though the use of engine maps for current production engines provided to Sierra by manufacturers participating in a study Sierra performed for the Canadian government in 1999. The results of the validation runs performed for that study are shown in Table 1.

In performing the validation runs, engine maps, shift logic, gear ratios, vehicle weight, aerodynamic drag coefficient, frontal area, rolling resistance, and other parameters specific to particular makes and models were used as input to the VEHSIM model and the model-predicted fuel economy results were compared to actual test results for the vehicles being represented. Sierra also made minor adjustments to default values in VEHSIM for tire efficiency based on suggestions provided by General Motors. As shown in Table 1, the predicted composite fuel economy results for individual vehicles differ from the measured results by as much as 3.7%; however, there were absolutely no adjustments made to "calibrate" the model, and the variation is within the range of variation that can be caused by such factors as fuel energy content, driver variation, and vehicle-to-vehicle variability. Additional runs confirmed that the VEHSIM model correctly predicts results for changes in vehicle weight, aerodynamic drag, and tire rolling resistance appearing in the technical literature.

Table 1
VEHSIM Validation Results
(circa 1999)

Model	City MPG		Hwy MPG		Combined MPG	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
Ford Taurus	22.0	23.6	38.0	36.4	27.1	28.1 (+3.7%)
Pontiac Sunbird	24.5	25.6	39.1	40.2	29.5	30.6 (+3.7%)
Chevy Pickup	14.8	15.2	22.3	22.0	17.4	17.7 (+1.7%)

The VEHSIM modeling done in the current study was used to simulate several different "composite" vehicles representative of the average vehicles in specific vehicle categories (e.g., mid-size sedans). To model "baseline" vehicles, modified versions of the "blended" engine maps used during Sierra's 1999 study for the Canadian government were used. The maps were constructed by averaging engine maps provided to Sierra by several large-volume manufacturers. Separate maps were created to represent OHC and OHV engines. None of the engines represented in the baseline engine maps used cylinder deactivation, cam phasers, or variable valve lift. All of the maps were for regular fuel (87 R+M/2) engines. All maps were adjusted to reflect an assumed 2.5% reduction in engine friction, which was forecasted to occur in the Canadian study through the use of lower viscosity lubricants and other miscellaneous changes. (Such changes in lubricants did occur.) The maps were adjusted to match the displacement of the vehicles being simulated using a "resize" routine built into the VEHSIM model. Transmission gear ratios were set to represent the actual gearing of high-volume models. Shift logic was configured to represent typical current shift logic provided to Sierra by high-volume automobile manufacturers. Table 2 shows how the model predicted the fuel economy of the four types of "composite" 2003 baseline vehicles subject to detailed evaluation.

Given the wide range of vehicles represented by the simulations, the agreement between the EPA-reported CAFE test results and the VEHSIM model is excellent. The minor simulation error shown in the table was used to establish category-specific correction factors applied to all modeling of future cases.

In Sierra's previous work with VEHSIM, engine maps and other modified components were developed to represent a variety of engine and transmission changes, including variable valve lift and timing, cylinder deactivation, aggressive shift logic. For the current effort those maps were updated to reflect the latest available information regarding the extent to which these technologies have been successfully demonstrated in

Table 2
VEHSIM Modeling Results for Composite 2003 Baseline Vehicles

	Reported by EPA	Modeled by VEHSIM	VEHSIM Error
Mid-Size Sedan	28.53	29.67	+4.0%
Minivan	23.53	22.86	-2.9%
Large 2WD Pickup	19.21	18.70	-2.7%
Mid-Size SUV	22.66	22.85	+0.9%
Average Error			-0.2%

either prototype or production vehicles. For example, the potential for efficiency improvement through the use of variable valve lift and timing was developed from peer-reviewed technical literature. (insert refs) Modeling of alternative transmission designs, such as automated manual transmissions, was accomplished by modifying the automatic transmission modules within VEHSIM to eliminate torque converter losses immediately after launch. 6-speed automatic transmissions that had not been previously modeled were simulated through relatively straight-forward changes to program modules representing 4- and 5-speed automatics by adding additional gears and adjusting gear ratios to match known values for 6-speed transmissions in current use.

The engine maps used to represent variable valve lift and timing and cylinder deactivation were evaluated by using them in conjunction with other known characteristics of current production vehicles incorporating such technology. Table 3 shows how the VEHSIM results compare to actual CAFE levels reported by EPA.

Table 3
VEHSIM Runs for Vehicles With VVLT and Cylinder Deactivation

Specification	BMW 741 (VVLT)	Chrysler 300C (DeAct)
Weight	4376	4046
Frontal Area	25.09	23.96
Drag Coefficient	0.29	0.35
Rolling Friction Coefficient	0.0105	0.0100
Rolling Radius	1.023	1.145
Displacement	268	345
Axle Ratio	3.38	2.82
Valve Train	4-Valve Continuously Variable Lift & Timing	2-Valve with Cylinder Deactivation
Transmission	6-Speed Automatic	5-Speed Automatic
Modeled CAFE	24.5	22.5
Actual CAFE	24.4	23.0
Simulation Error	+0.5%	-1.9%

As shown in the table, the simulation results for both vehicles closely matches the EPA reported values.

Attachment C-7
Rolling Resistance

Tire rolling resistance is the force that a rolling tire generates and exerts on the road opposite to its direction of travel. It is sometimes expressed in dimensionless form as a coefficient of rolling resistance (CORR), which is the ratio of rolling resistance force to the downward load on the tire from the weight of the vehicle. For on-road light duty vehicles in the US, CORR is on the order of 1 percent, i.e. moving a typical 3000-pound car requires about 30 lbs of force just to overcome the repelling force created by the tires.*

While NESCCAF and CARB assume that CO_2 reductions associated with a 10% reduction in rolling resistance are readily achievable, our analysis indicates otherwise for three reasons. First, even if manufacturers could reduce rolling resistance by 10%, replacement tires will, on average, have significantly higher rolling resistance, eliminating most of the theoretical benefit over the lifetime of the vehicle. Second, significant reductions in rolling resistance have already been achieved in recent years and the potential for further reductions is limited. Finally, recent changes in Federal Motor Vehicle Safety Standards (FMVSS) will likely require the use of tires with higher rolling resistance.

Current Design Criteria for OEM and Replacement Tires

In order to provide improved fuel economy and help meet new car and light truck fuel economy standards, low rolling resistance is a factor in the selection of tires for new cars and light-duty trucks by original equipment manufacturers (OEMs). In contrast, most

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* The Society of Automotive Engineers (SAE) has adopted standard test procedures for measuring the rolling resistance of tires. The traditional method, which is embodied in SAE J1269, involves rolling the test tire against a 1.7-meter diameter steel road wheel at a fixed speed and measuring its resistive force by one of several means. A newer method, SAE J2452, requires testing the tire under a variety of speeds and loads, as does the ISO DIN 8767 method that is used in Europe. An alternative method that may be used to infer the rolling resistance of tires (along with other friction elements such as brake drag and other drive train frictional losses), derives from the SAE practice that describes using vehicle coast-downs to determine "road load". To perform the test, vehicles are operated on a level track and undergo numerous coast-downs in both directions, making precise measurements of vehicle speed and acceleration throughout. According to this SAE practice, data are corrected to standard conditions to account for the effects of wind, ambient temperature, and any changes in weight between the test vehicle and other similar vehicles that the test may be used to represent. In addition, the effective vehicle mass is adjusted upwards, to account for the rotational inertia of rotating components attached to the tires. A two-parameter road load force equation (accounting for aerodynamic drag force and the sum of all other forces) is then fitted to the data and evaluated at a speed of 50 mph, yielding "track road load horsepower" at that speed. Thus, by knowing track road load horsepower, the mass of a test vehicle, and aerodynamic drag, which can be calculated from speed, frontal area, and drag coefficient, it is possible to calculate the road force that is generally associated with tire roll loss. Dividing this force by the loaded weight of the vehicle provides an estimate of the CORR for the test vehicle.

replacement tires, whose rolling resistance is generally unknown to consumers, have higher rolling resistance than OEM tires.[*]

Low rolling resistance is an important property of tires for maximizing fuel economy but it represents only one of many critically important requirements for tires. Tire design, according the Rubber Manufacturer's Association, involves "balancing among a complex list of tire performance criteria, including: load, strength, endurance, traction, bead unseating, speed rating, mass, ride and handling, noise, rolling resistance, temperature resistance, tread wear and tire life and recycled content in tires." Thus, applications that demand certain properties, such as high traction in winter or on wet roadways, cannot be simultaneously optimized for lowest possible rolling resistance. Even in vehicle design applications where a premium appears to be placed on high fuel economy, such as the hybrid-powered Toyota Prius, lower rolling resistance is not the only determining factor in tire choice, as evidenced by the fact that the model year 2004 Prius, unlike predecessor Prius models, no longer uses "low rolling resistance tires."[†,‡]

Potential for Further Reductions

The open literature contains little data on rolling resistance of automotive tires, and the above-referenced study funded by the California Energy Commission concluded that substantially more tire data is needed before an efficient (replacement) tire program could be developed. Michelin, which was the world's largest tire manufacturer in 2003, has published data (reflected in the graph below) showing the trend of "rolling resistance index" for its lowest resistance high-volume tires.[§] Michelin's graphic[**] indicates a

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[*] "California State Fuel-efficient Tire Report: Volume II", Consultant Report, prepared by TIAX LLC and ECOS Consulting for California Energy Commission, Report No. 600-03-001CR, January 2003.

[†] According to CTCarsAndTrucks.com, the 2004 Toyota Prius achieves better fuel economy than the 2003 model but it no longer uses low rolling resistance tires. They report: "Early Prius models came with low-rolling resistance tires that were designed to maximize fuel economy. But these tires didn't have as much grip in wintry weather as all-season tires do, and even on dry pavement, there were a lot of chirps and squeals when I tested an earlier-model Prius. Thankfully, Toyota officials dropped the low-rolling resistance rubber and put all-season tires on the new Prius. I didn't get a single chirp during my test drive."

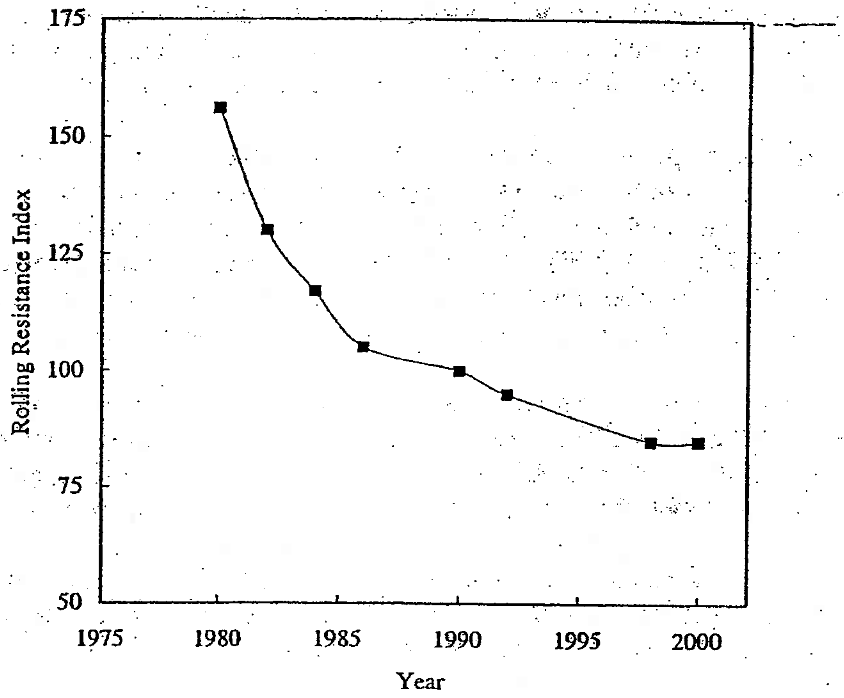
[‡] According to one self-acknowledged Prius enthusiast (http://john1701a.com/prius/prius-tires.htm): " Prius (model year 2001-2003) comes standard with LRR (low rolling resistance) tires. This type maximizes MPG (miles per gallon). Switching to Non-LRR tires means you can expect a drop in fuel efficiency by approximately 3 MPG. Owners have found this an acceptable trade-off for getting better handling and significantly increased tread life."

[§] "Tire Rolling Resistance, Its Impact on Fuel Economy, and Measurement Standards", presented at the California Energy Commission Fuel Efficient Tire Workshop by Tim LaClair, Michelin, September 19, 2002.

[**] A similar graphic but one which shows rolling resistance rather than rolling resistance index may be found on Michelin's copyrighted web site at: http://www.michelin.com/corporate/front/templates/affich.jsp?codeRubrique=91&codePage=PAG_SOL_MICH&lang=EN

downward trend in rolling resistance[*] over about the last 25 years. The graph also indicates a diminishing rate of progress over time and a decided flattening of the downward trend beginning in the late 1990s.

Figure 1
Michelin Estimate of Rolling Resistance vs. Time



Green Seal Inc. has published data on the rolling resistance of "recommended tire models" according to its own multi-factor rating scheme. The rolling resistance of its 17 recommended tires, covering 5 tire sizes, ranged from 0.0062 to 0.0104, with an average value of 0.0093.[†] (Tires that were tested but not recommended by Green Seal had rolling resistance that was greater than average for the sample and as high as 0.015 and/or poor performance in other measures that Green Seal judged to be critical).

Umweltbundesamt (UBA) of Germany has reported[1] measurements that it sponsored of the rolling resistance and certain other properties of several sizes and types of tires. Tires were tested according to ISO 8767. Tires were assigned an "ecolabel" if they met a variety of criteria, including CORR of ≤ 0.011 for summer tires and ≤ 0.012 for winter tires.

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[*] The units of Kg/T are numerically equivalent to dimensionless CORR.

[†] Green Seal Inc., www.greenseal.org.

Sandberg *et al* conducted a study[*] of noise emission, friction and rolling resistance of car tires in Sweden, reporting no connection between noise and rolling resistance but finding a statistically significant relationship between rolling resistance and friction ("optimum slip"). However, data were not reported for individual models of tires.

Traditionally, low rolling resistance tires required the use stiffer compounds and/or high inflation pressures, both of which had negative consequences for traction and ride. However, over the past several decades, materials of construction, improvements to tread pattern and other changes have allowed significant reductions in rolling resistance in tires with overall characteristics suitable for OEM tires on a broad range of vehicles.

Michelin uses silica compounds in its Energy MXV4 and Radial XSE tires in place of carbon black to reduce rolling resistance,[2] and Bridgestone has used elongated bonds between carbon particles to reduce rolling resistance. While both approaches have limitations, the use of silica to improve rolling resistance, with or without elongated bonds between carbon particles, has been reported to provide improvement in the rolling resistance of OEM tires without significantly sacrificing other key properties.

In addition to the introduction of silane-treated silica in tires, another important breakthrough occurred in the 1990s with the application of phase transfer catalysis for the more economical production of silane for use in silica treatment of tires[3]. Together, these innovations have resulted in the widespread use of silica in low rolling resistance tires.[4,5]

Considering the varying needs of different vehicle types, a pertinent question about future tires is what levels of rolling resistance can be expected in the post-2008 timeframe without compromising the needs for traction, handling, wear and other critical characteristics?

A number of researchers have offered their projections or opinions about the potential for future reductions in rolling resistance (of OEM tires), generally with little or no supporting information. Typically, these projections have been in the range of about 10-30%[6,7,8,9] and have been based on unspecified assumptions or, apparently, assumptions about continuation of past trends. However, it is unclear whether the breakthroughs in improving materials of construction and tread pattern that have occurred in the past 25 years can be repeated indefinitely or will tend to level off, as Michelin's graph of rolling resistance index appears to suggest. It is likewise unclear to what extent the new federal TREAD Act[†] will limit vehicle manufacturers' options for selecting OEM tires. Of particular concern to vehicle manufacturers are the new NHTSA requirements for low tire pressure monitoring which may, according one vehicle manufacturer,[10] ultimately

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[*] Sandberg, Ulf, et al, "Noise Emission, Friction and Rolling Resistance of Car Tires – Summary of an Experimental Study", paper published in the Proceedings of the 2000 National Conference on Noise Control Engineering (NOISE-CON 2000), Newport Beach, CA, December 3-5, 2000.

[†] "TREAD Act" refers to the Transportation Recall Enhancement, Accountability and Documentation Act (HR 5164) that was enacted on November 1, 2000, as a consequence of Congressional hearings on the safety of Firestone tires and related matters. The Act addresses a broad range of issues and imposes certain requirements on vehicle and tire manufacturers that are likely to restrict their ability to fully utilize the lowest rolling resistance tires in the future.

require the use of tires with greater load carrying capacity at low inflation pressure, which will adversely affect rolling resistance.

Based on the available literature, it is clear that there is potential for reducing the rolling resistance of aftermarket tires; however, OEM tires already are selected to achieve the minimum rolling resistance consistent with other design constraints and the rate of progress in low rolling resistance technology has decreased significantly in recent years.

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