The California Greenhouse Gas Initiative and Its Implications to the Automotive Industry

June, 2005

Prepared for

The Center for Transportation Research
Argonne National Laboratory

and the

United States Department of Energy

by the

Center for Automotive Research
Ann Arbor, MI

Acknowledgements

As with any project, this report is the result of many people contributing in many ways. The authors of this report would like to thank Karen Esper and Diana Douglass, who contributed greatly by creating and formatting the document. Their expertise and patience were critical to the project's success. Chris Gulis and Emilio Brahmst spent many long hours researching, documenting and detailing powertrain technologies and manufacturing processes.

Dr. Richard Gerth created, applied, and wrote analysis for the single and multiple Logit statistical models used for forecasting. Dr. Gerth also served as an advisor for the regression modeling, and overall statistical analysis. Jillian Lindsay Gauthier contributed by assisting with the statistical modeling and overall document review. Chris Powers also added document review support.

Finally, we would like to thank those in the automotive industry that took time to guide the authors. This topic presents many challenges, not the least of which being the political risks involved in participating in any discussion. The arena of advanced powertrain technology—is a highly controversial and emotional issue. Several industry experts were willing to rise above the fray and offer their time and highly knowledgeable insight into the many challenges of advanced powertrain technology. For this, CAR is greatly appreciative.

Brett C. Smith,
Assistant Director, Manufacturing Engineering and Technology

Raymond T. Miller,
Research Assistant

Executive Summary

Introduction
CAR undertook this investigation to better understand the costs and challenges of a local (state) regulation necessitating the implementation of alternative or advanced powertrain technology. CAR will attempt to add insight into the challenges that local regulations present to the automotive industry, and to contribute further to the discussion of how advanced powertrain technology may be used to meet such regulation.

Any local law that (directly or indirectly) affects light duty motor vehicle fuel economy creates what in effect is a specialty market for powertrain technology. As such these small markets present significant challenges for automotive manufacturers. First, a small market with unique standards presents a significant challenge to an industry that has sustained growth by relying on large volumes to achieve scale economies and deliver products at a cost acceptable to the consumer. Further, the challenges of the additional technology make it likely that any powertrain capable of meeting the stringent emissions standards will include costly additional components, and thus will be more costly to manufacture. It is likely that manufacturers would consider the following actions as steps to deliver products to meet the pending California regulatory requirements anticipated as a result of prior California legislation:

1. Substituting more fuel efficient vehicles: Bring in more efficient vehicles from global operations, while likely dropping existing domestic products.
2. Substituting powertrains: Add existing downsized engines (i.e. turbocharged versions, etc.) into California market-bound vehicles.
3. Powertrain enhancements: Add technology to current engine and transmission offerings to improve efficiency and reduce emissions.
4. Incorporating alternative powertrains into existing vehicle platforms: Develop a hybrid or other type of powertrain for an existing vehicle.
5. New powertrains and new platforms: Develop vehicles specifically intended to incorporate new powertrain technologies, materials and/or design (e.g. the General Motors EV1 or the Toyota Prius).

These five actions represent the gamut from the least complicated solution to the most complex. They also generally represent the least expensive response to the most expensive. It is possible that the least expensive responses may be least likely to meet market demands while achieving required GHG emission limits. At the same time, the most expensive option may produce a vehicle that satisfies the GHG reduction requirements and meets some consumer requirements, but is far too costly to manufacture and sell profitably. The response of a manufacturer would certainly have to take market size, consumer acceptance, technology implication and cost, as well as internal capacities and constraints, into consideration. It is important to understand that individual companies may respond differently in the short term. However, it is probable that there would be a more consistent industry-wide response in the longer term.

Options 1 and 2 present the simplest responses. A company may reach into its global portfolio to deliver vehicles that are more fuel-efficient. These vehicles are usually much smaller and significantly less powerful than current U.S. offerings. Industry respondents indicated that such a strategy may be possible but would likely be met with less than positive reaction from the buying public. A general estimate for the cost to homologize a vehicle—that is, to prepare an existing vehicle for entry into the United States provided all business conditions were met (reasonable product, capacity availability, etc.), would be approximately $50 million. Assuming an estimated cost for homologation to meet U.S. standards of $50 million and a 20,000 vehicle per year sales volume in California, the company would then incur a $2,500 per-vehicle cost to bring them into the market. A manufacturer may also choose to incorporate a more efficient powertrain into a vehicle already sold in the market. The costs associated with such a strategy would include re-engineering the vehicle engine compartment to accept the new powertrain, and developing, engineering and manufacturing those parts unique to the vehicle. Costs would also be incurred to achieve emission certification. Total costs per vehicle, if sold only in California would be similar to nationally averaged costs per vehicle when bringing a new vehicle into the national market.

While companies may consider the importation of a more fuel-efficient vehicle from their current global portfolio, or the addition of a powertrain from another market, it is likely that these would be seen as stop-gap responses to the legislation. Many of the candidate vehicles and powertrains would likely not meet California consumer expectations, and may not provide enough fuel savings to achieve more severe emission regulations, thus offering only a step toward any solution.

Internal Combustion Engine Manufacturing Investment and Flexibility

A major concern for any manufacturer is uncertainty in future markets. In few areas of the automotive business is this more noticeable than the engine plant. Designed to take advantage of high-volume scale economies, engine facilities have evolved into highly efficient, but relatively inflexible, operations. Flexibility at engine plants has traditionally been limited to engines of similar cylinder number, with similar geometry. Thus, any rapid change in product mix (i.e., 4-cylinder, 6-cylinder, 8-cylinder, gasoline, diesel, etc. or even a change in head or block design) presents a threat to most manufacturers. By comparing three separate estimates, CAR was able to develop a reasonable target cost for investing in new tooling for an existing engine facility. We estimate the approximate cost to be $170 to $185 million dollars of investment for a six-cylinder V-configuration gasoline engine at a volume of 300,000 per year (production lost to downtime). Any change in engine configuration—or the inclusion of a low-volume version of an engine (as in the case of a 'high mileage' variant)—would present several cost hurdles. The addition or substitution of technologies to existing engine programs would likely require change to the manufacturing system, and thus additional cost.

Traditional engine head and block machining lines have used highly fixed transfer lines. The transfer line, while offering high-volume scale economies, requires significant re-work (possibly requiring as much as 24 months for changeover, including 6 months of tool design change preceding an actual down time as high as 18 months) for the addition of a new product. Increasingly manufacturers have been incorporating computer numerically controlled (CNC) machinery as a means to gain flexibility. CNC machines offer increased flexibility, but at a higher up-front investment cost. CAR estimates that it would require investment of between $675 million and $1.1 billion for the automotive industry to re-tool engine facilities to create a series of significantly more fuel efficient internal combustion engines in order to provide adequate reductions in carbon dioxide emissions.

The cost of product development must also be considered when investigating the costs of adaptation. While the cost of developing an engine program varies drastically, it is possible to make some assumptions based on published estimates. CAR estimates that the development cost of high volume 6-cylinder V configuration engine is approximately $69 per engine, and $333 per-unit cost for a low volume derivative.

Internal Combustion Engine Component Cost Modeling

CAR used an internally developed engine cost model to estimate component costs for this project. CAR has used the model for previous internal and external projects. It is intended to represent a stylized cost model for the complete vehicle, divided into basic systems. For this project, CAR used input from several sources to further tune the model. The model includes engine mechanical, fuel delivery, engine electrical and exhaust. The model assumes a single overhead cam engine configuration and is closely matched to the NAICS codes. These are stylized costs assuming a scale volume manufacturing scenario. This model does not attempt to capture the component development costs, nor other various overhead costs. Table 1 shows the cost estimates for each of the four engine modules as derived from the model.

Exec Sum Table 1 – Cost of Engine: Stylized Cost of ICE Engines; Inline 4, V6, Inline 6 Diesel (CIDI), and V8 Configurations

Engine Module as a Percent of Total	4-Cylinder SI Inline Configuration (dollars)	6-Cylinder SI V Configuration (dollars)	6-Cylinder *CIDI* Inline Configuration (dollars)	8-Cylinder SI V Configuration (dollars)
Engine Mechanicals	$816	$1,225	$1,932	$1,523
Fuel Delivery	$374	$509	$1,176	$609
Engine Electrical	$321	$452	$420	$479
Exhaust	$189	$264	$560	$276
Additional Exhaust Technology	N/A	N/A	$1,500	N/A
Total Stylized Cost	$1,700	$2,450	$5,588	$2,886

The after-treatment for diesel engines presents a great challenge for the industry. There was some belief by the sources that that lean NO_x catalysts or NO_x absorbers and selective catalytic reduction (SCR) are likely to be technologically viable methods of meeting Tier 2 Bin 5 for NO_x reduction. Yet, there was also strong concern expressed that these technologies were not yet able to meet high mileage durability standards, and may be too costly in their final form. Several companies are also focusing on selective catalytic reduction (SCR) technology for NO_x reduction. A common strategy for SCR is to periodically inject urea into the exhaust, thus neutralizing NO_x. However, this strategy relies on the user—the driver—to be responsible for assuring that there is adequate urea in the canister. Initially there was great doubt that the technology would be a viable option for the U.S. market. Many felt that the E.P.A. would only cautiously consider the implications of shifting responsibility from the manufacturer to the driver. However, given recent discussions with industry sources, SCR appears to be considered an increasingly viable option going forward.

Internal Combustion Engine Component Cost and Fuel Economy Estimates

An important element of any vehicle sales forecast for 2009 is whether or not the technology is likely to be used on those vehicles. Given lead time required by the automotive industry to incorporate new technology into their products, the technology choices for 2009 are relatively limited. This report will address (and attempt to quantify) possible near-term technologies, and also briefly investigate those technologies that appear to be possible long-term options. Through literature searches CAR collected a list of potential technologies that served as a foundation. CAR then discussed the technology options with more than 25 individuals (stakeholders from various segments of the industry).

The estimates for carbon dioxide reduction[1] and cost (Table 2) are presented as averages of the responses given by the experts. However, CAR wishes to include the 'it depends' variable in the discussion. That is, invariably, the experts would estimate a cost and efficiency gain for the technology and then comment that their response depended greatly on a wide variety of factors. Some of these variables were controllable—such as base engine, vehicle segment, etc. However, there were others that were far more qualitative. For example, there is a wide range of current expertise among companies in core engine engineering; it is possible for a top performer to get significantly better efficiency gains from a given technology than a company with lesser engineering expertise. Conversely, it is also possible that a poor performer may be able to get more out of a technology because there is, "room for improvement." Several panelists were impressed with (and generally accepted) recent reports that performed modeling on various vehicle segments. However, they indicated that much variance for a 'real world' application should still be expected. They also believed that variance may tend to be downward biased—that is, real world performance would be less than modeled.

---

[1] The respondents provided estimates of fuel economy benefits, which CAR converted in the report to carbon dioxide reduction estimates.

Exec Sum Table 2 – Gasoline Engine Technology

	Incremental Cost	CO_2 Emissions Reduction
Valvetrain Technologies		
Intake Cam Phasing	$85	4
Exhaust Cam Phasing	$90	2
Dual Equal Cam Phasing	$150	4
Mechanical Variable Valve Lift and Duration	$350	7
**Electromagnetic Actuation*	*$600*	*9*
**Electrohydraulic Actuation*	*$700*	*9*
Cylinder Deactivation	$150	7
Combustion Chamber		
Variable Compression Ratio	$350	5
GDI-Stoichiometric	$225	6
**GDI - Lean Burn Stratified Charge*	*$500*	*11*
**Gasoline HCCI*	*$700*	*12*
Transmission Technologies		
6-Speed Automatic Transmission	$100	6 percent
Continuously Variable Transmission (CVT)	$50	8 percent
**Automated Manual Transmission (5/6 sp)	-$140 to -$80**	6-7 percent over (A/T)

* These technologies were not expected to be viable for full market penetration until after 2015.
** These estimates represent the range from least expensive (SSC) to most expensive option (DC)

Hybrid Electric Technology

Currently two formats of hybrid, with several variations, are considered the likely candidates to gain market acceptance. Honda has chosen to use the integrated motor assist (IMA) layout for their initial entries, while Toyota and Ford offer products using Parallel-series HEV technology. For this report (specifically the 2009 forecast), CAR will only consider vehicles that use electric power for motive purposes. Thus, the General Motors Sierra and Silverado pick-up trucks are not considered for this report. CAR spent time discussing each of the systems with several industry sources. The general theme of their responses confirmed the belief that the IMA offered a more attractive cost hurdle, while the parallel systems might offer more efficiency. Those familiar with HEV design were strongly convinced of two things. First, they believed there is a wide range of performance and efficiency gains possible from both systems. Thus, the ability to 'tune' similar systems differently made it nearly impossible to rule out any efficiency estimates, nor confirm that there was any one best approach. In essence, what they said was that at this point there are too many variables to choose the one right path to hybridization. Second, many suggested that the modeling done to test these vehicles was not yet as precise as needed. The ability to predict real world performance is, for obvious reasons, not as advanced as that of the internal combustion engine. Several sources indicated that these challenges should not be viewed as reasons to forgo discussion on the subject, but instead to treat all results with great care.

Given those challenges, CAR attempted to gain insight into the cost of hybrid electric vehicle component technology. Most respondents were not able to present specific cost estimates, relying instead on likely cost ranges. Many of the sources indicated that there are numerous approaches to hybridization, thus creating vast differences in component performance requirements

Table 3 shows the range of component cost estimates for a 4-cylinder DOHC compact passenger car. It was assumed that the vehicle would achieve equivalent performance, with a 23 to 26 percent reduction in carbon dioxide emissions. We present these cost estimates with several caveats. First, the estimates were for an assumed volume of 100,000 components per year—levels that have yet to be achieved by any single manufacturer. Realistically, scale economies for such technologies will be achieved at much higher volumes—as one respondent noted; "The Auto supplier industry doesn't do anything in volumes of 100,000—and make money at it." Second, as indicated, all of the individuals interviewed were hesitant to discuss costs. All agreed there is great uncertainty regarding the cost structure. Finally, there are some who believe the initial current costs are significantly higher, and specifically with regard to batteries, may be difficult to reduce even with added volumes.

Exec Sum Table 3 – Cost Comparison
Parallel and Integrated Starter Layouts

Parallel	Component	Integrated Starter Generator
$1,800-$2,200	Battery (NiMH)	$1,500-$1,800
$600-$680	Inverter (power conditioning)	$500-$550
$850-$900	Power Control Unit	$600-$800
$500-$600	Electric Motor	$700-$800
$350-$500	Generator	Not applicable
$50-$100	Transaxle/power conversion*	Not applicable
$4,150-$4,890	Total Target Cost	$3,300-$3,950
*Increase over replaced transaxle		

Finally, it has been common to assume that a portion of the added cost of hybrid technology would be offset by the use of a smaller engine. For such cost adjustment, one could use engine cost estimates presented earlier in this report to estimate a cost savings. However, at least three recent HEV entries have used the same—or even more complex engines than their non hybridized variant—thus eliminating any cost benefits from engine downsizing—but offering performance improvements.

2009 U.S. and California Market Segmentation Forecast

The Center for Automotive Research acquired (through a partnership with R.L. Polk) U.S. and California vehicle registration data for the years 1999-2003. All passenger cars and the portion of LTD1s equal to or less than 3750 lbs. (loaded vehicle weight) were grouped together (hereafter referred to as PCLDT1). All LDT2s and the portion of LDT1s 3751 lbs. and greater were also grouped together (LDT2).[2] The LDT2 also

---

[2] The vehicle weights were taken from Wards 2003 Annual Report. There are a number of vehicles counted that were discontinued before 2003. For these vehicles, the appropriate yearbook was used. There were several models (such as the Chevrolet Colorado) which had trim levels both above and below the 3750 mark. Since trim level is not found in the Polk data we differentiated by drivetrain (i.e. the heavier 4x4 models were separated from the lighter 2x4 models). CAR also made some alterations to Conversion

includes vehicles with a GVRW of over 8,500 lbs., but a less than 10,000 loaded vehicle weight. Once vehicles were segmented into PCLDT1 and LDT2, CAR then separated the data by transverse (FWD) and longitudinal (RWD), and then two-wheel-drive (2WD), all-wheel-drive (AWD), and four-wheel-drive (4WD). The data was further divided by cylinders (3 and 4, 5 and 6, 8, and 10 and 12 cylinders), and fuel/powertrain type (gasoline, diesel, HEV, etc.).

The orientation of the engine is essential to the differentiation of FWD/RWD vehicles. The transverse mounted engine is the predominant orientation of FWD, while RWD vehicles have longitudinally mounted engines. This engine orientation is important because it is a possible differentiator for hybrid drivetrain component technology. Those vehicles offered only in AWD were placed into FWD or RWD depending on engine orientation.

Finally, it is important to note that the California data was included in the total U.S. data to represent the current light vehicle market—that is, a representation of current national market segmentation. This was done to compare the status quo, with the California market as a unique entity.

The data shows the U.S. market has seen an increase in LDT2s as a percent of the total market during the years 1999 through 2003. The California market has seen a similar—if not more pronounced—shift during the same period. It is important to note that this change represents a significant continued shift in consumer vehicle preference that has taken place for over a decade, and has greatly affected vehicle fuel economy and concomitant emissions. However, there are some indications that the 'light-duty truck boom' of the last decade may be quickly fading. The State of California represented approximately 11.1 percent of the U.S. light duty vehicle market in 1999. However, that percentage grew to 12.1 percent by 2003. Importantly, the California market represents a somewhat different vehicle mix than the overall U.S. market. The California market includes a higher percentage of PCLDT1, and, a smaller percent of LDT2s weighing 3751 pounds (loaded weight) or greater.

CAR relied on two prominent industry forecasts to estimate total sales for 2009. These two estimates were averaged to present a consensus forecast of vehicle sales. It is important to note that the R.L. Polk data used to estimate market segmentation was derived from registration; the consensus vehicle forecast for 2009 is presented as vehicle sales. There were instances were registrations did not necessarily match with reported sales. For example, the Polk data somewhat under-represents *reported* hybrid sales for the time period covered by the registration period. However, it is generally agreed that registrations represent a strong proxy for sales. Thus, CAR believes that basing the sales forecast on registration data presents a reasonable solution.

CAR used a logit model to create a forecast for the California and U.S. markets and the split between longitudinal and transverse drivetrains for the years 2004 through 2009. Tables 4 – 6 show the forecast for the 2004-2009 model years for total sales, and longitudinal and transverse drivetrains for the U.S. and California markets. The model forecasts further growth of the California market as a percent of the total U.S. market (12.1 percent in 2004 to 12.3 percent in 2009). Although this rate of change is less than

---

vehicles (i.e. those vehicles that were designed to be converted to run off CNG). These were divided as "gasoline" or "natural gas" powered vehicles per CAR's estimates of vehicles actually converted.

in the period during which the historical data was examined, it is important to note that California as a percent of U.S. registrations actually decreased from 2002 (12.3) to 2003 (12.1). California has a lower proportion of LDT2s than the U.S. as a whole. The model forecasts a shift from PCLDT1 to LDT2s during the period. By 2009, the model estimates that 50.9 percent of California and 53.1 percent U.S. vehicles sales will be LDT2s as defined here. These are up from 2004 values of 42.8 and 46.8% respectively.

Exec Sum Table 4 – Total PCLDT1 and LDT2 Sales Forecast 2004-2009 Results (in units)

	Total Market		PCLDT1		LDT2	
Year	**California**	**U.S.**	**California**	**U.S.**	**California**	**U.S.**
2004	2,050,950	16,925,000	1,173,557	9,007,272	877,393	7,917,728
2005	2,075,150	17,150,000	1,161,515	8,909,846	913,635	8,240,154
2006	2,105,400	17,400,000	1,152020	8,818,956	953,379	8,581,044
2007	2,159,400	17,700,000	1,154,333	8,746,274	1,005,066	8,953,726
2008	2,171,600	17,800,000	1,133,371	8,569,819	1,038,229	9,230,181
2009	2,201,700	17,850,000	1,121,152	8,367,815	1,080,547	9,482,185

The PCLDT1 segment is forecast to have a slight decrease in longitudinal—or rear-wheel-drive share. Although some manufactures are returning a portion of their portfolio to rear-wheel-drive layout, we also expect to see an increase in front-wheel-drive cross-over vehicles. However, it various parties within the industry believe that technology development (i.e. traction and stability control) will be capable of offsetting the traditionally poor bad-weather handling characteristics of rear-wheel-drive vehicles, which could change this forecast.

Exec Sum Table 5 – PCLDT1: Transverse and Longitudinal Sales Forecast 2004-2009 Results (in units)

	California		U.S.	
Year	**Transverse**	**Longitudinal**	**Transverse**	**Longitudinal**
2004	899,425	274,132	7,204,211	1,803,062
2005	896,337	265,178	7,168,376	1,741,470
2006	895,004	257,017	7,136,162	1,682,794
2007	902,708	251,626	7,117,182	1,629,092
2008	892,018	241,353	7,011,902	1,557,917
2009	887,948	233,205	6,883,323	1,484,492

Exec Sum Table 6 – LDT2 Transverse and Longitudinal Sales Forecast 2004-2009 Results (in units)

	California		U.S.	
Year	**Transverse**	**Longitudinal**	**Transverse**	**Longitudinal**
2004	208,351	669,042	1,880,190	6,037,537
2005	227,251	686,383	2,049,601	6,190,552
2006	248,215	705,164	2,234,100	6,346,943
2007	273,698	731,368	2,438,266	6,515,460
2008	295,503	742,726	2,627,118	6,603,063
2009	321,198	759,349	2,818,630	6,663,555

In contrast to the PCLDT1 segment, CAR forecasts transverse drivetrains to see an increased percentage of the LDT2 segment. This increase is driven by the rapid introduction in recent years of car-based utility vehicles, or CUVs. These vehicles have begun to take share from the traditional rear-wheel drive sport utility segment. Given future product plans, it is highly likely the CUV segment will be a growth segment in the coming years, it is reasonable to expect this trend to continue for several years.

CAR used the results of the Logit model as the basis for the final forecast. However, because the model used only five years of historical data, it failed to realistically predict future sales when applied to several individual powertrain options. Therefore, CAR applied the logit model to the split between PCLDT1 and LDT2, and to transverse and longitudinal drivetrains within the PCLDT1 and LDT2 segments. Using those results, CAR then applied linear regression to each of the powertrain segments, and made use of regression models in most cases to construct forecasts. When regression results were inconclusive, illogical, or not applicable to a powertrain type, CAR staff judgment was used. Selected segments are presented in Table 7. Full results are presented in appendix IV.

Exec Sum Table 7 – 2009 Forecast: Selected Segments

	U.S.		California	
	1999	2009	1999	2009
PCLDT1 Transverse				
FWD/3-4cyl/Gas	52.8%	53.8%	60.4%	55.8%
FWD/5-6cyl/Gas	42.1%	27.6%	35.5%	19.9%
FWD/6cyl/Flex	0.1%	0.9%	0.0%	0.9%
FWD/4cyl/Diesel	0.2%	0.3%	0.1%	0.8%
FWD/3-4cyl/Gas-Elec HEV	0.0%	6.0%	0.0%	12.0%
FWD5/6Gas-Elec HEV	N/A	1.6%	N/A	2.0%
AWD and 4WD, 4-8 cyl.	2.2%	9.2%	2.1%	8.5%
Share represented	97.4%	99.4%	98.1%	99.7%
LDT2 Transverse				
FWD/3-4cyl/Gas	4.9%	2.8%	6.9%	2.8%
FWD/5-6cyl/Gas	73.4%	44.7%	84.8%	44.7%
FWD/6cyl/Flex	16.7%	5.0%	0.3%	5.0%
Diesel (any)	0.0%	0.0%	0.0%	0.0%
4WD & FWD//3-4cyl/Gas-Elec HEV	NA	6.0%	NA	6.0%
4WD & FWD5/6Gas-Elec HEV	NA	6.0%	NA	6.0%
AWD+4WD/4 cyl./Gas	0.0%	4.9%	0.0%	4.9%
AWD 5-6cyl/Gas	5.1%	15.0%	8.0%	15.0%
4WD+FWD 5-6cyl/Gas	0%	15.6%	0%	15.6%
Share represented	100.1%	100.0%	100%	100.0%
PCLDT1 Longitudinal				
RWD/4cyl/Gas	19.9%	11.6%	21.2%	13.0%
RWD/5-6cyl/Gas	25.1%	41.0%	37.7%	53.1%
RWD/8cyl/Gas	25.8%	25.8%	23.3%	20.0%
RWD/4-6 cyl. flex	5.9%	2.0%	6.5%	0.2%
RWD/6cyl/Diesel	0.2%	0.3%	0.1%	0.2%
HEV (any)	0.0%	0.0%	0.0%	0.0%
AWD + 4WD 4-6 cyl.	22.9%	15.7%	10.8%	8.8%
AWD + 4WD 8-12 cyl.	0.1%	2.8%	0.1%	1.8%
Share represented	99.9%	99.2%	99.7%	97.1%
LDT2 Longitudinal				
RWD/4cyl/Gas	1.5%	0.1%	3.1%	0.2%
RWD/6cyl/Gas	17.8%	11.6%	25.8%	13.5%
RWD/8-10cyl/Gas	22.6%	19.6%	31.1%	38.9%
All/6&8cyl/Flex	1.2%	6.8%	0.5%	3.2%
All 4-6 cyl./Diesel	1.1%	3.2%	1.0%	1.3%
RWD/8cyl/Diesel	1.4%	1.5%	1.2%	1.3%
4WD/8cyl/Diesel	2.5%	7.4%	1.4%	5.5%
AWD+4WD/4-6cyl/Gas	21.2%	19.3%	14.0%	11.4%
AWD+4WD/8-10cyl/Gas	30.7%	29.4%	21.8%	22.4%
4WD/8cyl/HEV/Gas	NA	1.0%	NA	2.0%
Share represented	100.0%	99.9%	99.9%	99.7%

There were segments that were not realistically modeled by the linear regressions. For these segments, CAR relied upon its knowledge of industry trends and future product plans to ‘tune the results’ and better indicate likely future sales trends. The changes (and the explanation for those changes) to the linear regression models can be found in Appendix V.

CAR believes this forecast represents a reasonable estimate of the 2009 U.S. and California markets. However, it is important to note that, as with any prediction, there are many variables that can affect the actual numbers. With regard to powertrain technology, this is one of the most uncertain times since the early years of the industry.

Currently, the automotive industry is struggling to understand the developing advanced powertrain paradigm. There are several competing technologies that may offer increased fuel efficiency and reduced emissions—albeit at an increased cost. The hybrid electric vehicle presents opportunity for significant decreases in carbon dioxide emissions when driven in congested areas; but may not deliver similar gains when used in less congested areas; and may suffer from poor battery performance in cold weather climates. Conversely, the diesel engine offers potential efficiency gains over the current spark-ignited gasoline engine (and maybe the HEV in some driving cycles) but suffers from cost and emissions challenges. The spark-ignited gasoline engine may also offer increased efficiency but at a cost. It is wholly possible that each of these powertrains could gain acceptance. It is also possible—although unlikely—that each of these technologies could fail to meet consumer requirements, and vanish from the marketplace in the coming years.

In addition to technological uncertainty, we must consider the ongoing public policy discussions regarding fuel economy and vehicle emissions. To complete this model, CAR has made several assumptions regarding technology and policy issues. We believe these assumptions to be reasonable—albeit, highly debatable. The following is a review of market factors we believe add increased variability to the powertrain segmentation.

1. Hybrid Technology: The CAR forecast calls for what we would describe as a strong growth in hybrid penetration. However, there will most certainly be critics that the market will be either significantly lower—or higher—than the CAR estimates. Although there are indications that hybrid technology is becoming a viable option for a portion of the light vehicle market, the extent and duration of that market is still uncertain. Cost will remain an issue; appropriateness for the driving cycle of several segments is also uncertain. CAR relied on announced plans and discussions with various industry sources to develop an estimate for HEV penetration for 2009.

We believe, given our cost and efficiency gains estimates and a reasonable continuation current fuel prices, the HEV will not be an economically attractive choice within the forecast timeframe. Thus, the forecast for HEVs may seem strangely optimistic. We suggest that the technology may be enticing to some consumers for reasons other than fuel savings. It is likely that there are an increasing number of purchasers that value environmental status offered by the purchase of such technology. It is very difficult to estimate the size of this market.

2. Diesel Technology: The forecast calls for a modest increase in diesel application in PCLDT1 and a slightly more aggressive increase in LDT2 (although some of the growth

in trucks is due to the inclusion of GVW over 8,500 lbs.). Most experts interviewed by CAR believed there will be positive resolution regarding the environmental acceptability (i.e. at a minimum, the ability to meet Tier 2 Bin 5) of the diesel engine within the next five years. The diesel engine, especially diesel after-treatment technology, represents a variable which could be considered highly uncertain. As such, developments in diesel technology could change the forecast markedly.

3. All-Wheel-Drive in the Passenger Car Market: While this technology does not present the high visibility of the other technology choices, it does present unique difficulty in forecasting. Several manufacturers have recently, or will soon, introduce all-wheel-drive as an option on high-volume models. Many of these vehicles are being positioned as an alternative to the perceived safety advantages offered by all-wheel-drive SUV and CUV offerings. However, some of these all-wheel-drive vehicles are being positioned as performance vehicles. This has important implications for the California market, where the poor weather performance attributes of all-wheel-drive are not a strong market driver, but where a higher mix of performance type rear-wheel-drive passenger cars are sold.

4. Flex Fuel Vehicles: The inclusion of flex fuel vehicles in the forecast presents opportunity for a significant amount of variability. The offering of a flex fuel option is highly variable and is often driven by many factors including, but not limited to, government encouragement, corporate policy and emissions, and even corporate public relations. The conversion of an existing gasoline engine to a flex fuel capable engine is a *relatively* low cost[3] method of gaining credits toward emission standards, or even gaining public relations benefits. Therefore it is difficult to forecast the total number of products available to the market—and even more difficult to estimate by powertrain segment. CAR has been very cautious with the forecast for flex fuel or other alternative fueled vehicles (note that CNG and propane were significant enough to be included only in LDT2 longitudinal segment). This caution should not be read as doubt for the given technologies. Their benefits and costs are rather well understood. Instead, it can be attributed to the fact that these technologies are driven by policy, and do not necessarily reflect a 'normal' business strategy. The Alternative Motor Fuel Act of 1988 (and its recent extension) will assure that the manufacturers continue to consider flex-fuel and dedicated alternative fuel vehicles. At least one Midwest state continues to contemplate legislation that would require increased availability of ethanol capable vehicles. Conversely, other states have indicated some concern as to the actual number of flex fueled vehicles that ever use alternative fuels.

---

[3] Manufacturers will understandably have difficulties with the term 'relatively' low cost. However, their actions suggest that the use of flex fuel vehicles to gain emission credits is at least to some extent, a cost effective measure.