FUTURE POTENTIAL OF HYBRID AND DIESEL POWERTRAINS IN THE U.S. LIGHT-DUTY VEHICLE MARKET

David L. Greene
Oak Ridge National Laboratory
National Transportation Research Center
2360 Cherahala Boulevard
Knoxville, TN 37932

K.G. Duleep
Energy & Environmental Analysis, Inc.
1655 North Fort Meyer Drive, Suite 600
Arlington, VA 22209

Walter McManus
J.D. Power and Associates
5435 Corp Drive, Suite 300
Troy, MI 48098

July 30, 2004

Prepared by the
OAK RIDGE NATIONAL LABORATORY
P.O. BOX 2008
Oak Ridge, Tennessee 37830
managed by
UT-Battelle, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract No. DE-AC0500OR22725

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

ABSTRACT

Diesel and hybrid technologies each have the potential to increase light-duty vehicle fuel economy by a third or more without loss of performance, yet these technologies have typically been excluded from technical assessments of fuel economy potential on the grounds that hybrids are too expensive and diesels cannot meet Tier 2 emissions standards. Recently, hybrid costs have come down and the few hybrid makes available are selling well. Diesels have made great strides in reducing particulate and nitrogen oxide emissions, and are likely though not certain to meet future standards. In light of these developments, this study takes a detailed look at the market potential of these two powertrain technologies and their possible impacts on light-duty vehicle fuel economy. A nested multinomial logit model of vehicle choice was calibrated to 2002 model year sales of 930 makes, models and engine-transmission configurations. Based on an assessment of the status and outlook for the two technologies, market shares were predicted for 2008, 2012 and beyond, assuming no additional increase in fuel economy standards or other new policy initiatives. Current tax incentives for hybrids are assumed to be phased out by 2008. Given announced and likely introductions by 2008, hybrids could capture 4-7% and diesels 2-4% of the light-duty market. Based on our best guesses for further introductions, these shares could increase to 20% for hybrids and 10% for diesels by 2012. The resulting impacts on fleet average fuel economy would be about +2% in 2008 and +6% in 2012. If diesels and hybrids were widely available across vehicle classes, makes and models could capture 40% or more of the light-duty vehicle market.

1. INTRODUCTION

Direct-injection diesel engines and hybrid-electric power trains can significantly increase fuel economy without sacrificing attributes consumers value, but at a higher cost. At present, only a few makes and models offer these power train options and there is considerable uncertainty about their future in the U.S. light-duty vehicle market. This study assesses the future market potential of these technologies in competition with conventional gasoline power trains, and their potential impact on light-duty vehicle fuel economy. Estimates are developed of the market potential for these technologies in competition with the conventional gasoline internal combustion engines that dominate the U.S. market today.

Diesel and hybrid technologies each have the potential to increase any given light-duty vehicle's fuel economy by a third or more without loss of performance, yet these technologies have typically been excluded from technical assessments of fuel economy potential on the grounds that hybrids are too expensive and diesels cannot meet Tier 2 emissions standards (NRC, 2002). However, hybrid vehicles are already present in the automotive marketplace and are selling well; sales increased 26% from 2002 to 2003 despite the availability of only three hybrid models (CNN, May 17, 2004). In Europe, sales of modern, direct-injection, high-pressure-injection diesel cars comprised 44% of 2003 passenger car sales (Schmidt, 2004). Yet only one manufacturer offers light-duty diesels in the United States today and captures about 0.2% of the market. Diesels have achieved significant reductions particulate and nitrogen oxide emissions in recent years and appear to be poised to meet Tier 2 emissions standards for at least bin 8 and very likely bin 5 (Duleep, 2004).

Honda introduced the first hybrid vehicle into the U.S. market in 1999, the two-seater Honda Insight. Toyota followed with the Prius in 2000, a vehicle they had introduced into the Japanese market in 1997. Hybrid sales in the U.S. reached 38,000 units in 2002 (J.D. Power, 2003) and increased to 43,500 units in 2003 and from January to April 2004 23,000 hybrids were sold (Miller, 2004). Response to the redesigned model year 2004 Prius was especially strong: more than 12,000 purchase requests were made before the model was introduced in October 2003 (Toyota, 2004). As a result, Toyota raised its production plan for the U.S. from 36,000 to 47,000 units (Toyota, 2003). With demand for hybrids spurred on by higher fuel prices in 2004, manufacturers have been unable to keep pace with demand and waiting lists for hybrids have lengthened.

The potential impact of hybrid technology on light-duty vehicle fuel economy if all vehicles were converted to hybrids was assessed by Burke and Abeles (2004). They estimated that if all light-duty vehicles were mild hybrids, fleet average fuel economy would increase to 38 miles per gallon (mpg), at a cost increase of 7-9%. If all were full hybrids 42 mpg could be achieved for a price increase of 16-18%. Their study did not address the market acceptance of hybrid technology, however.

In light of the fact that both technologies are present in the U.S. light-duty vehicle market today and are selling well, albeit with very limited product availability, it is no longer reasonable to assume that these technologies will play no role in determining future light-duty vehicle fuel economy. This study assesses the market potentials of hybrid and diesel technologies in the U.S. light-duty vehicle market, as well as their likely impacts on the fleet average fuel economy of new light-duty vehicles. The impacts on fuel economy are based on estimated consumer demand for these technologies, with no subsidies or further increases in fuel economy standards.

The estimated market potentials and fuel economy impacts assume no new policies to drive the market toward high fuel economy vehicles, such as higher CAFE standards or tax incentives for hybrid vehicles. Indeed, the existing federal tax incentives for hybrid vehicles are assumed to expire, as planned, before 2008. No significant technological advances are assumed for any of the technologies except for those needed to control diesel NO_X emissions to Tier 2, bin 5 levels. Economies of scale and learning-by-doing in the production of hybrid vehicles and emissions control systems for diesels are also assumed. Finally, the analysis is based on the mix of vehicles sold in the United States in model year 2002 and their attributes. No attempt has been made to project how consumers preferences or manufacturers offerings may change over the next 5-10 years, except for the introductions of new hybrid and diesel powertrains.

The following section briefly reviews the status and prospects for the cost and performance of diesel and hybrid technologies. In Section 3, previous projections of hybrid and diesel market shares are reviewed. In Section 4, the data and methods used to assess future market potential are presented. Readers less interested in mathematical details may wish to skim this section. In Section 5, results are presented for eight scenarios to 2012 and beyond.

2. HYBRID AND DIESEL TECHNOLOGY STATUS AND PROSPECTS

Although hybrid and diesel vehicles already have a limited presence in the North American light-duty vehicle market, they both face challenges to their future market success. Diesels must find a way to meet future Tier 2 emissions standards at the bin 5 level if they are to capture more than a niche market in the United States. Both hybrids and diesels face the challenge of consumer acceptance of their higher costs. In this section the status and outlook for these technologies are briefly reviewed, and our assumptions about future attributes are presented. The review draws heavily on in-depth reviews of the status of these technologies (Duleep, 2003; 2004).

2.1 DIESELS

Turbo-charged, direct-injection, high-pressure common rail, light-duty diesel engines are a well established technology that captured 43% of the European passenger car market in model year 2003 (Schmidt's, 2004). While higher motor fuel prices in Europe are clearly part of the explanation for the diesel's success there, there is also no doubt that car buyers consider the modern diesel an acceptable alternative to the gasoline engine despite its higher price. Diesels have other advantages and disadvantages than simply fuel economy and cost that will affect their success in the North American market. Advantages such as greater driving range and higher torque may allow the diesel to capture a significant share of the North American market despite lower fuel costs.

2.1.1 Diesel Advantages

The diesel's much higher compression ratio, lean burn operation and direct injection make it not only more energy efficient but more powerful than a spark-ignition gasoline engine of the same displacement. In addition, diesel fuel contains about 10% more energy by volume than gasoline, a fact that further increases the diesel's advantage in miles per gallon. Manufacturers are unlikely to try to downsize diesels to fully match the performance of a comparable gasoline engine vehicle. In our judgment, manufacturers will design diesel vehicles with not only higher fuel economy but also increased torque. Table 1 shows by calendar year the increases in fuel economy and torque we assume diesels will offer relative to a comparable gasoline vehicle. Tighter emissions standards account for the decrease in the diesel's fuel economy benefit from 2005 to 2008. Improved technology is assumed to restore most of the emissions penalty by 2012.

Table 1. Estimated Additional Torque and Fuel Economy of Light-Duty Diesel Vehicles

	Torque	MPG
2005	25%	35%
2008	25%	30%
2012	25%	33%

For a given make and model of vehicle, manufacturers are likely to offer the same size of fuel tank on gasoline and diesel versions. This implies that diesels will provide 30-35% greater range, an added plus. In a 2002 survey by J.D. Power and Associates (McManus, 2003), 32% of respondents rated driving range as "extremely important" (8-10 on a scale of 1 to 10). Of those citing range as extremely important, 73% gave "have to refuel less frequently" as a key concern, while 44% cited "saves time." This suggests that there is nuisance cost of refueling over and above the value of the time saved. Indeed, 27% said they simply "don't like to refuel." In the quantitative modeling presented below, only the value of time saved and not the avoided nuisance cost of refueling is considered, implying that we have most likely underestimated the value of greater range to consumers.

2.1.2 Market Barriers

Diesel fuel availability is a concern of many motorists. In a 2002 survey by J.D. Power and Associates (McManus, 2003), 46% cited limited diesel fuel availability as a concern for clean diesels. In a more recent survey (Caravan, 2004), only 35% of respondents said diesel fuel availability would be of no concern if they were considering buying a diesel vehicle (Figure 1). Another 20.8% considered it somewhat of a problem, but not a big deal, while another 8.2% viewed it as a problem, but not one that would prevent them from buying a diesel. On the other hand, only 27% said it was a serious enough problem that they either might not (7%) or would not (21%) buy a diesel because of it. In total, almost two thirds of respondents did not consider fuel availability a show stopper for diesels.

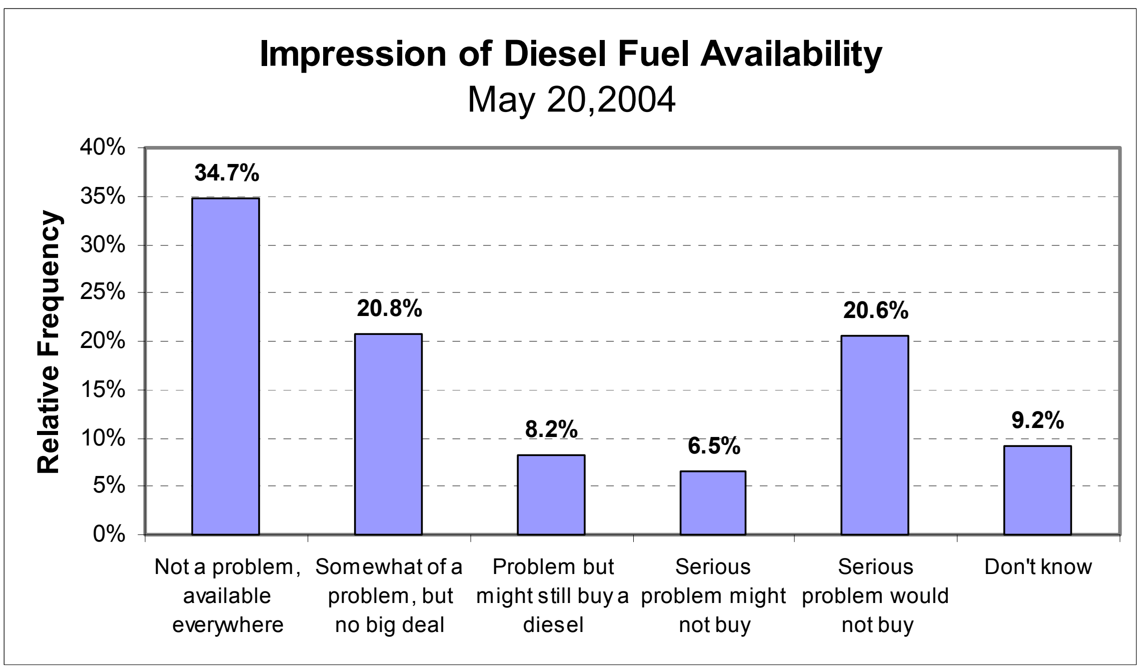

Figure 1. The Public's Impression of Diesel Fuel Availability in May, 2004

Owners of gasoline vehicles generally still believe that diesels are noisy, smelly and underpowered relative to gasoline vehicles. In the 2002 J.D. Power survey, 32% cited engine noise as a concern, and 27% cited exhaust odor. Thirty-one percent indicated lower performance was a concern. In large part, this is due to unfamiliarity with modern diesel technology. Compared with 1988 diesel technology, modern diesels have 100% more torque, 60% less noise, 90% lower emissions and 30% less fuel consumption (Birch, 2003). Modern diesels are not noisier than gasoline engines, do not produce a diesel odor, and accelerate as well as comparable gasoline vehicles. This suggests that many of the negative perceptions about diesels held by car buyers could be overcome with advertising and greater exposure to modern diesel vehicles.

Two of the top three concerns emerging from the 2002 J.D. Power survey were the availability of service and repair locations, and the fact that the type of vehicle a car buyer wanted might not be available as a diesel. Both of these concerns would be addressed if more manufacturers offered diesels on more makes and models. Thus, a key question is whether diesels could significantly increase their market share even with the current level of fuel availability and limited product offerings, i.e., can the diesel solve its "chicken or egg" problem on its own?

Surveys of owners of gasoline vehicles and diesel vehicles conducted by J.D. Power and Associates (McManus, 2004) reveal two key insights about the potential market for diesel vehicles. First, diesel vehicle owners have strongly positive perceptions of diesel vehicles, except for their higher price (Figure 2). Second, owners of gasoline vehicles have generally positive perceptions of diesel vehicles, but they are more negative than those of the owners of diesel vehicles (Figure 3). Diesel owners perceive their vehicles to be much more reliable, powerful, and fuel efficient than gasoline vehicles. They see them as cleaner and having about equal acceleration performance. More than half, however, consider the price of a diesel to be "worse." More than half of gasoline vehicle owners believe diesels are more powerful and (surprisingly) cleaner; about three quarters consider them to be more fuel efficient. But they view diesels as about equally reliable, slower, and more expensive. Because the vast majority of gasoline owners are unfamiliar with diesels, it is likely that their perceptions would improve with greater exposure to diesels. These insights suggest that diesels are potentially a mass-market technology in the United States, provided that their price can be held at an acceptable level.

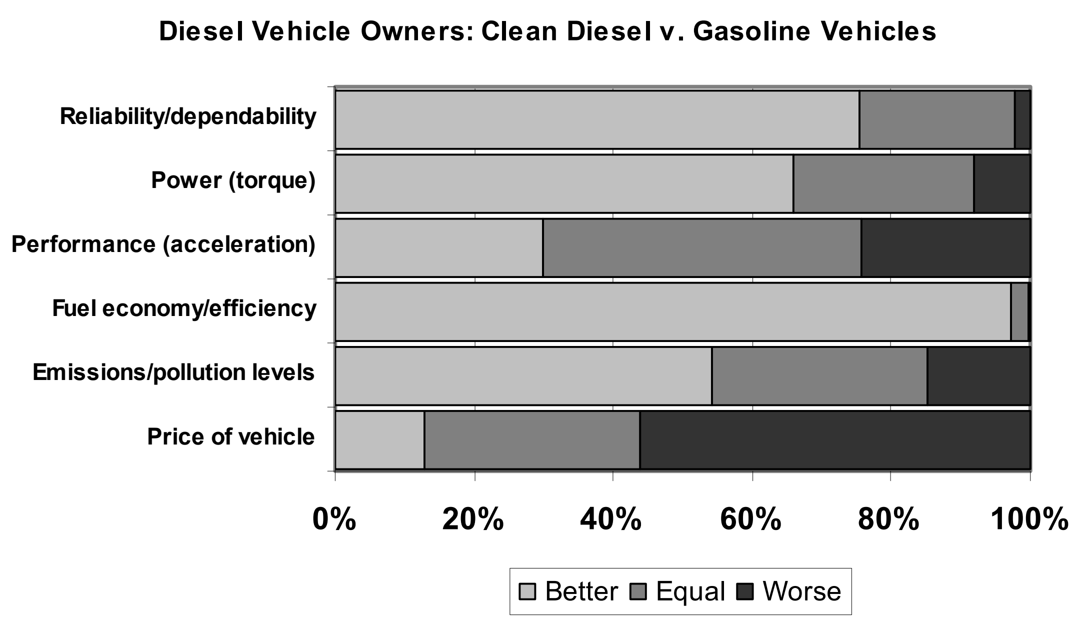

Figure 2. Diesel Vehicle Owners' Views on Clean Diesel Vehicles

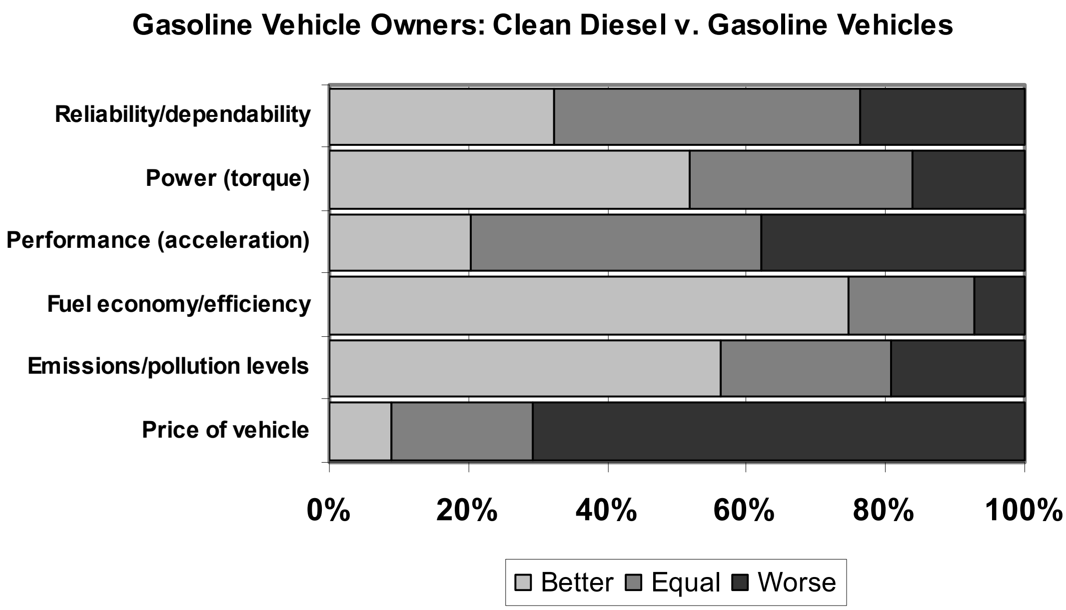

Figure 3. Gasoline Vehicle Owners' Views on Clean Diesel Vehicles

Undoubtedly the most significant downside of the diesel in the eyes of the consumer is its higher price. Diesels are more costly to manufacture chiefly because of their much higher pressure fuel injection systems and what we project will be far costlier emissions control systems. The estimates shown in Table 2 reflect the view that meeting Tier II bin 5 standards will add $550 to the retail price of a small diesel vehicles and $750 to the price of a larger one. The retail price equivalent (RPE) measures used throughout this report reflect a full mark-up over manufacturing costs, including all normal overheads and profits.

Table 2. Estimated Incremental Retail Price Equivalent for Diesel Engines

	Small Vehicle (2.0-2.5L I4)	Midsize Vehicle (3.0-3.5L V6)	Large Vehicle (4.5-5.0L V6)
2005	$1,750	$2,300	$2,500
2008	$2,280	$2,925	$3,200
2012	$2,300	$2,950	$3,250

We assume that diesels will have no greater durability than spark-ignition gasoline engines. We also assume that diesels will continue to have limited fuel availability, which we put at 33% of refueling outlets through 2008 (Hadder, 2004). However, with a larger number of light-duty diesel vehicles on the road, it is reasonable to assume that fuel availability will increase. The sensitivity of future market shares to this assumption was tested, however.

2.2 HYBRIDS

Hybrid vehicle designs can span a spectrum from 12-volt stop-start systems to over 300-volt systems with a substantial range of all-electric drive. In addition, for any given level of electric power capability, manufacturers may choose to emphasize fuel economy or performance. Discussions with manufacturers and review of their product plans indicate that the carmakers have divergent views about the desirability of the different design options and their potentials for market success (Duleep, 2003). On the one hand, this will lead to a broad array of designs tested in the marketplace. On the other hand, it will take more time to sort out the winners and losers. Details of our assessment can be found in EEA, Inc. (Duleep, 2004).

It is assumed that all manufacturers face the same costs and can achieve the same technology performance. While it is clear that this is not the case today, it is our view that competition will drive the market in this direction in the future. The key assumptions about vehicle attributes used in this market analysis are given below. Assumed market introductions are listed in the appendix.

Four types of hybrid systems are used in this assessment.

1. **Stop/Start (S/S)**: This hybrid system includes only the ability to shut off the engine when it would otherwise idle and to restart it instantly on demand. This provides no torque boost to aid acceleration, but offers a fuel economy advantage of 7.5% over the EPA test cycle.
2. **Integrated Starter Alternator with Damping (ISAD)**: This hybrid system will operate at 42 volts and will allow some power to be contributed by the electric drive system in addition to the stop/start capability.
3. **Integrated Motor Assist (IMA)**: This 114 volt hybrid system is expected to be produced only by Honda through 2012. In comparison to the ISAD design it has a larger electric motor and greater battery power and energy storage and allows more electricity to be used for motive power.
4. **Full Hybrid (FH)**: These 300+ volt systems permit limited all-electric drive in addition to supplementing the power of the internal combustion engine.

2.2.1 Hybrid Advantages

Surveys show that consumers think of fuel economy (mentioned by 78%) and low pollution (54%) when they think of hybrid vehicles (McManus, 2003). Apparently because of early hybrid designs, they do not think of increased performance. Even owners of conventional gasoline vehicles see hybrids as exceptional when it comes to fuel economy and emissions (Figure 4), according to survey data developed by J.D. Power and Associates (McManus, 2004). But when it comes to acceleration performance and power, most gasoline vehicle owners believe hybrids are inferior to gasoline vehicles. Gasoline vehicle owners also give hybrids low grades for reliability, and they believe they are much worse when it comes to price.

Owners of hybrid vehicles have very different opinions about their vehicles (Figure 5). Not only do they consider them to be entirely superior when it comes to fuel economy and air pollution, but they perceive the hybrid's performance and power to be just as good as that of a conventional gasoline vehicle and they give hybrids better marks for reliability. Even hybrid owners, however, see hybrids as more expensive.

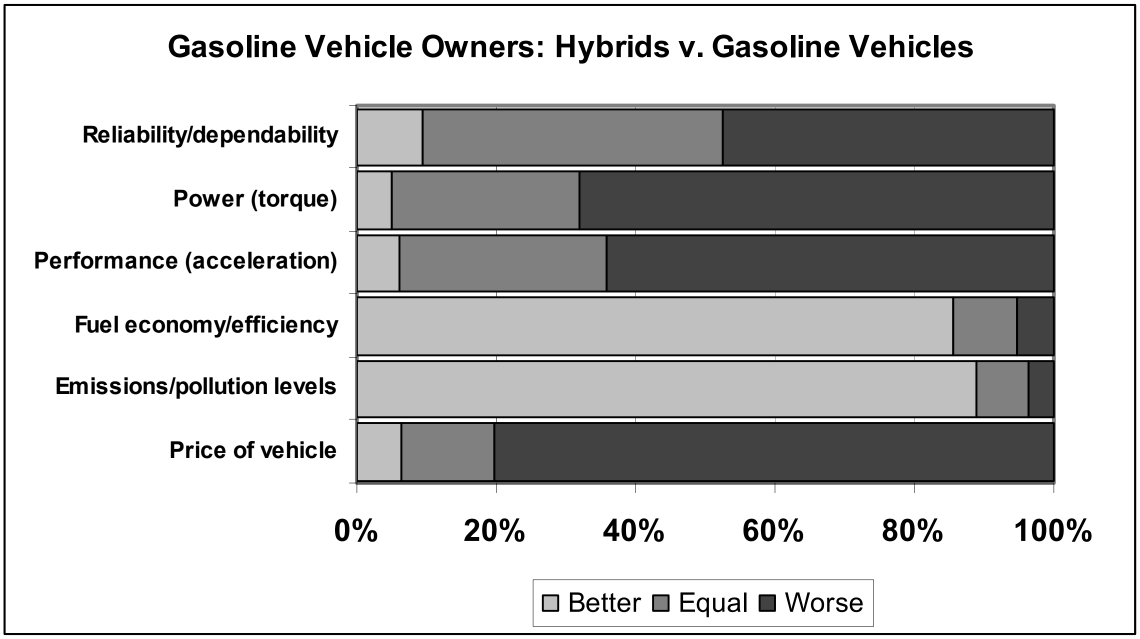

Figure 4. Gasoline Vehicle Owners' Views on Hybrid-Electric Vehicles

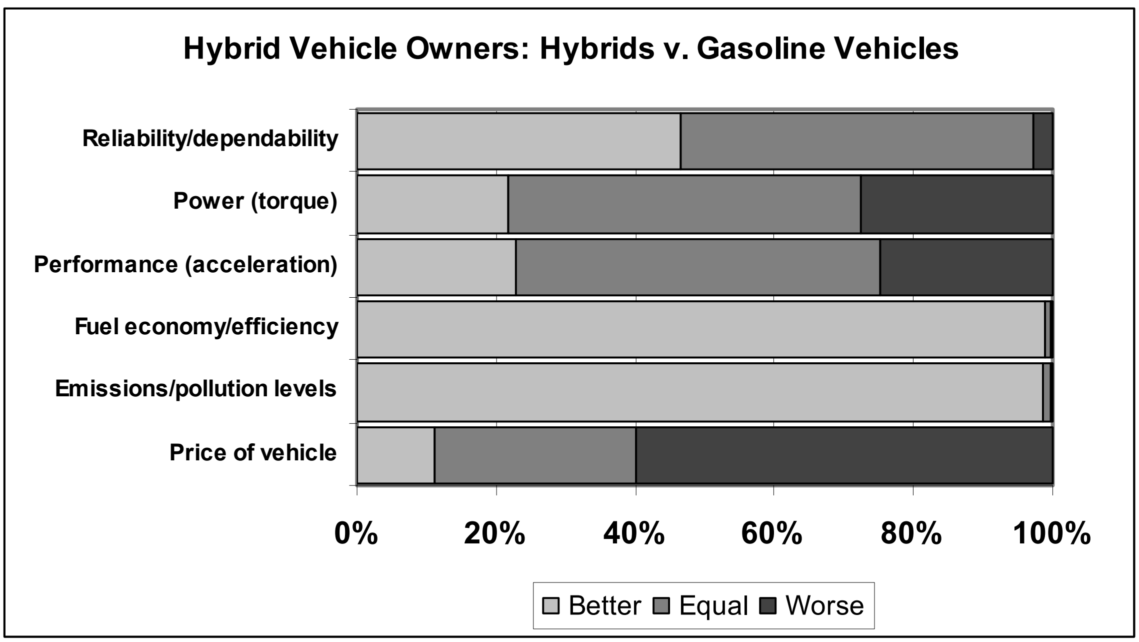

Figure 5. Hybrid-Electric Vehicle Owners' Views on Hybrid-Electric Vehicles

Just as diesel owners had a more favorable impression of their vehicles than non-diesel owners, hybrid owners hold a better opinion of hybrids. On the one hand, there is almost certainly self-selection bias in these survey results. The more significant point, however, is that owners of these alternative power trains find them to be as good or better than gasoline vehicles in all respects except price. The fact that those who know these vehicles well are happy with them is important, since it implies that except for price there is no major market barrier to the success of either hybrids or diesels. Both technologies have mass-market potential.

The combination of a conventional gasoline engine and an electric motor with high torque at low rpm permits exceptional launch and acceleration. Just as for diesels, it is likely that manufacturers will offer consumers both increased fuel economy and increased torque in future hybrid designs (Table 3). Stop/start systems will offer no increase in torque because they do not have the ability to use the starter/alternator for motive power. With other systems, torque will increase with the power of the electric motor. The full hybrid system is estimated to give only a 15% torque increase and 35% fuel economy benefit when used on larger light trucks.

Table 3. Estimated Additional Torque and Fuel Economy of Hybrid Vehicles

Hybrid System	Change in Torque	Change in MPG
S/S	0%	7.5%
ISAD	10%	12.5%
IMA	15%	20%
Full (cars / trucks)	20% / 15%	40% / 35%

Although a hybrid vehicle's battery pack will take up additional space, we do not expect manufacturers to reduce the size of a hybrid's fuel tank in comparison to a conventional gasoline vehicle. The Honda Civic hybrid's fuel tank, for example, holds 13.2 gallons, exactly the same as conventional gasoline engine Civics. With fuel tanks of equivalent size, increased fuel economy will translate into increased range.

Hybrids may have other advantages that we make no attempt to take into account. With smaller engines and all-electric drive at low speeds, hybrids are likely to be quieter than conventional gasoline vehicles. With two powerplants, hybrids could offer a kind of low-speed 4-wheel drive at little additional cost. Finally, with the ability to generate high-voltage electric power and considerable capability for storing electricity, hybrids can electrify many functions now performed mechanically or hydraulically, and can even provide electrical outlets for household appliances and tools. It seems likely that some combination of features will be found that will add value for customers. In the analyses presented below, however, we do not attempt to add extra value to hybrids to take account of this likelihood.

Finally, hybrids are perceived to be environmentally friendly vehicles, and some car buyers are willing to pay something extra for a green vehicle. Fifty four percent of respondents to a J.D. Power and Associates survey who said they would consider buying a hybrid cited lower pollution as a reason (McManus, 2003). Nevertheless, we do not attempt to quantify the value of environmental friendliness in the quantitative analysis presented below.

2.2.2 Market Barriers

Surveys of American consumers conducted by J.D. Power and Associates (McManus, 2003) indicate that insufficient power (34%), price (27%) and vehicle dependability (24%) are consumers' top concerns about hybrid vehicles. Another 12% mentioned battery reliability as a concern. As a novel technology, it is understandable for consumers to be concerned about hybrids' reliability. Very likely, only experience will fully overcome this barrier, though Toyota and Honda have made effective use of customer guarantees such as extended warrantees to allay the concerns of early purchasers.

The incremental price of a hybrid system is undoubtedly the biggest barrier to its success. Hybrid costs have already begun to come down, and further reductions are expected. Toyota claims that the costs of batteries and motors were reduced by 30-35% from the first to the second generation Prius (Duleep, 2003). By 2012, we expect that costs will fall to $3,000-$4,000 for full hybrid designs, and from $600 to $640 for simple stop/start systems (Table 4).

Table 4. Estimated Incremental Retail Price Equivalent of Hybrid Systems by Vehicle Type

Hybrid System	Small Cars	Midsize & Large Cars	Small Trucks	Large Trucks
Stop/Start	$600	$640	$640	--
ISAD	$1,250	$1,385	$1,450	$1,625
IMA	$1,620	$1,790	--	--
Full Hybrid	$3,320	$3,920	$3,700	$4,100

2.2.3 Manufacturers Near-Term Plans

The six largest-selling manufacturers in the United States have announced planned introductions of sixteen additional hybrid vehicle configurations by 2008 (Table 5). This would bring the total number of hybrids in the market to nineteen. If these plans are realized hybrid options would be available not just as small to mid-size passenger cars, but in small and large SUVs and pick-ups, and in luxury as well as standard models. These announced introductions are the starting point for our "best guess" 2008 and 2012 scenarios described in Section 5, below and listed in detail in Appendix B.

Table 5. Planned Introductions of Hybrid-Electric Vehicles in the U.S. Market

Model	Nameplate (Division)	Vehicle Name (Model)	Manufacturer	Market Segment	Certainty	Sales Start
Chevrolet Malibu Hybrid (BAS)	Chevrolet	Malibu	General Motors	Midsize-Entry	Announced	Jan-2007
Chevrolet Silverado Hybrid (AHS II)	Chevrolet	Silverado	General Motors	Pickup-Fullsize	Announced	Jan-2008
Chevrolet Silverado Hybrid (FAS)	Chevrolet	Silverado	General Motors	Pickup-Fullsize	Announced	May-2004
Chevrolet Tahoe Hybrid (AHS II)	Chevrolet	Tahoe	General Motors	SUV-Fullsize	Announced	Jul-2007
Dodge Ram Contractor Special	Dodge	Ram	DaimlerChrysler	Pickup-Fullsize	Announced	Oct-2004
Ford Escape Hybrid	Ford	Escape	Ford	SUV-Entry	Announced	Jul-2004
Ford Midsize Car Hybrid	Ford	Futura	Ford	Midsize-Premium	Announced	Oct-2007
GMC Sierra Hybrid (AHS II)	GMC	Sierra	General Motors	Pickup-Fullsize	Announced	Jan-2008
GMC Sierra Hybrid (FAS)	GMC	Sierra	General Motors	Pickup-Fullsize	Announced	May-2004
GMC Yukon Hybrid (AHS II)	GMC	Yukon	General Motors	SUV-Fullsize	Announced	Jul-2007
Honda Accord Hybrid	Honda	Accord	Honda	Midsize-Premium	Announced	Oct-2004
Honda Civic Hybrid	Honda	Civic	Honda	Compact-Premium	In Market	Apr-2002
Honda Insight	Honda	Insight	Honda	Compact-Premium	In Market	Dec-1999
Lexus RX400h	Lexus	RX 400h	Toyota	SUV-Luxury	Announced	Oct-2004
Mercury Mariner Hybrid	Mercury	Mariner	Ford	SUV-Entry	Announced	Oct-2006
Nissan Altima Hybrid	Nissan	Altima	Nissan	Midsize-Premium	Announced	Oct-2006
Saturn VUE Hybrid (BAS)	Saturn	VUE	General Motors	SUV-Entry	Announced	Jan-2006
Toyota Highlander Hybrid	Toyota	Highlander	Toyota	SUV-Midsize	Announced	Apr-2005
Toyota Prius	Toyota	Prius	Toyota	Midsize-Premium	In Market	Jul-2000

3. RECENT MARKET ASSESSMENTS

J.D. Power and Associates have been conducting continuing surveys of the market potential for hybrids and diesels over the past several years. Their surveys indicate substantial consumer interest in the two technologies. In their 2004 survey, 8.6% of respondents indicated that they would definitely buy or were very likely to buy a diesel as their next vehicle. The respondents were evenly divided with 4.3% in each category. Almost seven percent indicated they would definitely buy a hybrid vehicle, with 8.3% indicating a hybrid purchase was very likely. The sum of the two most likely categories ("definitely" and "very likely") suggests the following maximum near-term market potentials: 8.6% for diesels and 15.2% for hybrids.

In 2004, J.D. Power and Associates (McManus, 2004) presented a new, less optimistic forecast of hybrid market share to 2013. From 0.6% of the market in 2004, hybrids were projected to grow to 2.5% of the market in 2008 and 3.2% in 2013, with a lower and upper bound of 2.1% to 4.1%, respectively (Figure 6).

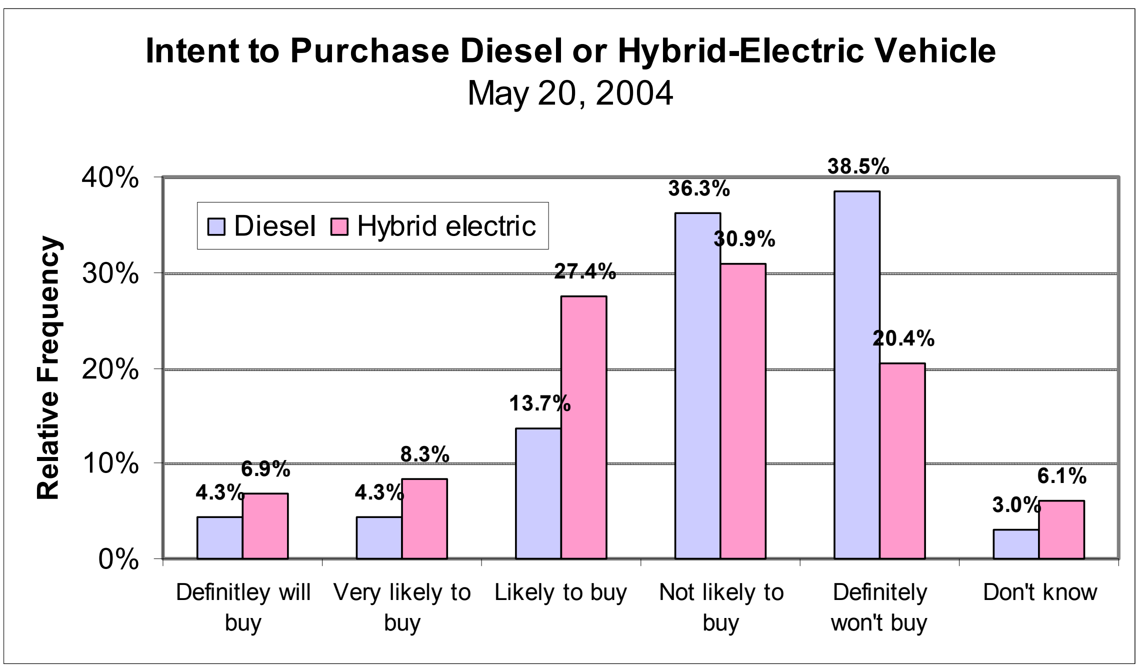

Figure 6. Intent to Purchase Diesel or Hybrid-Electric Vehicle

Robert Bosch GmbH (Qualters, 2004) carried out a study of the diesel's potential in the North American light-duty vehicle market. Key premises of the study were that emissions control strategies to achieve bin 8 would be available by 2007, bin 5 solutions by 2009, and that fuel availability would not hinder development of the diesel market. In addition, they assumed that total market volume would be approximately 17.5 million units, and that manufacturers' market shares would remain relatively static. The Bosch assessment did not consider competition from alternative power trains, such as the hybrid.

On the positive side, the Bosch study noted the enormous success of diesel engines in the larger (GVW class IIb) pick-up truck market, where they currently hold a 75% market share. In 2003, 550,000 diesel pick-ups were sold in the North American market. Bosch's opinion is that some of the appeal of the diesel in this market segment must surely carry over, albeit to a lesser degree, into the lighter truck markets. They therefore conclude that the most likely path for diesel market penetration is to migrate downward from class IIb light trucks to large SUVs, lighter-duty pick-up trucks, standard and smaller sized SUVs, crossover vehicles and minivans and, finally, passenger cars. If such a strategy is pursued, they foresee the North American diesel market share expanding from about 5% today to nearly 15% by 2012. The Bosch study includes class IIb light trucks (>8,500 lbs. GVW) which are not included in this study. Excluding class IIb trucks, the Bosch projection for 2012 is 10% of the light-duty market as defined here (Figure 7). Approximately half of the new sales are expected to come in the light-duty pick-up market segment, and only a very small fraction would be attributable to passenger car diesel sales.

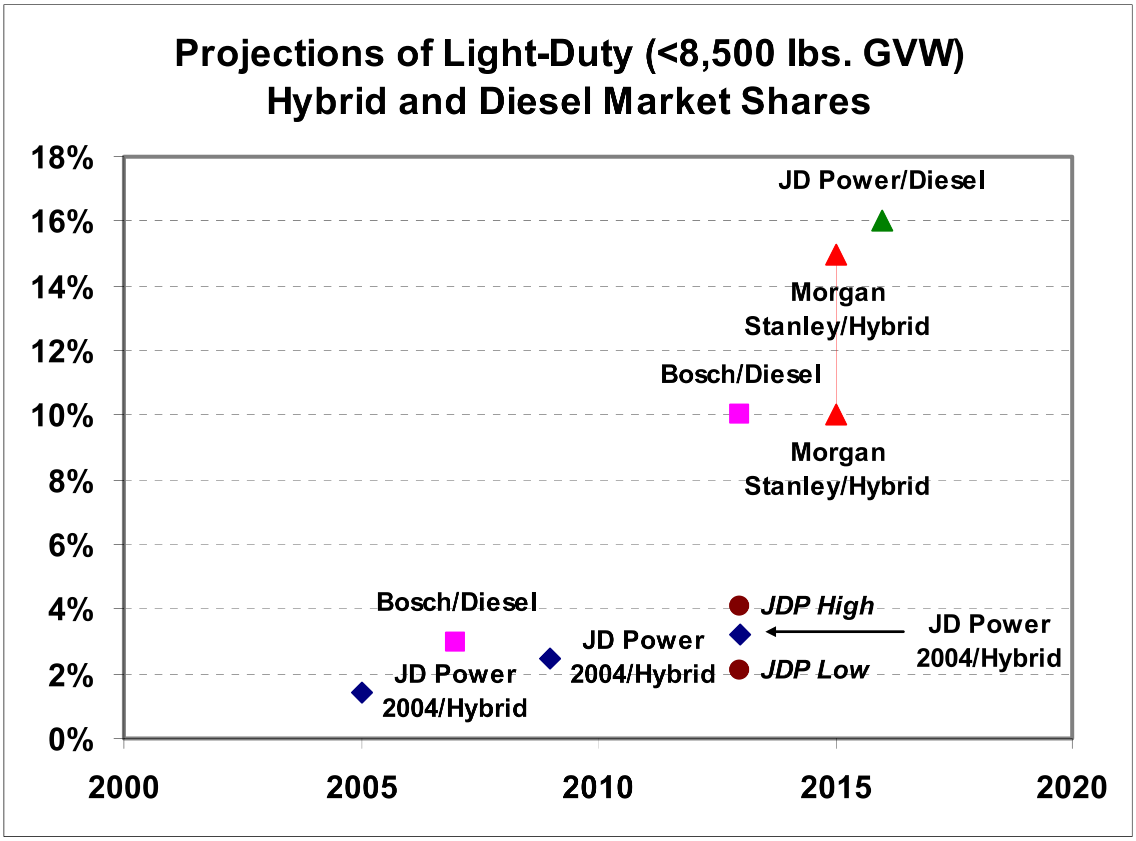

Figure 7. Projections of Light-Duty Hybrid and Diesel Market Shares (Passenger cars and class IIa light trucks, only)

3.1 DOE PROJECTIONS

Projections of future diesel vehicles sales have been made by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) and by the Energy Information Administration (EIA, 2004; Patterson, 2004). The EIA's projection foresees diesel sales reaching 585,000 units by 2005, increasing to 716,000 in 2010 and reaching 765,000 units in 2015. Both the EIA's and EERE's projections nominally include class IIb light trucks (>8,500 lbs. GVW). However, only the EIA forecast appears to have been calibrated to the current level of class IIb diesel sales. Current class IIb diesel sales amount to approximately 5% of total class

1 and 2 light truck sales. Over 95% of the light-duty diesels are projected to be light trucks. The EERE projection foresees only 179,000 light-duty diesels by 2010, followed by a rapid expansion to 2.1 million diesels in 2015 (Figure 8). Over 40% of the diesels in the EERE 2015 forecast are passenger cars.

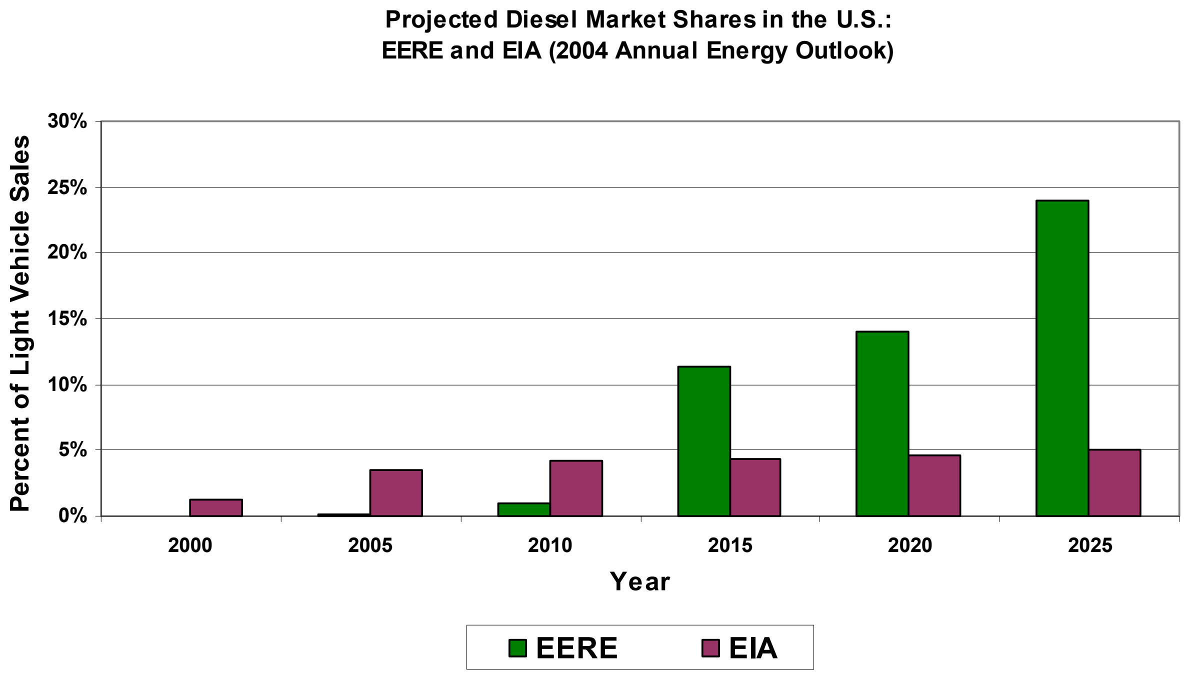

Figure 8. Projected Diesel Market Shares in the United States

These studies reflect a considerable range of uncertainty but also substantial competitive market potential for diesels and hybrids over the next decade. In the sections that follow, we describe a methodology and data for estimating future market success, based on explicit assumptions about both the attributes of hybrid and diesel technologies and the values consumers attach to them.

4. METHODOLOGY AND DATA

Evaluating the future market potentials of hybrid and diesel technologies requires: (1) estimating the extent to which manufacturers will offer products with diesel or hybrid options, and (2) predicting consumers' response to those offerings. The key piece is consumer acceptance, since it is reasonable to assume that if enough consumers are willing to pay for diesels and hybrids, manufacturers will, eventually, produce them in a variety of shapes and sizes. In the near term, to 2008 and even to 2012, the number of diesel or hybrid offerings will be limited by several factors:

(1) *risk*: uncertainty about the market's response to these technologies will lead manufacturers to proceed with caution;
(2) *response time*: redesigning vehicles to accommodate hybrid or diesel power trains takes time because engineering expertise is in limited supply and because accelerating the normal rate of retooling increases costs; and
(3) *technology status*: the technological readiness of both technologies is evolving; for the diesel, there remains a question of how successfully it can reduce pollutant emissions; for the hybrid the question is how quickly and how far it can be moved down the learning curve and its costs reduced.

Indeed, it is likely that almost all hybrid or diesel vehicles that will be available in 2008 have already been announced by manufacturers.

4.1 SCENARIOS OF DIESEL AND HYBRID INTRODUCTIONS

Our method for estimating the future market successes of diesels and hybrids consists of two steps. First, we specify a detailed scenario of diesel and hybrid product introductions. Second, we use a quantitative model of vehicle choice to predict the share of the new vehicle market those new products will capture. Scenarios are defined by, (1) time period (2008, 2012 and >2012), (2) technologies introduced (diesel, hybrid, type of hybrid), and (3) the makes-models-engines-transmissions to which the technologies are applied.

For 2008, our scenarios are based primarily on manufacturers' product announcements, with a few additional models added based on our judgment. For 2012 we have augmented the 2008 introductions with additional, likely product introductions, based on our judgment. The makes and models for which diesel and hybrid powertrains are assumed to be available in 2008 and 2012 are listed in tables A.1 and A.2 in the appendix. The 2012 scenarios are intended to represent market tendencies driven by customer demand and largely unconstrained by make and model availability.

If not every single vehicle configuration offers a diesel and a hybrid option, which configurations will offer them? This question is critically important to the calibration of the consumer choice model. Unfortunately, there is no obviously correct answer to this question, so we test two alternatives in the 2008 analysis: (1) the announced or most likely (based on our judgment) configuration of each nameplate, and (2) an "average" configuration for each nameplate. The average configuration is a typical configuration of a make and model; not the best selling, not the worst. A precise mathematical definition is provided in Appendix A. We use the average configuration method as a lower bound estimate since it is reasonable to assume that manufacturers would tend to offer hybrids or diesels on the configurations that would sell best (mathematical details of the average method are provided in the appendix).

In all, eight scenarios were analyzed:

1. >2012 all configurations have diesel available
2. >2012 all configurations have full hybrid available
3. >2012 all configurations have both full hybrid and diesel
4. >2012 all configurations have both ISAD hybrid and diesel
5. 2008 best guess, best-judgment make/model/configuration
6. 2008 product plans, average make/model/configuration
7. 2012 best guess, best judgment make/model/configuration
8. 2012 augmented product plan, average make/model/configuration

Diesel and hybrid vehicles will have to sell well enough for manufacturers to achieve scale economies or the product lines will be canceled. Because drivetrains can be used on more than one nameplate, determining exactly how many diesel engines or hybrid drivetrains of a particular design a manufacturer may be selling is difficult and beyond the scope of this study. Instead we eliminate low-selling models with a simple rule of thumb: if the sum of diesel or hybrid sales for a given nameplate (make and model name) is less than a specified threshold, all configurations of that nameplate are deleted and sales shares are recomputed. The default assumption for the 2008 scenarios is 5,000 units, for 2012 10,000 units must be sold and for >2012 the limit is raised to 25,000 units. In addition, in the >2012 scenarios every configuration must sell more than 2,000 units or it is deleted.

Finally, a sensitivity analysis was carried out on scenario 3 (>2012 Full Hybrid & Diesel) to generate a distribution of outcomes and identify the most important factors determining the market success of diesels and hybrids.

4.2 CONSUMER CHOICE MODEL

The model of consumer choice must be able to predict the effects of introducing new products into the market as well as predicting the impacts of changes in vehicle attributes such as price, fuel economy, range and power. In addition, it must be possible to calibrate the model to the base year sales of the nearly 1,000 makes, models and configurations in the National Highway Traffic Safety Administration fuel economy database. Furthermore, it is desirable to recognize that there are different segments of the light-duty vehicle market and that consumer preferences and sensitivity to price may vary across these segments, affecting their propensity to accept diesel or hybrid vehicles. The Nested Multi-Nomial Logit (NMNL) random utility model can be used to carry out all of these tasks.

Random utility models assume that consumers' vehicle choice decisions can be approximately represented as a problem of picking the vehicle which achieves the highest score on a ranking function. The simplest form of ranking, or utility function, is a weighted sum of relevant vehicle attributes such as price, performance, reliability, functionality, and so on. Recognizing that not every consumer attaches the same value to each attribute, and that there may be unmeasured or unmeasurable yet relevant attributes, a random component that varies across individual consumers is added to the ranking function. Let u_{ij} be the ranking score for the ith vehicle for the jth individual, let w_l be the weight of the l^{th} attribute, x_{il} , and let ε_{ij} be the jth individual's random component for the ith make and model. By convention, the weight for vehicle price, $w_P = 1$, so that the units of $w_l x_{il}$ are dollars.

$$u_{ij} = b\,(A_i + \sum_{l=1}^{K} w_l x_{il} + \varepsilon_{ij})$$

Equation 1

In equation 1, A_i is a constant term reflecting the value, in dollars, of attributes of vehicle *i* not included in the set of measured attributes, x_{il}. The parameter b is a critical parameter in that it determines the sensitivity of consumers' choices to changes in the dollar values of alternatives. Because w_p=1, the coefficient of price (or price slope) is b.

Assuming that the random terms follow the type I extreme value distribution (a somewhat skewed bell shaped distribution similar to the normal distribution), then the probability that the ith make and model will be chosen, given that the choice will be made from the kth vehicle class, is given by the multinomial logit (MNL) function.

$$p_{i|k} = \frac{e^{bu_i}}{\sum_{l=1}^{L} e^{bu_l}}$$

Equation 2

Given a large enough population of car buyers, p_i will also be the market share of the ith make and model. Sales for that carline can then be estimated by multiplying total light-duty vehicle sales by the predicted market share, $S_i = p_i\, S$. In equation 2, b is the coefficient of vehicle price and is also the inverse of the variance of the random utility term, ε.

The NMNL model assumes that choices within a class of vehicles, e.g. choices among makes and models of small SUVs, follow the logit model of equation 2. Choices among vehicle classes follow a similar logit model, in which the utility function for a class is a probability-weighted average of the utility scores of the vehicles within the class. The expected utility of class k, U_k , is given by the following log sum.

$$U_k = \frac{1}{b} \ln\left(\sum_{i=1}^{n_k} e^{u_{ik}} \right)$$

Equation 3

The probability that a consumer will choose a vehicle from class k is then given by the following logit function.

$$p_k = \frac{e^{A_k + BU_k}}{\sum_{K=1}^{n} e^{A_K + BU_K}}$$

Equation 4

Here K is used to index summation over all vehicle classes and n is the number of vehicle classes. A_K is a vehicle class-specific constant term analogous to the vehicle constant term A_i in equation 1. Likewise, B is a slope parameter that determines the sensitivity of choices among vehicle classes to changes in their expected value. The probability that vehicle i will be chosen from class k, which is equivalent to its expected market share, is given by the product of equations 2 and 4, the class and conditional vehicle choice probabilities $p_{ik} = p_{i|k}\, p_k$.

4.3 MARKET SEGMENTATION AND CHOICE MODEL STRUCTURE

The market structure assumed for this analysis is shown in Figure 9. Light-duty vehicles are divided into five classes (k = 1, 5): (1) standard passenger vehicles, (2) luxury vehicles, (3) sportscars, (4) pick-up trucks, and (5) standard vans. Standard passenger vehicles are further divided into passenger cars and passenger trucks. Passenger cars contain small, compact and midsize-large cars; passenger trucks comprise minivans, as well as small and large SUVs. Luxury vehicles are further divided into cars and trucks, sportscars are divided into luxury and standard segments, and pick-ups are split into small and large size classes (Table 6).

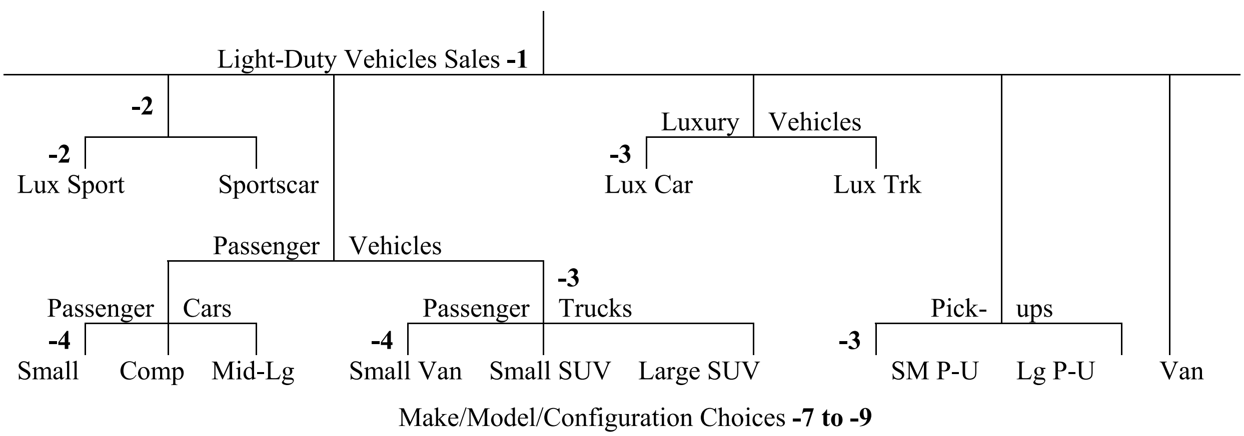

Figure 9. Nested Multinomial Logit Model Structure and Approximate Price Elasticities (shown in bold numbers)

A useful feature of the NMNL model is the ability to group more similar vehicle types into "nests" within which demand will be more sensitive to price (elastic) than choices among the nests. The implication of Figure 9, for example, is that the choice among a small, compact and midsize-large car will be more price sensitive than the choice between a car and all sizes of passenger trucks. Choices among (1) standard van, (2) pick-up, (3) luxury vehicle, (4) passenger vehicle, and (5) 2-seater vehicle will be even less price sensitive, because these vehicle types serve very different functions. Within the lowest level nests, choice among makes and models of large SUVs, for example, will be most sensitive to small price changes. A price elasticity of -7, for example, implies that a 2% increase in price would produce a 14% reduction in market share.

Table 6. Definitions of Vehicle Classes

Vehicle Class	CEC Class	Number of Configurations	Price
1. Minicompact & Subcompact	1,2	102	<$35,000
2. Compact	3	125	<$35,000
3. Midsize & Large		94	<$35,000
4. Small Van	9	36	<$35,000
5. Small SUV	11,13	162	<$35,000
6. Large SUV	12	13	<$35,000
7. Small Pick-up	7	64	<$35,000
8. Large Pick-up	8	56	<$35,000
9. Luxury Sedan	1-5	117	>$35,000
10. Luxury Truck	7-16	43	>$35,000
11. Standard Sportscar	6	37	<$35,000
12. Luxury Sportscar	6	49	>$35,000
13. Standard Van	10	32	<$35,000

4.4 CHOICE MODEL CALIBRATION

Calibration of the NMNL model to base year 2002 sales and vehicle attributes requires three steps. First, price slopes must be estimated for every nest and for every level of choice shown in Figure 1. The price slopes are critical parameters and are used in estimating coefficients for all the other attributes. Second, values per unit must be estimated for all variables included in the NMNL model. Attribute values are converted to NMNL model coefficients by multiplying values per unit by the purchase price coefficient. Third, intercept terms must be estimated to insure that the NMNL model exactly predicts the base year market shares of, (1) every make, model and configuration, and (2) every vehicle market segment shown in Figure 9.

Price slopes not only determine the sensitivity of demand to purchase price but to all other variables included in the model. In the NMNL model, the price coefficients define the importance of unobserved attributes, factors left out of the formal model. If choice is highly price-sensitive, it implies that consumers perceive vehicles to be very similar except for the factors explicitly included in the model. If choice is relatively insensitive to price, it implies that most of the important factors on which consumers base their choices are not explicitly represented in the model. If choice is insensitive to price, the choice model will tend to give all technologies an equal share of the market. In considering how sensitive choice may be to price, it is important to keep in mind that choices at the lowest level nests in Figure 1 are among a diesel, hybrid or conventional gasoline version of the same make and model. Thus, it is reasonable to assume a high degree of similarity with respect to attributes excluded from the model and, therefore, relatively high sensitivity to price. At the highest level, the choice among a sportscar, standard passenger vehicle, luxury vehicle, pick-up truck and standard van will be based primarily on factors not explicitly included in our NMNL model. Choices at this level should be much less sensitive to price. Indeed, the theory of NMNL models requires that price sensitivity uniformly decrease as one moves from the lowest level choices upward. This theoretical requirement is very useful in calibrating the model's price slopes.

Given the price and attribute coefficients, intercepts must be estimated for every make, model and configuration. This allows the expected utilities of classes to be computed. Given the class expected utilities and class price slopes, intercept terms can be calculated for each market segment. This calibration insures that the NMNL model exactly predicts each make, model and configuration share, and all the class shares for the base year.

4.5 PRICE SLOPES

Price slopes are computed using their relationship to price elasticity, vehicle price, and market share in the MNL model. Let β_k be the price elasticity for choices in vehicle class k, P_k the average price of a vehicle in the class, and let p_k be the average market share for vehicle configurations in class k. Then the price slope for class k is given by equation 5.

$$b_k = \frac{\beta_k}{P_k(1-p_k)}$$

Equation 5

The same relationship can be used to calculate price elasticities for choices among vehicle classes.

McManus (2004) presents useful survey data on the potential sensitivity of diesel and hybrid market shares to their incremental prices. For each of the two alternative powerplants, a J.D. Power and Associates survey asked respondents how likely they would be to buy that powerplant if it cost a certain amount more than a comparable gasoline engine vehicle. Demand, in terms of market share, was set equal to the sum of those responding they would definitely or probably want to buy the powertrain in question. For the diesel, the cost increments were $1,500, $2,500, and $3,500 (2003 dollars). For the hybrid the cost increments were $3,000, $4,000 and $5,000. Table 6 shows the market shares and cost increments, and implied price elasticities based on the midpoint formula for computing arc elasticities. In both cases, the price elasticities for the initial price increment are just over -8, indicating highly elastic demand. In both cases price elasticities decrease with increasing price.

The inferences shown in Table 7 must be interpreted with caution because they are based on what consumers say they would do rather than what they actually did, and because of the crudeness of the estimation method. Nonetheless, the numbers are generally consistent with other price elasticity estimates from the economic literature. Greene (1986) analyzed the choice between gasoline and diesel engines for the same make and model in the U.S. market between 1979 and 1983 and found a price elasticity of approximately -10 (Greene, 1994). For choices between makes and models, Irvine (1993) obtained price elasticities ranging from -4.6 to -17.0, with a mean of -10.4. Berry et al. (1995) analyzed choices among 2,217 carlines from 1971 to 1990 and found that elasticities for 1990 model year cars ranged from -6.5 to -3.1, with price sensitivity generally decreasing with increasing price. In a similarly comprehensive analysis, Bordley (1994) found an average own price elasticity of -5 for choices among makes and models. Bordley also found a price elasticity of -2 for choices among broad market segments (e.g., subcompact, sports car, etc.). Finally, there is a general consensus that the price elasticity of demand for light-duty vehicles overall is close to -1 (Kleit, 1990; McCarthy, 1996; Bordley, 1994).

Table 7. Estimated Price Elasticities for Diesel and Hybrid Market Shares Based on a Survey by J.D. Power and Associates

Price Increase	Market Share	Relative Change in Price (Base = $25,026)	Relative Change in Share	Arc Elasticity Using Midpoint Formula
Diesel				
$0	.75	-	-	-
$1,500	.44	.0599	-0.514	-8.6
$2,500	.34	.0400	-0.261	-6.5
$3,500	.28	.0400	-0.182	-4.6
Hybrid				
$0	.59	-	-	-
$3,000	.21	.1199	-0.971	-8.1
$4,000	.19	.0400	-0.057	-1.4
$5,000	.18	.0400	-0.061	-1.5

Price slope coefficients are calculated from assumed price elasticities, base year vehicle prices and market shares, as shown in equation 5. The default price elasticities assumed at each level of the choice structure are shown in Figure 9. The resulting price slopes and the data used to compute them are provided in Table 8.

4.5.1 Estimating the Value of Attributes

Attribute coefficients are calculated from the estimated value in dollars of one unit of an attribute. The slope coefficient for an attribute is its value per unit times the appropriate price slope. To the greatest extent possible, attribute values are derived from assumptions or taken from the existing economic literature. For example, it is possible to calculate the value of a change in fuel economy by calculating the present value of fuel savings. While this method requires making a number of arguable assumptions, it has the advantage of transparency. The behavior of the model is directly dependent on its coefficients which can be directly traced to specific assumptions about consumer behavior. Another virtue of this approach is that it makes it possible to test the sensitivity of model predictions to key assumptions such as the price of fuel, consumer discount rates, or the value of time spent refueling.

4.5.2 Fuel Economy

The value of fuel economy is derived from assumptions about vehicle use, the consumer's payback period and discount rate. EPA test fuel economy numbers are discounted to more accurately reflect real-world driving experience. For conventional gasoline vehicles, EPA MPG numbers are multiplied by 0.85. Although there is not yet definitive evidence, it appears that hybrid vehicle MPG should be discounted more severely (0.80) and diesel powered vehicles less (0.925). Since fuel costs are in units of dollars per mile, the attribute weight for fuel cost must be in units of present value miles, in other words miles driven over the consumers' payback period, discounted to present value. The assumptions for these calculations are shown in Table 7. The annual miles by vehicle class for the first year of ownership are shown in the first column. Usage decreases with age and the rates of decline are given in the second column. It is assumed that consumers demand a simple 3-year payback, that is, they count the first three years of undiscounted fuel savings.

Table 8. Price Slopes, Elasticities, Prices and Market Shares for Market Segments

	2002 Market Share (%)	Make/Model Count	Average Share	Price Elasticity	Average Price	Price Slope
All Vehicle Classes			20.00%	-2	$25,026	-0.000100
Passenger Vehicle	72.59%		50.00%	-3	$22,769	-0.000207
Passenger Car	43.35%		33.33%	-4	$20,349	-0.000295
Small Car	7.61%	102	0.98%	-7	$17,226	-0.000410
Midsize Car	14.53%	125	0.80%	-7	$19,234	-0.000367
Large Car	21.22%	94	1.06%	-7	$22,233	-0.000318
Passenger Truck	29.24%		33.33%	-4	$26,357	-0.000228
Minivan	7.01%	36	2.78%	-7	$25,651	-0.000281
Small SUV	20.40%	162	0.62%	-7	$26,208	-0.000269
Large SUV	1.83%	13	7.69%	-7	$30,718	-0.000247
Pick-up	15.31%		50.00%	-3	$22,451	-0.000267
Small Pick-up	5.19%	64	1.56%	-7	$19,099	-0.000372
Large Pick-up	10.12%	56	1.79%	-9	$24,170	-0.000379
Luxury	8.53%		50.00%	-3	$47,429	-0.000127
Luxury Sedan	3.95%	117	0.85%	-7	$47,256	-0.000149
Luxury Truck	4.59%	43	2.33%	-7	$47,578	-0.000151
Sportscar	2.88%		50.00%	-2	$29,534	-0.000135
Standard Sportscar	2.30%	37	2.70%	-7	$23,393	-0.000308
Luxury Sportscar	0.57%	49	2.04%	-9	$54,159	-0.000170
Van						
Standard Van	0.69%	32	3.13%	-7	$23,726	-0.000305

Fuel economy is measured in terms of the fuel cost per mile of travel, which equals the price of fuel, P_f, divided by fuel economy in miles per gallon, E. Thus, its value weight translates fuel cost per mile of travel into present value dollars (equivalent to dollars spent on purchase price). In effect, it answers the question, "How much is a change of $1 per mile in fuel costs worth at the time of purchase?" This depends on how many miles the vehicle will be driven over time, $M(t) = M_o e^{-\delta t}$, the buyer's payback period, L, and discount rate, r.[1] The present value of fuel cost is given by the following equation, in which w_f is the fuel cost per mile weight.

[1] It may be more accurate to view the discount rate as a required rate of return on an investment in fuel economy.

$$V_f = \int_{t=0}^{L} \frac{P_f}{E} M_o e^{-\delta t} e^{-rt} dt = \frac{P_f}{E} \int_{t=0}^{L} M_o e^{-\delta t} e^{-rt} dt = \frac{P_f}{E} w_f$$

Equation 6

Equation 6 reveals that the fuel cost per mile weight is in units of discounted or present value, miles. Multiplying w_f by the appropriate class-specific price slope yields the coefficient for fuel cost per mile. The reference assumptions are that consumers value fuel costs using a simple 3-year payback period, i.e., L=3, r=0 (Table 9). This same assumption was one of two used in the National Academy of Sciences (NRC, 2002) assessment of U.S. fuel economy regulations, and is also roughly consistent with a recent nationwide random sample survey (Caravan, 2004) which indicated a 2.5 year payback period with an unspecified discount rate. Estimates based on a recent survey of California residents implied payback periods ranging from 2 to 10 years (Adler, et al., 2004).

4.5.3 Range

The value of range is assumed to be the present value of time spent refueling. As noted above, it is likely that there is also a nuisance value associated with refueling events. However, in the absence of specific evidence about the nuisance cost of refueling and because we would prefer to undervalue rather than overvalue the attributes of diesel and hybrid vehicles in our analysis, the value of range is based solely on the value of time spent refueling without any additional nuisance value.

Total lifetime refueling cost is equal to the miles driven per year divided by the effective vehicle range (which gives the total number of refueling events per year) multiplied by the time required to refuel (in hours), multiplied by the value of time (in \$/hr), integrated over the consumers' ownership horizon and discounted to present value.

$$V_R = \int_{t=0}^{L} \frac{vH}{R} M_o e^{-\delta t} e^{-rt} dt = \frac{1}{R} \int_{t=0}^{L} vHM_o e^{-\delta t} e^{-rt} dt = \frac{w_R}{R}$$

Equation 7

Equation 7 reveals that range should appear as the inverse of range in the NMNL model.

The reference assumptions are a three year time horizon, zero discount rate, $20 per hour, an average refueling time of 6 minutes, and an effective storage volume of 80% of the total fuel tank volume. It is not clear that consumers use the same method to value future time spent refueling as they use to value future fuel savings. However, in the absence of specific evidence, we choose to use consistent methods.

Table 9. Coefficients of the NMNL Vehicle Choice Model

	FUEL ECONOMY SLOPES						RANGE SLOPES				FUEL AVAILABILITY		PERFORMANCE	
	Annual Miles	Rate of Use Decrease/yr	Payback Horizon (yrs)	Discount Rate	Present Value Miles	Fuel cost/mi Slopes	Tank Size (gals)	Minutes Per Refuel	Value of Time (2002 $/hr)	Slopes	C Scale	B Exponent	Value of 1 N-m (2002 $)	Slopes
Small Car	15,502	4.6%	3	0.0%	42,534	-17.456	13.6	6.6	$17.91	-34.5427	-0.5	-0.33333	$7	0.00287
Midsize Car	15,502	4.6%	3	0.0%	42,534	-15.604	14.5	6.7	$20.00	-35.0513	-0.5	-0.33333	$7	0.00257
Large Car	15,502	4.6%	3	0.0%	42,534	-13.536	17.4	7.1	$23.12	-36.9490	-0.5	-0.33333	$7	0.00223
Minivan	17,239	4.3%	3	0.0%	47,569	-13.352	20.7	7.5	$26.67	-44.3941	-0.5	-0.33333	$10	0.00196
Small SUV	17,955	5.7%	3	0.0%	48,262	-12.970	18.9	7.3	$27.25	-42.7935	-0.5	-0.33333	$10	0.00188
Large SUV	17,955	5.7%	3	0.0%	48,262	-11.914	26.0	8.1	$31.94	-51.5016	-0.5	-0.33333	$10	0.00173
Small Pick-up	19,151	5.8%	3	0.0%	51,381	-19.131	19.1	7.3	$19.86	-46.1849	-0.5	-0.33333	$10	0.00261
Large Pick-up	19,151	5.8%	3	0.0%	51,381	-19.480	25.8	8.1	$25.13	-66.1052	-0.5	-0.33333	$10	0.00265
Luxury Sedan	15,502	4.6%	3	0.0%	42,534	-6.355	19.2	7.3	$49.14	-60.6890	-0.5	-0.33333	$15	0.00224
Luxury Truck	15,502	4.6%	3	0.0%	42,534	-6.407	26.1	8.1	$49.47	-68.5169	-0.5	-0.33333	$15	0.00226
Standard Sportscar	15,502	4.6%	3	0.0%	42,534	-13.081	15.5	6.9	$24.32	-36.3521	-0.5	-0.33333	$7	0.00215
Luxury Sportscar	15,502	4.6%	3	0.0%	42,534	-7.216	17.5	7.1	$56.31	-76.7129	-0.5	-0.33333	$7	0.00119
Standard Van	19,151	5.8%	3	0.0%	51,381	-15.648	32.5	8.9	$24.67	-57.2262	-0.5	-0.33333	$10	0.00213

4.5.4 Torque/acceleration/power

The value of acceleration or power-to-weight is very subjective and a wide range of estimates can be found in the literature. Greene (2001) used a value of $12.50 per horsepower (in 1990$, or about $16 in 2002 $), based on studies by Donndenlinger and Cooke (1997) and Greene and Liu (1988). This is equivalent to $375 (2002 $) per second reduction in 0-60 mph acceleration time. A recent study suing stated preference survey data from California (Adler et al., 2004) found values over $1,000 per second.

Although there is no exact relationship between torque and horsepower, for most vehicles the ratio is typically about 3/2. This would make the value per ton about $10 in 2002. A value of $7 per 1-Nm of torque is assumed for all vehicles except luxury cars and trucks, for which a value of $15/Nm is used. For example, the willingness to pay for an increase in torque from 300 to 400 Nm would be $700 to $1,500, roughly what consumers would pay for a 6- instead of a 4-, or an 8- instead of a 6-cylinder engine.

The hybrid's increase in torque is likely to be more pronounced when accelerating from a stop or when rpm is otherwise low, while the diesel's torque will be most noticeable at mid-range engine speed. In the absence of information about the relative value of these two kinds of power, no attempt has been made here to resolve the issue of whether "off the line" acceleration is more valuable than passing acceleration (Santini, 2004). Both are assigned the same value.

4.5.5 Fuel Availability

The cost of limited fuel availability is assumed to be a power function of the fraction, x , of refueling outlets that offer the fuel in question.

$$V_A = Cx^a$$

Equation 8

Greene (1998) found that either a power function or an exponential function fit survey data on the perceived cost of low fuel availability. Nicholas et al. (2004) used a power function to fit data on the extra travel time necessary to refuel on home to work trips in the Sacramento area as the number of service stations was reduced in a simulation modeling analysis. Greene (2001) assumed that the value (cost) of 5% availability in present, purchase price equivalent dollars was -$2,750, while the cost of 10% availability would be only about -$1,000. A power curve fitted to the Nicholas et al. (2004) simulation results and assuming a value of time of $20.00 per hour, results in costs of about -$2500 at just under 0.5% availability, decreasing to -$500 at about 10% availability (Figure 10). The associated coefficients are C =-0.546 and a = -0.345. For this analysis, coefficient values of C = -0.5 and a = -0.33 were used. These estimates of the cost of limited fuel availability are considered to be conservative because they do not include any estimate of the risk of running out of fuel and because the value of many new car buyers' time is likely to be substantially higher than $20/hr.

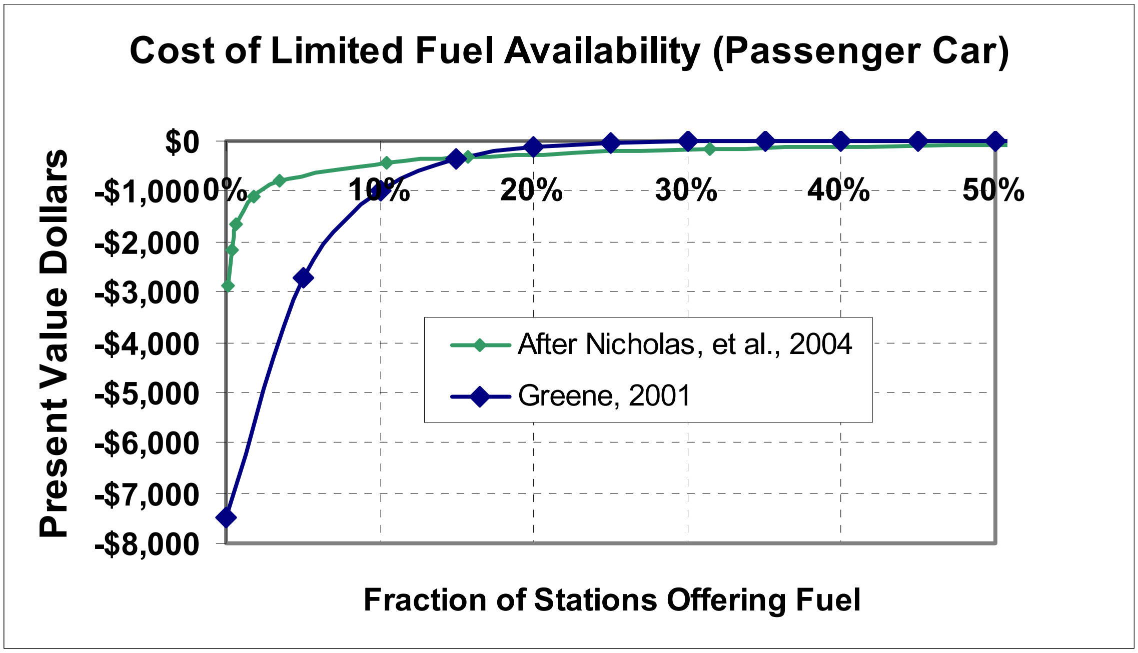

Figure 10. Power Functions Describing the Cost of Limited Fuel Availability

According to the Census Bureau, approximately 42,000 stations offered diesel fuel in 1997 (Hadder, 2004, p. D-6) out of a total of 127,000 refueling outlets (33%). Despite considerable uncertainty in these numbers, we assume 33% as the baseline availability in 2008.

4.5.6 High Quality Diesel Fuel

Every potential diesel manufacturer interviewed for this study expressed a desire to see higher quality diesel fuel in the U.S. market. In this study, we do not consider the potential impact of high-quality diesel fuel availability on the market potential for diesel vehicles. However, we note that widely available high-quality diesel fuel could only increase the market potential of light-duty diesels.

Manufacturers were unanimous in requesting diesel fuel that would meet the World-wide Fuel Charter requirements for Category 4 Diesel Fuel. None thought that high quality diesel fuel would be essential for meeting Tier 2 emissions standards; the low-sulfur diesel coming to U.S. markets in 2006-7 would be adequate for that purpose. Rather, high-quality diesel fuel would allow manufacturers to deliver benefits to diesel car buyers in terms of quicker, easier ignition at low temperatures, faster, smoother warm-up, cleaner injectors and fuel system and reduced engine wear.

Hadder (2004) has analyzed the likely fuel production, logistics and resulting consumer costs of high-quality diesel fuel significantly different from the ultra-low sulfur diesel fuel required to be in the market in 2010, and satisfying the World-wide Fuel Charter requirements. Depending on the volume of sales and market share, the distribution costs of high-quality diesel could add 0-5 cents per gallon to its pump price. Hadder found that the added costs of refining high-quality diesel, principally distillate dearomatization and cetane improver, would add about 3 cents per gallon. Finally, because the energy content per gallon of high-quality diesel is likely to be slightly lower than that of ultra-low sulfur diesel, consumers would suffer another 2 cents per gallon cost increase due to reduced fuel economy. All told, consumers could be expected to pay 6-10 cents per gallon more for high-quality diesel than for ultra-low sulfur diesel. This is, in general, less than the additional cost of premium gasoline versus unleaded regular. Premium gasoline, however, is often required to avoid engine knock. It is highly unlikely that manufacturers would require high-quality diesel fuel, though it might be recommended. Thus, high-quality diesel would be a customer option, purchased only when consumers felt it delivered more in benefits than it cost. In this respect, the availability of high-quality diesel could only increase the desirability of diesel vehicles.

4.5.7 Extra Features of Hybrids or Diesels

No attempt was made in this analysis to estimate the potential extra value that hybrids may be able to create due to the availability to generate and store high-voltage electricity or to impute extra value to diesels based on durability or other factors.

4.5.8 Make, Model and Configuration Intercepts

Configuration-specific intercepts ensure that the NMNL model exactly predicts base year market shares. The intercepts represent the value to the consumer of all vehicle attributes not explicitly included in this model (all attributes other than price, fuel economy, range, torque and fuel availability). The formulas for computing vehicle and class intercepts can be found in the appendix.

4.5.9 Minimum Sales Thresholds

After introducing the diesel and hybrid vehicles and predicting their market shares, we then delete diesel or hybrid carlines that fail to achieve minimum sales thresholds. This is done by summing sales of diesel or hybrid configurations to the make and model level, and checking for adequate sales to achieve scale economies. Diesels or hybrids with sales less than the threshold value (5,000 in 2008; 10,000 in 2012; 25,000 for >2012) sold within a given nameplate are deleted. Market penetrations are then be re-estimated.

5. RESULTS

Eight scenarios were developed, two each for 2008 and 2012, and four for beyond 2012 (>2012). For 2008, assumptions about the introductions of hybrid and diesel vehicles are based primarily on manufacturers' announced product plans (a list of makes and models assumed to be introduced can be found in the appendix). A "best guess" forecast is based on these announcements plus our own judgments about probable new introductions. In general, we believe that diesels and hybrids will most often be introduced on the better selling versions of makes and models. A lower forecast was also constructed based on the assumption that the diesel or hybrid configuration will be similar to the average configuration of its make and model. The mathematics of this method are described in the appendix. The 2012 scenario builds on the planned introductions of the 2008 scenario and extends them, again based on our judgment. The average 2012 scenario uses the same method of averaging configuration intercept terms as the 2008 scenario.

Two other factors are assumed to differ between 2008, 2012 and >2012. In 2008, the minimum sales for the hybrid or diesel versions of a a nameplate is set at 5,000 units, reflecting a willingness of manufacturers to accept low volumes during the first few years. In 2012, the minimum production volume is raised to 10,000. For the >2012 scenarios, a minimum make and model sales volume of 25,000 units is assumed. In addition, in the >2012 scenarios a minimum sales limit of 2,000 units is enforced for each individual diesel or hybrid configuration. For 2008, diesel fuel is assumed to be available at 33% of retail outlets. In 2012 and >2012, assuming that more diesel vehicles are on the road, availability is increased to 50%.

Because consumers value diversity of choice, the sales of diesel and hybrid vehicles are strongly dependent on the number of makes, models and configurations offered for sale (Table 10). However, economies of scale work against offering many makes and models; the more configurations offered, the fewer sold per configuration. The number of makes, models and configurations offering diesel and hybrid versions is strictly an assumption (see appendix for lists for 2008 and 2012). The model, however, determines which makes and models will exceed the assumed sales thresholds (5,000 for 2008, 10,000 for 2012 and 25,000/2,000 for >2012).

Table 10. Numbers of Diesel and Hybrid Configurations Offered, by Scenario

SCENARIO (921 Conventional Gasoline Configurations)	No. of Diesel Configurations	No. of Hybrid Configurations
2008 Best Guess	38	54
2008 Average Configuration	35	46
2012 Best Guess	46	90
2012 Average Configuration	46	72
>2012 Diesel Only	257	0
>2012 Hybrid Only	0	235
>2012 Diesel/Full Hybrid	210	155
>2012 Diesel/ISAD	176	228

5.1 THE LONG-RUN POTENTIAL MARKET SHARES OF DIESEL AND HYBRID VEHICLES

We begin by exploring the implications of consumers' preferences, unconstrained by the availability of diesel and hybrid offerings. Four >2012 scenarios address the question, "How big could the diesel and hybrid markets become if hybrids and diesels were generally available throughout the light-duty vehicle market?" No particular date is attached to these scenarios because they are intended to represent the long-run tendencies of the marketplace. Assuming that customers' preferences will eventually dictate manufacturers' decisions, these scenarios should indicate the direction in which the market will move after the initial hurdles have been overcome. How fast and how far the market will move will depend on a number of factors, including the rates of technological progress and learning, manufacturers' willingness to take risks, future fuel prices, government policies towards fuel economy and greenhouse gas emissions, and the evolution of consumers' preferences.

Rather than guessing which models manufacturers will choose to introduce, we initially assume that all models, body styles and engine-transmission combinations, (*except sports cars for diesels and standard vans for both technologies*) will be available in conventional gasoline, hybrid and diesel versions. However, if the total diesel or hybrid sales within a make and model do not sum to at least 25,000 units, all diesel or hybrid configurations for that make and model are canceled. In addition, if any individual configuration's sales fall below 2,000 units, that configuration of the make and model is also deleted. No such minimum sales requirements are imposed on conventional gasoline vehicles, which should tend to bias our estimates against hybrids and diesels, to some degree.

Four >2012 scenarios have been created. Two introduce only diesels or only full hybrids to explore how each competes head-to-head against gasoline. A third assumes that both diesels and full hybrids are widely available, but no other types of hybrids are considered. A final scenario introduces diesels and only the milder ISAD-type hybrids, to determine whether a less expensive but lower fuel economy hybrid would be more or less successful than the full hybrid design.

5.1.1 Diesels Only

In head-to-head competition with gasoline, and under the availability assumptions described above, diesels succeed in capturing 31% of the light duty vehicle market. Were there no minimum sales volume constraints, diesels would have had a 38% market share. Diesels do better in the light truck market, as anticipated by the Bosch North American diesel market study. Diesel passenger truck sales amount to 1.9 million units, 960,000 diesel pick-ups are sold, and luxury trucks include 250,000 diesels (Figure 11). But 1.8 million diesel passenger cars are also sold, 1.1 million of which are large cars. The tendency to predict a greater diesel market share for trucks is underlined by the fact that more diesel passenger trucks are sold despite the fact that there are fewer configurations of passenger trucks (82) to choose from than passenger cars (95) (Figure 12).

Despite the greater success of diesels in the light truck segment, diesel light-duty vehicles average 31.3 MPG in comparison to 24.3 for gasoline. The 31% diesel market share produces a 7.4% increase in light-duty vehicle average fuel economy.

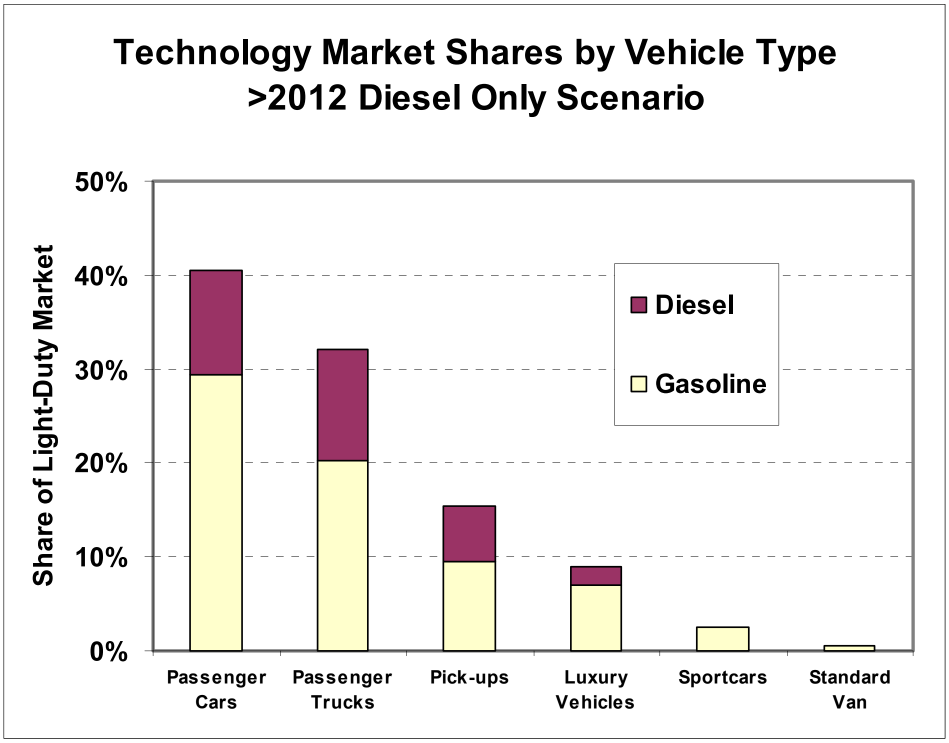

Figure 11. Technology Market Shares by Vehicle Type >2012 Diesel Only Scenario

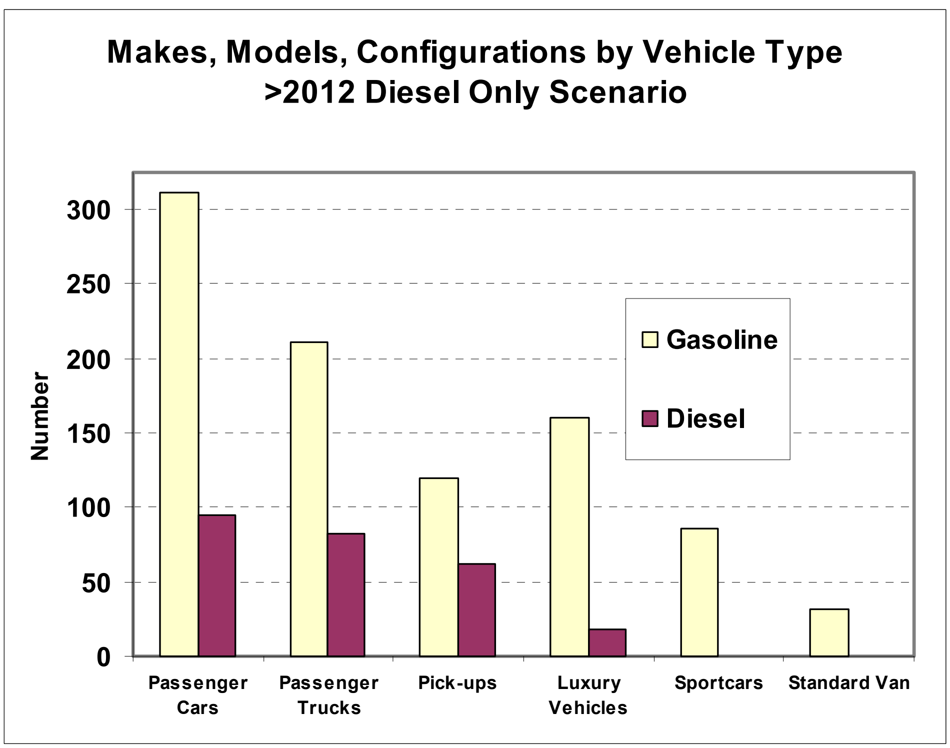

Figure 12. Makes, Models, Configurations by Vehicle Type >2012 Diesel Only Scenario

5.1.2 Full Hybrids Only

Full hybrids take 26% of the market in direct competition with conventional gasoline engines, (this compares with 31% for diesels). The somewhat smaller market share for hybrids is a result of the diesel's lower price (see Tables 2 and 4) and slightly greater torque (25% versus 15-20%). The hybrid's greater fuel economy (35-40% versus 33%) and therefore greater range are not enough to make up for the diesel's price and torque advantages. Thus, the diesel seems to offer customers value closer to its purchase price premium than the hybrid, but only a little closer.

Hybrids do reasonably well across vehicle types, selling 1.5 million passenger cars, 1.6 million passenger trucks, 700,000 pick-ups and 270,000 luxury vehicles (mostly trucks) (Figure 13). Hybrids do better in the passenger car segment than diesels despite the smaller number of hybrid configurations available.

The 26% market share of full hybrids raises overall light-duty vehicle fuel economy to 25.9 from 24.3, a 6.7% increase. Although full hybrids are assumed to deliver 40% better fuel economy for any given passenger car and 35% for any light truck, on average the hybrid light-duty vehicle fleet has only 32% higher fuel economy due to the somewhat greater prevalence of hybrid offerings among trucks (Figure 14) and large cars. Once again, the increase in offerings in these market segments tends to mitigate the potential fuel economy improvement potential of hybrids.

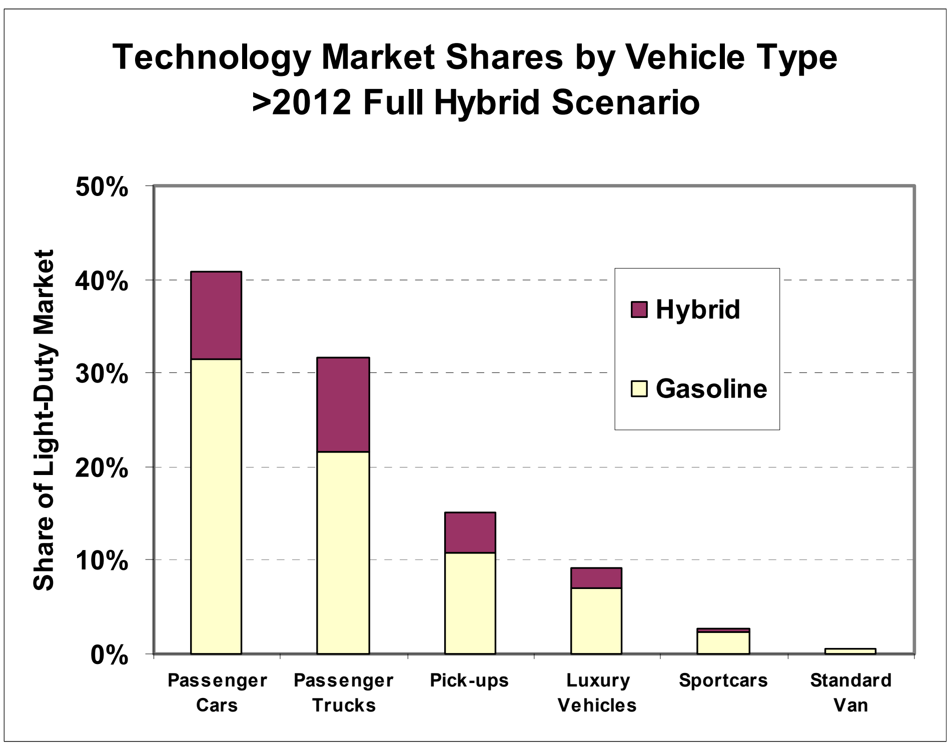

Figure 13. Technology Market Shares by Vehicle Type >2012 Full Hybrid Scenario

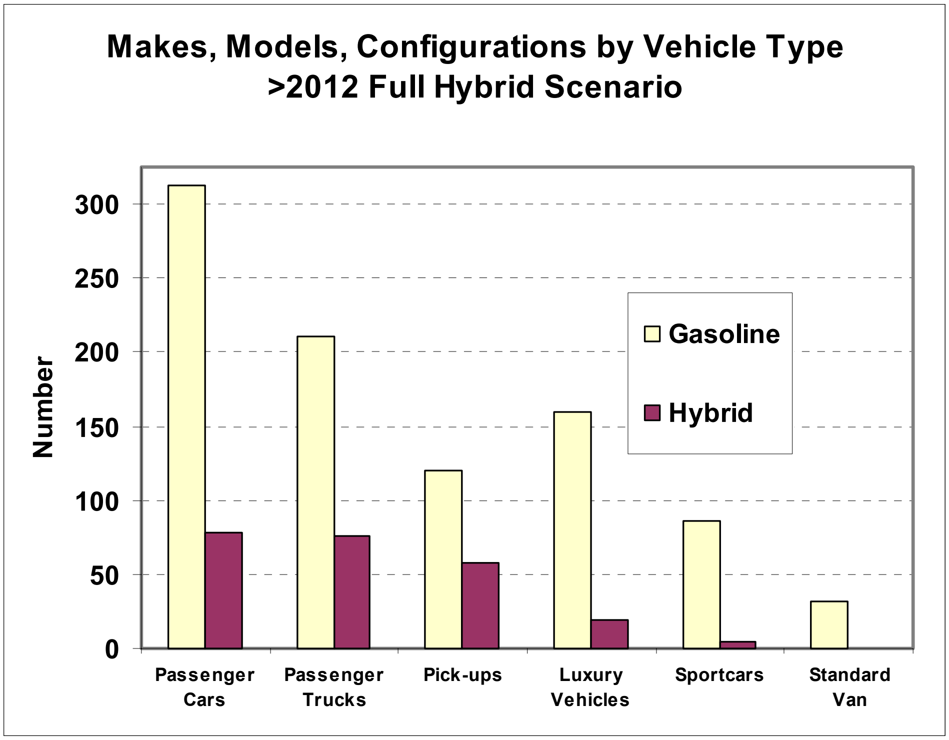

Figure 14. Makes, Models, Configurations by Vehicle Type >2012 Full Hybrid Scenario

5.1.3 Diesels and Full Hybrids

With equal assumptions about availability of makes and models to start with, diesels do slightly better than hybrids in a three-way competition with conventional gasoline vehicles. Together they capture 40% of the light-duty vehicle market, with diesels taking 23.8% to the hybrids' 16.5% (Figure 15). Both technologies appear to compete better in the light-truck market than in the passenger car market. The diesel's greater success is consistent with the head-to-head results presented above. Not surprisingly, more diesel vehicle makes, models and configurations turn out to be available than hybrid versions (Figure 16).

The combined effect of both technologies is to raise overall light-duty vehicle fuel economy by almost 10% to 26.7 MPG. On average, hybrids get 31.3 MPG and diesels 31.0, in comparison to 24.3 for gasoline vehicles.

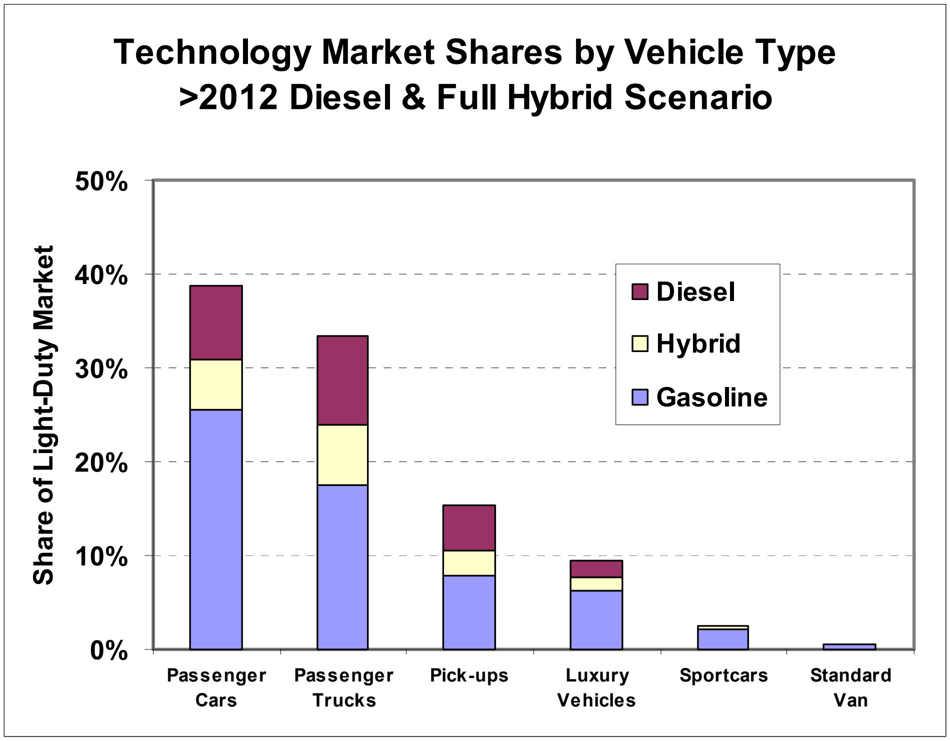

Figure 15. Technology Market Shares by Vehicle Type >2012 Diesel & Full Hybrid Scenario

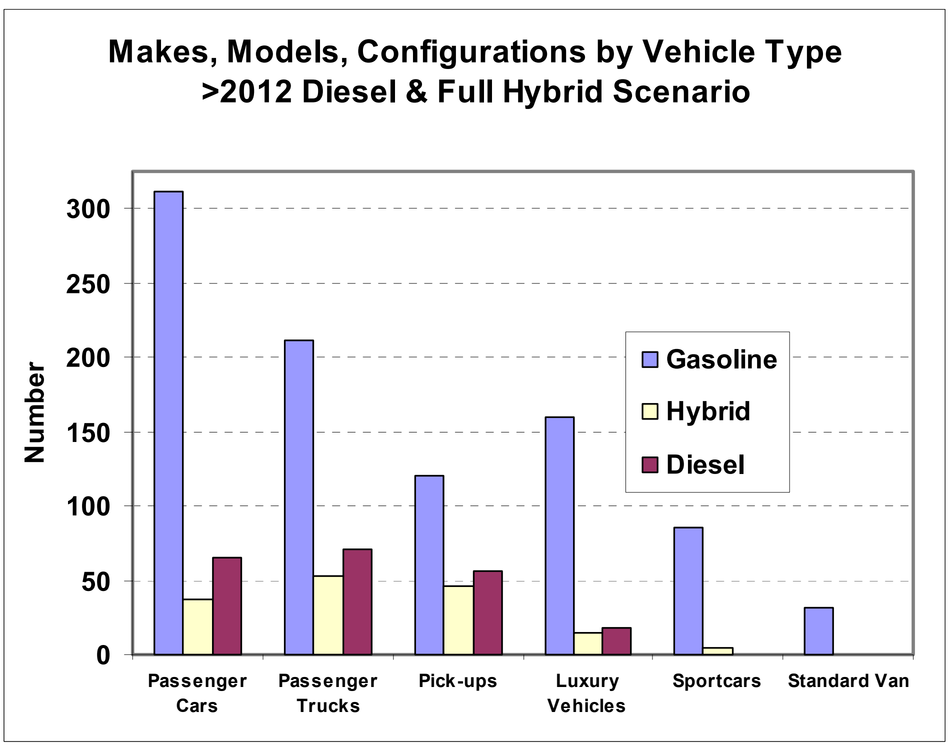

Figure 16. Makes, Models, Configurations by Vehicle Type >2012 Diesel & Full Hybrid Scenario

5.1.4 Diesels and ISAD Hybrids

Mild, ISAD hybrids offer only a 12.5% increase in fuel economy versus a 35-40% increase for a full hybrid design. ISADs also increase torque only 10% in comparison to 15-20% for a full hybrid. On the other hand, the ISAD system is considerably less expensive, $1,385 versus $3,920 for a midsize or large passenger car. The lower cost of the ISAD hybrid more than offsets its smaller benefits, with the result that ISAD hybrids capture a larger share of the market (27%) than diesels (19%) in a three-way competition with conventional gasoline vehicles. The assumption that consumers count only the first three years of fuel savings, rather than the full discounted present value of fuel savings over the life of a vehicle has a great deal to do with the preference seen here for less expensive but less fuel efficient vehicles.

This is the first scenario in which more hybrid passenger cars are sold than hybrids or diesels in any other vehicle class (Figure 17). There are also more makes, models and configurations of hybrids than diesels in every vehicle class (Figure 18). But ISAD hybrids achieve only 26.8 MPG in comparison to 24.3 MPG for conventional gasoline vehicles and 30.6 MPG for diesels. As a consequence, despite the greater combined market share of hybrids and diesels, overall light-duty vehicle MPG increases by only 7% to 26.0.

The result that hybrid market share would be higher for milder hybrid technology than for full hybrid technology is consistent with Santini's (2004) findings that mild hybrids and stop/start hybrids are more cost-effective than full hybrids.

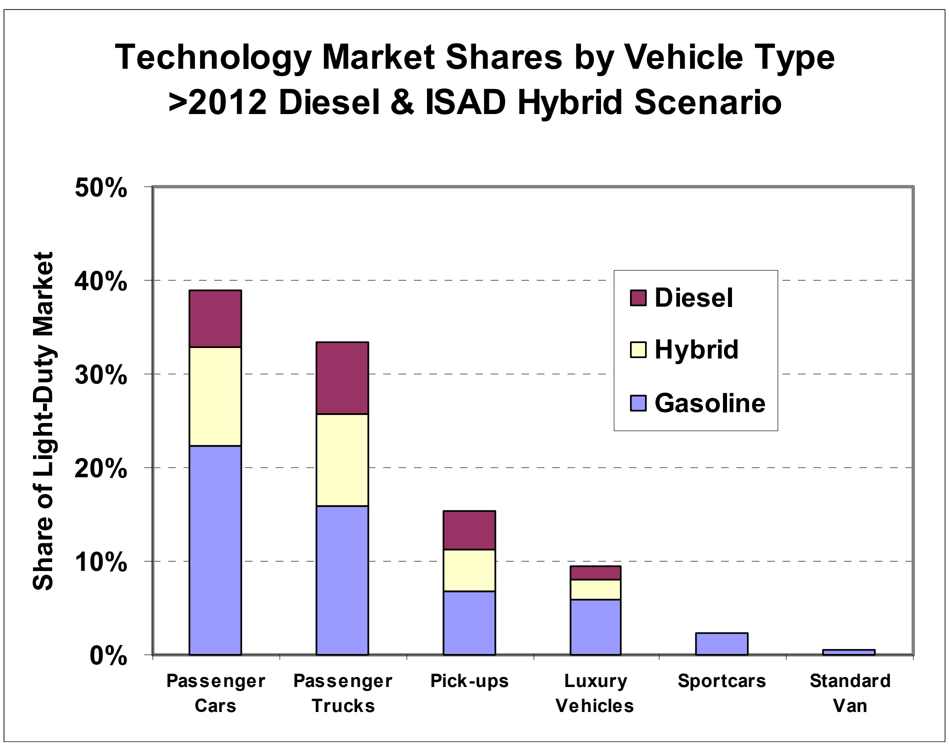

Figure 17. Technology Market Shares by Vehicle Type >2012 Diesel & ISAD Hybrid Scenario

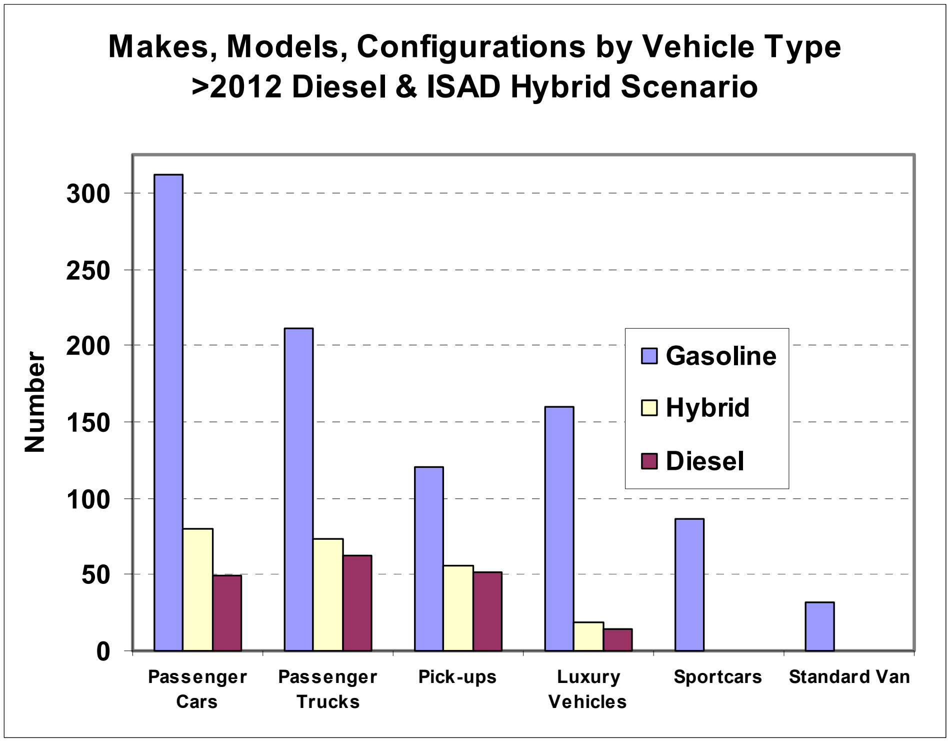

Figure 18. Makes, Models, Configurations by Vehicle Type >2012 Diesel & ISAD Hybrid Scenario

5.2 2008 SCENARIOS

The two 2008 scenarios produce diesel market shares ranging from 2.4 % (0.4 million units) to 3.9% (0.6 million units) of light-duty vehicle sales. The higher estimate is obtained under our "best guess" assumptions. The lower estimate is based on the assumption that the diesel will be similar to the average configuration for the make and model in question (i.e., an average intercept is used). Diesel sales are concentrated in the passenger truck, luxury truck, and pick-up truck market segments in 2008 (Figures 19 & 21).

The predicted market shares for hybrid vehicles are larger, ranging from 4.6% (750,000 units) assuming average intercepts to 7% (1.1 million units) when the best-guess configurations are assumed. In large part, the greater success of hybrids can be attributed to the fact that more hybrid configurations are expected to be introduced (54 hybrids versus only 38 diesels in the best-guess scenario). Manufacturers are planning to move more cautiously into the diesel market, most likely due to uncertainties about the diesel's ability to meet the Tier 2, bin 5 emissions standard. Hybrids are more concentrated in the passenger vehicle segments (Figures 19 & 21).

In the 2008 average scenario, 450,000 passenger cars, 220,000 passenger trucks and 70,000 luxury vehicles are hybrids. Only 16,000 hybrid pick-ups are sold and there are no hybrid sportscars or standard vans. In the "best-guess" scenario, 640,000 passenger cars are hybrids, as are 360,000 passenger trucks. Among hybrid technologies, full hybrids are the most prevalent, followed by stop-start and IMA, with ISAD capturing only a small share of the market (Figures 20 & 22).

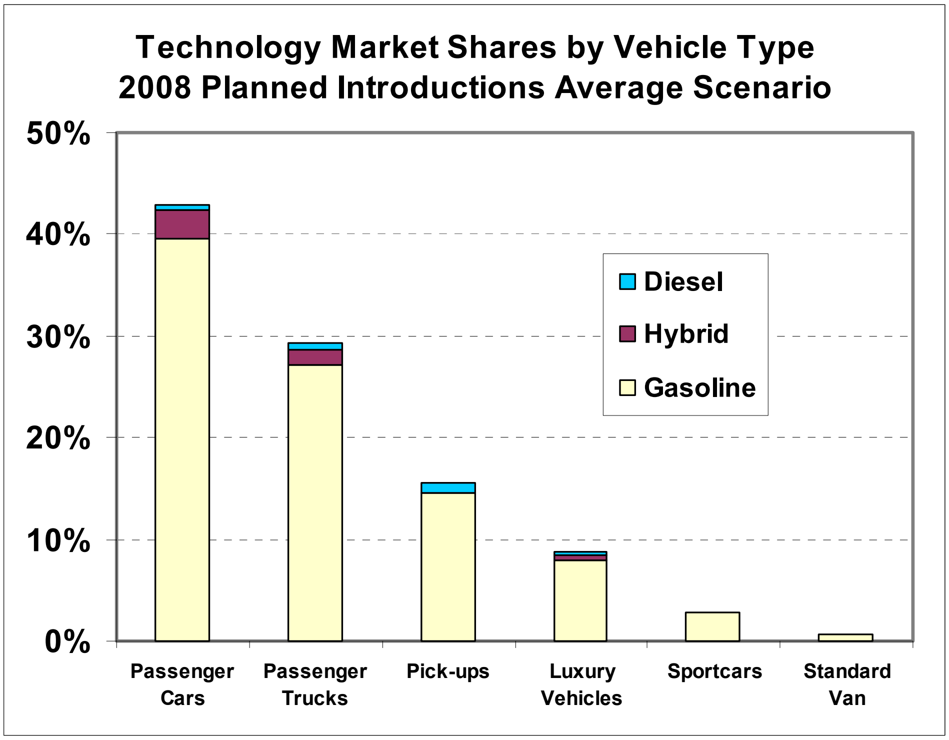

Figure 19. Diesel and Hybrid Vehicle Market Shares by Vehicle Type: 2008 Average Scenario

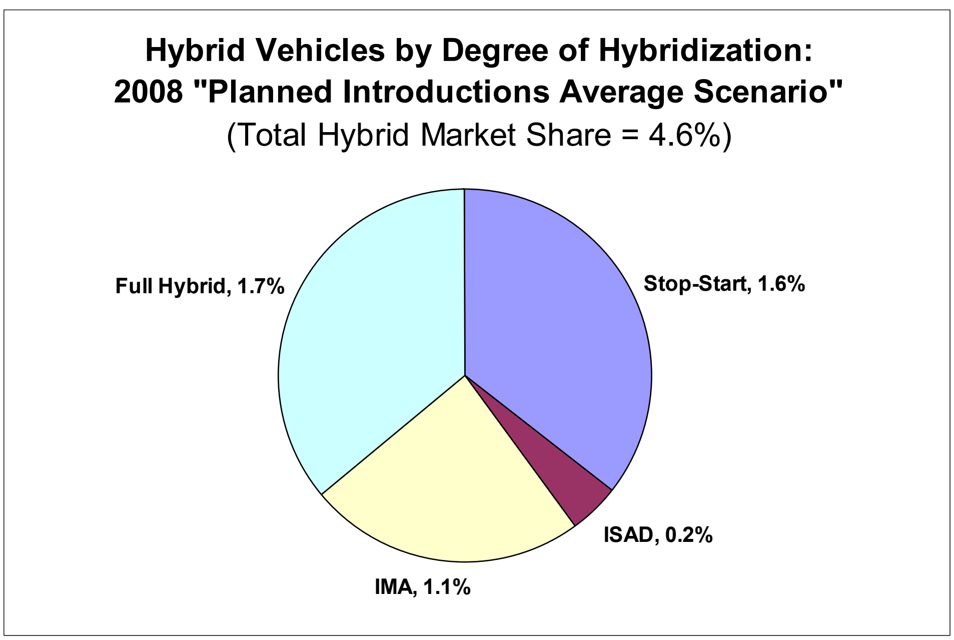

Figure 20. Distribution of Hybrid Vehicle Sales by Degree of Hybridization, 2008 Average Scenario

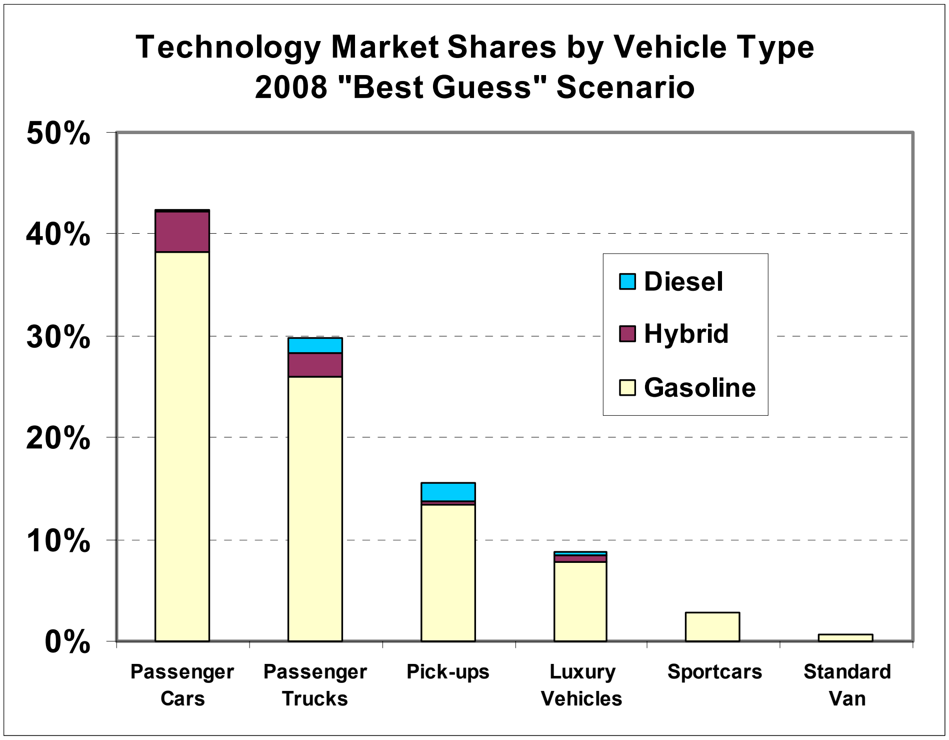

Figure 21. Diesel and Hybrid Market Shares by Vehicle Class, "Best Guess" Scenario

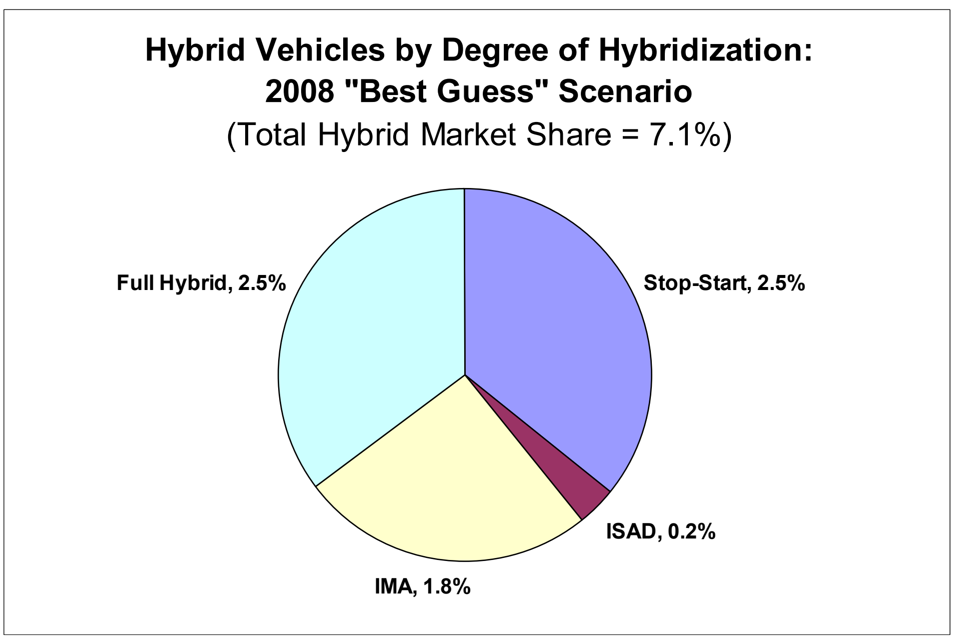

Figure 22. Distribution of Hybrid Vehicle Sales by Degree of Hybridization, 2008 "Best Guess" Scenario

5.3 2012 SCENARIOS

In the 2012 scenarios, diesel's market share ranges from 4.1% (680,000 units) in the average scenario to 7.2% (1.2 million units) in the "best guess" scenario (Figure 23). While light trucks still predominate, sales of diesel passenger trucks (small and large SUVs) outnumber diesel pick-ups. In both scenarios passenger cars are a small market for diesels (30,000 units in the "best guess" scenario; 50,000 in the "average" scenario). Diesels also make inroads in the luxury truck market with 170,000 to 180,000 luxury diesel trucks sold in the 2008 scenarios.

The 2012 hybrid share ranges from 10% (1.7 million units) for the average scenario to 15% (2.5 million units) in the "best guess" scenario (Figure 24). Passenger cars are still the largest hybrid market (0.86 to 1.25 million units), followed by passenger trucks (0.56 to 0.92 million units), but hybrids also achieve some success among pick-ups (60,000 to 70,000) and luxury vehicles (190,000 to 220,000 units).

Full hybrids still capture more than half of the market, followed by the inexpensive stop-start system, but ISAD systems make considerable inroads relative to IMA systems (Figure 25).

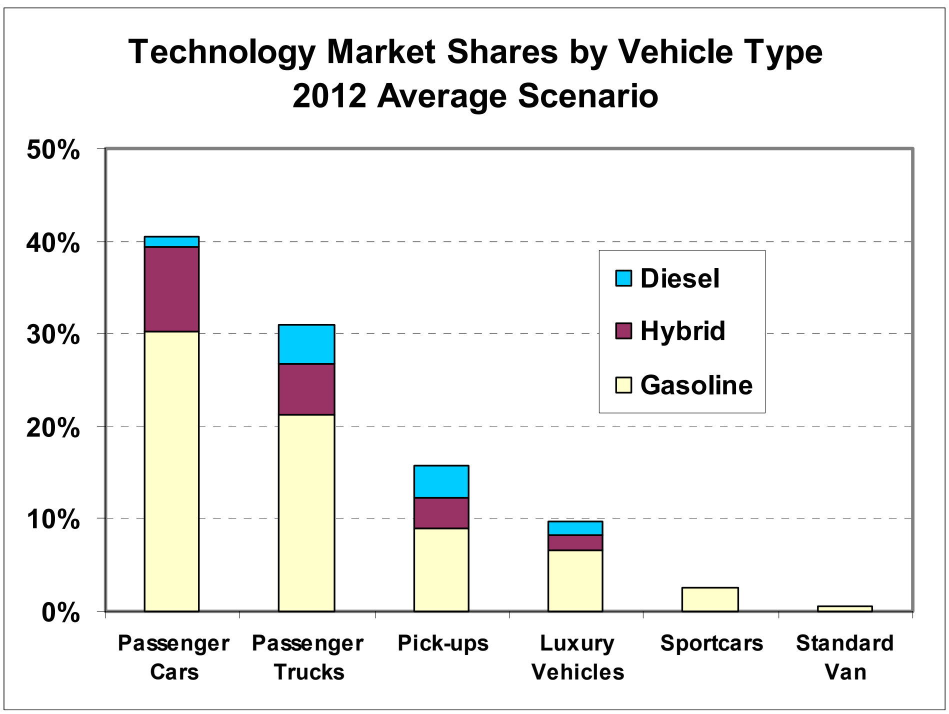

Figure 23. Hybrid and Diesel Market Shares by Vehicle Class, 2012 "Average" Scenario

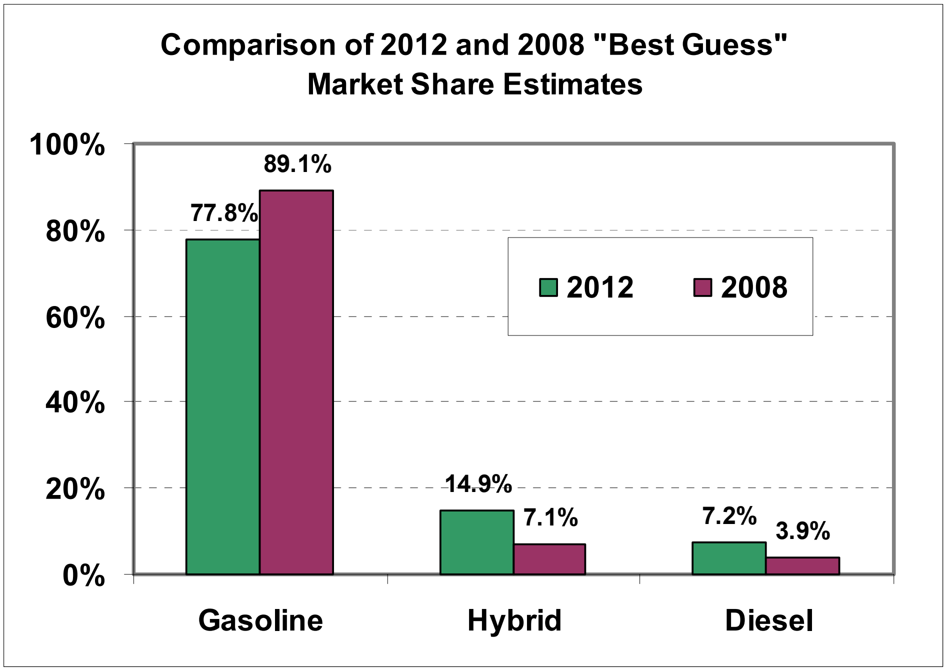

Figure 24. Comparison of Market Success Given Availability on a Single Average Configuration versus a Full Range of Choices

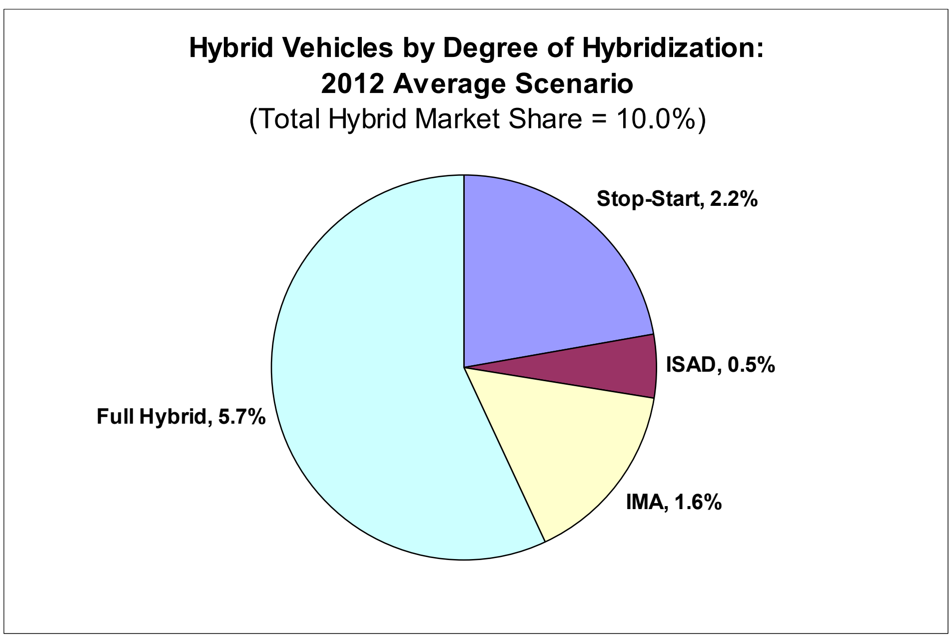

Figure 25. Distribution of Hybrid Vehicle Sales by Degree of Hybridization, 2012 "Best Guess" Scenario

The difference in combined diesel and hybrid sales between the "average" and "best guess" scenarios is an indication of the uncertainty of future market success, even given the specific makes and models assumed to be introduced: a combined 15% versus 32% of the market, respectively (Figures 26 and 27). This reflects the critical importance of the specific configurations on which manufacturers choose to offer these technologies. If diesels and hybrids are available on the more popular body styles and trim lines, they will fare better than if they are available only in a single, average style. This boosts sales and helps makes and models get over the 10,000 units sales threshold. In the "average configuration" scenario, only 72 configurations of hybrids are available (Table 10) whereas in the best guess scenario there are 90 different hybrid configurations.

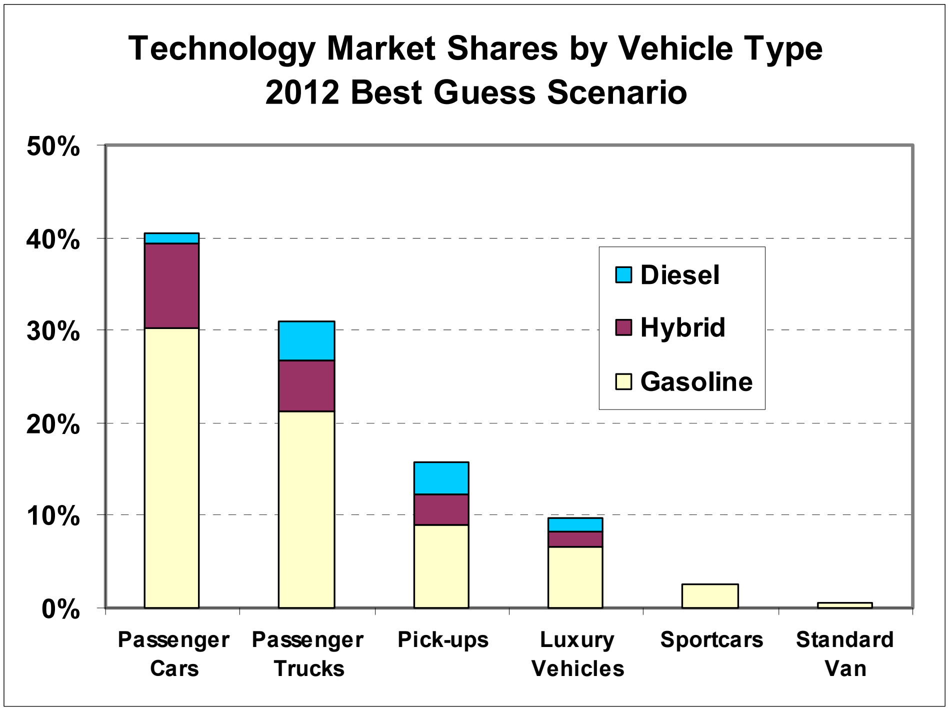

Figure 26. Distribution of Hybrid Technology Types in the 2012 "Best Guess" Scenario

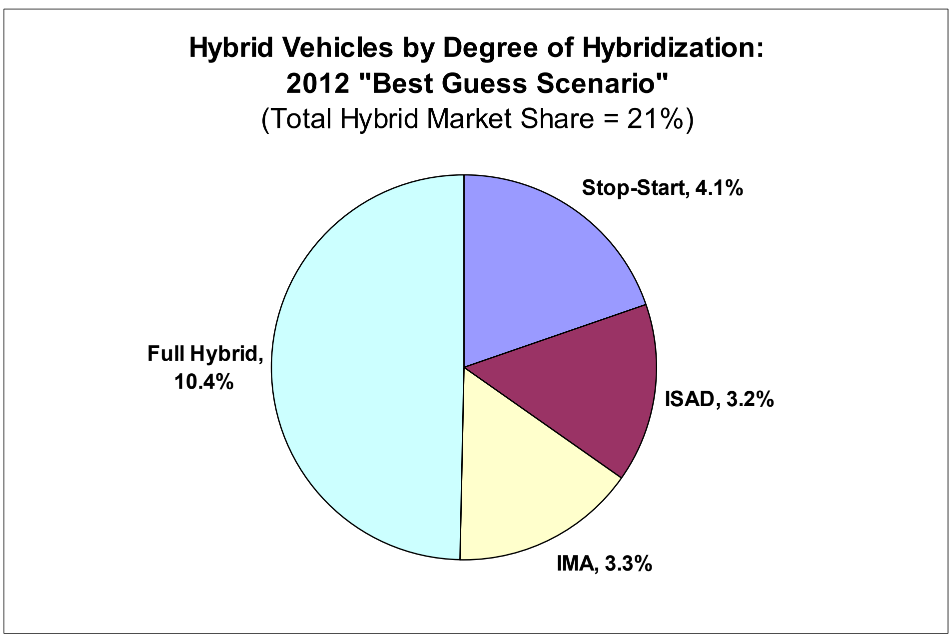

Figure 27. Distribution of Hybrid Vehicle Sales by Degree of Hybridization, 2012 "Best Guess" Scenario

5.4 IMPACTS ON FUEL ECONOMY

The moderate market successes of diesel and hybrid technologies raise average fuel economy by 1.5% to 2% in the 2008 scenario, 3% to 4% in the 2012 scenarios and up to 10% beyond 2012 (Table 12). These scenarios assume no significant policy changes that would drive up fuel economy and no significant change in the price of motor fuel. In the 2008 and 2012 "best guess" scenarios, fuel economy increases from 24.3 MPG to 24.8 and 25.2, respectively (Figure 28). Fuel economy increases the most in the >2012 Diesel/Full Hybrid scenario, reaching 26.7 MPG.

In the 2008 and 2012 scenarios light truck fuel economy gains are somewhat greater than the increases for passenger cars. For example, in the 2012 "best guess" case, light truck MPG is 6.3% higher than the 2002 base level of 21.0 MPG, while passenger car MPG increases by 3.2% over the 2002 base of 28.8 (Table 11).

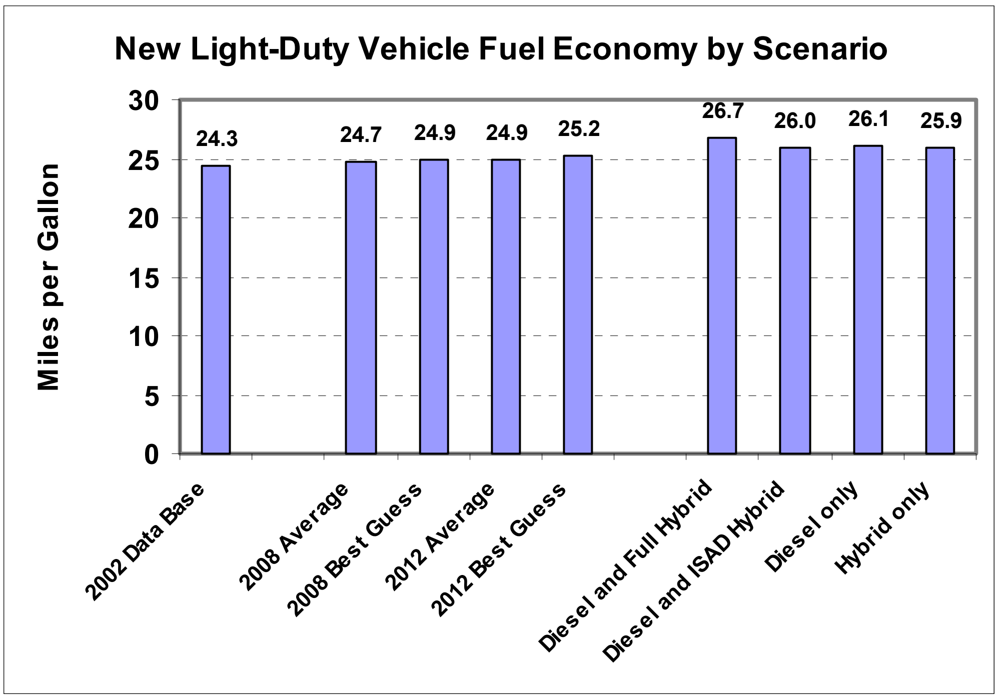

Figure 28. New Light-Duty Vehicle Average Fuel Economy by Scenario

Table 11. Average Fuel Economy of Passenger Cars and Light Trucks

	2008 Best Guess	2008 Average	2012 Best Guess	2012 Average	2002 Base
Passenger cars	29.4	29.2	29.7	29.4	28.8
Light trucks	21.7	21.4	22.3	21.8	21.0
All light-duty vehicles	24.9	24.7	25.2	24.9	24.3

These fuel economy impacts may seem small at first. How could technologies offering 30% to 40% better fuel economy and capturing 40% of the market raise MPG by only about 10%? Part of the answer is harmonic averaging. The harmonic mean of a 0% increase (1.0) with a share of 0.6 and a 35% increase (1.35) with a share of 0.4 is only 11.6%.

$$\frac{1}{\left(\frac{0.6}{1.0}+\frac{0.4}{1.35}\right)} = 1.116 \Rightarrow 11.6\%$$

Equation 9

The difference between the value of 11.6% produced by this rough calculation and the model's calculation of 9.5% is mainly the result of sales mix shifts that mitigate against fuel economy increases. Hybrid and diesel technologies tend to sell better on vehicles with low fuel economy than on those with the highest fuel economy because the value of the fuel saved is greater relative to the cost of the technology. For example, in the Full Hybrid and Diesel scenario, in which any vehicle could be a hybrid or diesel providing it meets minimum sales requirements, 25 of 37 hybrid passenger car models turn out to be large cars, and 113 of 155 total hybrid models are trucks. For diesels, 143 models are trucks out of a total of 210. The success of the new technologies in those market segments increases their overall market share. In addition to raising fuel economy, this causes an overall sales mix shift towards lower fuel economy vehicles, which mitigates the technologies' fuel economy benefit.

Deleting diesel and hybrid makes and models selling under 25,000 units also has a significant effect on fuel economy. If all makes and models selling over 5,000 are included in the Full Hybrid and Diesel scenario, the average MPG of a hybrid increases from 31.3 (all <25,000 excluded) to 32.3. Including diesel makes and models with sales in the interval 5,000-25,000 raises the average MPG of a diesel car from 31.1 to 31.5. Overall, had the lower limit on sales volume been 5,000 instead of 25,000 in the >2012 diesel/full hybrid case, light-duty vehicle average MPG would have been 27.6, an increase of 14% instead of 9.5%. Diesels would capture 28% of the market instead of 24%, and hybrids would claim a 23% market share instead of 16%. When the higher sales limits are imposed, small and midsize cars are the greatest losers. The number of small and midsize makes and models offered drops from 140 hybrids to only 12, and from 161 diesels to only 34. In the following section the sensitivity of the model's predictions to assumptions about scale economies is tested and measured.

Table 12. Summary of Results of Diesel Hybrid Market Scenarios

Scenario	Shares (%)			Sales (1,000s)			Fuel Economy (MPG)				MPG Gain
	Gasoline	Hybrid	Diesel	Gasoline	Hybrid	Diesel	Gasoline	Hybrid	Diesel	Total	Total (%)
2002 Data Base	99.6%	0.1%	0.2%				24.3	58.4	43.4	24.3	
2008 Average	93.0%	4.6%	2.4%	15092	752	387	24.2	32.1	27.9	24.6	1.5%
2008 Best Guess	89.1%	7.1%	3.8%	14484	1148	627	24.3	31.6	26.8	24.8	2.0%
2012 Average	85.1%	10.4%	4.6%	13735	1678	735	24.3	30.1	26.3	24.9	2.3%
2012 Best Guess	67.7%	21.0%	11.3%	10940	3385	1823	24.4	30.0	27.3	25.7	5.7%
Diesel and Full Hybrid	60.4%	16.1%	23.4%	7895	3669	4583	24.3	31.3	31.1	26.6	9.4%
Diesel and ISAD Hybrid	53.8%	27.2%	18.9%	8692	4398	3058	24.3	26.9	30.7	26.0	6.7%
Diesel only	69.6%	0.0%	30.4%	11233	0	4915	24.3		31.5	26.1	7.2%
Hybrid only	74.6%	25.4%	0.0%	12041	4107	0	24.3	32.1		25.9	6.3%
Total Vehicle Sales	16148										

5.5 SENSITIVITY ANALYSIS

The sensitivity of the choice model's predictions to eight key factors was tested using Monte Carlo simulation. In a Monte Carlo simulation inputs are treated as random variables rather than fixed parameters. Samples are drawn from the distributions of the random variables, the model is run, and the process is repeated (here 1,000 times), producing a distribution of output values rather than a single set of values. Given the resulting data base of outputs, one can measure the sensitivity of outputs of interest (e.g., diesel or hybrid market shares) to the input variables by means of regression analysis.

The eight parameters are the incremental prices of (1) hybrid and (2) diesel vehicles, (3) the general sensitivity of vehicle choices to price, the prices of (4) gasoline and (5) diesel fuel (these are so highly correlated, about 0.95, that they should count as only one variable), (6) the overall sensitivity of vehicle choice to price diesel fuel availability, (7) the nameplate, and (8) configuration sales volumes, for hybrids or diesels to be viable on a particular make and model. Table 13 lists the variables and describes the assumed probability distributions. Most of the distributions have the same or almost the same means as the >2012 scenarios described above. A notable exception is the minimum production volume, which has a mean of 15,000 units. This will result in considerably greater hybrid and diesel sales and higher fuel economy than the other >2012 scenarios.

Table 13. Assumptions for Sensitivity Analysis of Hybrid and Diesel Choice

Input Variable	Mean/Mode	Distribution	Minimum	Maximum
Incremental Price of Hybrid Vehicle	1.0 (relative)	Triangular	-50%	+50%
Incremental Price of Diesel Vehicle	1.0 (relative)	Triangular	-50%	+50%
Price Sensitivity	1.0 (relative)	Triangular	-50%	+100%
Price of				
Gasoline /	$1.50	Triangular	$1.25	
Diesel Fuel	$1.50		$1.25	
Availability of Diesel Fuel	50%	Triangular	20%	80%
Minimum Nameplate Sales	15,000	Triangular	5,000	25,000
Minimum Configuration Sales	1,500	Triangular	500	2,500

Of the inputs chosen, all are factors exogenous to the consumers choice except price sensitivity. It would have been of interest to test the sensitivity of the model's predictions to assumptions about the value of fuel savings, range, torque, etc., but these factors are interdependent with the price sensitivity of vehicle choice in ways that are too complex for the Monte Carlo simulation to handle easily.

The sensitivity analysis was carried out using the >2012, Diesel/Full Hybrid scenario. This scenario produced the greatest impact on fleet average fuel economy. Given the probability distributions shown in Table 11, the simulation produced a 90% confidence interval for diesel market share of 16% to 34%, with an expected value of 25% (Figure 29). This is higher than the original >2012 Diesel/Full Hybrid scenario partly because the mean minimum production threshold is lower, 15,000 versus 25,000 units. This allows a greater number of diesel and hybrid makes and models to be offered.

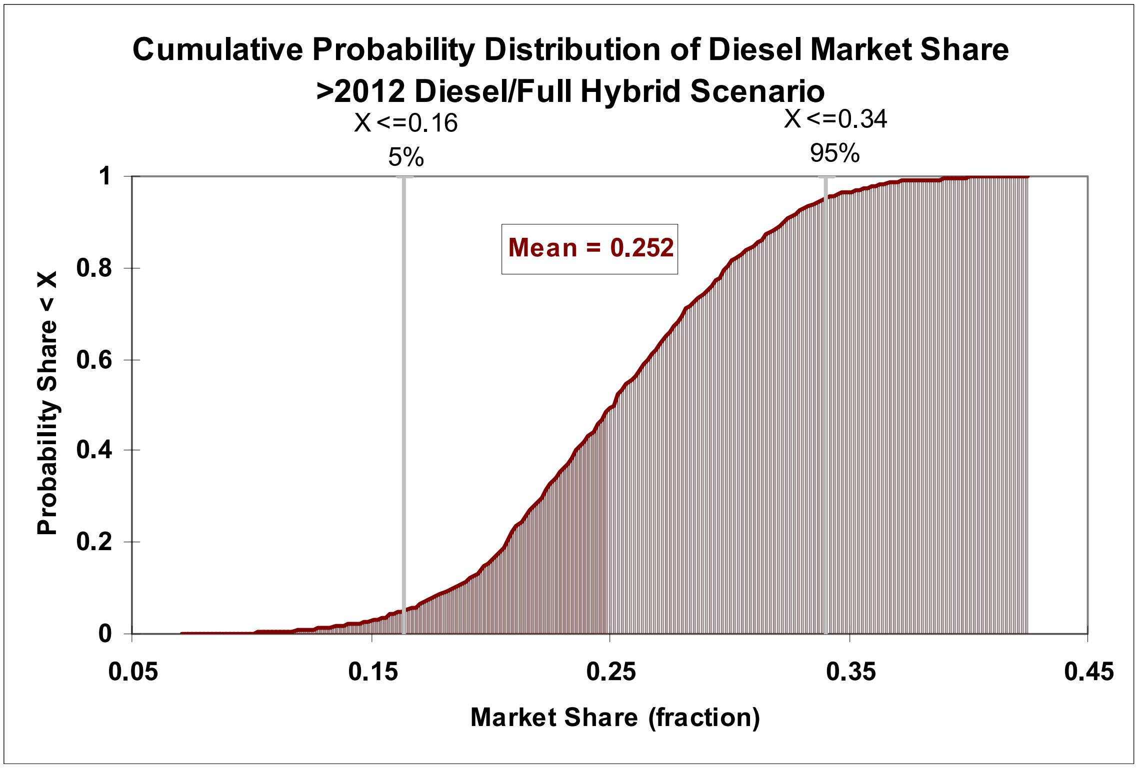

Figure 29. Sensitivity Analysis of Diesel Market Share, >2012 Diesel/Full Hybrid Scenario

The tornado chart (Figure 30) shows which variables have the greatest influence on diesel's market share. Not surprisingly, the incremental price of the diesel vehicle is the single most important factor, with a standardized regression coefficient (similar to a partial correlation) of -0.9: the higher the diesel's price, the lower its market share. Next in importance are the prices of gasoline and diesel fuel: higher gasoline prices boost diesel sales, higher diesel prices lower sales. Gasoline and diesel prices are assumed to be highly correlated; a correlation coefficient of 0.95, which is based on historical data, is used. Thus, it is very unlikely that the two prices would move in opposite direction and their effects will approximately cancel each other most of the time. The price of hybrid vehicles is next in importance, followed by diesel fuel availability. Diesel and hybrid power trains compete to a limited degree, so that as the price of hybrids increases, sales of diesels increase somewhat. The greater the price elasticity of vehicle choice the smaller the diesel share will be. Since the price elasticity is an assumed parameter, it is comforting that its influence is not great despite varying -50%/+100% from its average value. The final two variables show that the higher the minimum production volume the lower diesel sales will be due to a reduction in diversity of choice.

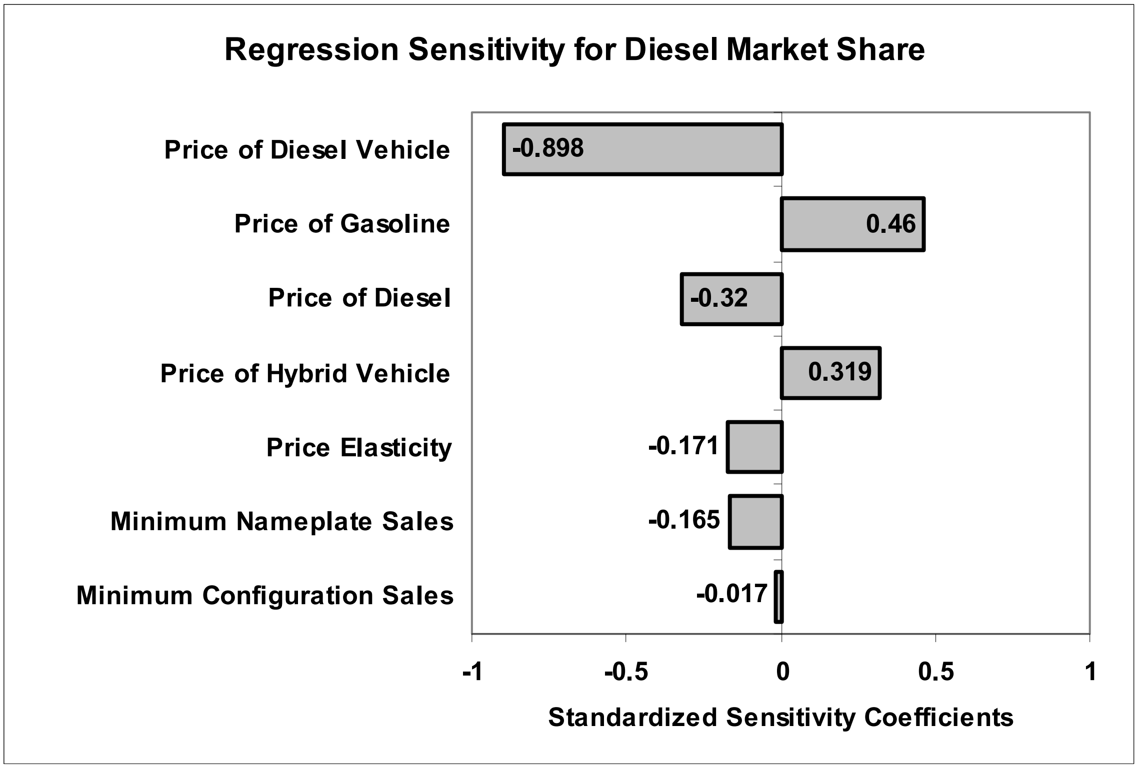

Figure 30. Tornado Chart Showing Influence of Inputs on Diesel Market Share

Hybrid market shares have a similarly wide 90% confidence interval from 18% to 29%, with a mean of 19% (Figure 31). Again, the chief determinant of the hybrid's market share is its own incremental price (Figure 32). The second most important determinant, however, is the assumed price elasticity of choice, indicating that the hybrid forecasts are much more sensitive to this assumption than those for diesels. The minimum production volume is about equally important for hybrids as for diesels. The fact that the predicted hybrid market share is more sensitive to the assumed price sensitivity suggests that the hybrid forecasts should be considered somewhat more uncertain than the diesel forecasts. The hybrid share will increase when diesel prices increase, but it may be a surprise that the hybrid share decreases when gasoline prices increase. This indicates that in the Diesel/Full Hybrid scenario, hybrids compete more directly with diesel vehicles than with conventional gasoline vehicles. In addition, because gasoline and diesel prices are highly correlated, in most cases they will rise together and the net effect will be an increase in hybrid's market share.

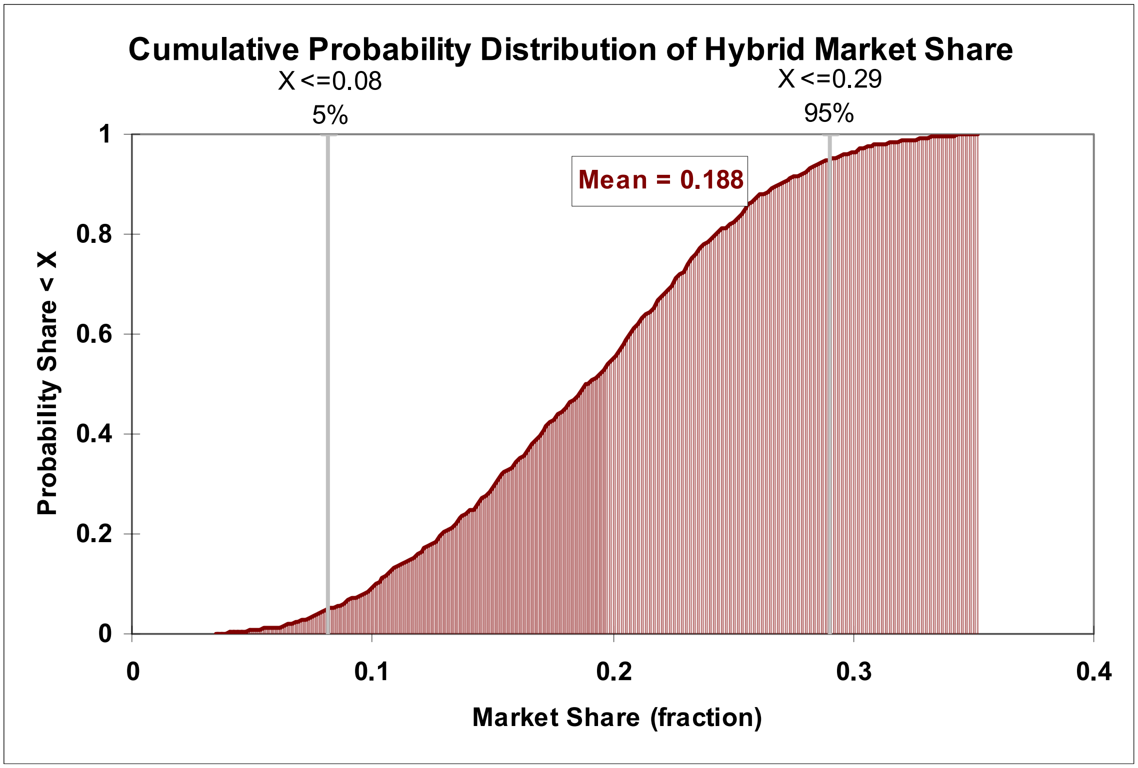

Figure 31. Sensitivity Analysis of Hybrid Market Share, >2012 Diesel/Full Hybrid Scenario

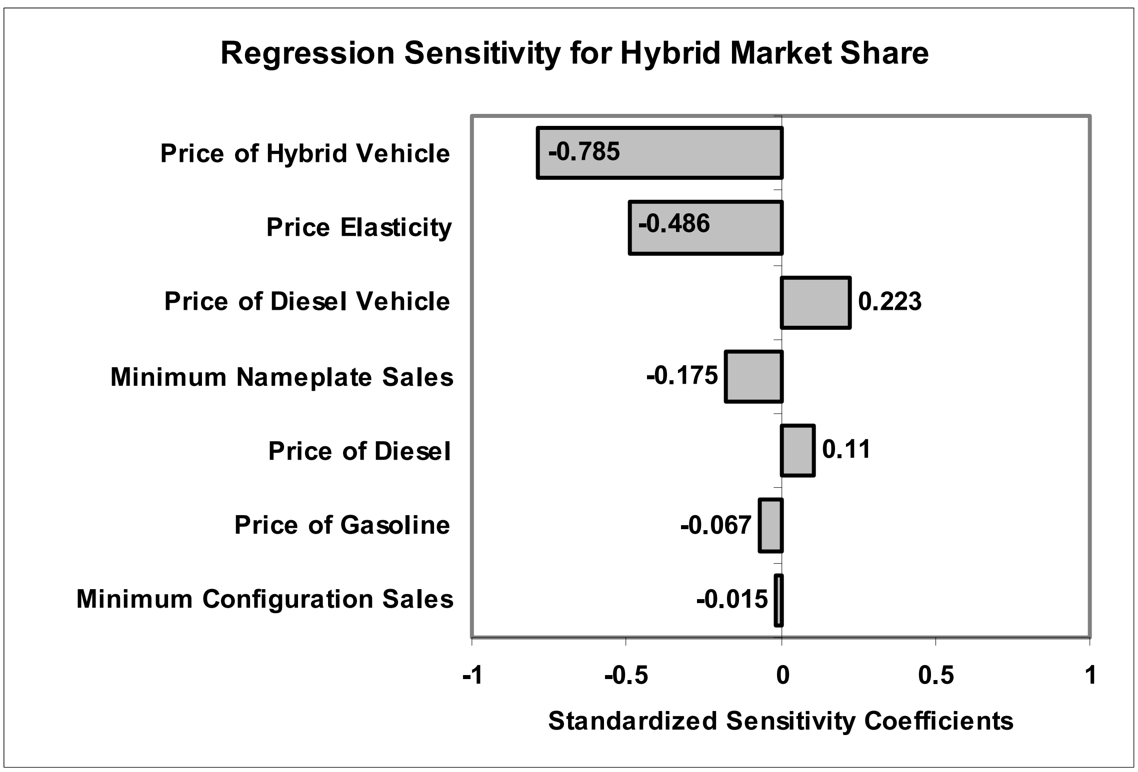

Figure 32. Tornado Chart Showing Influence of Inputs on Hybrid Market Share

The average fuel economy of new light-duty vehicles has a confidence interval ranging from 26.1 to 27.8 MPG, with a mean value of 27 (Figure 33). This is higher than the mean value of 26.6 for the original >2012 Diesel/Full Hybrid scenario partly because the mean minimum production value of the sensitivity analysis is 15,000 rather than 25,000.

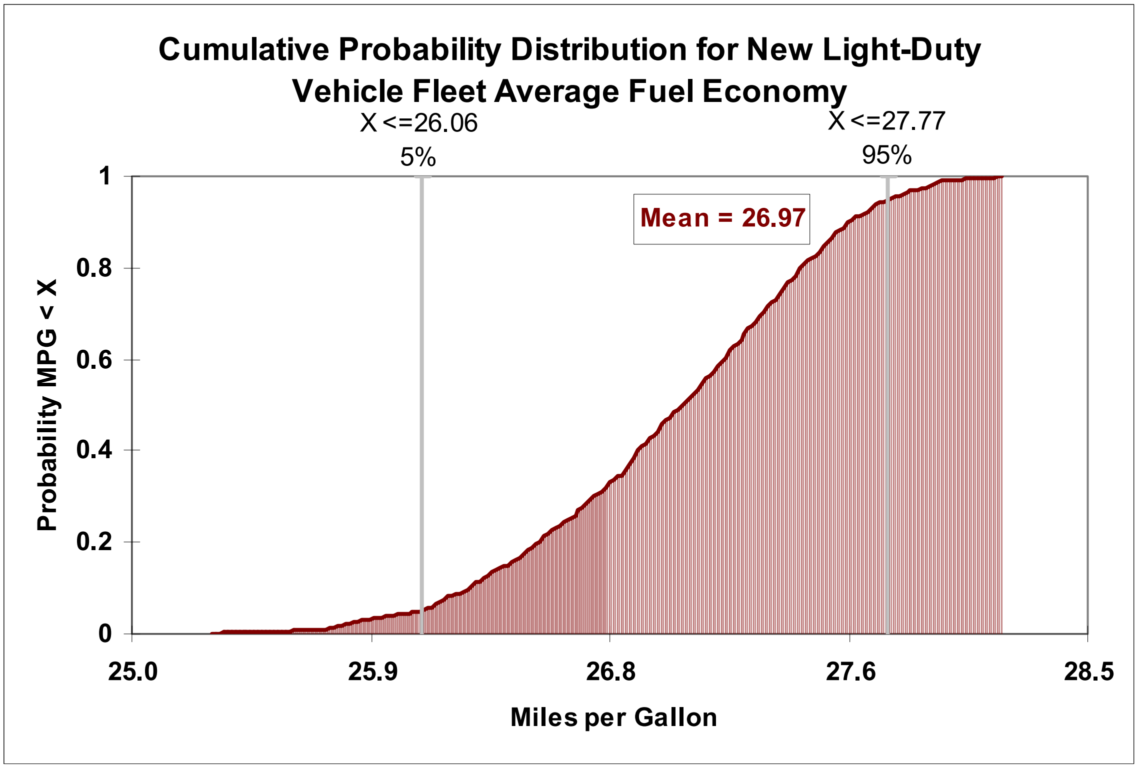

Figure 33. Sensitivity Analysis of LDV Fuel Economy, >2012 Diesel/Full Hybrid Scenario

The most important determinants of the average MPG of new light-duty vehicles are the assumed price elasticities of vehicle choice and the incremental prices of hybrid and diesel vehicles (Figure 34). If consumers are much more sensitivity to price than assumed in this analysis, the MPG impacts of diesels and hybrids could be considerably lower. Next in importance are the incremental prices of diesels and hybrids, hardly a surprise. Also, if the range of choices available to consumers as influenced by the minimum nameplate sales requirement are much more limited, again the MPG impact will be reduced. Finally, an increase in the price of gasoline will tend to raise MPG as consumers shift to hybrids and to conventional gasoline vehicles with higher fuel economy. An increase in diesel price, however, tends to discourage diesels sales which have a net negative impact on fleet average fuel economy. Greater diesel fuel availability has no significant impact.

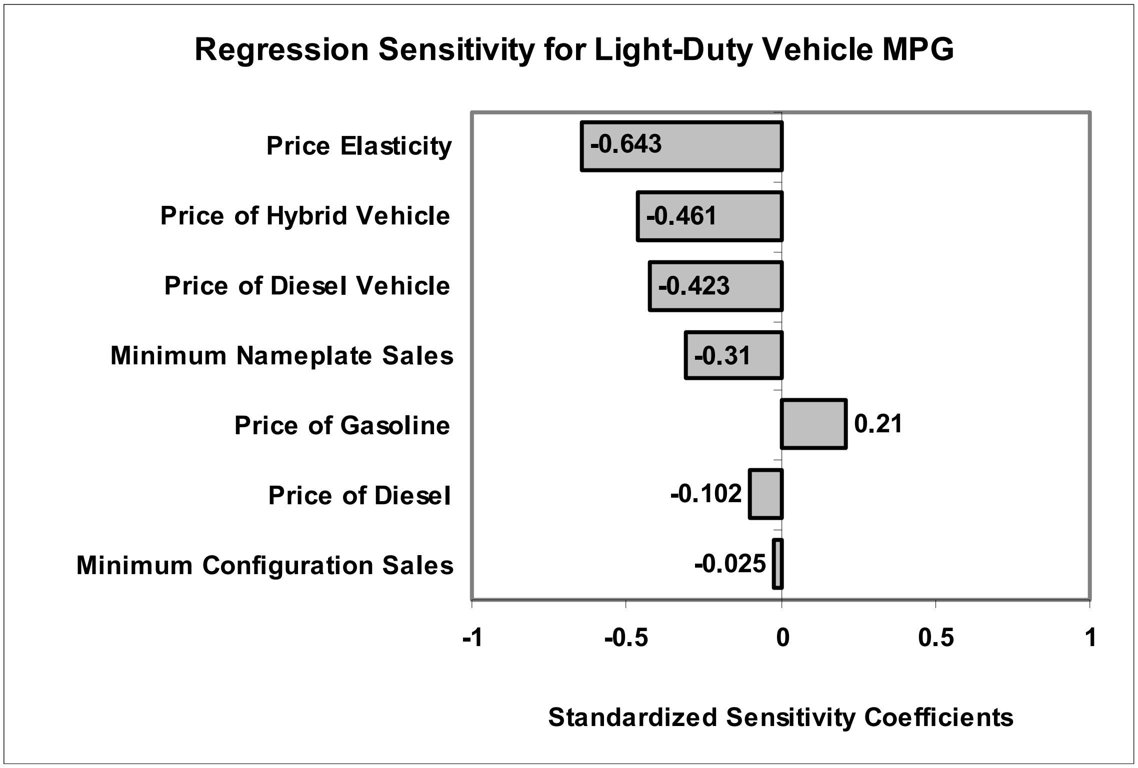

Figure 34. Tornado Chart Showing Influence of Inputs on LDV Fuel Economy

6. CONCLUSIONS

This analysis indicates that if diesels and hybrids can achieve the technology goals we expect they will, they will have a future as mainstream drivetrain technologies for light-duty vehicles in the United States. Diesels must meet Tier 2 bin 5 emissions standards, an achievement that is almost but not quite within reach at the present. Hybrids must reduce costs to roughly half the cost increment of the first generation hybrids, a goal they are well on their way to reaching. If they can achieve these goals, diesels and hybrids should be able to capture 10-15% of the U.S. light-duty vehicle market by 2008, and 15-25% by 2012 (Figure 35).

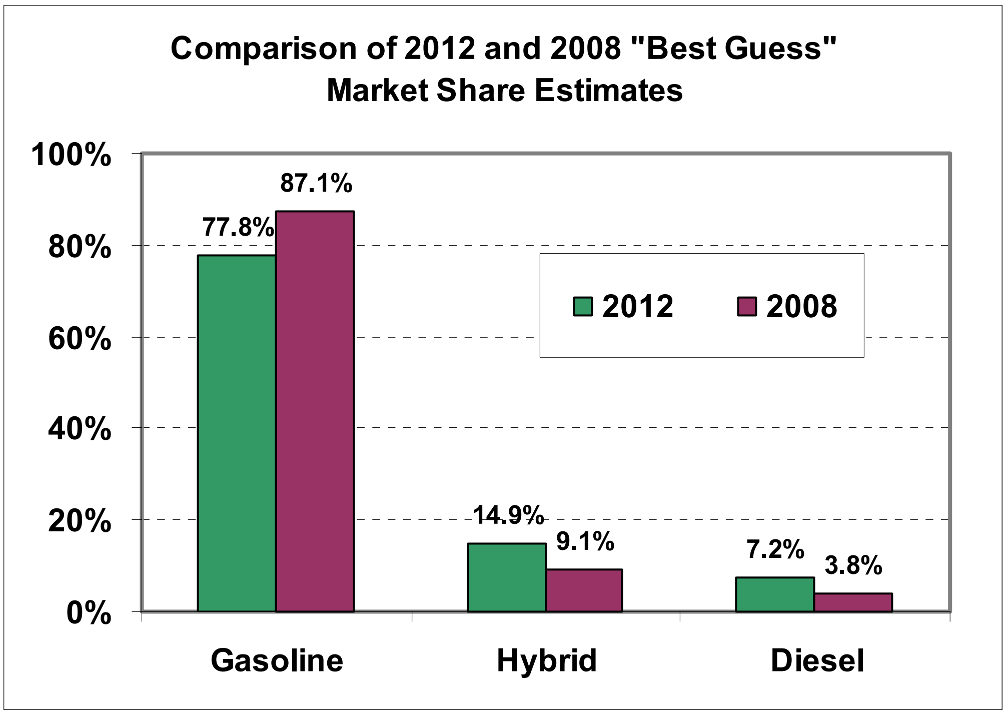

Figure 35. Comparison of Market Success in 2008 and 2012 under "Best Guess" Scenarios

Because of their higher costs, the combined market share of diesels and hybrids is likely to be limited to half or less than half of all light-duty vehicles even in the long-run, unless policy and market conditions change significantly in their favor. Such changes are not unlikely, given continuing concerns about energy security and global climate change. As a result, their long-run impact on fuel economy is likely to be about a 10% increase in the absence of additional policy initiatives to boost fuel economy. Largely, this is a result of harmonic averaging: the harmonic mean of a 0% and 35% increase in fuel economy is a 13% increase, not a 17.5% increase. In addition, shifts in the mix of vehicles sold mitigate somewhat the potential fuel economy gain. Still, it is certainly possible, and indeed likely that increased sales of diesels and hybrids could raise new light duty vehicle fleet fuel economy by 1% to 3% by 2008, and by 3% to 5% by 2012, without new policies.

The market success of diesels and hybrids is highly dependent on manufacturers' decisions to introduce a diverse array of makes and models in different vehicle classes. In 2008, when diesel and hybrid offerings are assumed to be very limited, diesels capture only 2-4% and hybrids only 4-7% of the light-duty market. In >2012, when the number of diesel configurations is much greater either can claim 20-30% of the market. Manufacturers face considerable risk in introducing diesel and hybrid vehicles due to their higher costs and the possibility that diesels may be unable to meet Tier 2, bin 5 standards. Thus, the timing of diesel and hybrid introductions and therefore their market success is uncertain, despite announced product plans.

REFERENCES

Adler, T., L. Wargelin, L. Kostyniuk, C. Kalavec and G. Occhiuzzo. 2004. "Experimental Assessment of Incentives for Alternate Fuel Vehicles," presented at the *83rd Meeting of the Transportation Research Board*, Washington, DC, January 11-15.

Berry, S., J. Levinson and A. Pakes. 1995. "Automobile Prices in Market Equilibrium," *Econometrica*, vol. 64, no. 4, pp. 841-890.

Birch, S. 2003. "Ricardo's Diesel Future," *Automotive Engineering International*, vol. 111, no. 2, pp. 78-79.

Bordley, R. 1994. "An Overlapping Choice Set Model of Automotive Price Elasticities," *Transportation Research B*, vol. 28B, no. 6, pp. 401-408.

Burke, A. and E. Abeles. 2004. "Feasible CAFE Standard Increases Using Emerging Diesel and Hybrid-Electric Technologies for Light-Duty Vehicles in the United States," UCD-ITS-RR-04-9, Institute of Transportation Studies, University of California at Davis, Davis, CA, April.

CARAVAN. 2004. "ORC Study #713228," conducted for the National Renewable Energy Laboratory by Opinion Research Corporation, Princeton, NJ, May 27, 2004.

CNN.com. 2004. "Hybrid vehicles electrify 2003 sales," http://www.cnn.com/2004/TECH/science/04/22/hybrid.popular.ap/, April 22.

Donndenlinger, J.A. and H.E. Cook. 1997. *Methods for Analyzing the Value of Automobiles*, SAE Technical Paper 970762, Society of Automotive Engineers, Warrendale, PA.

Duleep, K.G. 2004. "Diesel Technology and Product Plan Review," presentation to the U.S. Department of Energy, Office of Policy, prepared by Energy and Environmental Analysis, Inc., Arlington, Virginia, April.

Duleep, K.G. 2003. "Analysis of Hybrid Technology," presentation to the U.S. Department of Energy, Office of Policy, prepared by Energy and Environmental Analysis, Inc., Arlington, Virginia, November.

Energy Information Administration. 2004. *Annual Energy Outlook 2004*, DOE/EIA-0383-04, U.S. Department of Energy, Washington, DC, January.

Greene, D.L. 2001. *TAFV Alternative Fuels and Vehicles Choice Model Documentation*, ORNL/TM-2001/134, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July.

Greene, D.L. 1998. "Fuel Availability and Alternative Fuel Vehicles," *Energy Studies Review*, vol. 8, no. 3, pp. 215-231.

Greene, D.L. 1994. *Alternative Fuels and Vehicles Choice Model*, ORNL/TM-12738, Center for Transportation Analysis, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October.

Greene, D.L. 1986. "The Market Share of Diesel Cars in the U.S.A., 1979-83," *Energy Economics*, vol. 8, no. 1, pp. 13-21.

Greene, D.L. and J.T. Liu. 1988. "Automotive Fuel Economy and Consumers' Surplus," *Transportation Research A*, vol. 22A, no. 3, pp. 203-218.

Hadder, G.R. 2004. "High Quality Diesel Fuel Production, Logistics and Consumer Costs," Engineering Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN, May.

Irvine, F.O. 1993. "Demand Equations for Individual New Car Models Estimated Using Transaction Prices with Implications for Regulatory Issues," *Southern Economic Journal*, vol. 49, no. 3, pp. 764-782.

J.D. Power and Associates. 2003. "Hybrid Electric Vehicle Sales Expected to Increase Dramatically over Next Decade," news release, Westlake Village, CA, May 28.

Kleit, A.N. 1990. "The Effect of Annual Changes in Automobile Fuel Economy Standards," *Journal of Regulatory Economics*, vol. 2, pp. 515-172.

McCarthy, P.S. 1996. "Market Price and Income Elasticities of New Vehicle Demands," *The Review of Economics and Statistics*, vol. LXXVII, no. 3, pp. 543-547.

McManus, W. 2004. "Hybrids and Clean Diesels: If you Build It, Will They Come?" J.D. Power and Associates, Detroit, Michigan.

McManus, W. 2003. "Consumer Demand for Alternative Powertrain Vehicles," J.D. Power and Associates, Detroit, Michigan.

Miller, J.B. 2004. "Higher Gas Prices May Fuel Hybrid Sales," Norwich Bulletin, www.norwichbulletin.com/news/stories/20040609/localnews/603888.html , June 9, 2004.

(NRC) National Research Council. 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, National Academy Press, Washington, DC.

Nicholas, M.A., S.L. Handy and D. Sperling. 2004. "Siting and Network Analysis Methods for Hydrogen Stations Using Geographical Information Systems," presented at the *83rd Annual Meeting of the Transportation Research Board*, January 11-15, 2004, Washington, DC.

Patterson, P. 2004. Personal communication, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC, July 16.

Qualters, C. 2004. "Diesel Market Discussion," private briefing, Bosch, GmbH, Farmington Hills, MI, February 5.

Santini, D. 2004. "Customer Benefits and Attributes of Diesels and Hybrids: Market Competitors or Complements?" presentation slides dated April 14, 2004, Center for Transportation Research, Argonne National Laboratory, Argonne, IL.

Schmidt's Auto Publications. 2004. "Diesel Still Sizzling," AID Newsletter no. 0401, Warwick, England.

Schmidt's Auto Publications. 2003. "Diesels at 40% and Climbing," AID Newsletter, no. 0302, Warwick, England, and on-line update, "Diesel Car Prospects to 2009," May 17, 2003, www.eagleaid.com/dsltxt.htm.

Toyota Motor Sales, U.S.A., Inc. 2004. "The 2004 Prius – A Wildly Successful Launch!" *PRIUS View*, Issue 5, Spring 2004, p. 1.

Toyota Motor Sales, U.S.A., Inc. 2003. "Toyota Prius Hybrid Production Increased by 31 Percent for U.S. Market," www.toyota.com/about/news/product/2003/12/08-1-Prius-Production.html , December 10.

APPENDIX A

CALCULATION OF CONFIGURATION AND CLASS CONSTANTS

APPENDIX A

CALCULATION OF CONFIGURATION AND CLASS CONSTANTS

Given the base year market shares for every configuration, the measured attributes of configurations, and the calculated attribute weights, an intercept term can be estimated for each configuration that causes the NMNL model predictions to exactly match base year sales. These intercept terms reflect the average value of all unmeasured attributes. The same can be done to insure that the NMNL model exactly predicts base year vehicle class shares.

Let p_o be the base year sales share of an arbitrarily chosen reference configuration. The logarithm of the ratio of any configuration's market share to the reference market share is equal to the difference in the utility indices of the two vehicles.

$$\ln\left(\frac{p_i}{p_o}\right) = \ln\left(\frac{e^{U_i}}{e^{U_o}}\right) = U_i - U_o = A_i - A_o + \Delta U_i$$

Equation A-1

In equation A-2, ΔU_i is the difference of the measured utility indices of configuration i and the reference configuration. Solving for A_i , and summing over all configurations, i=1, n, and imposing the additional condition that $\sum A_i = 0$, gives an equation that can be solved for A_o .

$$A_o = \frac{1}{n}\left(\sum_{i=1}^{n}\left(\Delta U_i - \ln\left(\frac{p_i}{p_o}\right)\right)\right)$$

Equation A-2

Inserting this value for A_o back into equation A-1 yields the equation for estimating all remaining A_i 's.

$$A_i = A_o + \ln\left(\frac{p_i}{p_o}\right) - \Delta U_i$$

Equation A-3

Estimation of vehicle class constants follows the same method; the difference of the expected class utilities are used in place of ΔU_i .

CALCULATION OF AVERAGE CONSTANT TERMS

The average configuration is intended to be a vehicle that is typical of (or the average of) all the configurations of a make and model with respect to all attributes not explicitly included in the vehicle choice model (i.e., other than price, fuel economy, range, fuel availability and torque).

The average nameplate constant was defined as follows. Let the average share for the i=1,n_i configurations of nameplate i be $\mathbf{s}_i$.

$$\bar{s}_i = \frac{1}{n_i}\sum_{i=1}^{n_i}\frac{e^{U_i}}{\sum_{j=1}^{n_i} e^{U_j}} \qquad \text{and} \qquad U_i = A_i + \sum_{k=1}^{K} b_k x_{ik} = A_i + Y_i$$

Equation A-4

We wish to find an average constant term, **A**, such that if every configuration of nameplate i had a constant term equal to **A**, nameplate i would have exactly the same average share, $\mathbf{s}_i$.

$$\sum_{i=1}^{n_i} e^{A_i + Y_i} = \sum_{i=1}^{n_i} e^{A} e^{Y_i}$$

$$A = \ln\left[\frac{\sum_{i=1}^{n_i} e^{A_i + Y_i}}{\sum_{i=1}^{n_i} e^{Y_i}}\right]$$

Equation A-5

A is the average unobserved value of the configurations of nameplate i. It is not the constant term that would give a vehicle with the average observed characteristics of the configurations of nameplate i the average market share of those configurations.

APPENDIX B

ASSUMED PRODUCT INTRODUCTIONS

APPENDIX B

ASSUMED PRODUCT INTRODUCTIONS

Makes, Models, Configurations of Hybrid and Diesel Light-Duty Vehicles Assumed to Be Available in 2008 "Best Guess Scenario"

2008 Hybrid Cars

Manufacturer	Division	Name	2002 Sales	2002 Price	Hybrid Type
DCC	Mer-Benz	A-Class	24,000	$22,500	ISAD
GMC	Chevy	Cavalier	210,244	$15,890	SS
Honda	Honda	Civic FIT	20,000	$14,860	IMA
Honda	Honda	Civic FIT	10,000	$13,860	IMA
Toyota	Toyota	Echo	9,229	$11,780	SS
Toyota	Toyota	Echo	23,266	$11,385	SS
VWA	VWA	Jetta	47,846	$18,775	ISAD
VWA	VWA	Jetta Wagon	5,605	$19,575	ISAD
GMC	Pontiac	Grand Am	2,059	$18,465	SS
GMC	Pontiac	Grand Am	67,168	$19,290	SS
GMC	Saturn	L100/200	63,071	$19,065	SS
GMC	Saturn	LW200	5,552	$20,130	SS
GMC	Saturn	LW200	364	$19,270	SS
Honda	Acura	Acura 3.2TL	60,860	$28,880	IMA
Honda	Honda	Civic dx 4Dr	107,863	$14,060	IMA
Toyota	Lexus	ES 300	70,517	$33,065	FULL
Toyota	Toyota	Prius	22,737	$19,995	FULL
FMC	Ford	Taurus	54,537	$22,445	FULL
FMC	Ford	Taurus Wagon	9,942	$21,495	FULL
FMC	Mazda	626	35,363	$19,525	FULL
FMC	Mazda	626	12,787	$22,425	FULL
FMC	Mercury	Sable	59,858	$20,020	FULL
FMC	Mercury	Sable Wagon	4,201	$23,560	FULL
GMC	Chevy	Malibu	144,946	$19,855	SS
Honda	Honda	Accord	122,800	$25,300	IMA
Nissan	Nissan	Altima	146,503	$18,849	FULL
Toyota	Toyota	Camry	93,460	$23,700	FULL

2008 Hybrid Trucks

Manufacturer	Division	Name	2002 Sales	2002 Price	Hybrid Type
Honda	Honda	Odyssey	148,857	$26,750	IMA
Toyota	Toyota	Sienna	85,417	$28,012	FULL
FMC	Ford	Escape 4x2	67,376	$22,075	FULL
GMC	Chevrolet	Blazer 2WD	1,394	$25,005	SS
GMC	Chevrolet	Blazer 2WD	36,159	$26,005	SS
GMC	Chevrolet	Blazer 4WD	437	$27,005	SS
GMC	Chevrolet	Blazer 4WD	65,351	$28,005	SS
GMC	Saturn	Vue AWD	1,052	$18,860	SS
GMC	Saturn	Vue FWD	717	$17,265	SS

Manufacturer	Division	Name	Sales	Price	Hybrid Type
Honda	Honda	CR-V	29,053	$19,050	IMA
Honda	Honda	CR-V	99,884	$20,250	IMA
TKM	Mazda	Tribute 4x2	22,249	$21,485	FULL
TKM	Mazda	Tribute 4x4	24,854	$22,685	FULL
Toyota	Toyota	Highlander 2WD	42,567	$25,460	FULL
Toyota	Toyota	Rav4 2WD	48,231	$17,575	FULL
Toyota	Toyota	Rav4 4WD	39,291	$18,975	FULL
GMC	Chevrolet	C1500 Tahoe 2WD	61,519	$33,409	FULL
GMC	GMC	C1500 Yukon 2WD	7,193	$33,596	FULL
GMC	GMC	K1500 Yukon 4WD	1,746	$34,996	FULL
GMC	Chevrolet	C1500 Suburban 2WD	49,314	$36,143	FULL
GMC	Chevrolet	K1500 Suburban 4WD	71,668	$38,209	FULL
GMC	Chevrolet	K1500 Tahoe 4WD	5,017	$35,475	FULL
GMC	GMC	C1500 Yukon XL 2WD	16,472	$36,501	FULL
GMC	GMC	K1500 Yukon XL 4WD	22,731	$39,034	FULL

2008 Diesel Cars

Manufacturer	Division	Name	2002 Sales	2002 Price
DCC	Mer-Benz	A-Class	24,000	$22,500
VWA	VWA	Golf	3,255	$15,250
VWA	VWA	Golf TDI	1,655	$17,420
VWA	VWA	Golf TDI	6,025	$16,545
VWA	VWA	Jetta	7,133	$18,950
VWA	VWA	Jetta	11,326	$20,135
VWA	VWA	Jetta	1,102	$24,700
VWA	VWA	Jetta Wagon	340	$21,000
VWA	VWA	New Beetle	4,766	$18,775
VWA	VWA	Audi A4	1,174	$33,190
VWA	VWA	Passat	8,167	$21,750
VWA	VWA	Passat Wagon	8,379	$23,625
VWA	VWA	Passat Wagon	695	$25,050
BMW	BMW	525i	12,579	$38,275
DCC	Mer-Benz	C320	12,483	$38,135
DCC	Mer-Benz	E320	14,749	$48,450
DCC	Mer-Benz	S 430	14,919	$71,850
VWA	Audi	Audi A6	2,529	$36,400
VWA	Audi	Audi A6	1,412	$50,650
VWA	Audi	Audi A6 Avant	2,148	$39,350

2008 Diesel Trucks

Manufacturer	Division	Name	2002 Sales	2002 Price
DCC	Jeep	Liberty 2WD	46,124	$22,994
DCC	Jeep	Liberty 4WD	157,615	$24,479
DCC	Jeep	Wrangler	25,831	$19,860
Isuzu	Isuzu	Trooper	7,917	$29,405
FMC	Ford	Expedition 4x2	32,851	$30,430

Manufacturer	Division	Name	2002 Sales	2002 Price
FMC	Ford	Expedition 4x4	4,096	$33,300
GMC	Chevrolet	C1500 Tahoe 2WD	14,214	$32,709
GMC	Chevrolet	K1500 Tahoe 4WD	97,036	$27,857
GMC	GMC	C1500 Yukon 2WD	16,240	$34,296
GMC	GMC	K1500 Yukon 4WD	24,313	$34,996
DCC	Dodge	Dakota 2WD	43,412	$19,625
DCC	Dodge	Dakota 4WD	16,789	$22,835
FMC	Ford	F150 4x2	108,687	$22,520
FMC	Ford	F150 4x4	35,368	$25,935
GMC	Chevrolet	C1500 Silverado 2WD	72,250	$24,184
GMC	Chevrolet	K1500 Silverado 4WD	150,295	$27,134
GMC	GMC	C1500 Sierra 2WD	22,782	$21,868
GMC	GMC	K1500 Sierra 4WD	44,469	$26,435
Nissan	Nissan	Titan 4x2	40,000	$24,000
Nissan	Nissan	Titan 4x4	22,000	$26,500
Toyota	Toyota	Toyota Tundra 2WD	42,344	$22,975
DCC	Mer-Benz	ML320	30,686	$37,595
Toyota	Toyota	Land Cruiser Wagon 4	6,331	$52,595
VWA	Audi	Allroad Quattro	4,463	$40,950

Makes, Models, Configurations of Hybrid and Diesel Light-Duty Vehicles Assumed to be Available in 2012 "Best Guess" Scenario

2012 Hybrid Cars

Manufacturer	Division	Name	2002 Sales	2002 Price	Hybrid Type
DCC	Mer-Benz	A-Class	24,000	$22,500	ISAD
FMC	Ford	Excort	40,921	$15,015	SS
GMC	Chevy	Cavalier	210,244	$15,890	SS
Honda	Acura	RSX	16,507	$21,850	IMA
Honda	Honda	Civic ex	540	$14,860	IMA
Honda	Honda	Civic ex	960	$13,860	IMA
Nissan	Nissan	New Model	12,000	$11,750	SS
Nissan	Nissan	New Model	28,000	$12,650	SS
Toyota	Toyota	Echo	9,229	$11,780	SS
Toyota	Toyota	Echo	23,266	$11,385	SS
VWA	VWA	Jetta	47,846	$18,775	ISAD
VWA	VWA	Jetta Wagon	5,605	$19,575	ISAD
BMW	BMW	325i	30,738	$29,425	ISAD
Neon	Dodge	Neon	103,205	$15,090	ISAD
DCC	Dodge	Neon	16,048	$15,915	ISAD
FMC	Ford	Focus	83,424	$16,050	SS
FMC	Ford	Focus	95,367	$16,050	SS
FMC	Ford	Focus Wagon	33,265	$17,565	SS
FMC	Volvo	S60	20,570	$27,125	FULL
GMC	Pontiac	Grand Am	2,059	$18,465	SS
GMC	Pontiac	Grand Am	67,168	$19,290	SS
GMC	Saturn	L100/200	63,071	$19,065	SS
GMC	Saturn	LW200	5,552	$20,130	SS
GMC	Saturn	LW200	364	$19,270	SS
Honda	Acura	Acura 3.2TL	60,860	$28,880	IMA

Manufacturer	Division	Name	Sales	Price	Hybrid Type
Honda	Honda	Civic dx 4Dr	107,863	$14,060	IMA
Suzuki	Suzuki	Aerio	7,529	$14,491	SS
Suzuki	Suzuki	Aerio	1,652	$13,571	SS
Suzuki	Suzuki	Aerio SX	1,229	$13,847	SS
Suzuki	Suzuki	Aerio SX	3,256	$14,767	SS
Toyota	Lexus	ES 300	70,517	$33,055	FULL
Toyota	Toyota	Camry Solara	12,719	$22,485	FULL
Toyota	Toyota	Prius	22,737	$19,995	FULL
VWA	Audi	Audi A4	1,174	$33,190	ISAD
DCC	Chrysler	300M	36,663	$28,415	FULL
DCC	Chrysler	Concorde	14,548	$22,510	FULL
DCC	Dodge	Intrepid	91,428	$20,520	FULL
FMC	Ford	Taurus	54,537	$22,445	FULL
FMC	Ford	Taurus Wagon	9,942	$21,495	FULL
FMC	Lincoln	Lincoln LS	12,363	$33,220	FULL
FMC	Mazda	626	35,363	$19,525	FULL
FMC	Mazda	626	12,787	$22,425	FULL
FMC	Mercury	Sable	59,858	$20,020	FULL
FMC	Mercury	Sable Wagon	4,201	$23,560	FULL
GMC	Buick	LaSabre	137,737	$24,495	FULL
GMC	Chevy	Impala	118,204	$20,540	FULL
GMC	Chevy	Malibu	144,946	$19,855	SS
GMC	Pontiac	Bonneville	37,343	$28,890	FULL
Honda	Honda	Accord	122,800	$25,300	IMA
Hyundai	Hyundai	Sonata	49,666	$18,824	FULL
Mitsubishi	Mitsubishi	Galant	80,656	$18,517	Y
Nissan	Nissan	Altima	146,503	$18,849	FULL
Nissan	Nissan	Maxima	79,206	$25,449	FULL
Toyota	Toyota	Camry	93,460	$23,700	FULL
VWA	VWA	Passat	8,167	$21,750	ISAD
VWA	VWA	Passat	14,544	$25,325	ISAD
VWA	VWA	Passat Wagon	8,379	$23,625	ISAD
BMW	BMW	525i	12,579	$38,275	ISAD
DCC	Mer-Benz	C320	12,483	$38,135	FULL
DCC	Mer-Benz	E 320	14,749	$48,450	FULL
DCC	Mer-Benz	S 430	14,919	$71,850	FULL
FMC	Volvo	S80	10,790	$38,450	FULL
GMC	Cadillac	Seville	25,128	$44,039	FULL
Toyota	Lexus	LS 430	27,162	$54,405	FULL
VWA	Audi	Audi A6	2,529	$36,400	ISAD
VWA	Audi	Audi A6 Avant	2,148	$39,350	ISAD
DCC	Chrysler	Town & Country 2WD	69,325	$26,240	FULL
DCC	Dodge	Grand Caravan 2WD	23,583	$24,950	FULL
FMC	Ford	Windstar Van	18,364	$20,250	FULL
FMC	Ford	Windstar Wagon	4,232	$28,625	FULL
FMC	Mercury	Villager Wagon	142,042	$24,340	FULL
Honda	Honda	Odyssey	148,857	$26,750	IMA
Nissan	Nissan	Quest	21,099	$27,194	FULL
Toyota	Toyota	Sienna	85,417	$28,012	FULL
DCC	Chrysler	PT Cruiser	22,197	$17,197	SS
DCC	Chrysler	PT Cruiser	147,362	$18,815	SS
DCC	Chrysler	Pacifica	40,000	$28,845	FULL
DCC	Chrysler	Pacifica	20,000	$32,300	FULL
DCC	Jeep	Grand Cherokee 2WD	39,048	$25,425	FULL
DCC	Jeep	Grand Cherokee 4WD	91,965	$27,395	FULL
FMC	Ford	Escape 4x2	67,376	$22,075	FULL

Manufacturer	Division	Name	2002 Sales	2002 Price	Hybrid Type
GMC	Chevrolet	Blazer 2WD	1,394	$25,005	SS
GMC	Chevrolet	Blazer 2WD	36,159	$26,005	SS
GMC	Chevrolet	Blazer 4WD	437	$27,005	SS
GMC	Chevrolet	Blazer 4WD	65,351	$28,005	SS
GMC	Chevrolet	Trailblazer 2WD	87,430	$28,840	FULL
GMC	Chevrolet	Trailblazer 4WD	165,819	$31,065	FULL
GMC	GMC	Envoy 2WD	30,715	$31,935	FULL
GMC	GMC	Envoy 4WD	77,935	$34,160	FULL
GMC	Saturn	Vue AWD	1,052	$18,860	SS
GMC	Saturn	Vue FWD	717	$17,265	SS
Honda	Honda	Pilot	80,000	$29,470	IMA
Honda	Honda	CR-V	29,053	$19,050	IMA
Honda	Honda	CR-V	99,884	$20,250	IMA
TKM	Mazda	Tribute 4x2	22,249	$21,485	FULL
TKM	Mazda	Tribute 4x4	24,854	$22,685	FULL
Toyota	Toyota	Highlander 2WD	42,567	$25,460	FULL
Toyota	Toyota	Rav4 2WD	48,231	$17,575	FULL
Toyota	Toyota	Rav4 4WD	39,291	$18,975	FULL
GMC	Chevrolet	C1500 Tahoe 2WD	61,519	$33,409	FULL
GMC	GMC	C1500 Yukon 2WD	7,193	$33,596	FULL
GMC	GMC	K1500 Yukon 4WD	1,746	$34,996	FULL
TKM	Mazda	Mazda B3000 4x2	7,231	$18,070	FULL
FMC	Ford	EX SP Trac 4x2	40,864	$23,880	FULL
FMC	Ford	EX SP Trac 4x4	30,725	$26,650	FULL
GMC	Chevrolet	C1500 Silverado 2WD	85,182	$22,689	FULL
GMC	Chevrolet	K1500 Silverado 4WD	35,847	$25,639	FULL
GMC	GMC	C1500 Sierra 2WD	27,113	$21,068	FULL
GMC	GMC	K1500 Sierra 4WD	9,917	$25,635	FULL
BMW	BMW	X5 3.0	30,564	$41,225	FULL
Honda	Acura	MDX	48,998	$37,300	IMA
GMC	Cadillac	Escalade 2WD	10,692	$48,735	FULL
GMC	Cadillac	Escalade AWD	43,311	$52,230	FULL
GMC	Chevrolet	C1500Suburban 2WD	49,314	$36,143	FULL
GMC	Chevrolet	K1500 Suburban 4WD	71,668	$38,209	FULL
GMC	Chevrolet	K1500 Tahoe 4WD	5,017	$35,475	FULL
GMC	GMC	C1500 Yukon XL 2WD	16,472	$36,501	FULL
GMC	GMC	K1500 Yukon XL 4WD	22,731	$39,034	FULL

2012 Diesel Cars

Manufacturer	Division	Name	2002 Sales	2002 Price
DCC	Mer-Benz	A-Class	24,000	$22,500
VWA	VWA	Golf	3,255	$14,250
VWA	VWA	Golf TDI	1,655	$17,420
VWA	VWA	Golf TDI	6,025	$16,545
VWA	VWA	Jetta	7,133	$18,950
VWA	VWA	Jetta	11,326	$20,135
VWA	VWA	Jetta	1,102	$24,700
VWA	VWA	Jetta Wagon	340	$21,000
VWA	VWA	New Beetle	4,766	$18,775
DCC	Mer-Benz	C240	33,611	$31,735
VWA	Audi	Audi A4	1,174	$33,190

Manufacturer	Division	Name	2002 Sales	2002 Price
VWA	VWA	Passat	8,167	$21,750
VWA	VWA	Passat Wagon	8,379	$23,625
VWA	VWA	Passat Wagon	695	$25,050
BMW	BMW	525i	12,579	$38,275
BMW	BMW	745i	10,575	$67,850
DCC	Mer-Benz	C320	12,483	$38,135
DCC	Mer-Benz	E 320	14,749	$48,450
DCC	Mer-Benz	S 430	14,919	$71,850
FMC	Jaguar	Jaguar S-Type 6	8,033	$43,675
VWA	Audi	Audi A6	2,529	$36,400
VWA	Audi	Audi A6	1,412	$50,650
VWA	Audi	Audi A6 Avant	2,148	$39,350
DCC	Dodge	Durango 2WD	16,800	$29,320
DCC	Dodge	Durango 4WD	33,133	$31,440
DCC	Jeep	Liberty 2WD	46,124	$22,994
DCC	Jeep	Liberty 4WD	157,615	$24,479
DCC	Jeep	Wrangler	25,831	$19,860
FMC	Ford	Explorer 4x2	125,415	$29,190
FMC	Ford	Explorer 4x4	217,575	$31,155
FMC	Mercury	Mountaineer 4x2	7,070	$29,645
FMC	Mercury	Mountaineer 4x4	27,422	$31,645
Isuzu	Isuzu	Trooper	7,917	$29,405
Nissan	Nissan	Pathfinder 2WD	15,861	$28,999
Nissan	Nissan	Pathfinder 4WD	38,712	$32,499
Nissan	Nissan	Xterra V6 2WD	40,628	$24,199
Nissan	Nissan	Xterra V6 4WD	1,684	$26,449
Nissan	Nissan	Xterra V6 4WD	34,714	$26,199
FMC	Ford	Expedition 4x2	32,851	$30,430
FMC	Ford	Expedition 4x4	4,096	$33,300
GMC	Chevrolet	C1500 Tahoe 2WD	14,214	$32,709
GMC	Chevrolet	K1500 Tahoe 4WD	97,036	$27,857
GMC	GMC	C1500 Yukon 2WD	16,240	$34,296
GMC	GMC	K1500 Yukon 4WD	24,313	$34,996
DCC	Dodge	Dakota 2WD	43,412	$19,625
DCC	Dodge	Dakota 4WD	16,789	$22,835
DCC	Dodge	Ram 1500 2WD	114,196	$19,990
DCC	Dodge	Ram 1500 4WD	55,866	$22,730
FMC	Ford	F150 4x2	108,687	$22,520
FMC	Ford	F150 4x4	35,368	$25,935
GMC	Chevrolet	C1500 Silverado 2WD	72,250	$24,184
GMC	Chevrolet	K1500 Silverado 4WD	150,295	27,134
GMC	GMC	C1500 Sierra 2WD	22,782	$21,868
GMC	GMC	K1500 Sierra 4WD	44,469	$26,435
Nissan	Nissan	Titan	40,000	
Nissan	Nissan	Titan	22,000	
Toyota	Toyota	Toyota Tundra 2WD	42,344	$22,975
BMW	BMW	X5 4.4	8,246	$50,420
DCC	Mer-Benz	ML 320	30,686	$37,595
FMC	Lincoln	Navigator 4x2	9,367	$44,590
FMC	Lincoln	Navigator 4x4	8,517	$48,340
FMC	Rover	Range Rover 4.6	3,927	$68,000
GMC	Chevrolet	C1500 Suburban 2WD	49,314	$36,143
GMC	Chevrolet	K1500 Suburban 4WD	71,668	$38,209
GMC	GMC	K1500 Yukon XL 4WD	22,731	$39,034
Mitsubishi	Mitsubishi	Montero	17,461	$35,897
Nissan	Infiniti	Infiniti QX4 2WD	4,018	$35,150

Manufacturer	Division	Name	2002 Sales	2002 Price
Nissan	Infiniti	Infiniti QX4 4WD	11,925	$36,550
Nissan	Nissan	Armada	15,000	$36,450
Nissan	Nissan	Armada	25,000	$39,250
Toyota	Toyota	Land Cruiser Wagon 4	6,331	$52,595
Toyota	Toyota	Sequoia 2WD	41,737	$39,405
Toyota	Toyota	Sequoia 4WD	38,158	$42,752
VWA	Audi	Allroad Quattro	4,463	$40,950
FMC	Ford	E150 Van	20,688	$21,430