

Future Potential of Hybrid and Diesel Powertrains in the U.S. Light-Duty Vehicle Market

Implications for Light-Duty Vehicle Fuel Economy

David L. Greene, ORNL

K.G. Duleep, EEA, Inc.

Walter McManus, J.D. Power & Assoc.

DEER Conference

August 30, 2004

San Diego, California

There appears to be substantial potential for both hybrid and clean diesel technologies in the U.S. LDV market.

- **No longer reasonable to assume hybrids too expensive, diesels can't meet emissions stds.**
- **Premises:**
 - Diesels meet bin 5; Hybrids cut cost penalty to \$3-4,000
 - No new fuel economy policies; no backsliding over 2002
- **Scenarios indicate**
 - 2008 market shares: 4-7% hybrids, 2-4% diesels
 - 2012 market shares: 10-15% hybrids, 4-7% diesels
 - >2012 combined 40% share, +10% fuel economy impact

Light-duty diesel technology will continue to improve.

- **Several manufacturers are bullish on the prospects of meeting Bin 5 standards even on SUV size diesels by 2010**
- **Partial HCCI will be a common feature on engines by 2010 with HCCI up to 10 bar BMEP likely on 1 or 2 models by 2010.**
- **Injection system sophistication will grow with piezo injectors, vario-nozzle and hydraulically amplified systems.**

But advanced technologies and aftertreatment systems for emissions control will likely increase diesel prices.

- **Separate NOx adsorber + PM trap unlikely to succeed due to cost, and integrated solution like DPNR system more likely.**
- **Urea-SCR making a comeback as after-treatment cost is about 20% cheaper than integrated adsorber + trap.**
- **HCCI engine likely to allow lean NOx catalyst + trap as lowest cost solution in cars up to 3500lb. inertia weight.**

Diesel prices are assumed to increase with Tier II standards.

	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

The costs of hybrid components are coming down.

- **Costs of motors have decreased by 40% in last 6 years and another 40% decrease is likely by 2010.**
- **Costs of Ni-MH batteries in \$/kw has declined by 35 to 40% in last 5 years and another 30% decrease seems likely.**
- **System cost will decline 30% by 2010**
- **Yes, Toyota is making tons of money now on the Prius!**

Hybrid incremental prices depend on vehicle size and type of system (2012 prices shown).

	Small Cars	Mid-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

Hybrids and diesels are expected to deliver both higher MPG and more torque.

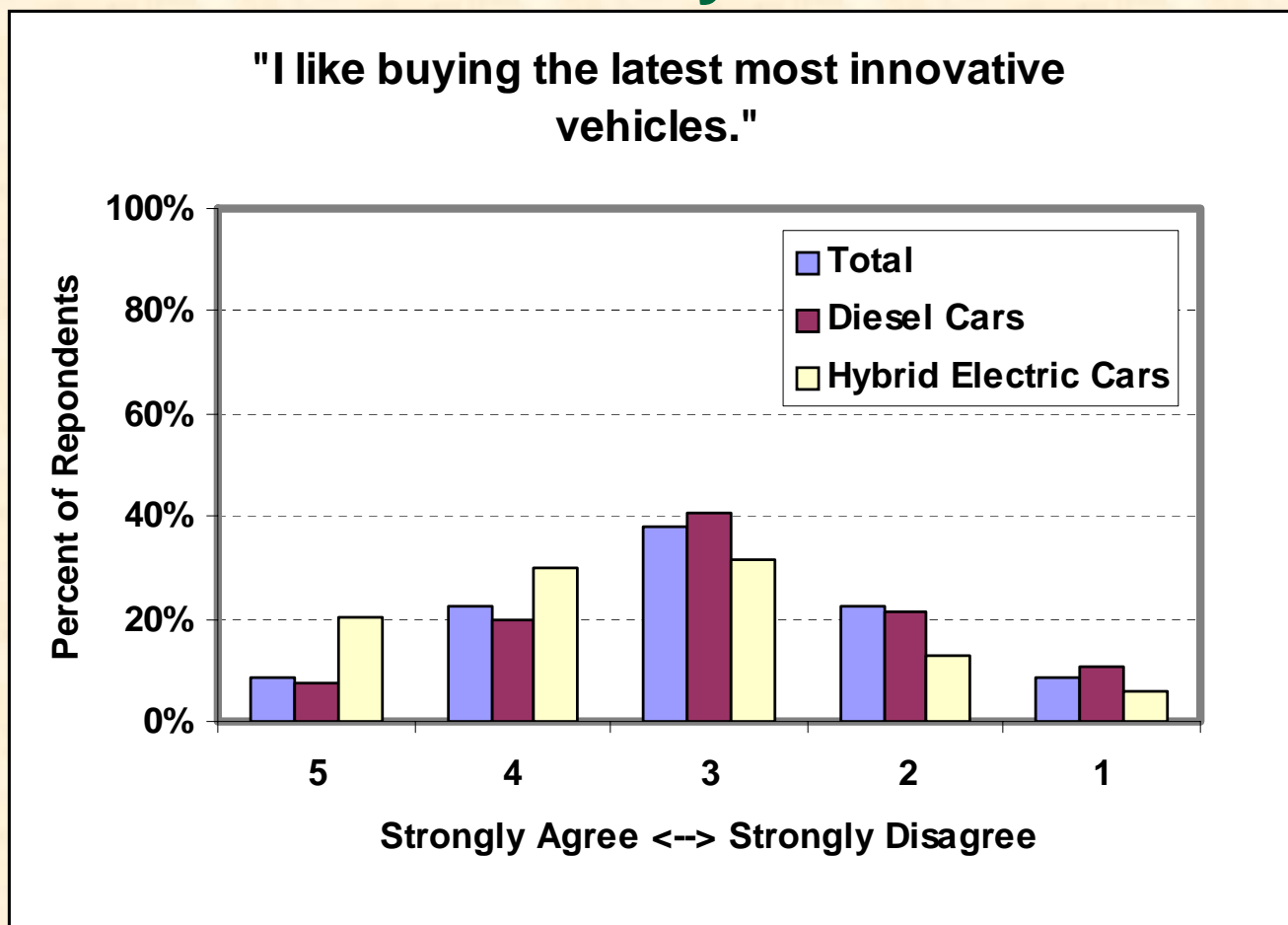
- Hybrids

	Torque	MPG
S/S	0%	7.5%
ISAD	10%	12.5%
IMA	15%	20%
Full Lg. Trk.	15%	35%
Full Car & Sm. Trk.	20%	40%

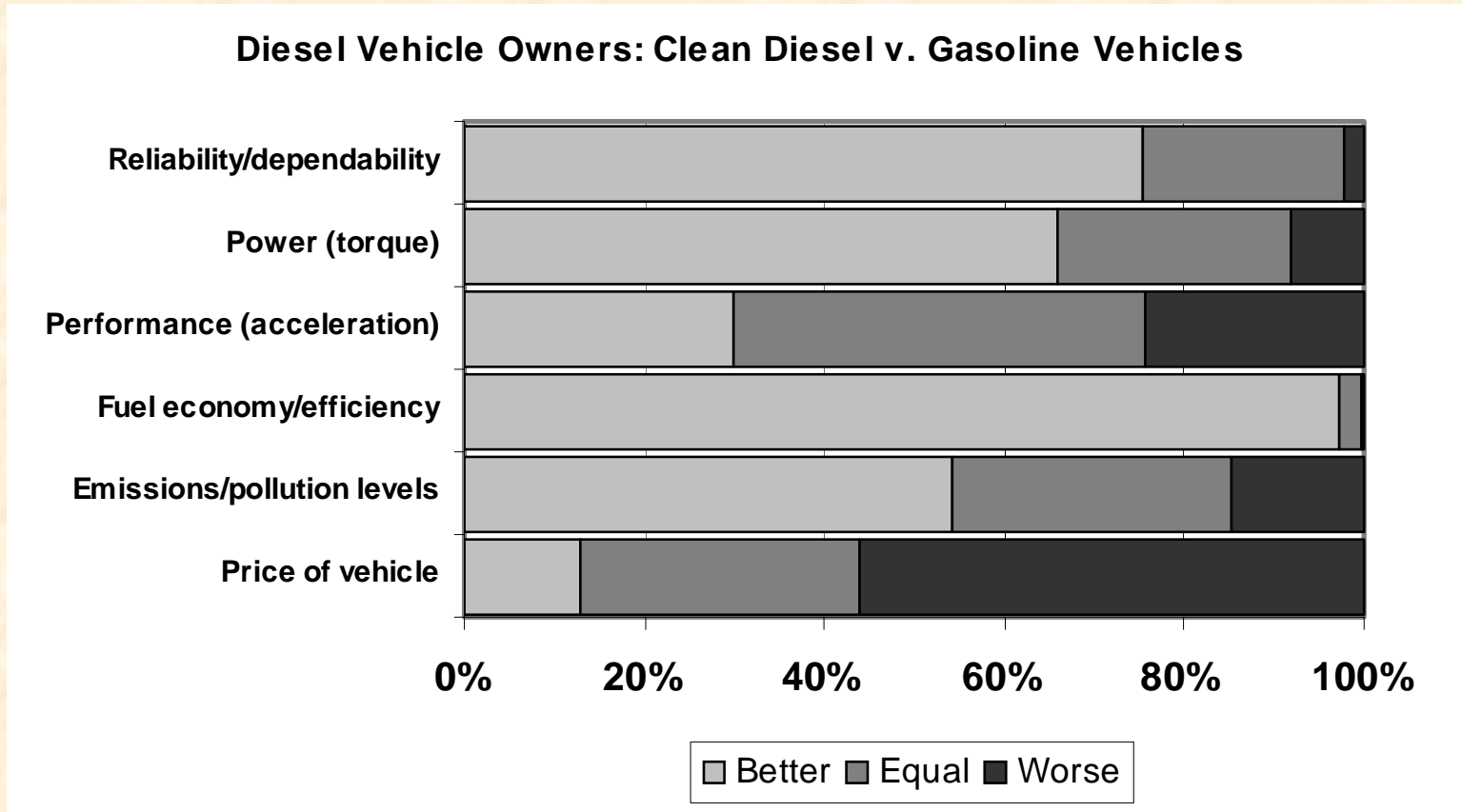
- Diesels

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

Current diesel and hybrid owners are not much different from all car buyers.

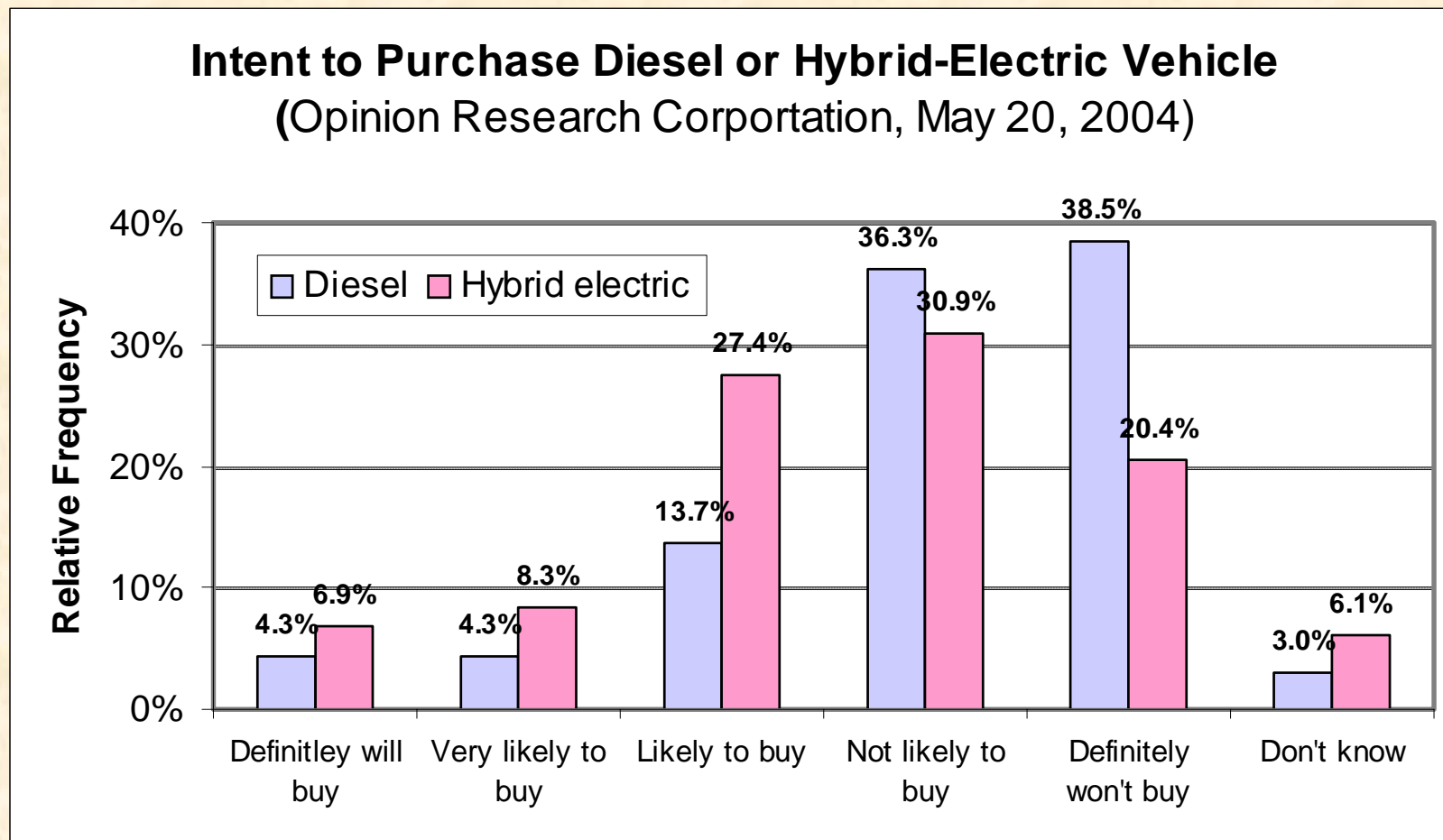


Diesel vehicle owners are more than satisfied with their vehicles, except for their price.

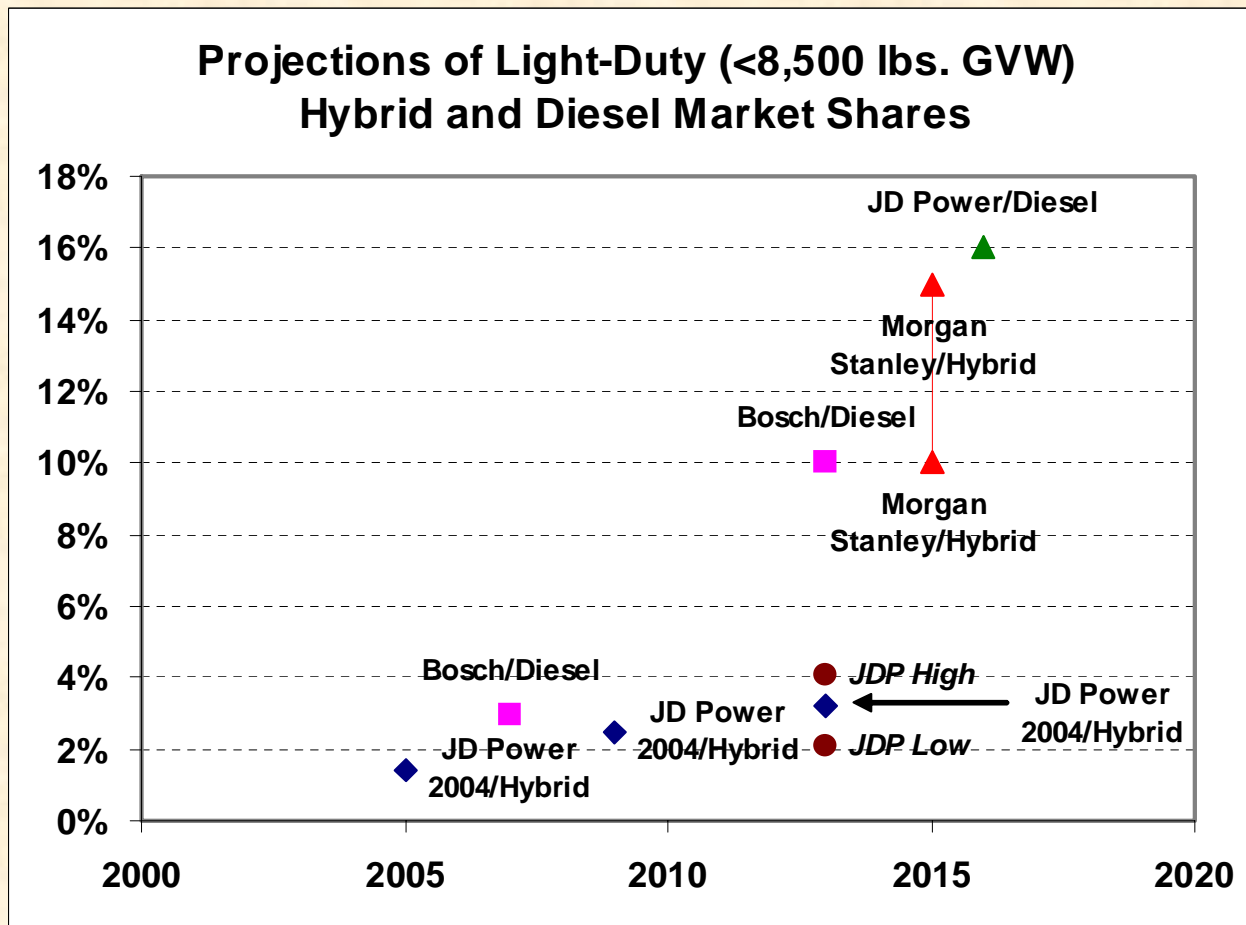


J.D. Power 2004 Consumer Acceptance of Alternative Powertrains Study, data used with permission of Walter McManus. J.D. Power retains all rights.

Recent opinion surveys reflect substantial consumer interest in both diesels and hybrids.



Recent proprietary clean diesel market studies have predicted N.A. LDV market shares up to 10% to 15% in the next 12 years.



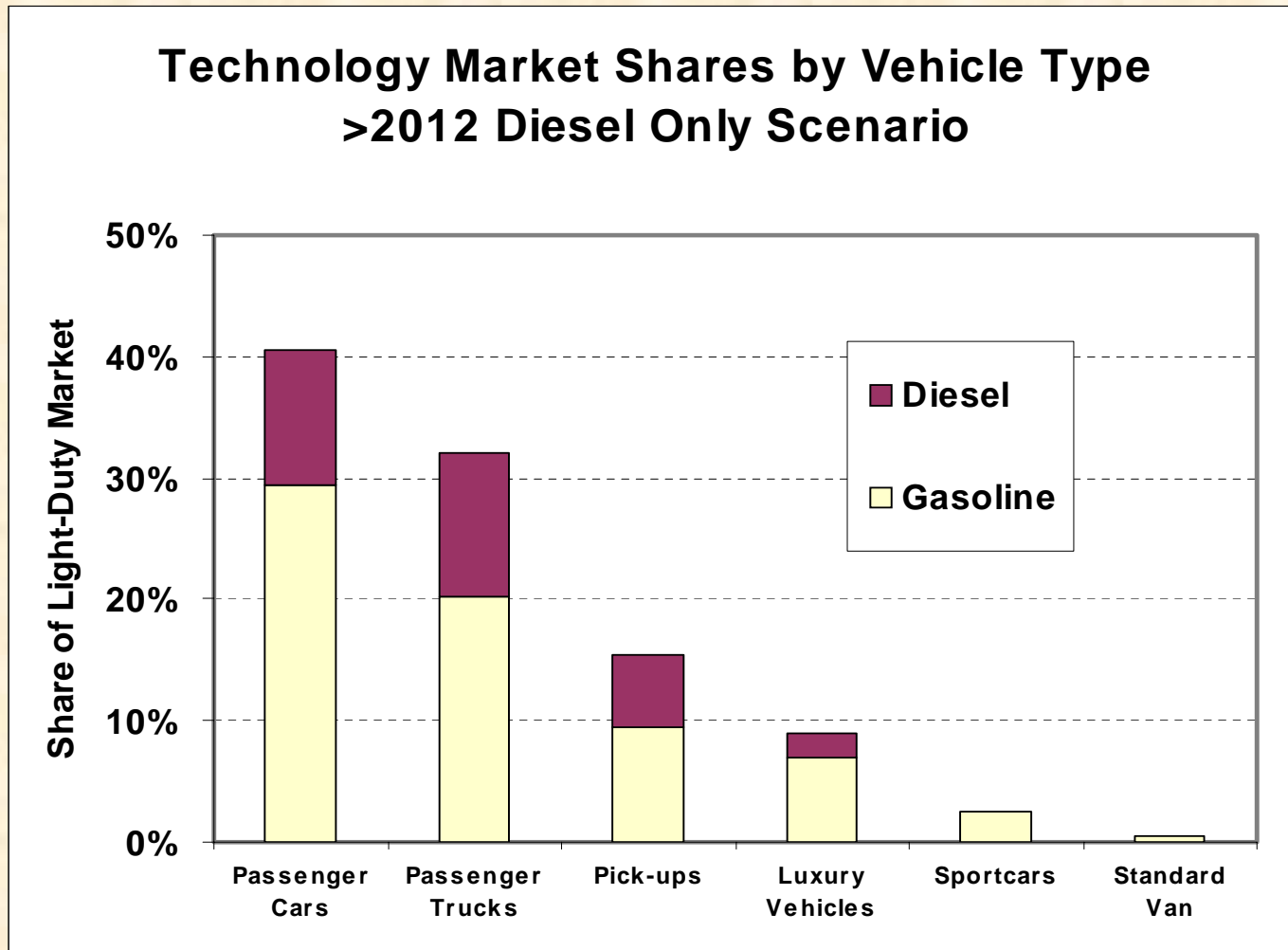
We used an economic choice model (NMNL) to predict future market shares.

- Derive or assume values of **fuel economy, range, fuel availability, torque** and **price**.
- Calibrate NMNL model to 920 model year 2002 LDV configurations.
- “Create” new diesel and hybrid nameplates & configurations based on announced introductions and judgment.
- Estimate new market shares and fuel economy impacts.
- Conduct sensitivity analysis.

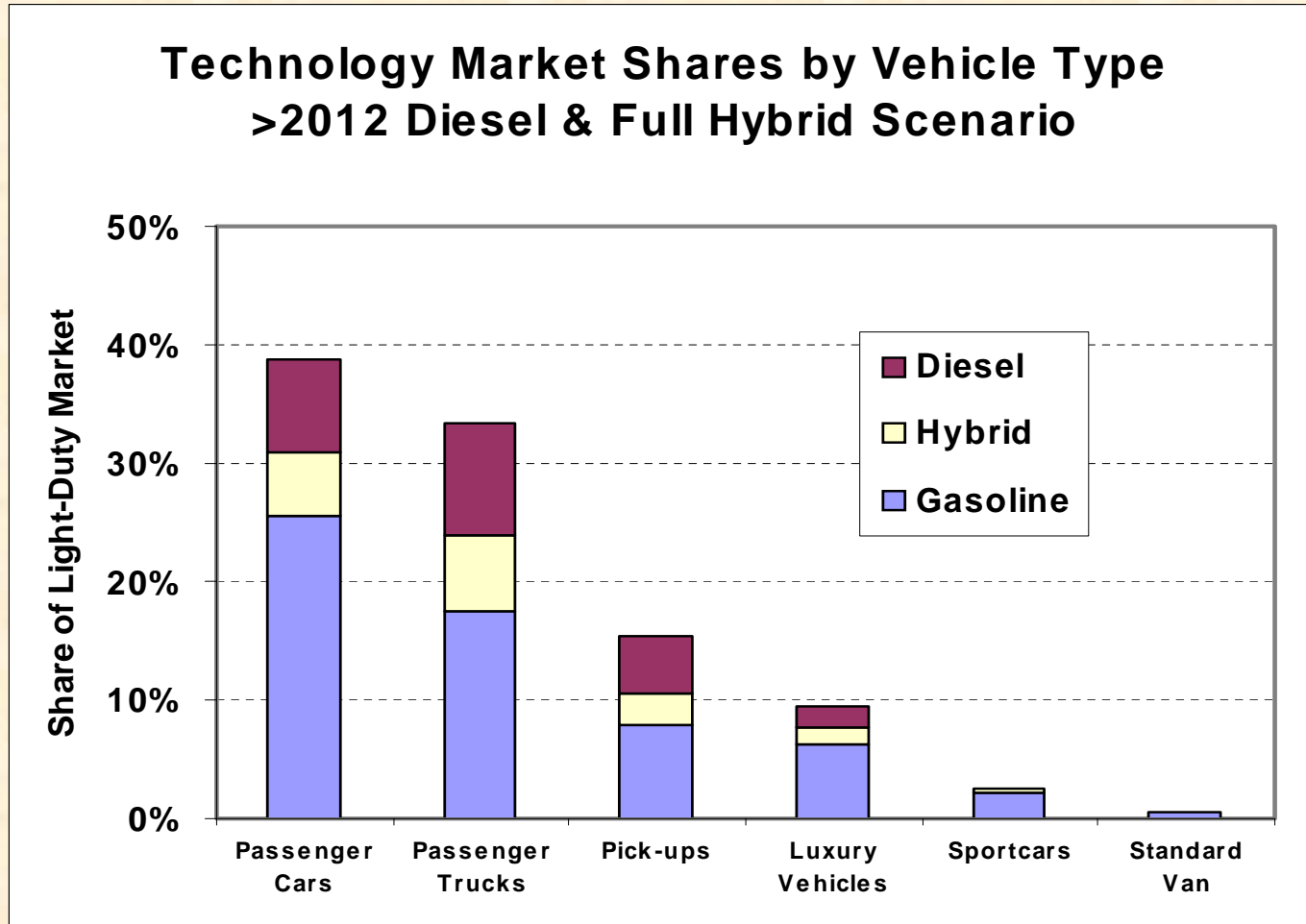
Eight scenarios were compared with 2002 sales and fuel economy.

- 2008 “best guess” and “average”
- 2012 “best guess” and “average”
- Diesel + Full Hybrid for all vehicles
- Diesel + ISAD for all vehicles
- Full Hybrid only for all vehicles
- Diesel only for all vehicles
- **Minimum nameplate sales levels**
 - 2008: 5,000 units
 - 2012: 10,000 units
 - >2012: 25,000/2,000

Given potentially full availability of diesels, and no competition from hybrids, diesels capture 30% of the light-duty market (5 million units).



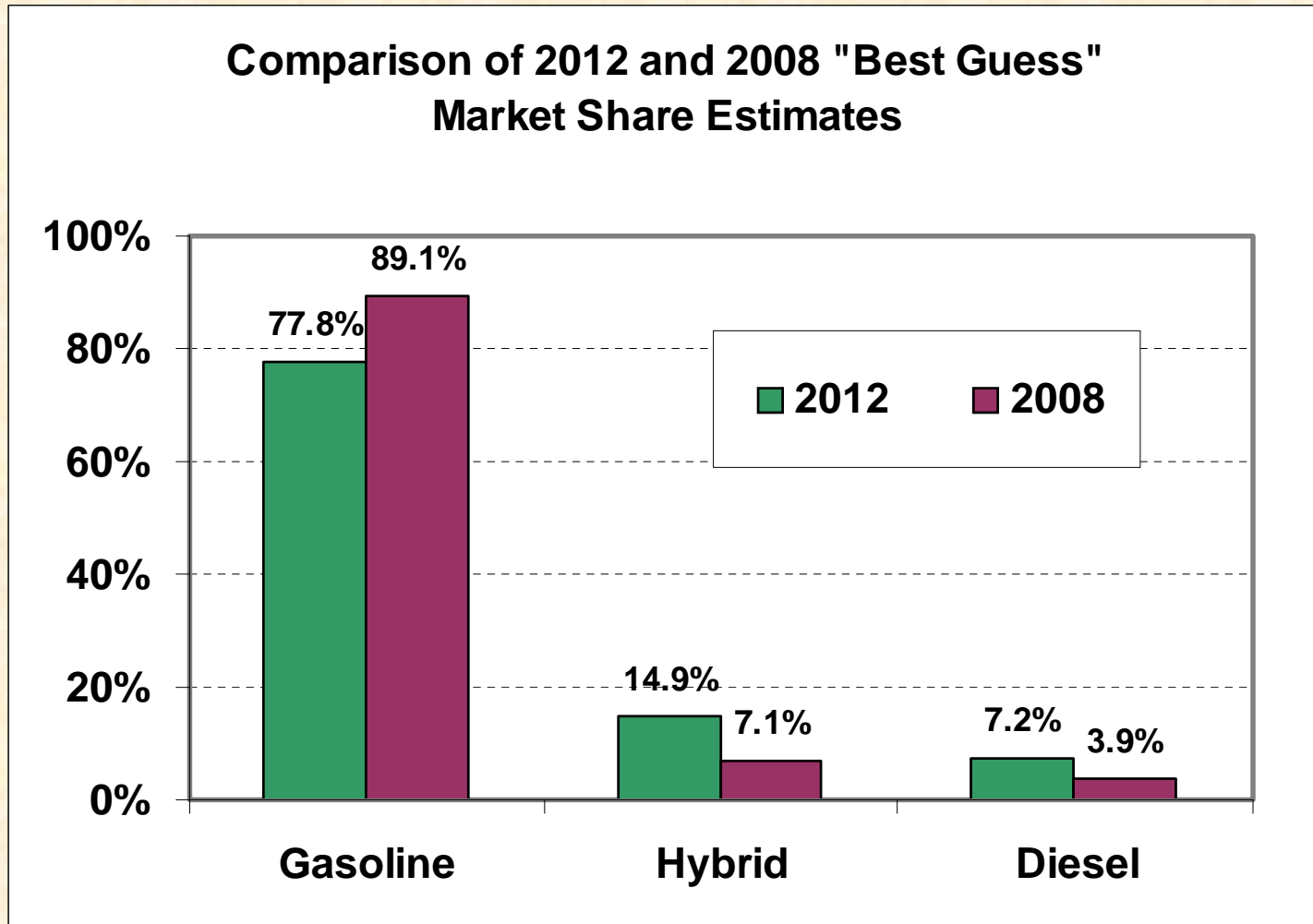
With potentially full availability of hybrids *and* diesels, diesel's LDV share is almost 25% (3.8 million units).



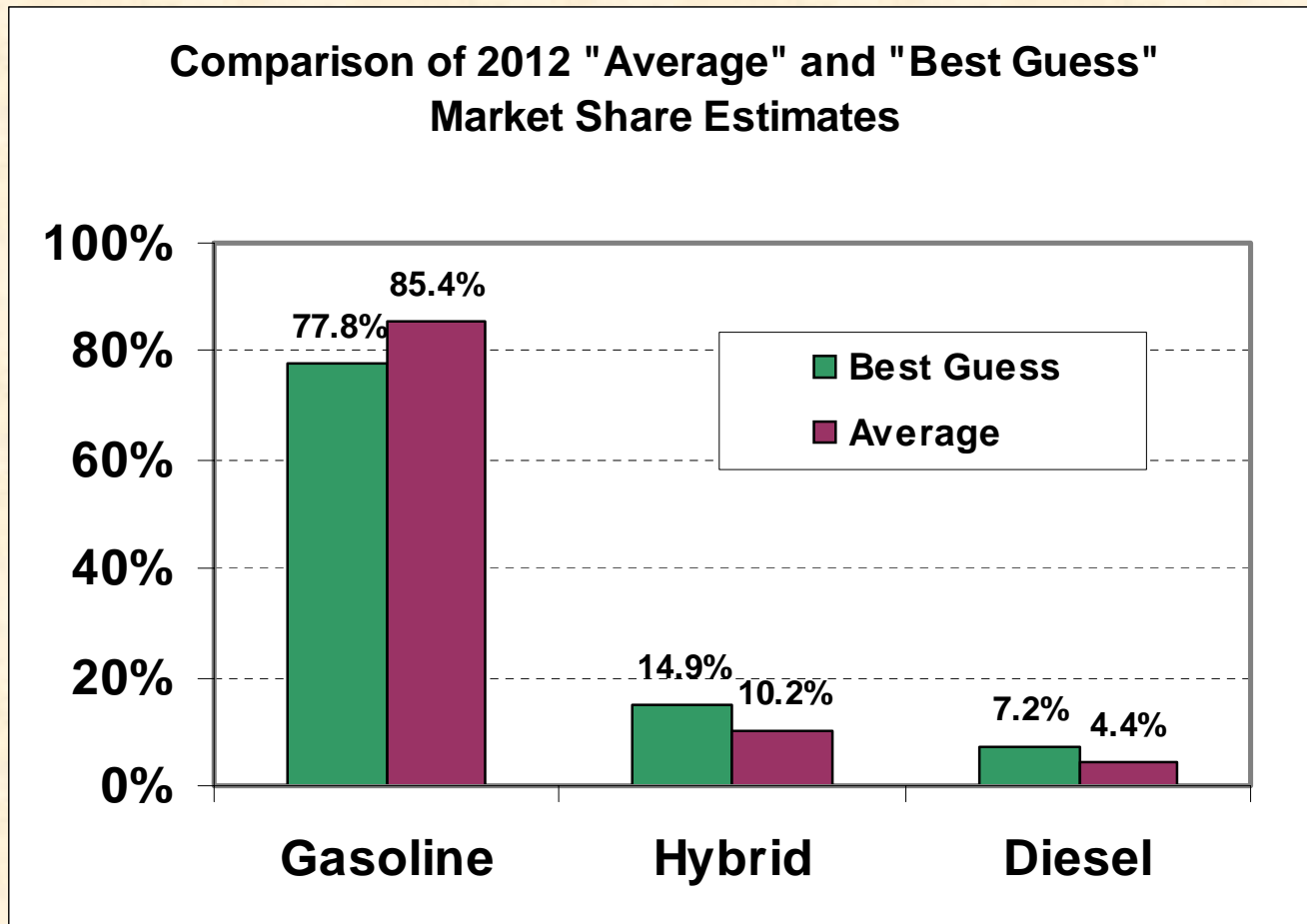
How many and which product lines offer diesels is critical to market success.

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

In our 2008 and 2012 scenarios, more hybrids are sold, primarily because more hybrid products are offered.

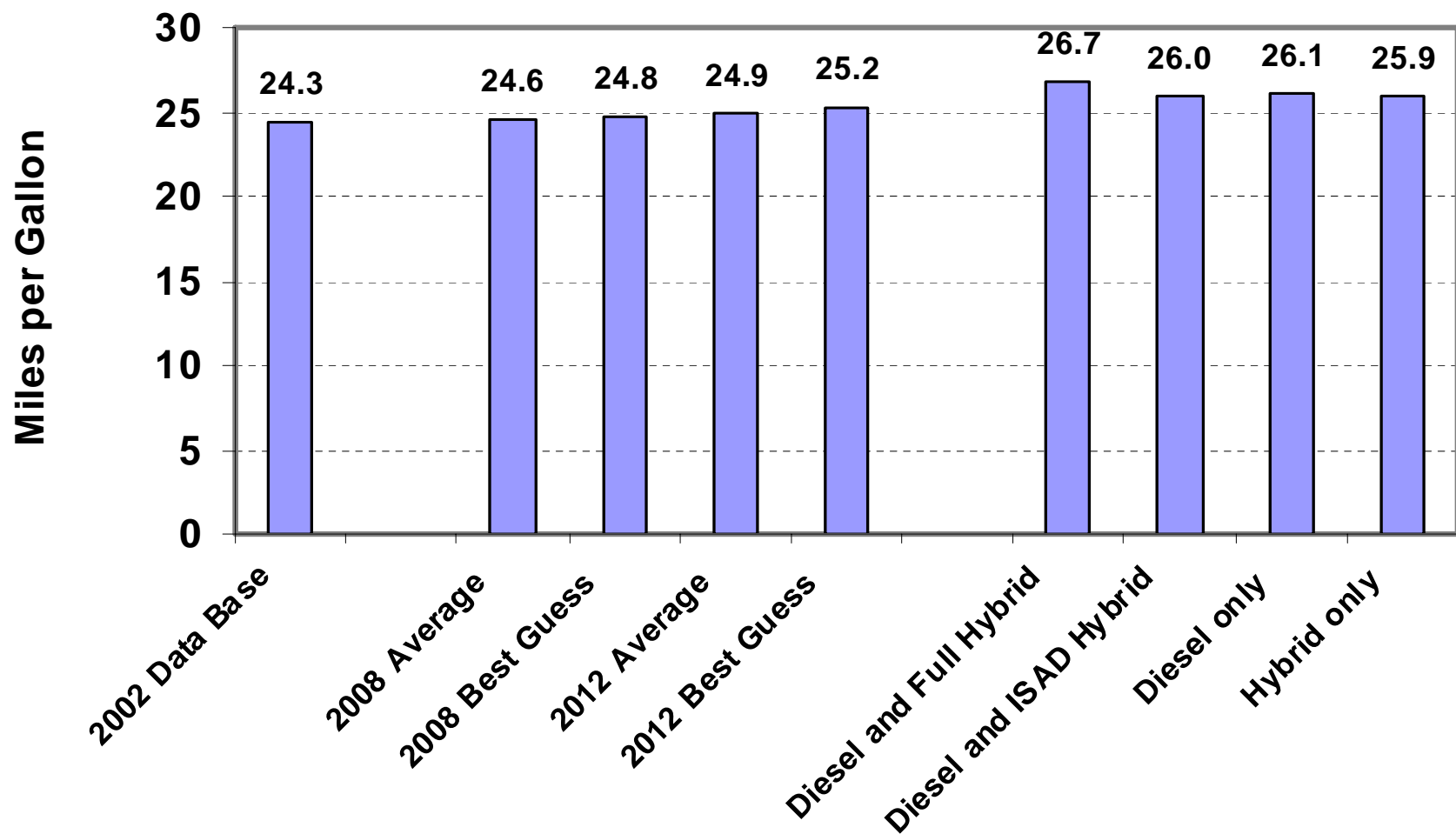


The difference between the “average” and “best guess” cases reflects the importance of which configuration is offered as a diesel or hybrid.



Fuel economy improvements range from 1.5% to 9.6% (Diesel only is 7.4%).

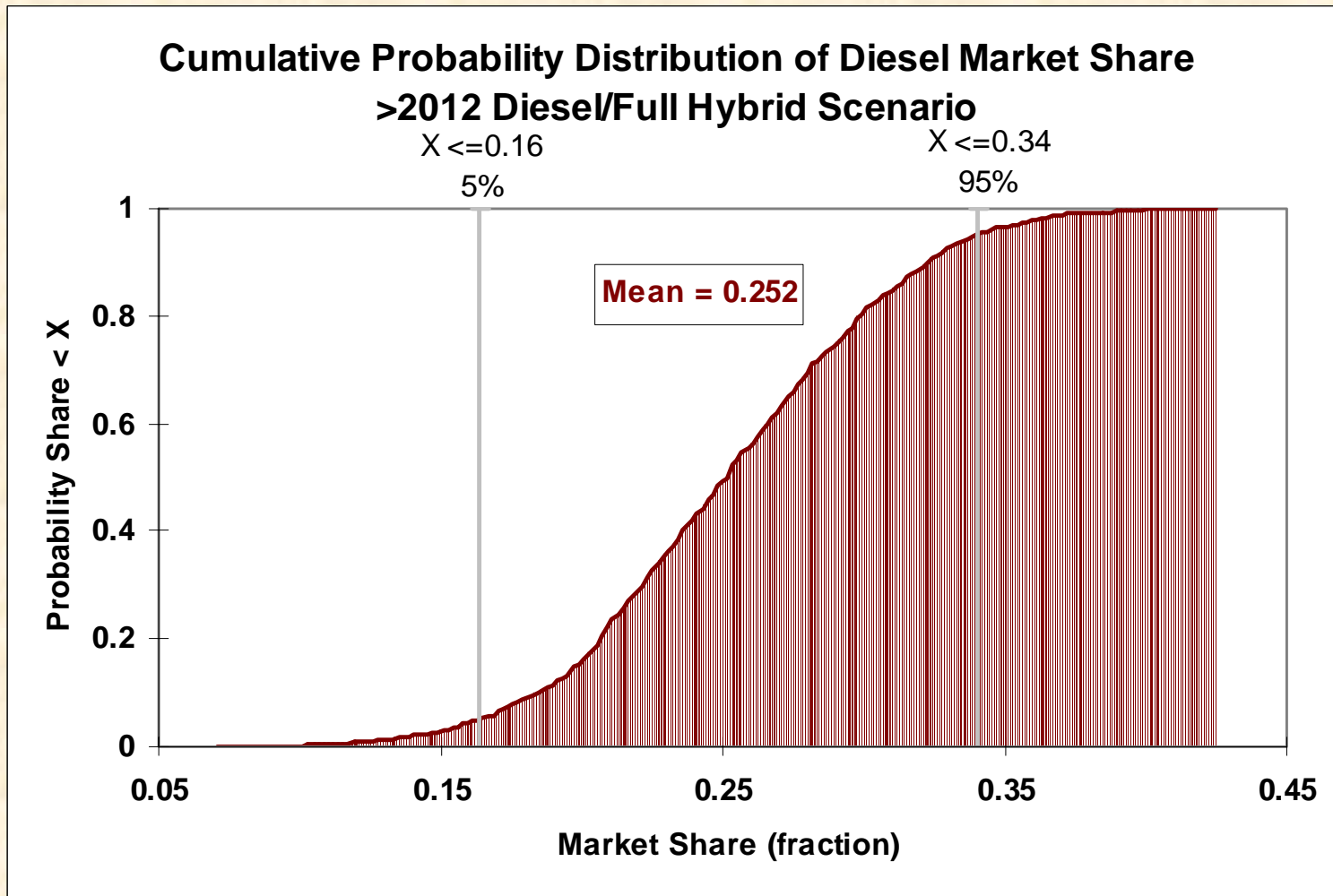
New Light-Duty Vehicle Fuel Economy by Scenario



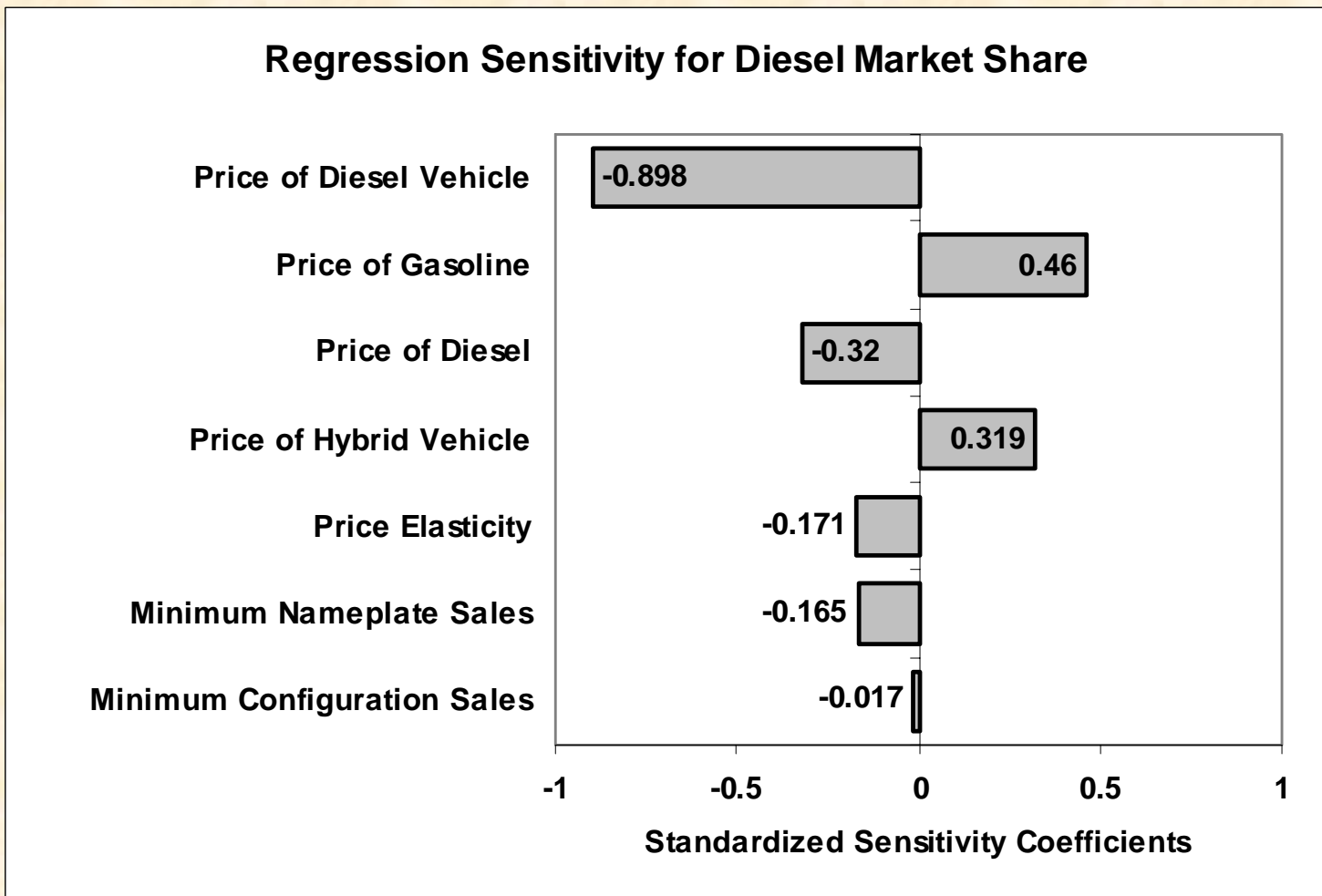
Several key variables were specified as probability distributions for the risk analysis.

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 / Diesel Fuel	\$1.50 \$1.50	Triangular	\$1.25 \$1.25	\$2.00 \$2.00
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

In the >2012, Diesel/Full Hybrid scenario, the sensitivity analysis produces a range of market shares from 15-35%.



Vehicle prices, fuel prices are the key factors. Price elasticity (fortunately) is less important.



Assuming widespread availability and mass production levels, both hybrids and diesels can be successful in the US market.

- **Definite advantages in fuel economy, torque and range to offset cost disadvantage.**
- **Long-run potential diesel market share of 15% to 35%.**
- **New LDV fleet fuel economy impact of about 10% for diesels and hybrids.**
- **Still, considerable uncertainty about new model introduction due to Tier II standards and risk to manufacturers.**
- **Assume no new policies, no “take back” by manufacturers, moderate fuel prices.**

Thank you.

Final report available at:

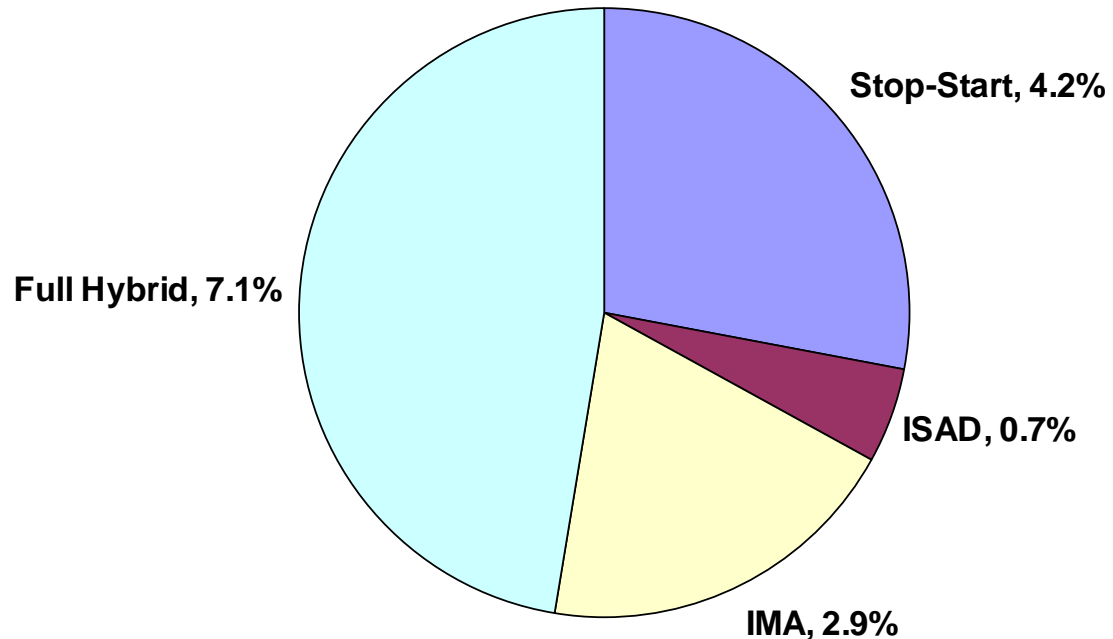
http://www-cta.ornl.gov/cta/Bio/GreeneDL_Bio.html

Not all hybrids are full hybrids, which increases hybrids' market share but decreases their fuel economy impact.

Hybrid Vehicles by Degree of Hybridization:

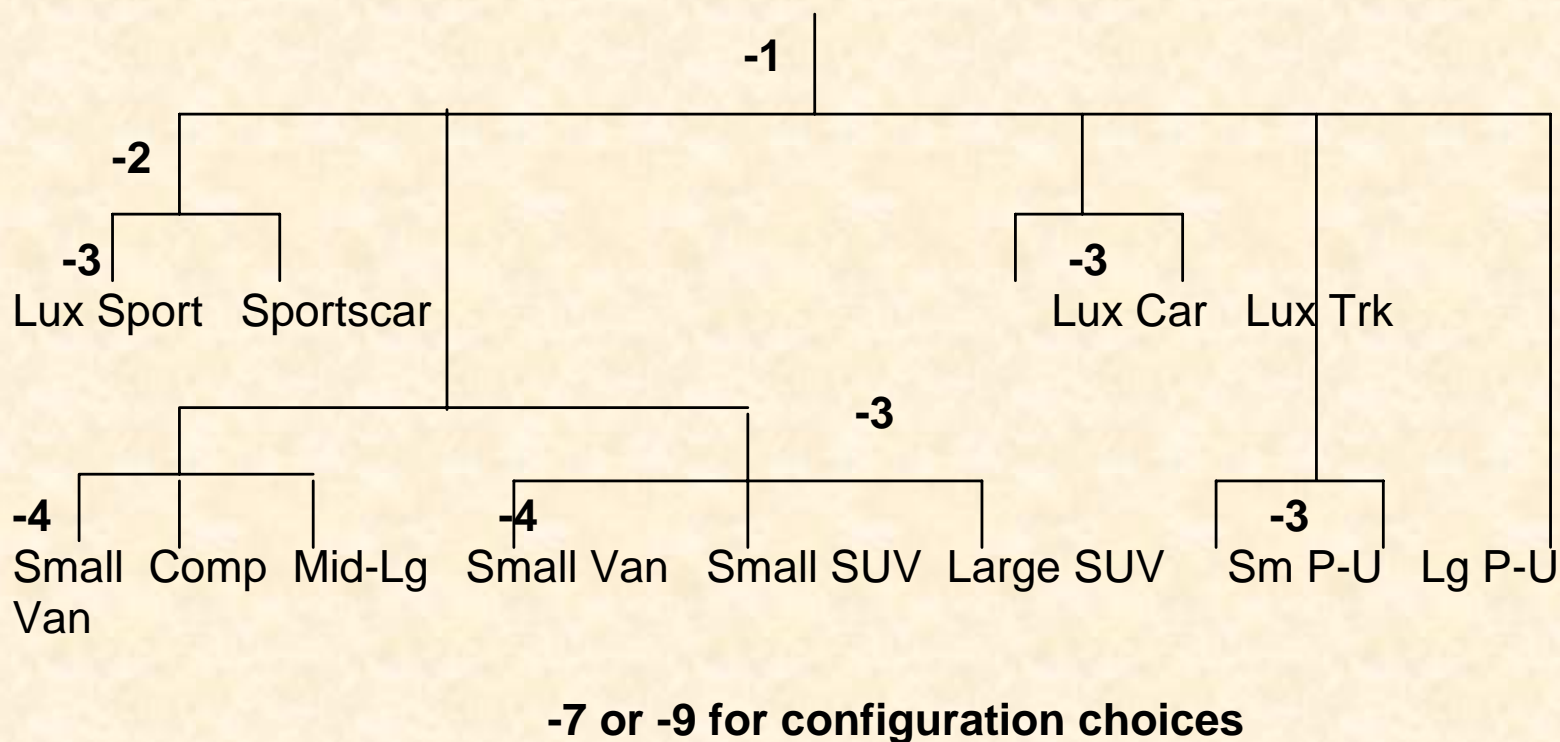
2012 "Best Guess Scenario"

(Total Hybrid Market Share = 14.9%)



The nested multinomial logit model allows market segments to be defined.

Figure 1. Nested Multinomial Logit Model Structure and Approximate Price Elasticities (shown in bold numbers)



Attribute values were calculated from assumptions, and the model calibrated to match 2002 model year sales.

The NMNL model allows new choices to be added to an existing set.

$$p_i = \frac{e^{u_i}}{\sum_{l=1}^L e^{u_l}}$$

It can also be readily calibrated to base year sales and measured attributes.

$$u_{ij} = A_i + \sum_{k=1}^K a_k x_{ik} + \varepsilon_{ij}$$

Price coefficients are calculated from assumed elasticities and actual average market shares.

NESTED MULTINOMIAL LOGIT MODEL COEFFICIENTS

	2002 Market Share (%)	Make/Model Count	Median Share	Average Share	PRICE SLOPES		
					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
1 Small Car	7.61%	102	0.45%	0.98%	-7	\$17,226	-0.000410
2 Midsize Car	14.53%	125	0.24%	0.80%	-7	\$19,234	-0.000367
3 Large Car	21.22%	94	0.39%	1.06%	-7	\$22,233	-0.000318
Passenger Truck	29.24%			33.33%	-4	\$26,357	-0.000228
4 Minivan	7.01%	36		2.78%	-7	\$25,651	-0.000281
5 Small SUV	20.40%	162		0.62%	-7	\$26,208	-0.000269
6 Large SUV	1.83%	13		7.69%	-7	\$30,718	-0.000247
Pick-up	15.31%			50.00%	-3	\$22,451	-0.000267
7 Small Pick-up	5.19%	64		1.56%	-7	\$19,099	-0.000372
8 Large Pick-up	10.12%	56		1.79%	-9	\$24,170	-0.000379
Luxury	8.53%			50.00%	-3	\$47,429	-0.000127
9 Luxury Sedan	3.95%	117		0.85%	-7	\$47,256	-0.000149
10 Luxury Truck	4.59%	43		2.33%	-7	\$47,578	-0.000151
Sportscar	2.88%			50.00%	-2	\$29,534	-0.000135
11 Standard Sportscar	2.30%	37		2.70%	-7	\$23,393	-0.000308
12 Luxury Sportscar	0.57%	49		2.04%	-9	\$54,159	-0.000170
Van							
13 Standard Van	0.69%	32		3.13%	-7	\$23,726	-0.000305
Total	100.00%	930		0.11%	-2	\$25,026	-0.000100

The value of fuel economy depends on miles driven and consumers' payback period or discount rate.

FUEL ECONOMY SLOPES						
Annual Miles	Rate of Use Decrease/yr	Payback Horizon	Discount Rate	Present Value Miles	Fuel cost/mi Slopes	
15,502	4.6%	3	0.0%	42,534	-17.456	
15,502	4.6%	3	0.0%	42,534	-15.604	
15,502	4.6%	3	0.0%	42,534	-13.536	
17,239	4.3%	3	0.0%	47,569	-13.352	
17,955	5.7%	3	0.0%	48,262	-12.970	
17,955	5.7%	3	0.0%	48,262	-11.914	
19,151	5.8%	3	0.0%	51,381	-19.131	
19,151	5.8%	3	0.0%	51,381	-19.480	
15,502	4.6%	3	0.0%	42,534	-6.355	
15,502	4.6%	3	0.0%	42,534	-6.407	
15,502	4.6%	3	0.0%	42,534	-13.081	
15,502	4.6%	3	0.0%	42,534	-7.216	
19,151	5.8%	3	0.0%	51,381	-15.648	

Three different hybrid system types are under development.

- - belt drive alternator starter (BAS)
- - single crankshaft mounted motor/generator
- - dual motors integrated with transmission
- - system cost, complexity and fuel economy increase progressively but optimal tradeoff is viewed differently by each manufacturer

There appear to be no inherent deficiencies of diesel or hybrid technologies, other than cost.

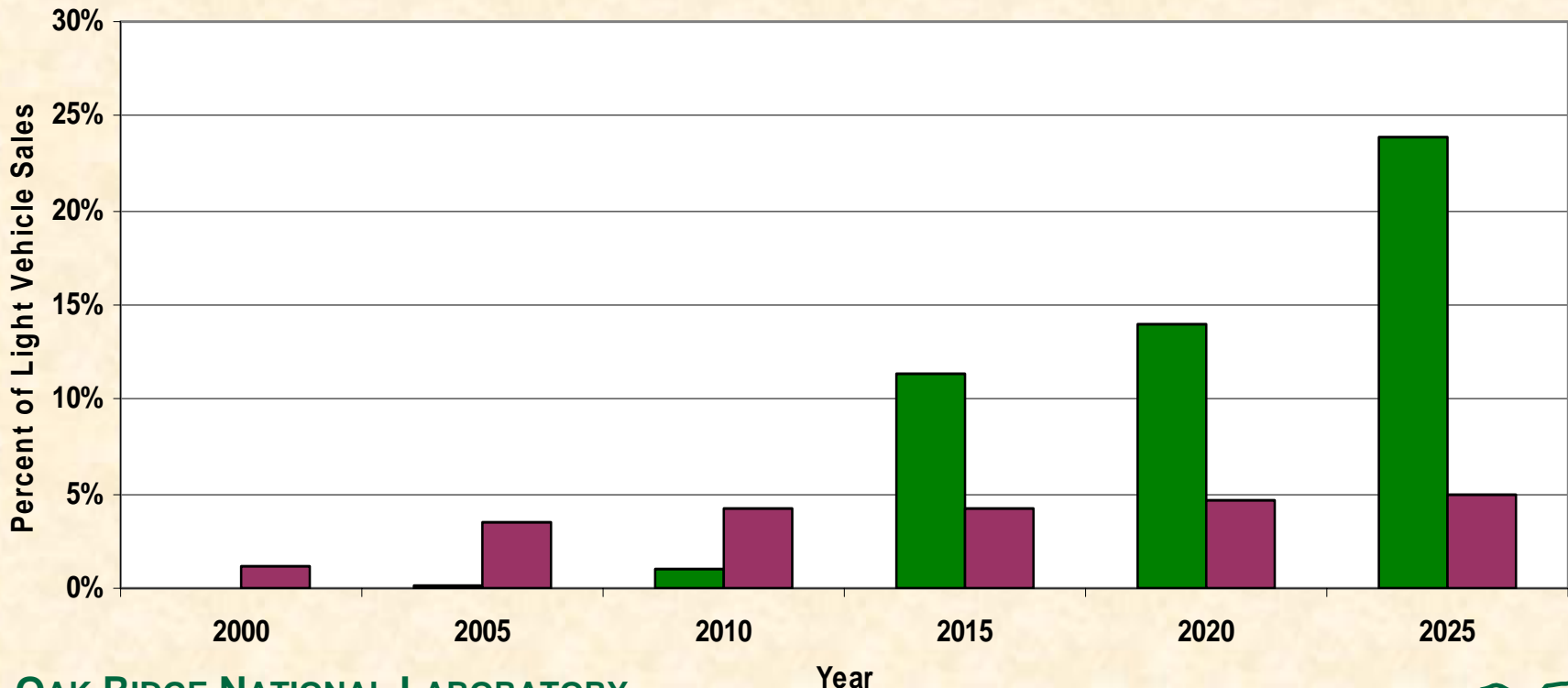
- **Costs will come down significantly from prices being paid today.**
- **Misperceptions about performance, etc. can be corrected.**

What consumer attributes were explicitly included?

- **Retail Price Equivalent**
- **Fuel Economy (3-yr payback)**
- **Range**
- **Torque**
- **Fuel Availability**
- **No diesel or hybrid “extra value”**

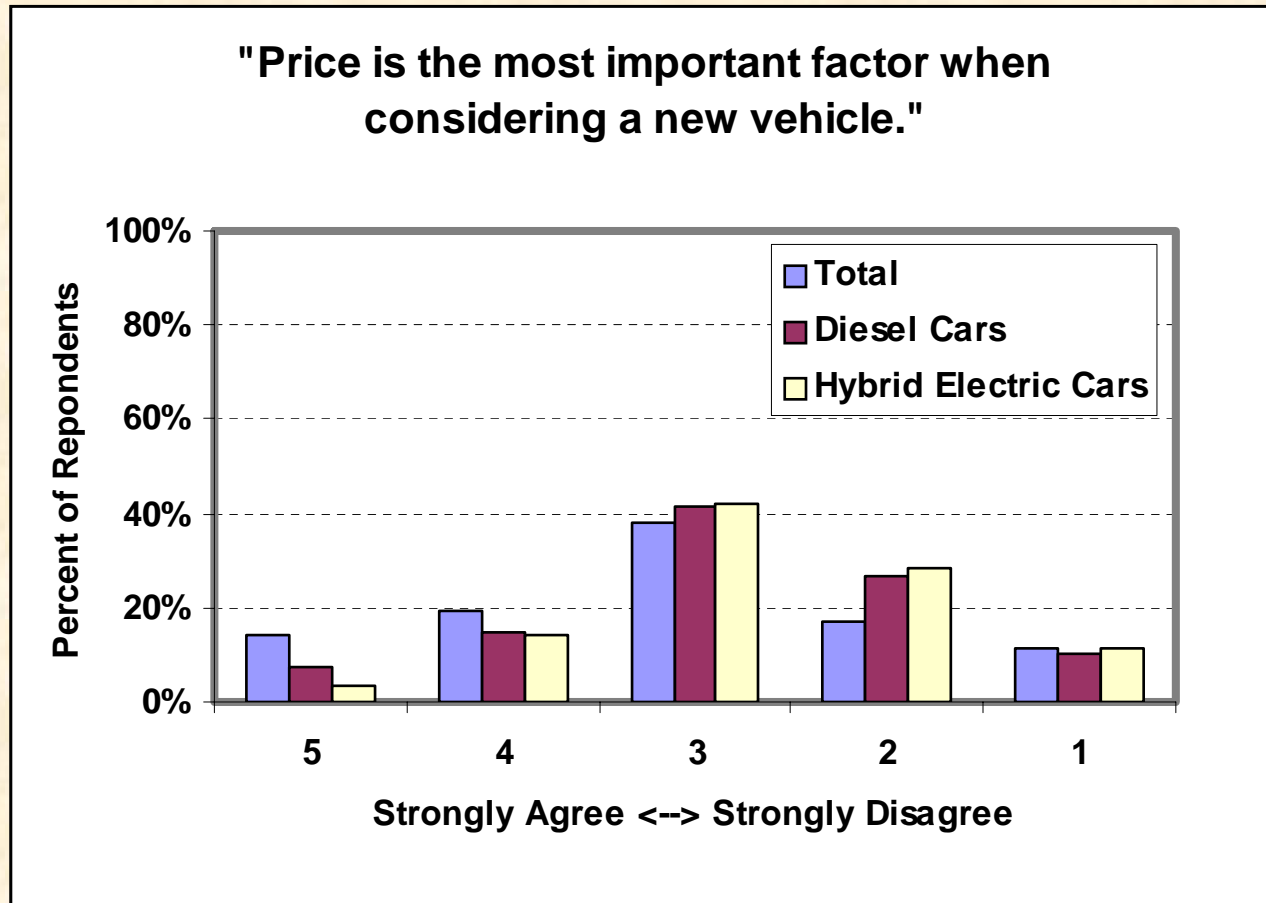
EIA's projected diesel sales are similar to our 2008 levels, but much less than our full market potential.

Projected Diesel Market Shares in the U.S.: GPRA
(Used to Estimate the FCVT Benefits in the FY05 Budget)
and EIA (in the 2004 Annual Energy Outlook)



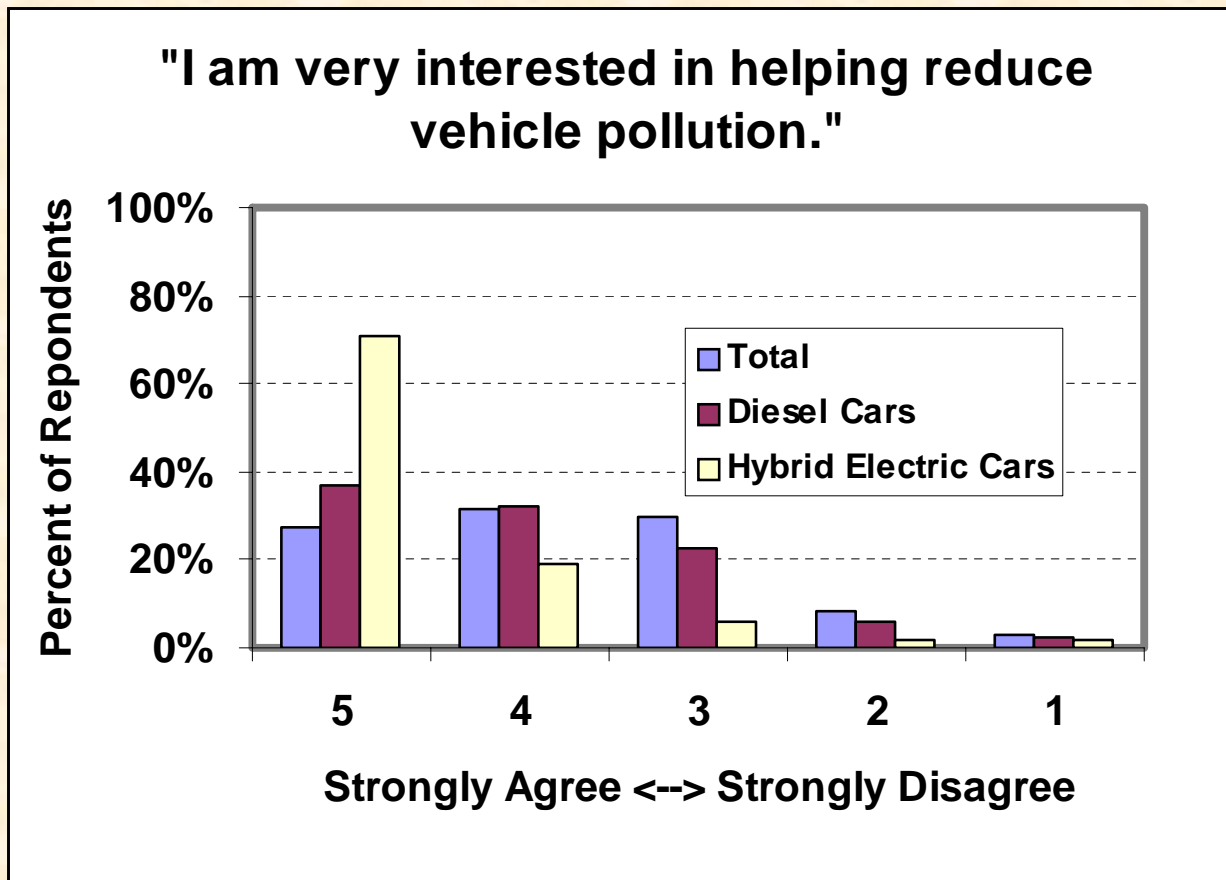
J.D. Power 2004 Consumer Acceptance of Alternative Powertrains Study, data used with permission of Walter McManus. J.D. Power retains all rights.

Diesel and hybrid owners are somewhat less concerned about price.

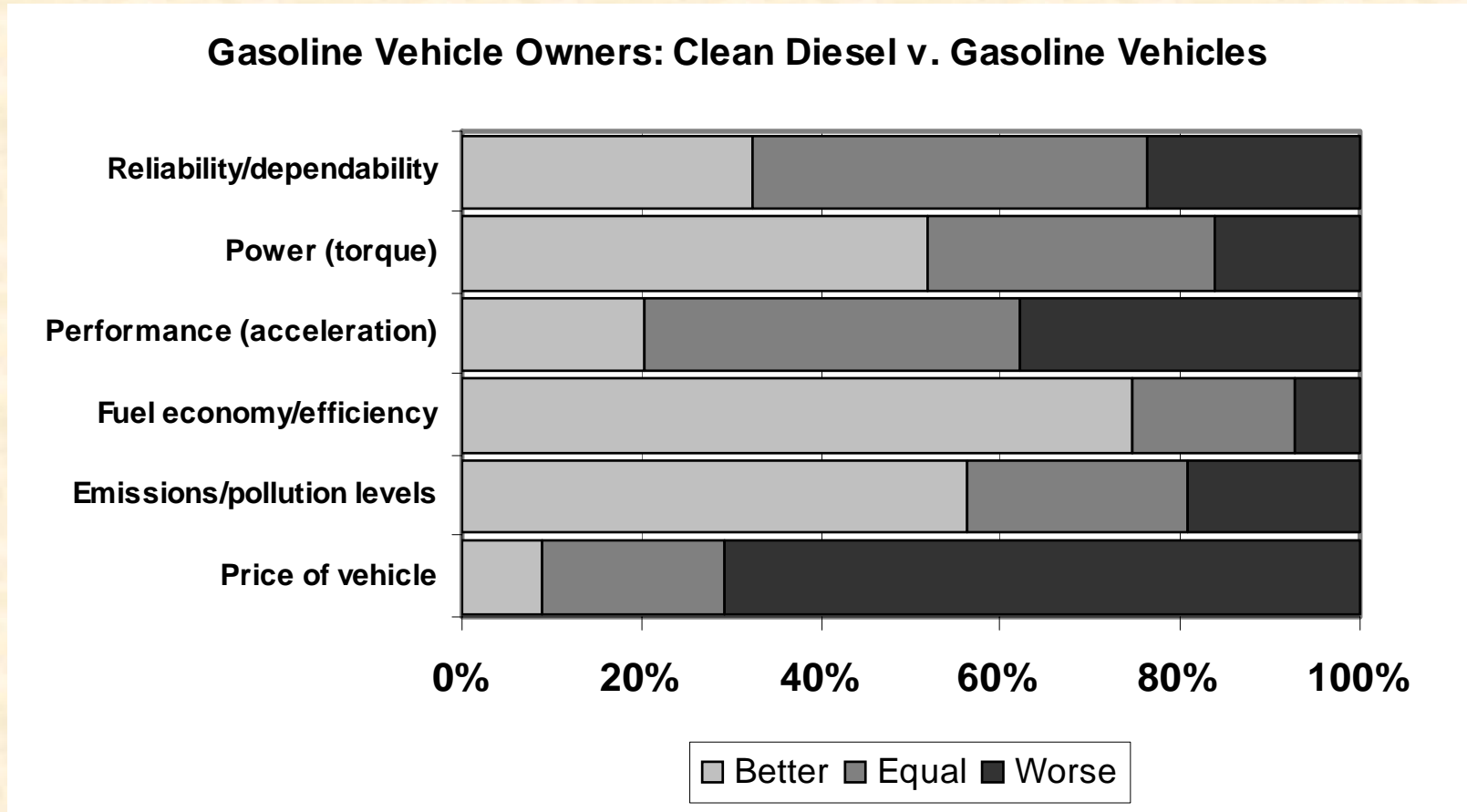


J.D. Power 2004 Consumer Acceptance of Alternative Powertrains Study, data used with permission of Walter McManus. J.D. Power retains all rights.

The single strongest attitudinal difference between hybrid vehicle owners and others is their desire to reduce pollution.



Owners of conventional gasoline vehicles think diesels are slow and expensive.



J.D. Power 2004 Consumer Acceptance of Alternative Powertrains Study, data used with permission of Walter McManus. J.D. Power retains all rights.

Some hybrid technology trends clearly emerged.

- **42 Volts is no longer relevant and driveline voltage will be cost determined.**
- **BAS systems are low cost (<\$400) on manual transmission vehicles without AC, but more expensive on automatic transmission vehicles with AC**
- **Single motor systems cannot have pure electric drive and efficiency benefit is more limited than 2 motor systems.**

However, diesel engine costs are likely to increase.

- **Current VW benchmark price of \$1300 increment is low since VW is the lowest cost producer, and engine is older design**
- **Increased injection system costs in future and electric EGR will add several hundred dollars to engine cost by 2010.**
- **HCCI will add more costs due to airflow and pressure control at cylinder level.**

JD Power's 2004 Consumer Acceptance of Alternative Powertrains Study suggests two key premises of our study:

- **Current diesel and hybrid buyers are not radically different from the overall car-buying population.**
- **Current diesel and hybrid owners are generally happy with their vehicles.**
- **Therefore, we believe, these are potentially mass-market technologies.**