# Delphi VIII

FORECAST AND ANALYSIS OF THE NORTH AMERICAN AUTOMOTIVE INDUSTRY

***Marketing • Technology • Materials***

# Technology

## VOLUME 2

*Office for the Study of Automotive Transportation*

University of Michigan Transportation Research Institute

# DELPHI VIII
# Forecast and Analysis of the North American Automotive Industry

## VOLUME 2: TECHNOLOGY

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# FOREWORD

Delphi VIII is a detailed analysis of forecasts by three separate panels of automotive industry executives, directors, managers and engineers who are expert in automotive technology, materials or marketing. These individuals were selected because they occupy positions of responsibility within the automotive industry and have strategic insight into important industry trends. In many cases they are in a position to influence these trends. This report, published in three volumes, is eighth in a series of in-depth studies of long-range automotive trends, which began with Delphi I in 1979 and continued with Delphi II in 1981, Delphi III in 1984, Delphi IV in 1987, Delphi V in 1989, Delphi VI in 1992 and Delphi VII in 1994.

The Office for the Study of Automotive Transportation (OSAT) collects the data, and analyzes, interprets and presents the results. Since the forecasts are those of the panelists, Delphi VIII is essentially the industry's own consensus forecast. These forecasts are not "crystal ball" predictions but, rather, well-informed estimates, perspectives and opinions. Such forecasts present an important basis for business decisions and provide valuable strategic planning information for those involved in all areas of the North American automotive industry: manufacturers; service, component and materials suppliers; government; labor; public utilities; and financial institutions. We believe these to be the most authoritative and dependable North American automotive forecasts available.

A key point to keep in mind is that the Delphi forecast presents a vision of the future. It obviously is not a precise statement of the future but rather what the industry thinks the future will likely be.

As an industry-wide survey, the project also allows individual companies to benchmark their vision and strategy against consensus industry opinions.

## The Delphi method: general background

The study is based on the Delphi forecasting process. This process requires that experts consider the issues under investigation and make predictions about future developments. Developed by the Rand Corporation for the U.S. Air Force in the late 1960s, Delphi is a systematic, interactive method of forecasting based on independent inputs regarding future events.

The Delphi method is dependent upon the judgment of knowledgeable experts. This is a particular strength because, in addition to quantitative factors, predictions that require policy decision are influenced by personal preferences and expectations. Delphi forecasts reflect these personal factors. The respondents whose opinions are represented in this report are often in a position to influence events and, thus, make their forecasts come true. Even if subsequent events result in a change of direction of a particular forecast, this does not negate the utility of the Delphi. This report's primary objective is to present the direction of technological, materials and marketing developments within the industry, and to analyze potential strategic importance.

## Process

The Delphi method utilizes repeated rounds of questioning, including feedback of earlier-round responses, to take advantage of group input while avoiding the biasing effects possible in face-to-face panel deliberations. Some of those biasing effects are discussed in this excerpt from a 1969 Rand memorandum:

> The traditional way of pooling individual opinions is by face-to-face decisions. Numerous studies by psychologists in the past two decades have demonstrated some serious difficulties with face-to-face interaction. Among the most serious are: (1) Influence, for example, by the person who talks the most. There is very little correlation between pressure of speech and knowledge. (2) Noise. By noise is not meant

> auditory level (although in some face-to-face situations this may be serious enough) but semantic noise. Much of the "communication" in a discussion group has to do with individual and group interest, not with problem solving. This kind of communication, although it may appear problem-oriented, is often irrelevant or biasing. (3) Group pressure for conformity. In experiments at Rand and elsewhere, it has turned out that, after face-to-face discussions, more often than not the group response is less accurate than a simple median of individual estimates without discussion (see N. C. Dalkey, The Delphi Opinion. Memo RM 5888 PR, p. 14, Rand Corp., 1969).

In the Delphi method, panelists respond anonymously, preventing the identification of a specific opinion with any individual or company. This anonymity also provides the comfort of confidentiality, allowing panelists to freely express their opinions. Among other advantages, this process enables respondents to revise a previous opinion after reviewing new information submitted by other panelists. All participants are encouraged to comment on their own forecasts and on the combined panel results. The information is then furnished to the panel participants in successive iterations. This procedure reduces the effects of personal agendas or biases and assists the panelists in remaining focused on the questions, issues and comments at hand.

## Panel characteristics and composition

The very essence of a Delphi survey is the careful selection of expert respondents. The selection of such experts for this Delphi survey is made possible by the long-standing association between The University of Michigan's Office for the Study of Automotive Transportation and representatives of the automotive industry. Lists of prospective experts were assembled for Technology, Marketing and Materials panels. Members were selected on the basis of the position they occupy within the automotive industry and their knowledge of the topic being surveyed. They are deeply knowledgeable and broadly experienced in the subject matter.

The names of the panel members and their replies are known only to our office and are maintained in the strictest confidence. Replies are coded to ensure anonymity. The identity of panel members is not revealed. Upon publication of the final Delphi report, all questionnaires and lists of panelists are destroyed.

The characteristics of the 317 member panels are as follows: 26 percent of the Technology Panel was composed of CEOs, presidents, or vice presidents; 22 percent were directors; 33 percent were executives, managers or supervisors; 18 percent were engineers (chief, assistant chief and staff); and 4 percent of the panel was made up of academic specialists and consulting technical-engineering specialists. The Marketing Panel was composed of 38 percent CEOs, presidents, or vice-presidents; 26 percent directors; 30 percent managers; and 6 percent academic and consulting marketing specialists. Among Materials panelists, 7 percent were CEOs, presidents and vice presidents; 21 percent were directors; 51 percent managers and supervisors; 14 percent engineering specialists; and 7 percent academic and consulting materials specialists. Approximately 36 percent of the Delphi VIII panelists were employed by vehicle manufacturers; 59 percent by components and parts suppliers; and 5 percent were specialists, consultants, academics, and representatives of associations and publications.

## Presentation of Delphi forecasts and analyses

**Data tables.** When a question calls for a response in the form of a number, responses are reported as the median value and the interquartile range (IQR). The median is a measure of central tendency that mathematically summarizes an array of judgmental opinions while discounting extremely high or low estimates; it is simply the middle response. The IQR is the range bounded at the low end by the 25th-percentile value, and at the high end by the 75th-percentile value. For example, in a question calling for a percentage forecast, the median answer might be 40 percent and

the IQR 35-45 percent. This means that one-quarter of the respondents answered 35 percent or less, another one-quarter chose 45 percent or more, and the middle half of all responses ranged between 36 percent and 44 percent, with 40 percent as the middle response. That narrow interquartile range would indicate a fairly close consensus among the respondents.

In contrast, the percentage forecast for a different question might show a similar median forecast of 40 percent, but with an interquartile range of 20-70 percent, indicating less consensus and a considerable degree of uncertainty about the issue in question.

Uncovering differences of opinion is one of the major strengths of the Delphi method. Unlike other survey methods, where differences of opinion among experts are often obscured by statistical averages, the Delphi highlights such differences through the presentation of the interquartile range.

**Discussion.** Narrative discussions are presented to highlight and explain a particular set of data.

**Selected edited comments.** Selected, edited comments from the Delphi panelists are shown following each data table in order to provide some insight into the deliberative process by which panelists arrived at their forecast.

In a Delphi survey, respondents are encouraged to contribute comments to explain their forecast and to perhaps persuade other respondents to change their positions. Many of these edited comments are included. These replies may provide important information which is not evident in the numerical data. An individual panelist may have unique knowledge that planners should carefully consider. However, readers should be careful not to overemphasize a particular comment. It is possible for a well-stated contrary opinion to mislead the reader into ignoring an important majority opinion which is accurately reflected in numerical data.

**Manufacturer/supplier comparison.** Delphi VIII panelists include respondents from the North American automotive manufacturers; the major suppliers of components, parts, and materials for the industry; as well as consultants and academics. A concerted effort is made to obtain a relatively equal distribution of manufacturer and supplier panelists. Within the context of this survey, categorizations will refer simply to either Manufacturer (or for brevity in tables, OEMs—Original Equipment Manufacturers) and Suppliers.

For obvious competitive reasons, the automotive manufacturers seek to maintain a degree of secrecy regarding their design, engineering and marketing plans. While the relationship between the manufacturer and supplier is moving toward an increasingly closer degree of cooperation and integration, a considerable element of proprietary concern remains. Additionally, the very size and complexity of the automotive industry works against optimum information transfer. Therefore, where it is considered relevant to a better understanding of or perspective on the forecast, our analyses include a comparison of the forecast from manufacturer and supplier panelists in an attempt to illustrate where significant agreements or differences exist.

**Comparison of panels.** The three groups of Delphi panelists (Technology, Marketing and Materials) are asked questions that specifically focus on their respective areas of expertise. However, a few questions are considered common to two or more panels. For example, the fuel-price question (see MAT-1) is considered so basic that it was submitted to all three panels.

At times, the panels will give differing responses to these questions. This may reflect the makeup of a particular panel and the panelists' subjective perception of the issue in question. Where differences do exist between the panels, serious consideration should be given to whether the difference reflects the composition and proprietary interest of that particular panel or whether there exists a substantial degree of uncertainty regarding the issue in question. We try to highlight both the differences and similarities.

**Trend from previous Delphi surveys**. A single Delphi survey is a snapshot which collects and presents the opinions and attitudes of a group of experts at a particular point in time. Some questions, in various forms, were asked in previous Delphi surveys, and thus provide trend data. The fact that forecasts for a particular question may exhibit considerable variation over the years does not diminish their relevance and importance to strategic planning. The forecasts reflect the consensus of expert opinion at the time. These opinions and forecasts are predicated on the best information available at the time. However, market, economic and political factors do change. Trend data can reveal the stability or volatility of a particular market, material or technology issue. A careful analysis of trend data is an important consideration in strategic business planning decisions.

**Strategic considerations**. Based on the replies to a particular question, other relevant Delphi VIII forecasts, other research and studies, and OSAT's extensive interaction with the automotive industry, this report makes inferences and interpretations as to the core issues in questions and their potential impact on the industry. By no means are they exhaustive statements of critical issues. Rather, they are points that the reader might consider useful.

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# EXECUTIVE SUMMARY

Many challenges are expected to confront automobile manufacturers and suppliers in the next decade as they address environmental issues, face tough global competition, and encounter more demanding customers. Furthermore, shortages of capital and skilled human resources and pressures to do more, better, yet faster, exacerbate their challenges. *The Delphi VIII Forecast and Analysis of the U.S. Automotive Industry: Technology* survey identifies many issues facing the industry and provides insight as to industry direction. In a real sense this is a benchmarking study in that it enables an individual or organization to compare (benchmark) their vision of the future to an industry consensus vision. Panelists expect rapid changes in technology and knowledge, as well as increased regulation and accelerating globalization. Increased reliance on technology to enhance design and manufacturing efficiency is anticipated. Organizations that effectively develop and implement this rapidly changing technology to reduce cost and improve customer satisfaction (increase value) will certainly have a competitive advantage.

The Technology volume of Delphi VIII is divided into nine sections addressing Strategic Planning Factors, Engineering and Sourcing Issues, Emerging Technology and Technology Issues, Materials and Recycling, Body and Chassis Product Trends, Safety, Powertrain/Drivetrain, Electrical/ Electronics, and Other Issues.

**Strategic Planning Factors.** Emissions, fuel economy, and safety standards are expected to be more restrictive over the next ten years. Fuel prices are expected to increase steadily, but moderately, to $1.40 per gallon for regular unleaded gasoline by 2005. High concentration alcohol and natural gas fueled vehicles are expected to comprise 3% and 2% respectively of North American-produced passenger cars and light duty trucks by the year 2005. Electric vehicle penetration is forecast to be 2% of passenger cars in the same time frame. Increased cooperation between traditional North American manufacturers and between traditional manufacturers and suppliers is anticipated.

CAFE standards are expected to increase to 32 m.p.g. (16% increase) by 2005 for passenger cars and 25 m.p.g. (24% increase) for light trucks and vans. This is in contrast to stable passenger car CAFE standards of the past six years, and an increase of only 5.8% in the last 12 years. The forecast for increased CAFE standards will present a major challenge to all manufacturers.

Considering the agreement of the domestic manufacturers and the Federal Government to pursue development of clean, super-efficient cars, panelists forecast a fuel economy of 40 m.p.g. would be possible for a commercial advanced technology five passenger car for the year 2020, far short of the stated goal of 87 m.p.g.

Panelists forecast that manufacturers will be willing to add $200 to the cost of a vehicle to improve fuel economy by one mile per gallon in 2005 at a CAFE standard of 35 mpg.

Significantly more sharing of vehicle platforms and technologies is expected between divisions of a manufacturer by 2005. More sharing of technologies between manufacturers is also forecast.

**Engineering and Sourcing Issues.** Panelists believe that 75% of product design and engineering by traditional domestic vehicle manufacturers for North American-produced passenger cars will be done in North America in 2005 compared to 90% today. Foreign owned vehicle manufacturers are expected to conduct 25% of their product design and engineering for North American-produced passenger cars in North America compared to 10% today.

Traditional domestic manufacturers are forecast to source the majority (70% in 2005) of parts, components, and subassemblies from the United States, Canada, and Mexico in the next decade. An increasing percentage is expected to be sourced outside of North America, including increases in Asia Pacific (except Japan), South America and Eastern Europe. North American production operations of foreign-owned vehicle manufacturers are expected to continue sourcing a significant fraction of parts, components, and subassemblies from Japan over the next decade. However, an increasing percentage is forecast to be sourced in North America (40% in 2005 vs. 30% today).

Sourcing from Asia Pacific (except Japan) is also expected to increase, as it was from domestic manufacturers. Traditional domestic manufacturers are expected to expand their Mexican component and subassembly sourcing from 10% today to 20% by 2005. Similarly, an increase from 8% to 18% is forecast for foreign manufacturers.

Panelists forecast a substantial reduction in the product development time of a new platform for both the Japanese and U.S. manufacturers in the next decade. The Japanese advantage is expected to be greatly reduced from 12 months currently to 5 months by 2005.

Japan is believed to have the most advanced product and process technology today, but the gap with the U.S. is expected to be nearly eliminated in the next decade.

**Emerging Technology and Technology Issues.** Advances in computer technology, and software and better use of currently available technology and software, are expected to have substantial positive influence on quality, reliability and durability. These advances will be used throughout the process of vehicle design, development, manufacture, and sale.

"Smart" materials, including electro-rheological fluids and electrochromatic glass, are forecast to see some limited application by the year 2000.

Low heat rejection, two-stroke and Miller cycle engines are expected to see limited application in the next decade.

**Materials and Recycling.** Panelists forecast reductions in steel and cast iron use of 15%, and increases in the uses of aluminum and plastics/composites of 20% and 15% respectively in the next decade if CAFE requirements increase to 35 m.p.g. The use of aluminum and plastic for exterior body components is expected to increase substantially in the next decade, but steel should remain the dominant material.

Total vehicle weight reductions of 10% for passenger cars and 8% for light trucks are envisioned by 2005. The value of a pound of weight saved in a vehicle is forecast to escalate from $1.00 per pound today to $3.00 per pound in 2005, assuming a CAFE requirement for passenger cars of 35 m.p.g. in 2005.

Modifications of used vehicles to accommodate non-CFC refrigerants are expected to cost approximately $100, but some panelists forecast that these modifications may cost as much as $1000.

Recycling legislation and regulations are thought to be highly probable by 2005 in the areas of disposal of automotive fluids and used tires, and establishment of uniform identification/coding standards to facilitate separation of materials.

**Body and Chassis Product Trends.** The integral body/frame is expected to remain the major passenger car platform through 2005. Space-frame and separate body/frame construction are forecast to be used on 5% and 2% respectively of passenger cars in that same timeframe.

MacPherson strut front suspensions are expected to continue in a dominant position in passenger cars (70% in 2005), but increased penetration of variations of twin A-arm designs is forecast. Rear independant suspensions in passenger cars is forecast to increase. Electrical/electronic power steering and hydraulic power steering with electronic control are expected to see some limited use by 2005. Passive-driver selected, semi-active and active suspensions are forecast to attain penetrations of 5%, 8%, and 2% respectively by 2005.

Anti-lock brake penetration on passenger cars is forecast to approach 100% during the next decade while traction control is expected to see an application rate of 25% in the same time frame. Four wheel antilock brakes are expected on 70% of light trucks in 2005 compared to 32% today.

A small but growing application of tire failure sensing devices (10%), puncture resistant/self sealing tires (15%), and run-flat tires (10%) is forecast by 2005.

**Safety.** Passenger-side airbags are forecast on 90% of light trucks in 2005. Modest use of rear seat occupant and side airbags is also expected in passenger cars and light trucks. It was

assumed that all passenger cars would have airbags for driver and passenger and that all light trucks would have driver airbags. Other safety features such as in-vehicle message systems, adaptive cruise control and collision warning systems are envisioned in limited numbers over the next ten years.

**Powertrain/Drivetrain.** For passenger cars, 8-cylinder engine usage is forecast to decline to only 8% penetration in the next decade, with both 4- and 6-cylinder engine penetration increasing slightly. Similar trends are forecast for light trucks, but with an 8-cylinder engine application level of 28% in 2005.

Following trends of recent Delphi forecasts, nearly half of today's engines are forecast to be fundamentally redesigned during the next decade. This will certainly require a major committment of both financial and human resources.

Diesel engines are envisioned for 3% of passenger cars and 9% of light trucks in 2005 compared to 0% and 4% respectively today.

The future role of two-stroke gasoline engines is uncertain but they are still forecast to have some application by 2001 and an application rate of 25% by 2010.

Port fuel injection is forecast in 95% of passenger cars and 80% of light trucks with spark ignited engines by 2005. In contrast, throttle body injection is expected to disappear in passenger cars and be used on only 10% of light trucks. Direct cylinder gasoline injection could see limited application in the next decade in both passenger cars and light trucks.

Turbocharging and supercharging of passenger car engines are expected to see minimal application of only 1% and 2% respectively by 2005. On the other hand, four valve per cylinder engines are expected on 45% of passenger car engines compared to 31% in 1994. The increase in multi-valve engines is certainly a factor in the low expectations for turbochargers and superchargers.

From 1994 to 2005, push rod valve actuation penetration is expected to decrease from 69% to 50% in engines with a "V" engine configuration while single and dual overhead cam penetrations are forecast to expand to 30% and 15% respectively. For "in-line" engines, push rod valve actuation is expected to decrease from 16% in 1994 to 5% in 2005. Variable valve timing and lift control are forecast at 15% and 5% respectively for engines produced in North America in 2005.

The use of distributorless ignition systems on spark ignited engines is expected to increase to 75% of passenger car engines and 60% of light truck engines by 2005. Individual cylinder control and cylinder pressure control of ignition timing are forecast to see limited application by 2005. Knock adaptive control of ignition is forecast for 70% of passenger car engines and 50% of light truck engines by 2005. Furthermore, the use of features such as balance shafts, hollow camshafts, and roller lifters are all expected to expand in the next decade.

The use of aluminum in cylinder heads and blocks in passenger car engines is expected to increase dramatically to 90% and 33% respectively by the year 2005. A smaller, but growing, use of aluminum for cylinder heads and blocks in light trucks is also envisioned in the next decade. Several applications of plastic engine components (intake manifolds, valve covers, fuel rails), are expected to see significant use while ceramic engine components are forecast to see limited application by the year 2005.

Pre-heated catalytic converters and NOx catalysts are believed to be required in some applications to meet both Federal and California emission standards over the next decade. Start-up converters without a bypass are expected in 25% of passenger cars to meet Federal emission standards and 40% of passenger cars to meet California emission standards. Some use of start-up converters with a bypass is forecast. Some use (10% or less) of particulate controls, lean NOx traps and start-up HC traps is expected to meet both Federal and California emission requirements.

The five-speed manual transmission is expected to be the only manual transmission for passenger cars with any significant volume in the next decade. The decline of the three-speed automatic transmission is forecast to continue in favor of four-speed designs, with only 5% three-

speeds expected for 2005. Five-speed automatic transmissions are forecast to emerge (5%) in upscale vehicles. Electronic control is expected to become almost standard (95% application level) by 2005. Continuously variable transmissions are expected to see very limited (1%) application in the next decade.

For light trucks, four- and five-speed manual transmissions are each expected to see an application rate of 10% in 2005. By 2005, no use of three-speed and limited use (5%) of five-speed automatic transmissions is envisioned. Four-speed automatic transmissions are forecast to be used on 75% of light trucks in 2005, little changed from today.

In the opinion of our panelists, front engine, front drive will be the dominant drivetrain configuration in passenger cars (92%), and 96% of these are expected to use transverse engine mounting in 2005.

**Electrical/Electronics.** Vehicle electronic content is forecast to continue to grow, from a 1994 estimate of 15% total vehicle value to 20% by 2005. This is in spite of the the continuing reduction in the cost of individual electronic components. Vehicles with at least one major multiplexed power system are forecast to expand from a current market estimate of 3% to 20% by 2005 with some use of fiber optics in the control, but significant economic and technical problems must be resolved. Cost, packaging and weight are important advantages of multiplexing.

Application of electronic/electrical features such as anti-theft, CD player, electronic keyless entry, and on-board diagnostic via expert systems is expected to increase significantly in the next decade. Vehicle system voltage is forecast to increase to 24 volts or 12/24 volts on 15% of passenger cars in the next decade. The number of electric motors on standard passenger cars (<$25,000) is expected to double from 10 currently to 20 in 2005. For upscale vehicles (>$25,000), the number is forecast to grow from 20 currently to 30 in 2005.

A number of components that have previously been driven off of the engine are expected to be driven by electric motors in limited numbers (10% or less) by 2005. These components include A/C compressors, air pumps, power brakes and power steering pumps.

Electronic noise cancellation technology is forecast to see limited application in the next decade.

**Other Issues.** Service activity in dealerships is expected to increase modestly in the areas of electrical/electronics and non-CFC refrigerant conversion. Dealership body shop and mechanical service are forecast to remain unchanged in the next decade.

Skilled labor supply deficiencies have been identified for the near and long term. Management of human resources is expected to be a critical challenge for the industry over the next decade.

**TECH-1. Please estimate U.S. retail fuel prices, per gallon, for 2000 and 2005, including fuel tax. (Please use constant 1995 dollars without adjusting for inflation.)**

| Unleaded Gasoline | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Regular | $1.10 | $1.25 | $1.40 | $1.18/1.40 | $1.25/1.71 |
| Premium | 1.30 | 1.45 | 1.65 | 1.38/1.59 | 1.45/1.91 |

* **Source**: United States Energy Information Administration

## Selected edited comments

- After years of estimating high and never seeing any increases, we've reduced the price levels this time.
- An aggressive energy policy could result in a significant tax increase.
- By 2005, gasoline tax will have increased significantly.
- Demand for fuel being lowered due to more fuel efficient vehicles; OPEC strength diminished.
- Expect another issue with supply between 2000 and 2005. Decreased supply will drive price up.
- Expect most of the increase to be in the form of taxes, both state and federal.
- I think that raising fuel taxes is such an emotional issue that I don't think that it can be done. Political events beyond the control of the United States are the biggest risk for causing rising prices.
- Increased dependence on foreign oil; expect increase in fuel taxes.
- Increasing worldwide demand and taxation opportunity (vs. more politically incorrect tax alternative) will drive higher fuel prices. Significant uncertainty (risk) of sharp fuel price increases due to political developments, possible supply interruptions and shortfalls. This becomes intensified as increasing worldwide demand closes supply side "margin."
- Popular (voter) demand for low-priced fuel will be a strong market factor that, when combined with supplier competition to be low priced supplier, will keep per gallon costs relatively low.
- Proven oil reserves continue to grow faster (i.e., big find in Brazil this week) than growth of fuel consumption. Thus, I expect little market pressure to push up prices. Also, United States seems unwilling to tax fuel to reduce consumption like in Europe. Thus, only minor increases related to reformulation and lower sulfur content.
- Regulations and legislation forcing changes in fuel composition will increase costs. Prices are subject to upset of foreign supplies of petroleum. We should expect one such spike in the next decade. Taxes will be increased.
- Tax will play a bigger role here than fuel availability.
- Taxes must be increased to cover military costs for defending oil supplies. Political pressure will keep tax rise low.
- The United States can't continue to buy and sell gasoline at half the price of the rest of the world.
- There will be no technical or resource reason for prices to rise. Taxation is another question.
- World consumers will still force OPEC to hold prices to current levels. Cost of production will increase only modestly. Most of real increase will be taxes.

## Discussion

The price of gasoline has a significant impact on the design of future vehicles and on the mix of vehicles sold. This question has been asked in each Delphi forecast since the first one in 1979. Much higher future prices were forecasted in early Delphi studies which were conducted at the time of gasoline shortages.

Delphi VIII Technology panelists anticipate the prices of regular and premium gasoline to increase at rates of approximately 2.2 percent per year in 1995 dollars through 2005. This is somewhat less than the rate projected from recent forecasts.

## Manufacturer/supplier comparison

There is no statistical difference between responses of manufacturers and suppliers.

## Comparison of Forecast: MKT-3 and MAT-1

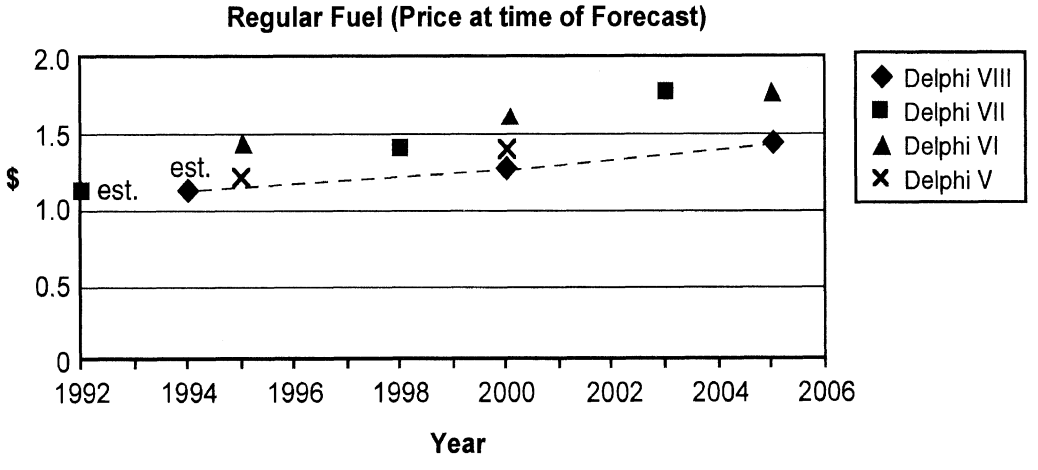
Results for the technology, marketing and materials surveys are in general agreement and are summarized in the following table.

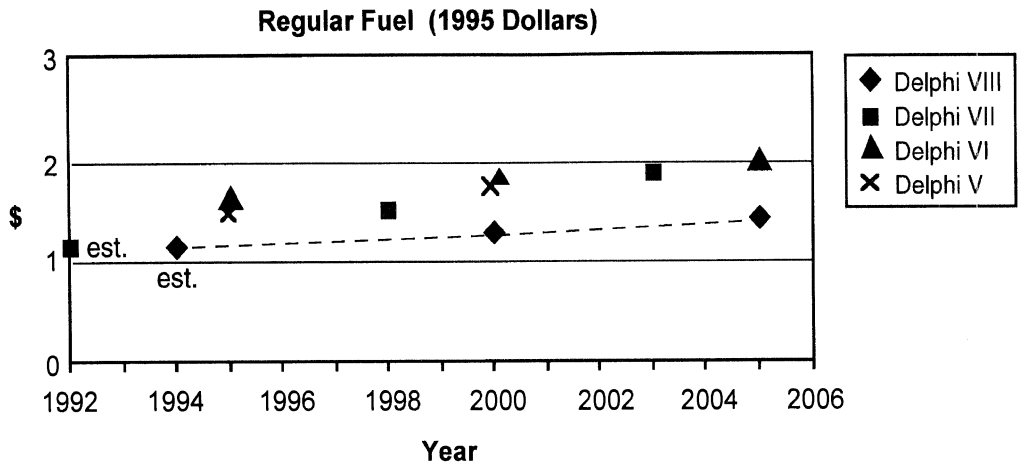
| Unleaded Gasoline | 1994* | Median Response | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2000 | | | 2005 | | |
| | | Tech. | Mkt. | Mat. | Tech. | Mkt. | Mat. |
| Regular | $1.10 | $1.25 | $1.25 | $1.25 | $1.40 | $1.45 | $1.50 |
| Premium | $1.30 | 1.45 | 1.49 | 1.50 | 1.65 | 1.68 | 1.73 |

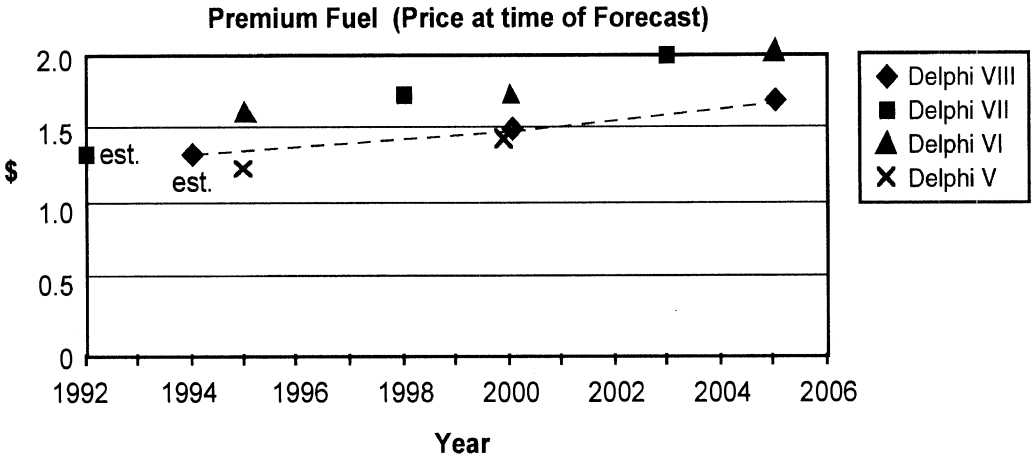
* **Source:** United States Energy Information Administration.

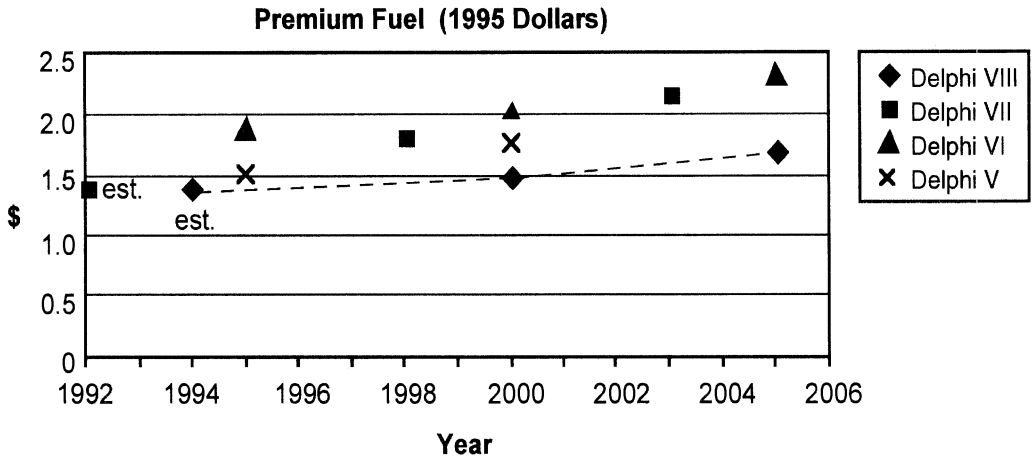
## Trend from previous Delphi surveys

The following graphs compare the prices of gasoline for this and the previous three Delphi forecasts in dollars at the time of the survey and also constant 1994 dollars.






Prices for regular and premium fuel are forecast to increase but less than in recent forecasts. The prices of regular fuel did not increase from 1992 to 1994, and the price of premium fuel increased only 1 cent. This period of price stability almost certainly influenced the forecast of panelists.

## Strategic considerations

Some of the factors that may influence the price and availability of gasoline are:

- World political stability
- Federal and state taxes
- The continued need by petroleum exporting countries to finance their economies through exports of petroleum
- The availability of alternative energy sources and the viability of consumer markets for those products
- Increases in product energy efficiency as a result of legislation, market demand or technological improvements
- Increasing demand by rapidly developing countries
- Declining petroleum reserves in the United States
- Potential new major discoveries of petroleum reserves throughout the world

Stable or moderately increasing fuel prices are expected to allow orderly planning and execution of future products. Low fuel prices will continue to allow customers to select vehicles that meet their passenger and cargo carrying requirements. Many factors affect the price of fuel, however, and the outlook can change rapidly as was seen in the late 1970s. Political problems causing disruptions in fuel supplies or pressure to increase the gasoline tax in the United States are the most likely causes of sudden increases in fuel prices. Pressure for increased taxes may come as a result of environmental concerns, the balance of payments problem caused by imported oil or the need to raise revenue. Taxes may be assessed by individual states or the federal government.

Manufacturers must consider contingency plans for rapid perturbations of fuel prices. These plans may include flexible assembly plants and reserve tooling capacity for components for high fuel economy vehicles. Low fuel prices are likely to continue to cause problems for manufacturers with regards to meeting future corporate average fuel economy (CAFE) standards as the customer continues to prefer large cars with relatively low fuel economy.

**TECH-2. What do you expect CAFE (Corporate Average Fuel Economy) standards for passenger cars and light trucks and minivans will be in 2000 and 2005?**

| Vehicle Type | CAFE Standards | | | | |
|---|---|---|---|---|---|
| | | Median Response | | Interquartile Range | |
| | 1994* | 2000 | 2005 | 2000 | 2005 |
| Passenger cars | 27.5 mpg | 29.5 | 32 | 28/30 | 30/33 |
| Light trucks and minivans | 20.2 mpg | 22 | 25 | 21.5/23 | 23/26.1 |

* **Source:** United States Department of Transportation, Automotive Fuel Economy Program.

## Selected edited comments

- As dumb as CAFE is, the greenhouse gas people and Vice President Gore will keep pushing for higher CAFE numbers. And V.P. Gore, through Partnership for New Generation Vehicle (PNGV) discussions, keeps talking about increases at 2 percent per year to offset increases in vehicle miles traveled (VMT). Higher CAFEs will be pushed to get United States back to 1990 greenhouse gas levels but those will not be passed by Congress.
- As the percentage of light trucks in the production population increases, political forces will come to bear on the CAFE standards for them, and they will be moved closer to those for passenger cars. The Partnership for New Generation Vehicle (PNGV), etc., results will be part of the pressure on CAFE; hopefully such programs will contribute technology to the improvement. Some contributions from allowances for ZEVs and alternate fuels is likely and will help.
- Government will allow consumers to determine CAFE standards by their purchase decisions. Additional taxes on gasoline will be used to affect actual CAFE results.
- I expect very little change in regulation, but who can predict the political process? Current sentiment seems to favor far less regulation in the future.
- I think there will be significant pressure to increase CAFE rather than artificially raise price of fuel to control oil imports. Trucks, with increasing sales percentage of market, will see even more CAFE pressure than passenger cars.
- It depends on who controls Congress and how much whining the Big Three do.
- Light trucks may be divided into work trucks and car-line trucks with different CAFE standards.
- Market demand and fuel prices will define vehicle requirements. Political swing away from huge government departments attempting to control details.
- Must be market driven—not legislated. I believe Republicans will repeal or at least put a lid on these.
- Pressure to increase trucks because they are 50 percent of market.
- Should be interesting political "tug-of-war" between conservative Republicans and more liberal Democrats (attempting to regain lost momentum, or possibly take advantage of "final" opportunity). Trucks vs. passenger car definition may be adjusted to reflect sport utility vehicles and vans as passenger car alternatives rather than trucks.
- There will be a great deal of resistance to increasing CAFE—neither the Congress nor consumers nor manufacturers want it to rise in the near future. However, as the environment will not go away as an issue, over time there will be pressure to push it up and electric vehicles will change the entire landscape.
- Will be limited by political considerations.
- Will CAFE rating survive in its present format?

## Discussion

Passenger car CAFE standards have been unchanged since 1990 and light truck CAFE standards since 1991. However, panelists anticipate increases of approximately 20 percent by 2005.

## Manufacturer/supplier comparison

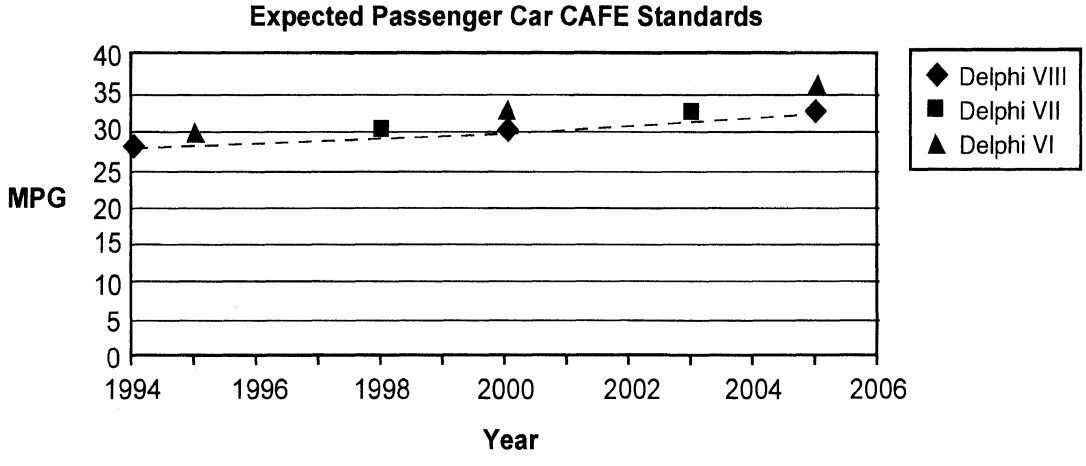
There is no statistical difference between responses of manufacturers and suppliers for passenger cars. There is a statistical difference for light trucks and minivans as shown in the following table.

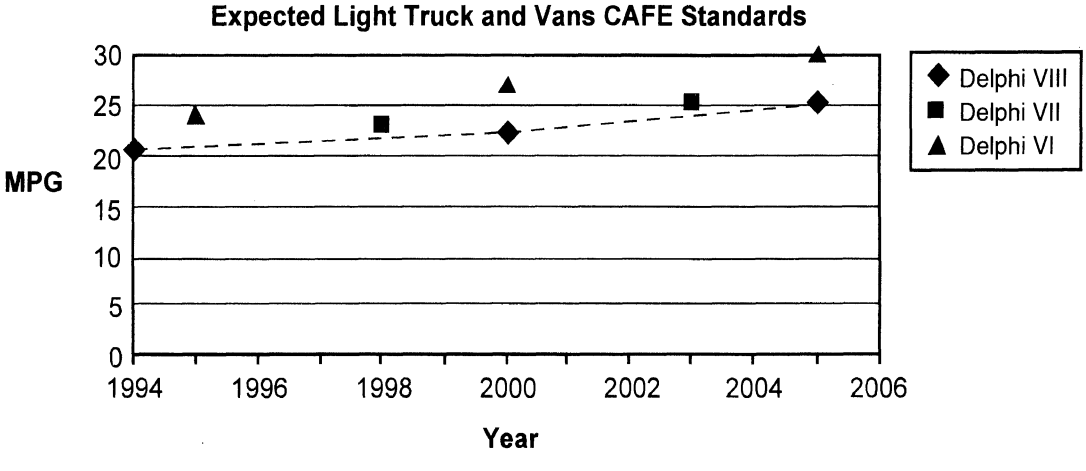
| Expected CAFE standards for Light Trucks and Minivans Mean MPG | | | |
|---|---|---|---|
| 2000 | | 2005 | |
| Mfr. | Sup. | Mfr. | Sup. |
| 22.1 | 22.9 | 24.2 | 25.8 |

Suppliers forecast somewhat higher standards than manufacturers.

## Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI study. Results for 1992 Delphi VI and 1994 Delphi VII studies are compared to the 1996 Delphi VIII study on the charts below.



The current panelists expect somewhat lower increases in future CAFE standards for both passenger cars and light trucks compared to those of earlier surveys.

## Strategic considerations

In spite of unchanged CAFE standards in the past few years, panelists expect increases in the future, suggesting they believe the political environment could shift from today's conservative agenda. Increased standards will require vehicle improvements to reduce fuel consumption. The customer will continue to have little incentive to drive smaller vehicles considering the fuel price forecasts in the previous question. As a result, a shift to smaller more fuel efficient vehicles is unlikely without price incentives.

It would not be surprising to see some manufacturers commit to a modest continuous fuel economy improvement to demonstrate a good faith effort to reduce fuel consumption and head off more restrictive legislation.

**TECH-3. What passenger car and light truck CAFE standards can the three traditional domestic manufacturers and other full-line vehicle importers reach, with reasonable effort, in 2000 and 2005? (Reasonable effort means utilizing practical technology, avoiding substantial reduction in passenger and luggage space, and avoiding excessive costs for manufacturers and suppliers.)**

| Manufacturers | 1994* mpg | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Passenger Cars | | | | | |
| Traditional domestic | 27.3 | 29 | 31 | 29/30 | 30/33 |
| Japanese - foreign and domestic | 30.2 | 32 | 33 | 31/33 | 32/35 |
| European - foreign and domestic | 25.9 | 28 | 30 | 27/29 | 29/31 |
| Light Trucks | | | | | |
| Traditional domestic | 20.7 | 22 | 24 | 22/23 | 23/26 |
| Japanese - foreign and domestic | 22.2 | 24 | 26 | 23/25 | 24/28 |
| European - foreign and domestic | 18.2 | 20 | 22 | 20/22 | 21/24 |

* **Source:** United States Department of Transportation, Automotive Fuel Economy Program, Motor Vehicle Manufacturers Association, Facts & Figures 1994

## Selected edited comments

- Cost to increase fuel economy vs. real economic benefit to consumers (fuel saved x cost per gallon) will constrain what's "reasonable." CAFE will challenge Japanese movement toward larger, more upscale vehicles.
- Depends on market pull of sales mix and fuel price.
- Fleet mix in light trucks will be heavier due to all the larger sport utility offerings.
- I suspect that many companies will be existing on credits in 2005, at best. There will come a point (unless people start getting physically smaller) that a practical vehicle will not be able to deliver greater mpg (current fuel).
- Increased size of Japanese cars will offset technology.
- Japanese mix shifts toward larger cars.
- Key issue is compromised safety.
- Modest improvements without downsizing.
- No major technology change will be available to permit big improvements by 2000. Safety systems will add weight for 2000.
- Only the rich will be able to afford to buy new cars and they are not interested in small, fuel efficient vehicles. Thus, model mix towards bigger cars gets even worse.
- The CAFE arguments will continue and cloud the picture and facts about what's reasonably achievable. "Mix" has some impact.
- The fuel efficiency of any given model is increasing at a much more significant rate. Model mix to bigger, more fully loaded cars and trucks (customer choice) is what's slowing down CAFE improvements. This is especially true in shift to large and four-wheel drive trucks.
- U.S. customer will not give up comfort for compliance in "family size" market.

## Discussion

The following charts show the anticipated CAFE requirement versus attainable values for traditional domestic, Japanese and European manufacturers, based on forecasts of our current panelists.

### *Passenger Car:*

| Expected Passenger Car CAFE | | | |
|---|---|---|---|
| | **1994*** | **2000** | **2005** |
| CAFE requirement ** | 27.5 | 29.5 | 32 |
| Traditional domestic | 27.3 | 29 | 31 |
| Japanese-foreign & domestic | 30.2 | 32 | 33 |
| European-foreign & domestic | 25.9 | 28 | 30 |

*** Source:** United States Department of Transportation, Automotive Fuel Economy Program, Motor Vehicle Manufacturers Association, Fact & Figures 1994

**** Results of Tech-2**

Attainable ***passenger car*** CAFE levels are forecast to be as follows for 2000 and 2005:

Traditional domestic → below the CAFE standard
Japanese- foreign and domestic → above the standard
European- foreign and domestic → below the standard

### *Light Trucks:*

| Expected Light Truck CAFE | | | |
|---|---|---|---|
| | **1994*** | **2000** | **2005** |
| CAFE requirement | 20.2 | 22 | 25 |
| Traditional domestic | 20.7 | 22 | 24 |
| Japanese-foreign & domestic | 22.2 | 24 | 26 |
| European-foreign & domestic | 18.2 | 20 | 22 |

***Source:** United States Department of Transportation, Automotive Fuel Economy Program, Vehicle Manufacturers Association, Facts & Figures 1994

Attainable ***light truck*** CAFE levels are forecast to be as follows for 2000 and 2005:

Traditional domestic → at or below the CAFE standard
Japanese- foreign and domestic → above the standard
European- foreign and domestic → below the standard

## Manufacturer/supplier comparison

Responses for manufacturers and suppliers are summarized in the following table.

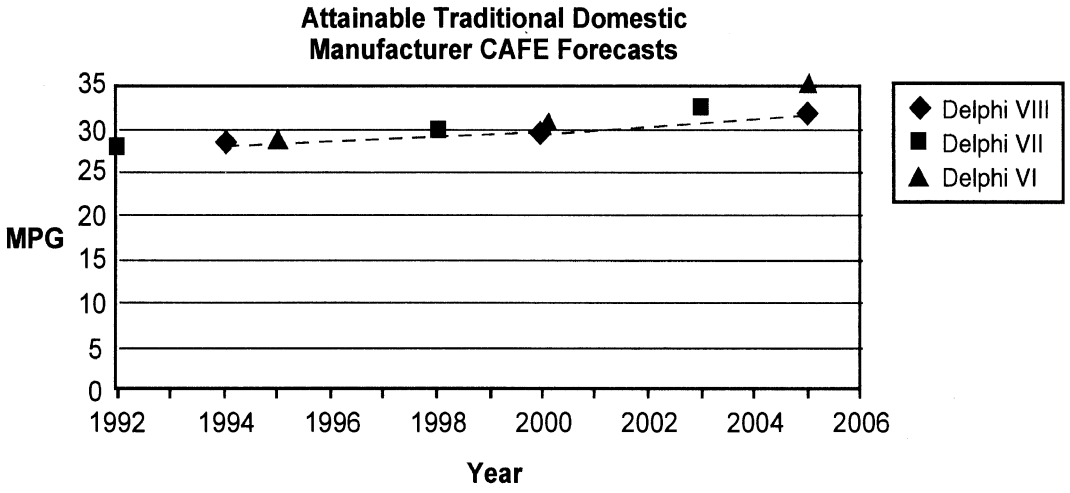
| Manufacturers | Passenger Cars | | | | Light Trucks | | | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | | 2005 | | 2000 | | 2005 | |
| | Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. |
| Traditional domestic | 28.9 | 29.7 | 30.9 | 32.5 | 22.2 | 23.4 | 23.6 | 25.8 |
| Japanese-foreign and domestic | 31.3 | 32.8 | 33.1 | 35.2 | 23.8 | 25.3 | 25.3 | 27.7 |
| European-foreign and domestic | 28.0 | 28.5 | 29.7 | 31.1 | 20.5 | 21.5 | 21.9 | 24.1 |

For all cases, suppliers forecast higher attainable CAFE than do manufacturers. Since suppliers are not involved in the calculation of CAFE or the determination of model mix which plays a major part in CAFE, it is possible that the most reasonable numbers are those of the manufacturers. It is also possible that the suppliers are more optimistic regarding the application of new technology or the use of more expensive materials or components to improve fuel economy. Replacing steel with aluminum would be an example.

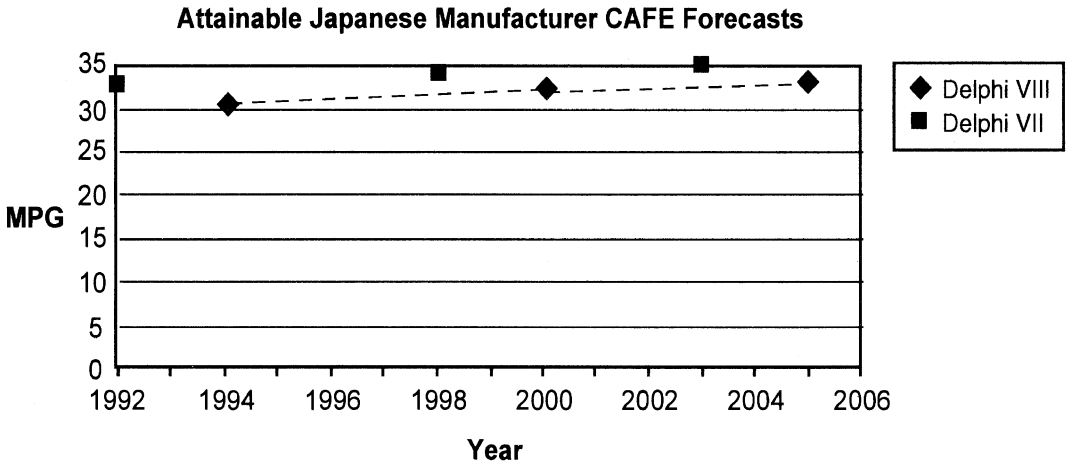
### Trend from previous Delphi surveys

This question was not asked previously for light trucks. The question was asked for passenger cars for the first time in the 1992 Delphi VI survey. The numbers are comparable for domestic manufacturers, but the full-line foreign manufacturers from all countries were lumped together in the 1992 Delphi VI survey. Results for foreign manufacturers from the 1994 Delphi VII and 1996 Delphi VIII surveys are comparable.

### *Passenger Cars:*




The expectations for future attainable CAFE in the current survey are somewhat below those of the previous two surveys for the traditional domestic manufacturers.




The expectations for future attainable CAFE in the current survey are below those of the previous survey for the Japanese foreign and domestic manufacturers.

## Strategic considerations

Estimates by current panelists of attainable CAFE levels indicate that the Japanese manufacturers may not be constrained by CAFE in the next decade for passenger cars or light trucks. The traditional domestic and European manufacturers, however, will continue to struggle to meet CAFE requirements for both groups of vehicles. This situation could continue to place the Japanese manufacturers in an advantageous position. They will not be required to spend the same financial and human resources to meet CAFE requirements. These resources may be very substantial for the traditional domestic and European manufacturers. In addition, model mix will not be constrained by CAFE for the Japanese manufacturers. The lack of model mix constraint means that the Japanese manufacturers can continue the trend to larger, higher profit vehicles while the traditional domestic and European manufacturers are pushed to the smaller, lower profit vehicles. Some European manufacturers may choose to pay a CAFE fine rather than downsize vehicles or add considerable vehicle cost.

As affordability concerns mount, manufacturers will be increasingly reluctant to employ higher cost technologies that could yield improved fuel economy. Driven by customers more concerned with price/value trade-off, manufacturers could face serious challenges if CAFE were to increase significantly.

We continue to be surprised by the industry's confidence in improving fuel economy by over 10 percent between now and 2005 considering the difficulty in improving fuel economy over the last 10 years.

Manufacturers may fall below the CAFE standard for a given year without paying a penalty through the use of carry-forward of carry-back credits for a year in which the standard is exceeded. On a long term average, however, the standard must be met. The penalty for non-compliance is $5 per 0.1 mpg for *every* vehicle sold by the manufacturer.

**TECH-4. What percentage improvement in fuel economy will be attributed to each of the following sources by 2000 and 2005? Percent improvement is approximately: (mpg improvement/current mpg) x 100.**

| Sources | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Accessory drives | 2% | 3% | 1/2% | 2/4% |
| Aerodynamics | 2 | 4 | 2/3 | 3/5 |
| Downsizing | 4 | 7 | 2/5 | 4/10 |
| Engine efficiency | 5 | 10 | 4/7 | 6/11 |
| Reduced tire rolling resistance | 2 | 3.5 | 1/3 | 2/4 |
| Supercharger/turbocharger with engine downsizing | 2 | 3 | 1/2 | 1/4 |
| Transmission efficiency | 4 | 5 | 2/5 | 4/7 |
| Weight reduction without downsizing | 5 | 8 | 3/5 | 5/10 |

**Other responses:**

Affordability: 2000 - 10 percent; 2005 - 20 percent (Editors note: affordability driving mix to smaller cars)

Alternative power sources: 2000 - 5 percent; 2005 - 20 percent

Direct valve activation: 2000 - 10; 2005 - 15

Electronically shifted mechanical (torque-converter less)

Energy recapture (electric vehicles, etc.): 2005 - 10 percent

Energy recovery device: 2005 - 3 percent

Fuel itself: 2000 - 10; 2005 - 10

Hybrid powertrain: 2005 - 25

Improved efficiency of fuel: 2000 - 10 percent; 2005 - 15 percent

Intelligent modal control of above: 2000 - 4 percent; 2005 - 15 percent

Powertrain friction: 2000 - 1 percent; 2005 - 3 percent

Reduced electrical loads, improved wheel bearings, improved steering systems: 2000 - 1 percent; 2005 - 3 percent

## Selected edited comments

- Aerodynamics are fairly well understood—there is not much left to be gained here. The added cost of supercharging/turbocharging will prevent its widespread use. Transmission efficiency improvements are limited.
- As long as you are talking about IC engines, significant improvements in engine efficiency are impossible unless you concentrate your development efforts on turbocharged, DI diesel engines. The latest developments on the "common-rail" technology open up possibilities for downsized (three-cyl.) but still powerful diesel engines. An 80 mpg car powered by a gasoline-fueled engine is a utopia unless you talk about a "city car" for one or two persons.
- Assume most vehicles will be four-cycle powered; downsizing reflected in mass and aero.
- Assumes fuel prices stay relatively low and vehicle cost is still king.
- Compounding of mass reductions with engine downsizing and powertrain efficiency will play a major role. High speed/high performance tire usage will be scaled back.
- Depends on gasoline tax which in turn may well be affected by global warming concerns.

- Depends on what CAFE is mandated. This is estimate for the modest gains projected in questions 2 and 3. Engine efficiency effect depends on what engines go into the mix. Supercharged diesel warrants attention.
- Downsizing heavy components to reduce weight is an opportunity not fully utilized.
- Each number looks feasible but totals are ridiculous. The numbers are not additive.
- Electronically shifted mechanical (torque-converter less) is attractive but requires an OEM's initiative. It could save fuel but (at least at first) is likely to cost more. Basically, fuel prices is a political/tax issue, on which engineers are not the best prognosticators.
- Engine technology will improve; alternative fuels will play a role; breakthrough technology.
- Fuel cells; flywheels; turbines.
- Full electronic transmission control (reduce engine torque with electronic throttle control) will provide a 10 percent fuel economy improvement.
- Government and fuel costs still play a major role in fuel economy technology and implementation. Reduced weight seems to always be an efficient way to improve fuel economy.
- I expect direct injection, lean burn gasoline powered engines to become a reality by 2005 with approximately 15 percent improvement. CVTs may finally become a production reality if a manufacturer decides to take the risk and commit the high investment required.
- In my opinion, downsizing is not a viable option.
- Main areas are aerodynamics, downsizing, engine efficiency, reduced tire rolling resistance, transmission efficiency, weight reduction without downsizing percentage depends on vehicle line.
- Most of the benefits of aerodynamics, materials and weight have already been realized. Future efficiency increases will be due to fundamental changes to the powertrain.
- Not additive!!
- Percentages here are only indicative of areas offering most potential. They are not numerically additive or significant other than as trend indicators.
- Re: Aerodynamics—Since the "fleet" is relatively fixed between now and 2000, the aero improvements of the new models must be balanced against the carry over aero of the carry over models! These are "fleet CAFE" fuel economy improvements. These numbers are for the "fleet of new cars sold in those years" a given model may go up dramatically and only raise the fleet 0.5 percent mpg. Make sure everyone is talking fleet mpg and not a model or given engine mpg!
- The expected improvement in engine efficiency by 2005 can only be achieved by resorting to direct injected, turbocharged diesel engines.
- There are many relationships between these factors. They are not additive. A downsized car will have smaller accessory drive requirements, for example.
- These are CAFE-weighted numbers; larger improvements on affected models.
- Vehicle synergism will require a combination of mass reduction, engine downsizing, and powertrain optimization. . .subject to cost constraints. Wide ratio 5-6 speed automatics, and some CVTs will allow powertrain downsizing, further improving fuel economy.
- Very difficult to arrive at percentage. Rather, rate of potential of opportunities (i.e., rolling resistance and aerodynamics) offers more opportunity than transmission efficiency and weight reduction on given sized vehicle.
- Who knows what the federal government will do—with the present administration, the real push for improvement has passed, unfortunately.

## Discussion

Panelists forecast that the most significant fuel economy increases by 2005 will come from engine efficiency (10 percent), weight reduction without downsizing (8 percent) and downsizing (7 percent).

## Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement with the exception of the items noted in the following table.

| Sources | Mean Response | | | |
|---|---|---|---|---|
| | 2000 | | 2005 | |
| | Mfr. | Sup. | Mfr. | Sup. |
| Downsizing | 3.1% | 5.7% | 5.5% | 8.8% |
| Transmission efficiency | 3.4 | 4.4 | — | — |
| Weight reduction without downsizing | — | — | 7.8 | 9.9 |

Suppliers forecast a higher fuel economy improvement than manufacturers for the items noted.

## Trend from previous Delphi surveys

In previous surveys the requested response was the "percentage of overall CAFE improvement that will come from each of the following sources." The sum of all of the responses should have added to 100 percent. Therefore, the results of past surveys are not directly comparable to the current survey. On a relative importance or ranking, however, comparisons can be made. As in previous Delphi forecasts, improved engine efficiency and weight reduction continue to be the most significant areas of anticipated improvement in fuel economy.

| Source of improvement | Percent of Total Fuel Economy Improvement | | |
|---|---|---|---|
| | Forecast for 2000 | | Forecast for 2003 |
| | 1989 Delphi V | 1992 Delphi VI | 1994 Delphi VII |
| Engine efficiency | 25% | 15% | 20% |
| Weight reduction | 20 | 20 | 20 |
| Downsizing | 5 | 20 | 10.5 |
| Transmission efficiency | — | 10 | 10 |

## Strategic considerations

Some earlier attempts at downsizing were rejected in the marketplace with significant financial consequences. This may place added pressure on vehicle costs as weight reduction is pursued through the use of lightweight more costly materials. The shift in material usage and the sources of efficiency improvements in engines and transmissions are addressed in later questions.

Most sources of fuel economy improvement will come about only with significant capital expenditures and potential increases in component piece cost as a result of materials changes.

Turbocharged diesel engines are noted by at least one panelist as having significant potential for fuel economy improvement. Emissions problems with diesel engines must be over-come before this can become a reality.

There is generally wide variability in the individual category responses suggesting that the specific median responses should be used more to indicate trends rather than specifics. Also, comments on addition of the increases associated with the various factors should be noted.

**TECH-5. How much weight reduction and downsizing would be required to meet a passenger car CAFE standard of 30 and 35 mpg by 2005? Please use the optimal combination considering cost, vehicle packaging, etc.**

| Effects of Increased CAFE Standards | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 30 Mpg | 35 Mpg | 30 Mpg | 35 Mpg |
| Percentage weight reduction without downsizing | 10% | 20% | 10/20% | 15/30% |
| Percentage downsizing | 10 | 15 | 5/17 | 10/26 |

## Selected edited comments

- Customer willingness to "trade" performance and comfort for fuel economy is a significant question in this equation.
- Customers do not want smaller cars, so the industry will have to make the current sized vehicles lighter and more fuel efficient.
- I don't think that you can get to 30 and 35 mpg through weight reduction alone; at least not at any reasonable cost.
- I doubt that anyone would achieve CAFE standards with only weight reduction and downsizing.
- May well result in vehicles not well received in marketplace relative to roominess, performance and appearance. May also switch market to utility type vehicles as opposed to passenger sedan type.
- Must assume other technologies will be employed (engine efficiency, transmission and accessory dissipation also) to meet requirement/target—also, does not consider safety issues.
- Only the rich will be able to afford to buy new cars and they are not interested in small, fuel efficient vehicles. Thus, model mix towards bigger cars gets even worse.
- Requires major re-engineering without any downsizing.
- Significant weight reduction not affordable. Downsizing (United States) not customer-accepted.

## Discussion

Panelists forecast that weight and size reductions of 10 percent would be required to meet a CAFE standard of 30 mpg. Weight and size reductions of 20 percent and 15 percent, respectively, would be required to meet a CAFE standard of 35 mpg.

## Manufacturer/supplier comparison

There is no statistical difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the same format in the 1994 Delphi VII survey. Comparisons of estimates are summarized in the following table.

| Effects of Increased CAFE Standards | Delphi VII | | Delphi VIII | |
|---|---|---|---|---|
| | 30 Mpg | 35 Mpg | 30 Mpg | 35 Mpg |
| Percent weight reduction | 15% | 20% | 10% | 20% |
| Percent downsizing | 10 | 15 | 10 | 15 |

The two forecasts are the same with the exception of weight reduction required to meet 30 mpg CAFE. For this scenario, the forecasts for the 1994 Delphi VII and the 1996 Delphi VIII studies are 15 percent and 10 percent, respectively.

## Strategic considerations

Based on the forecast CAFE of 32 mpg for passenger cars for 2005, panelists would project required weight reduction and downsizing of approximately 14 percent and 12 percent, respectively. These figures represent significant challenges to vehicle manufacturers. Weight reduction may carry a high cost if material substitutions are the primary means of attainment. Certainly some weight reduction may be obtained through design efficiencies, but some material substitution would likely be required. Some previous downsizing programs have been poorly received in the marketplace. It is likely that if fuel remains inexpensive as is forecast, downsizing will again be poorly received by the customer.

Certainly other vehicle systems such as the engine and transmission will contribute to future fuel economy improvements. It is likely, however, that a CAFE of 32 mpg will force significant weight reduction and downsizing.

**TECH-6. How much additional cost per vehicle, in current dollars, would a manufacturer be willing to add to a typical mid-size passenger car to improve fuel economy by one (1) mile per gallon? This cost may be added for a new device, alternate material, revised material, improved technology, etc. Assume CAFE requirements at 27.5 mpg in 2000 and 30 and 35 in 2005.**

| Vehicle Type | Median Response | | | |
|---|---|---|---|---|
| | 1995 Current Value CAFE = 27.5 mpg | 2000 CAFE = 27.5 mpg | 2005 CAFE = 30 mpg | 2005 CAFE = 35 mpg |
| Passenger car | $50 | $68.5 | $120 | $200 |
| | Interquartile Range | | | |
| Passenger car | $30/80 | $32.5/100 | $75/200 | $100/250 |

## Selected edited comments

- 1995 figures: +1 mpg not possible in '95 unless stop sales of CAFE regulated vehicles, thus profit loss and idle plants.
- All dependent on whether you're over or under standard!
- Customer value of 1 mpg over 25 mpg base and 20,000 miles/year is small. However, the value for a commercial truck on 10 mpg base and 200,000 miles per year is much more significant.
- Depends on gasoline price and life of vehicle except when CAFE goes up.
- Fuel prices and CAFE penalty will have a major influence on value of "1 mpg."
- Truck owners don't care about CAFE.
- Cost and affordability will be the key determinants.
- A lot depends on the manufacturer's situation relative to overall fleet.
- Bounded on the upper end by potential CAFE/guzzler fines; but somewhat constrained by lack of customer "willingness" to pay in advance for future fuel cost avoidance. Therefore, this value will be influenced by both future CAFE/guzzler penalties and future fuel prices.
- Depends on whether the OEM's CAFE meets the government's requirement. It is more likely that OEMs will need to employ more expensive means at higher CAFEs.
- How much you're willing to spend depends on proximity to target (i.e., I'd spend more to make last increment to guzzler or fleet average.)
- If you don't have to increase CAFE and customers continue not to put a high priority on fuel economy, why spend anything?
- Manufacturers talk like mpgs are important, but price is KING.
- Not an easy question to answer. Depends on where car company's current CAFE average is compared to target. Ideally do not want to add any cost.
- Not clear what "willing to add" means in the context of a legal requirement like CAFE (i.e., what is a given CAFE "likely to cost" if met with technology rather than reduction of function) or at what cost level would manufacturers use "mix" rather than technology?
- Of course, any car manufacturer would love to pass whatever cost increases it incurs on to the consumer. Unfortunately, competition from imports prohibits it from doing so.

- The fuel cost savings for 10,000 miles at $1.25/gallon for 27.5 mpg vs. 30 mpg is $38 or about $15.20/mpg. This is the value to the consumer. The manufacturers will spend hundreds of dollars/mpg to meet CAFE.
- The OEM would pay up to the amount required to keep vehicle in its EPA class (or lower a class).
- Value depends on how far from target the vehicle is.

## Discussion

Panelists forecast that manufacturers would be willing to spend $50 per vehicle to improve fuel economy by 1 mpg currently. This value is forecast to increase to $200 per vehicle in 2005 if CAFE increases to 35 mpg.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers for 1995 and 2000. The differences for 2005 are shown in the following table.

| Mean Response | | | |
|---|---|---|---|
| 2005 CAFE = 30 | | 2005 CAFE = 35 | |
| Mfr. | Sup. | Mfr. | Sup. |
| $184 | $110 | $286 | $157 |

Manufacturers forecast a higher value for 1 mpg improvement in 2005 than do suppliers. This difference may be a result of manufacturers' past reluctance to increase vehicle cost in order to reduce vehicle weight. Suppliers commented on this in the current and past surveys.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Strategic considerations

Manufacturers have added significant cost to vehicles in the recent past and are adding additional cost today to improve fuel economy. Examples include the shift from three-speed to four-speed automatic transmissions, the addition of lock-up torque converters, replacing cast iron cylinder heads and blocks with aluminum, the addition of roller lifters to valve trains and improved rolling resistance tires. As CAFE fuel economy standards increase, manufacturers will be forced to add additional cost to the vehicle to improve fuel economy.

For a midsized vehicle with a fuel economy of 27.5 mpg, the savings in fuel for 1 mpg improvement is approximately 132 gallons in 100,000 miles, or $158 at $1.20 per gallon. This is the savings for the customer over the life of the vehicle. If the manufacturer pays $50 today to save that 1 mpg, the cost of the vehicle will rise somewhat more than $50. The customer pays this increased cost up front. Considering the lost interest on this out-of-pocket up front money, the customer may break even on this change, assuming that he/she keeps the vehicle for its entire life.

At a cost of $200 per mpg, the customer will not recover the initial investment, excluding lost interest on the investment. The manufacturer will be forced to add cost to the vehicle, however, to avoid paying a CAFE penalty of $50 per mpg, assuming future increases in CAFE.

CAFE is an inefficient method of improving fuel economy if the cost of fuel is the only consideration. Other factors to be considered are the effect of fuel on the balance of payments of the United States and the impact of burning hydrocarbon fuels on the environment.

***Considering the industry/government Partnership for a New Generation of Vehicles (PNVG) program, please respond to the following questions.*** **(TECH 7-10)**

**TECH-7. What will be the likely average combined city/highway fuel economy mpg (EPA test procedures) in production family size (five passenger) cars in 2010 and 2020? Assume price, safety, convenience, range, performance, etc. on parity with today's vehicles.**

| | Median Response | Interquartile Range |
|---|---|---|
| Year | Maximum Fuel Economy | Maximum Fuel Economy |
| 2010 | 35 mpg | 32\35 mpg |
| 2020 | 40 mpg | 36\42 mpg |

## Selected edited comments

- By 2020, an mpg rating will most likely be obsolete. Mileage/energy unit (i.e., BTU) will be more likely; doesn't account for large volume of electric vehicles.

  Cost will prevent further improvement—there is no customer demand at expected fuel price.
- Depends on regulations and/or imposition of a major increase in fuel tax. Note that by 2020 other factors will impact total transportation fuel consumption and the disparity between requirements for minivans and passenger cars will become an issue and factor for change.
- Highly dependent on funding by the OEMs and government.
- Holding today's price will significantly constrain the application of technology and lightweight materials.
- If breakthrough technology is achieved (U.S. consortium with 80 mpg goal for C/D size car), average would increase 5 mpg in each year.
- Improvements constrained by value perception by marketplace without government regulation forcing function.
- PNGV is likely to go away soon, as it is corporate welfare and government boondoggle.
- PNGV vehicle will be very specialized, and the technology will be expensive and difficult to achieve in a short time (if ever) in a full-size production car.
- The mpg will probably be irrelevant by 2020 since other fuels will be involved. Miles per BTU or some other unit might be more appropriate.
- This forecast assumes that: a) the PNGV funding is not discontinued and there is a; b) renewed interest by the United States automotive industry in diesel technology also for passenger cars; c) a significant increase in gasoline prices relative to diesel prices, d) and a commercial break-through for the de-NOx catalyst.
- Unless the cost of fuel changes drastically, vehicle size will stay about the same and improvements will be limited to technical improvements in efficiency that do not greatly impact vehicle cost.
- Without a dramatic increase in the price of gasoline, the Republicans are not going to change the current CAFE levels.

## Discussion

Panelists forecast that the average combined city/highway fuel economy in production family-sized passenger cars will be 35 mpg in 2010 and 40 mpg in 2020. This is far below the PNGV goal of 87 mpg.

## Manufacturer/supplier comparison

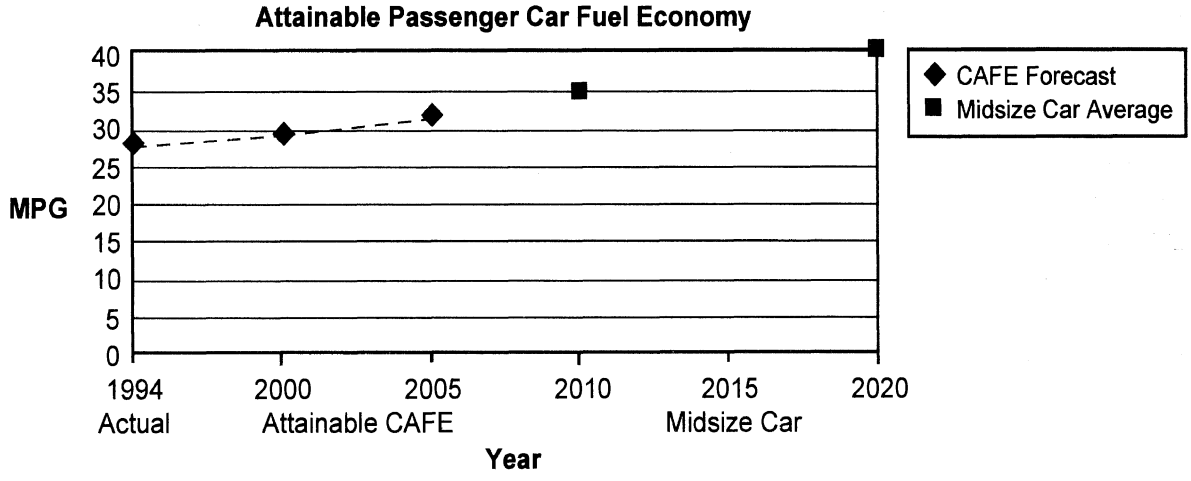
There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. In that survey, panelists forecasted 37.5 mpg in 2010 and 45 mpg in 2020.

## Strategic considerations

The responses to this question are compared to those of TECH-3 (which forecast fuel economy to 2005) in the following graph.




A midsized car today attains very close to the current CAFE standard of 27.5 mpg. Consequently, the results of this question for midsize cars may be quite comparable to the CAFE forecasts of TECH-3. There is not an apparent acceleration of gains in fuel economy forecast beyond 2005 which might be attributable to the PNGV program. It may be, however, that the rate of improvement through 2005 could not be sustained through 2020 without the PNGV program, as the "easy" gains will be made first.

Finally, it is only possible to speculate on the benefit of the PNGV program, as it is very early in that program. Synergistic effects are difficult to forecast. It is clear, however, that panelists expect significant shortfall to the PNGV fuel economy goal of 87mpg.

**TECH-8. Can the PNGV goal of 87 mpg be achieved in a production family-sized (five passenger) car? If yes, by what year?**

| YES | NO | Median Response | Interquartile Range |
|---|---|---|---|
| 35% | 65% | Year: 2019 | Year: 2008/2030 |

## Selected edited comments

- According to leading European engine experts, such fuel economy can only be achieved through a turbocharged, direct-injected diesel engine.
- Although achievable, cost will probably be prohibitive.
- But not at equivalent cost.
- Can it: Yes. Will it: No. The cost to achieve (piece cost, infrastructure cost, development/ investment cost) vastly exceeds both customer value and customer willingness/ability to pay.
- Costs will far outstrip customer willingness to pay.
- Depends on cost of fuel. With $5-6 per gallon of gas, maybe 87 mpg is economically viable.
- Depends on whether we customers really want to.
- Even if goals for PNGV are achieved, high investments will slow introductions.
- Goal is 87 mpg. Introduction will be dictated by investment constraints.
- Goal is 80 mpg (3x average of Concorde, Taurus, Lumina = 23.5mpg) not 3x CAFE standard of 27.55 mpg.
- Hard to answer: in two-seater, very small; perhaps three wheels. Maybe, but who would buy it?
- Highly dependent on funding by the OEMs and government.
- Large fuel economy gains will require loss of vehicle utility.
- Maybe by 2525. I'd be pleased (and surprised) if I ever saw a family size car at 45 mpg.
- No one would buy it.
- Not with production variations and reasonable costs and other requirements including emissions. Also, at some point we'll find (as an educated public) that we've exceeded the point of diminishing returns.
- Not within the constraints of reasonable cost. 60 to 70 may be achievable by 2010.
- Not without compromising safety, performance, utility and/or reasonable cost.
- Of the known capabilities to date, the achievement of 87 mpg would require complexities in the product to save and re-utilize energy. The complexities would quickly mount to a size that would destroy affordability to the consumer and cost recovery for the manufacturer.
- Only if significant compromises are made (i.e., room, comfort, and/or performance).
- Requires new engine technology.
- The issue of affordability will prevent achievement of the goal.
- We got to the moon in about that time.
- While I believe this is possible, it will be a small percentage of fleet. I did not include this effect in answering the previous questions on fuel economy.

- While it can be achieved—the compromises in performance, aesthetics and versatility will make it non-commercial.

## Discussion

Most respondents (65 percent) did not view 87 mpg as an attainable goal in the foreseeable future for a production five-passenger family car. For those that did see this as an attainable goal, the median year for accomplishment was 2019.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. Panalists were even less optimistic in that survey, with 72 percent of respondents stating that the goal was unttainable in the foreseeable future. For those that thought the goal was attainable, the median year for attainment was 2025.

## Strategic considerations

Only about one third (35 percent) of respondents felt that the goal of 87 mpg was achievable. Certainly many breakthroughs in technology would be required to allow attainment of this goal. One of the comments suggests that a turbocharged, direct-injected diesel would be a major contributor to this goal. Breakthroughs in exhaust emission control may allow application of the direct-injected diesel, which could possibly provide a 30 percent fuel economy improvement (9 mpg for a midsized family vehicle). This technology however carries a high price tag and would require high fuel prices to justify purchase by the customer. It is certainly possible that fuel prices will be very high in the next two or three decades. Many other technology breakthroughs throughout the vehicle will be required to attain this aggressive goal.

Perhaps the greatest challenge is that the technology breakthroughs that will contribute to improved fuel economy must carry a price tag that can be absorbed by the average consumer.

At this point the most likely technology to achieve the PNGV 3x goal is a combination of a composite intensive body structure and a heat engine electric hybrid powertrain. Cost would appear to be the greatest barrier to commercialization.

**TECH-9. What factors will make the greatest contribution to increased fuel economy in the PNGV program in the next quarter century?**

| Scale: 1 = extremely significant<br>3 = somewhat significant<br>5 = not at all significant |
|---|

| Factors | Mean Response |
|---|---|
| Weight reduction | 1.6 |
| Engine improvements | 1.8 |
| Electronic controls | 2.2 |
| Aerodynamics | 2.8 |
| Tire rolling resistance | 2.8 |
| Accessory drive | 3.1 |

The following additional responses were rated as either 1 or 2.

| Technologies | Number of Responses |
|---|---|
| Hybrid powertrain | 6 |
| Energy storage (flywheels, etc.) | 5 |
| Powertrain/transmission | 4 |
| Materials and assembly techniques | 2 |
| Fuel cells | 1 |
| Alternate fuels | 1 |
| TDI-engines | 1 |
| Direct valve actuation | 1 |

## Selected edited comments

- A hybrid drive with substantial storage of energy is the only way this goal will be achieved. This vehicle will have much less sustained power.
- Accessory (A/C) losses.
- Engine includes non-ICE.
- Even in today's cars on a long-distance drive, the use of air conditioning on a hot day causes a noticeable drop in fuel economy (mpg). Insulation and heat pump efficiency can be worth 5 to 10 percent. In time this will be involved in the EPA test and CAFE.
- Higher octane and better diesel fuels.
- Hybrids includes regenerative breaking, engine-off idles and decels, etc.
- Improved traffic control (i.e., coordinated signal lights, logical street layouts) would minimize need to speed up/slow down. Anticipate the EPA cycle would be adjusted accordingly.
- Industry must reinvent the car/truck: 1) how to store energy; 2) how to supply/convert energy as a function of drive mode; 3) how to control operation to give optimal performance at all times.
- One benefit will be the development of more cost/performance valued lightweight materials.
- PNGV will probably utilize an electric drive system, an energy storage system (battery/flywheel/ ultracapacitor) and either a fuel cell or some type of turbine/generator.

- PNGV as defined today has a 10-year span; not a "quarter century." Prefer "Accessories" to "Accessory Drive." "Energy storage" is not directly related to "Fuel Economy Rating," but it is critical to the capability to design a hybrid electric vehicle.
- Probably a forced induction diesel.

## Discussion

Panelists forecast that weight reduction, engine improvements, electronic controls, and energy storage will play the greatest role in attainment of the 87 mpg vehicle.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII forecast as an open-ended question. The results are summarized below.

| System /Technology | Responses |
|---|---|
| Engine improvements | 25 % |
| Weight reduction | 25% |
| Vehicle system improvements | 8% |
| Non-spark ignition engine | 7% |
| Electronics | 6% |
| Transmission | 4% |

Weight reduction and engine improvements were the most apparent expected contributors to the goal of an 87 mpg family vehicle in the current and past survey.

## Strategic considerations

The aggressive goal of 87 mpg in a family-sized vehicle will require technology breakthroughs in every system of the vehicle. Fuel economy improvement is only one part of the challenge. Obtaining fuel economy improvement without adding significant cost to the vehicle, while retaining vehicle utility and comfort is perhaps the greatest challenge. Maintaining vehicle cost has been made a requirement in the PNGV program.

**TECH-10. Please rate your expectations for the impact of PNGV on the following performance dimensions in the next quarter century.**

| Scale: 1 = very high expectations<br>5 = very low expectations |
|---|

| Performance Dimensions | Mean |
|---|---|
| Fuel economy | 2.0 |
| Materials | 2.0 |
| Emissions control | 2.6 |
| Competitiveness with foreign manufacturers | 2.9 |
| Production processes | 2.9 |
| Cost | 3.2 |
| Comfort/convenience | 3.6 |

**Other responses:**

Electronics: 2; Hybrid: 1; Performance (acceleration and hill climbing): 3; Safety: 4 (3 responses)

## Selected edited comments

- A lot depends on what stage of the cycle for government involvement in industry we will be in and where government support may come from.
- All above assumes PNGV initiatives will remain viable, which is a tenuous assumption under current political climate.
- Assumes PNGV continues—unlikely due to government funding cuts.
- Emissions control is not a big PNGV priority.
- Emissions control not a major part of PNGV. Answers assume PNGV actually does something—which it probably won't.
- Fuel economy will be high for vehicle line, modest for vehicle fleet/year because introduction will probably be slow.
- Good chance PNGV will disappear soon.
- I am probably optimistic in my expectations for the PNGV. Also, I would not be surprised to see the program die in the next few years.
- I don't put much stock in any government sponsored project, least of all the PNGV program.
- I don't really see the government as being a real enabler or even effective coordinator. They've not established themselves as a bona fide partner of the industry as has the Japanese government. They need to tear down some walls and have a major paradigm shift in how they interface, mentor and champion the industry. They are adversaries at this time.
- I don't think PNGV is viable under current political climate. Even the OEMs don't believe in it. We are trying to do it just to pacify the government.
- I expect the federal government to cancel this program as it moves to balance the budget.
- I really don't expect much for the effort.
- I would expect the PNGV to focus on global issues of energy conservation, emissions and safety, to deal with conflicting objectives and technology development, less with production processes, comfort and convenience.
- Impact is both positive and negative.

- Increased modulization; increased total quality performance; participation in assembly of vehicle; cost and investment reduction.
- It will involve some compromises in performance. It's assumed that impact means positive or negative change. Note: Vehicle mpg is driven by society (the group) and not by individual decisions (based on costs and perceived benefits). So, as long as gasoline is available and cheap, mpg will be approximately at the legislated/regulated level. The designs (and model mixes) will be those that minimize costs and maximize profits—that's natural.
- Much depends on the 1996 election. If the Republicans take the White House as well, the chances for the survival of the PNGV seem slim. Furthermore, with such a setup in Washington, the probability of major increases in the CAFE standards is significantly reduced.
- Never count on the government to sponsor anything productive. The PNGV program seems more like a PR campaign than a serious technical effort.
- New features such as comfort and convenience.
- Paint or coating protection; environmental impact free materials and processes; safety (crash research); ergonomics.
- PNGV's goal is to maintain product marketability of which comfort/convenience is a part. Thus, the expectation for maintaining comfort/convenience is high while the expectation for improving is low.
- PNGV doesn't make any economic sense. Fuel cost savings, even at $10/gallon, would not cover the additional cost for an 80 mpg midsized vehicle. (Fuel cost savings for 10,000 miles at $10/gallon is only $2,083.) Payback would be beyond the acceptance range for the new vehicle purchaser.
- PNGV has begun to get universities, government labs, and OEMs to work together. If it can continue, this PNGV will be very beneficial to the automotive industry and a model for other industries.
- Re: Comfort/convenience—PNGV was defined as same size as current mid-size vehicles. This is a fatal flaw in the program. Congress will probably not provide funds to continue.
- The vehicles will be a maintenance nightmare.
- There will be progress and change; that's an inherent part of the automotive industry dynamics. It will be more difficult to be sure whether they're due to the PNGV program or something else.
- This program, if successful, will create many new industry opportunities and new technology developments. An exciting time to be in the automotive business.
- Use of electric vehicle with some fuel economy "credits."

## Discussion

Panelists have high expectations for the impact of the PNGV program on materials and fuel economy. Panelists have moderate expectations for other aspects of the vehicle and its manufacture.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not asked in this format in any previous Delphi survey.

## Strategic considerations

There is a wide range of expectations for the PNGV program, as evidenced by the numerical scores and the comments by the panelists. Considering the hostile environment that has existed between government and industry for many years, it is perhaps not surprising to hear words of skepticism by panelists. Other panelists express a note of hope that industry and government can work together on a common goal for the benefit of all. It is certainly in the best interests of all that cooperation be nourished and used to its maximum advantage. Other countries have done this for years and have reaped the benefits of cooperation. Examples are the Japanese automobile industry and the European aircraft industry.

As is often observed in any technology stretching effort such as the space program, spin off technology can yield positive benefits in many areas. This could be an important attribute of the PNGV program.

The current administration has shown a willingness to work with industry. Hopefully this has established a foundation upon which to build a lasting relationship.

**TECH-11. What percentage of North American-produced passenger cars and light trucks (including fleets) will use each of the following alternate energy sources in 2000 and 2005?**

| Alternate Fuels | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| **Passenger Cars** | **1994*** | **2000** | **2005** | **2000** | **2005** |
| Alcohol or alcohol/gasoline (>10 percent alcohol; includes flex fuel or variable fuel) | <1 % | 2 % | 3 % | 1/5 % | 2/10 % |
| Diesel | 0.0 | 1 | 3 | 0/2 | 0.8/5 |
| Electric | 0.0 | 1 | 2 | 0.1/1 | 1/3 |
| Electric/gasoline hybrid | 0.0 | 0.5 | 2 | 0/1 | 1/5 |
| Hydrogen | 0.0 | 0 | 0 | 0/0 | 0/1 |
| Natural gas | 0.0 | 1 | 2 | 0.1/2 | 1/5 |
| Propane | 0.0 | 1 | 1 | 0/1 | 0/2 |
| **Light Trucks** | **1994*** | **2000** | **2005** | **2000** | **2005** |
| Alcohol or alcohol/gasoline (>10 percent alcohol; includes flex fuel or variable fuel) | <1 % | 2 % | 3 % | 1/5 % | 1/10 % |
| Diesel | 4.1 | 5 | 9 | 4/8 | 5/15 |
| Electric | 0.0 | 0 | 1 | 0/1 | 0/2 |
| Electric/gasoline hybrid | 0.0 | 0 | 0.1 | 0/1 | 0/2 |
| Hydrogen | 0.0 | 0 | 0 | 0/0 | 0/0 |
| Natural gas | 0.0 | 1 | 2 | 0.5/2 | 1/5 |
| Propane | 0.0 | 1 | 1 | 0/1 | 0/3 |

***Source:** *Ward's Automotive Reports*, January 2, 1995

**Other responses:**

Fuel cell electric: Passenger Cars: 2000 - <1 percent; 2005 - <1 percent

## Selected edited comments

- Consider whether biodiesel (including soy bean oil) will take root in city buses, big trucks, etc. and then move into light trucks. Its effects on smoke and other emissions could reduce those barriers. Cost is a problem, but tax treatment will impact that for a while. Note diesels are strongly preferred by one segment of the light truck market. Service vans are the likely and most amenable market and application for natural gas and electric. Also consider other oxygenates such as MTBE. This is more likely than greater use of >10 percent alcohol in fuel. A significant change in gasoline could occur if Ethyl won its court cases on the use of its manganese additive; it is very cost effective as an octane booster. Its use would probably be accompanied by a reduction in aromatic content.
- Electric requires battery breakthrough.
- Emission standards could be major obstacle to diesels—(particulates).
- Fossil fuels will diminish in use and will rise in price as alternatives in fuels are used and offered.
- Much will depend on economic incentives and CAFE credits, as without these there is little "market pull" for alternate fuels. 2005 outlook is largely dependent on future breakthroughs which are hard (impossible) to predict (i.e., diesel vs. LEV/ULEV emissions, electric vehicle battery developments).

- Particulates (less than 10 micron or less than 5 micron) will kill light-duty diesel.
- Weight of pressure storage systems make gaseous fuels impractical for passenger cars and more suitable for trucks, but infrastructure is developing very slowly. Battery technology, size and mass, are not likely to see a breakthrough that would allow significant use before 2005, even with 35-40 month product development cycles.
- Without the distribution infrastructure, alternative fuels won't be popular until something really drastic happens.
- Series hybrids will see some application in larger vehicles used for personal use. Parallel hybrids will be used for urban commercial delivery applications. Direct injection diesels with new fuel will gain popularity in cross country commercial hauling.

## Discussion

Limited use (3 percent or less) of a number of alternate energy sources is forecast for passenger cars and light trucks by 2005. Diesel engines are expected to be used in 9 percent of light trucks. Gasoline is expected to be the overwhelmingly dominant fuel through 2005. No use of hydrogen is forecast.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Comparison of Forecast: MKT-42 and MAT-4

There is no statistically significant difference in responses between the technology and materials panelists. There is a difference between technology and marketing panelists for the items noted in the following table.

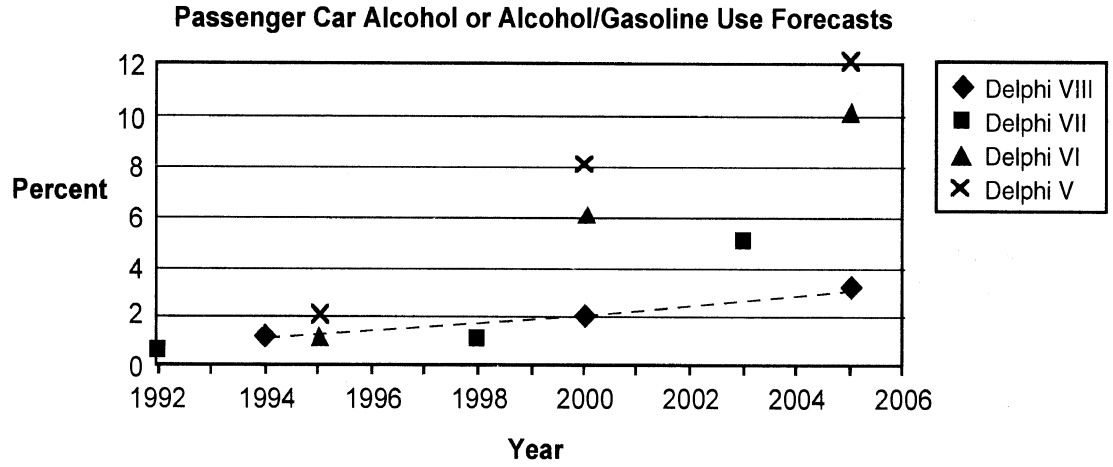
| Alternative Fuels | Passenger Cars | | | | Light-Duty Trucks | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean Response 2000 | | Mean Response 2005 | | Mean Response 2000 | | Mean Response 2005 | |
| | Tech. | Mkt. | Tech. | Mkt. | Tech. | Mkt. | Tech. | Mkt. |
| Alcohol or Alcohol/gasoline (>10 percent alcohol; includes flex fuel or variable fuel) | 6.4 % | 2.3 % | 10.2 % | 3.9 % | 7.1 % | 2.2 % | 10.9 % | 3.4 % |
| Diesel | — | — | — | — | — | — | 10.0 | 6.5 |
| Electric/gasoline hybrid | — | — | 3.7 | 1.8 | — | — | — | — |
| Natural Gas | 1.7 | 0.5 | 3.6 | 1.1 | 2.1 | 0.7 | 4.4 | 1.6 |

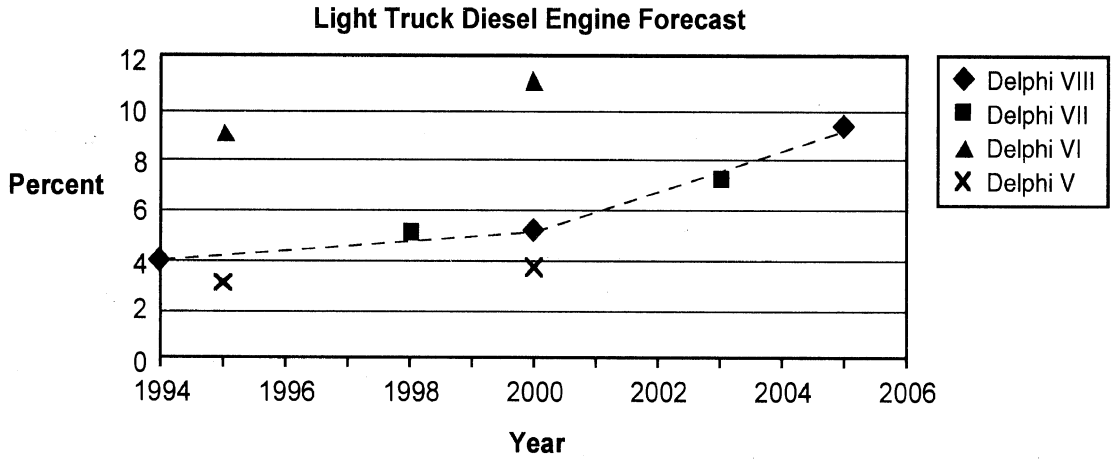
Technology panelists forecast higher penetrations of each of the items noted.

There was general agreement between the Technology, Marketing and Materials panels for all alternative fuels.

## Trend from previous Delphi surveys

Forecasts are in general agreement with past surveys. There is a declining forecast for alcohol-fueled passenger cars and a varied forecast for diesel-fueled light truck engines as shown by the following charts, however. Diesel engines in passenger cars are forecast at 3 percent in 2005 in this survey, whereas the forecasted penetration was 0 percent in the 1994 Delphi VII survey.




## Strategic considerations

At current prices, gasoline offers the customer many advantages over other fuels. Legislation or significant price changes will be required to displace gasoline as the fuel of choice for most customers. Diesel engines are forecast to increase in use, particularly in light trucks. Light trucks are sometimes used in conjunction with farm or construction equipment where diesel engines are used and the fuel is readily available. The disadvantages of noise, odor and purchase price may be overlooked in a light truck diesel engine when the significant fuel economy advantage is considered. Exhaust emissions from diesel engines are a technical problem that may limit diesel use in the future.

The mandated sale of electric vehicles (and possibly hybrids) in California and some Eastern states presents a major dilemma for vehicle manufacturers. They are placed in the unenviable position of selling vehicles that few customers want. It is likely that the added cost of electric vehicles will be amortized over the gasoline powered vehicles in the states mandating electric vehicles. This will increase the cost of all vehicles in those states. There is some question as to the effectiveness of reducing emissions with electric vehicles, as the increased vehicle cost may actually increase the number of older vehicles and cause slower elimination of high emitting vehicles, thus increasing overall emissions. This is a complex issue that may impact politicians. These

politicians could force legislation having significant negative impact on voters, with questionable benefit to those same voters. The electric vehicle may be one of the highest cost means to reduce emissions.

Since a large fraction of U.S. oil is imported, the use of some alternative fuels could reduce the unfavorable balance of payments and mitigate the dependency on foreign oil. These factors may drive legislation towards alternative fuels. In fact, however, air pollution has been the only area to date driving legislation that effects motor vehicle fuels. The U.S. has not developed, and does not appear ready to develop, a comprehensive energy policy.

Of all of the alternative fuels/power systems listed, natural gas for fleet use may be the most economical and competitive with current fuels.

Interest in alcohol fuels continues to wane as indicated by the results of the 1996 Delphi VIII and three previous Delphi surveys.

Clearly the gasoline fueled engine is still the benchmark for light duty vehicles and only policy factors are likely to erode its dominant position over the near and midterm.

## TECH-12. What are the major obstacles to the widespread (> 25 percent marketshare) use of alternative energy sources for passenger vehicles?

**Scale: 1 = major obstacle 3 = moderate obstacle 5 = minor obstacle**

| Energy Source | Infra-structure | Lifetime Vehicle Cost | Vehicle Range | Convenience | Retirement | Safety |
|---|---|---|---|---|---|---|
| Alcohol or Alcohol/gasoline | 3.4 | 3.6 | 3.8 | 4.0 | 4.4 | 4.3 |
| Diesel | 4.0 | 3.6 | 4.7 | 3.4 | 4.4 | 4.7 |
| Electric | 1.7 | 1.3 | 1.1 | 2.0 | 2.8 | 3.6 |
| Electric/Gasoline hybrid | 2.9 | 1.8 | 3.0 | 2.9 | 3.2 | 3.8 |
| Hydrogen | 1.2 | 1.9 | 2.5 | 1.9 | 3.1 | 1.8 |
| Natural gas | 2.0 | 3.1 | 2.7 | 2.4 | 3.7 | 2.8 |
| Propane | 2.2 | 3.1 | 2.9 | 2.5 | 3.7 | 2.8 |
| **Other**: Biodiesel | 1.0 | 3.0 | — | 3.0 | 5.0 | 5.0 |

### Selected edited comments

- Diesel fuel smell is a barrier. Major barrier to diesels are emissions regulations until a lean NOx converter is developed and made commercially available.
- In the case of diesel for automobiles, market/consumer acceptance is the issue.
- Infrastructure is the main barrier to alternative energy sources. Lifetime vehicle cost for electrics and hybrids includes disposal/recycling of old batteries.
- Infrastructure should be clarified as "refueling infrastructure."
- None of the alternatives come close to gasoline!
- Packaging and performance are also obstacles to some alternatives.
- Purchase price and fuel cost should be categories. Customers do not perform lifetime calculations.
- With today's much larger vehicle population and the proliferation of energy sources (and "routes") it's possible that coexistence of several fuels will be optimum and become the "semi-steady-state" with geographical variation.

## Discussion

All alternative energy sources have obstacles impacting the customer as compared to gasoline. Diesel and alcohol have the highest obstacle rating numbers or the lowest average forecast obstacles. Electric and hydrogen have the poorest ratings or greatest estimated obstacles.

| Energy Source | Ranking (1 = Best) | Average Obstacle Rating |
|---|---|---|
| Diesel | 1 | 4.1 |
| Alcohol or alcohol/gasoline | 2 | 3.9 |
| Propane | 3 | 2.9 |
| Electric/gasoline hybrid | 4 | 2.9 |
| Natural gas | 5 | 2.8 |
| Hydrogen | 6 | 2.1 |
| Electric | 7 | 2.1 |

Other factors must be considered when evaluating alternative fuels. These factors include effect on the environment, effect on balance of payments and national security, and availability within the United States.

## Manufacturer/supplier comparison

Responses for manufacturers and suppliers are in general agreement.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. Results for 1994 Delphi VII and 1996 Delphi VIII are compared in the following chart. Diesel and hydrogen were not included in 1994 Delphi VII. Results for the two surveys are very similar.

| Energy Source | 1994 Delphi VII | | 1996 Delphi VIII | |
|---|---|---|---|---|
| | Ranking (1 = Best) | Average Obstacle Rating | Ranking (1 = Best) | Average Obstacle Rating |
| Diesel | — | — | 1 | 4.1 |
| Alcohol or alcohol/gasoline | 1 | 3.3 | 2 | 3.9 |
| Propane | 2 | 2.9 | 3 | 2.9 |
| Electric/gasoline hybrid | 3 | 2.8 | 4 | 2.9 |
| Natural gas | 4 | 2.7 | 5 | 2.8 |
| Hydrogen | — | — | 6 | 2.1 |
| Electric | 5 | 2.3 | 7 | 2.1 |

## Strategic considerations

Any shift away from gasoline as the primary energy source for motor vehicles would require legislation or a significant increase in the price of gasoline compared to the alternatives.

Legislation could result from environmental considerations, the impact on the balance of payments of the United States or national security. An example of such legislation is the requirement for zero emission vehicles in California.

Gasoline prices could increase due to political disruption in or around the major oil-producing countries. Gasoline taxes to raise revenue or reduce the use of gasoline could also impact prices.

The outlook today is for gasoline to remain the primary energy source for motor vehicles.

**TECH-13. What is the likelihood of federal legislation mandating or regulating the following automotive features by 2005? Please identify in the comments section any other features you think are likely targets for legislation.**

**Scale: 1 = extremely likely 3 = somewhat likely 5 = not at all likely**

| Automotive Features | Mean Rating |
|---|---|
| Antilock braking systems (ABS) | |
| Passenger car | 2.5 |
| Light truck | 2.6 |
| Driver impairment interlocks | |
| Passenger car | 3.3 |
| Light truck | 3.5 |

**Other single responses:**

Additional passive crash integrity devices: 3; Airbags (driver, passenger):1; Control placement: 2; Heavy truck ABS: 1; Overspeed warning: 3; Radar assists: 3; Side air bags: 2 (3 responses); Speed limiters: 3.

## Selected edited comments

- ABS customer pull is moving faster than legislation.
- Antilock brakes will be standard by 2005 on cars by consumer demand.
- Clean fuel. California style pump vapor recovery in all states.
- Customer demand will make ABS almost standard. U.S. drivers don't want interlocks whether they're the old seat belt type or driver impairment type.
- Enthusiasm and perceived benefits must correlate with real world benefits for mandates to hold. In the case of ABS, the "real world" experience has been disappointing. . .at least in terms of data. Ironically, potential liability issues could stall impairment interlock development.
- Expect safety mandates in 2 years on collision avoidance and warning of operating parameters near vehicle or operator control limits.
- IVHS (ITS) elements - for ETC, AVI, etc. ABS is coming but it may develop fast enough without regulation to minimize the pressure for and likelihood of regulation. ITS too may develop in the same way and be separated by subsidies (though I don't favor them) for related infrastructure.
- Not that I favor them, but I think there's a likelihood that speed limiters (90 mph/100 mph) may be implemented.
- Numbers above emphasize mandating. From a regulation standpoint, numbers will all be higher.
- Standards will be written based on a performance specification that may drive ABS or driver interlock, not mandate them per se.
- This is a moot point because all vehicles will be equipped with ABS due to customer demand.
- Vehicle handling characteristics, rollover metrics are moderately likely as well as enhanced vision systems for greater fields of view and night vision.
- Wheels.

## Discussion

Panelists forecast that federal legislation mandating or regulating antilock braking systems and driver impairment interlocks is somewhat likely. Some panelists also expect legislation in the areas of speed limiting, and collision avoidance. It is expected that consumer demand will drive standardization of anti-lock braking systems (ABS) with or without legislation.

## Manufacturer/supplier comparison

Manufacturers rate the likelihood of federal legislation for light truck antilock braking systems at 2.2 versus 2.8 for suppliers. For the remaining responses, there is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results from this survey are very similar to those of 1994 Delphi VII. In all cases the mean rating was within 0.5 between the two surveys. All categories in this survey, however, were rated as more likely than those of Delphi VII.

## Strategic considerations

Legislation regarding ABS is considered to be somewhat likely. This may be a mute point, however, as manufacturers will likely be required to include this feature as standard equipment to meet consumer demand despite the recent controversy surrounding ABS and driver education on how to use ABS.

Driver impairment interlock legislation is also considered to be somewhat likely. It is likely that this feature would cause difficulty or at least inconvenience for some non-impaired drivers. Consequently, legislation may not be well received and may go the way of the seat-belt ignition interlock of the past. Although impaired drivers are responsible for a high percentage of accidents of all types, vehicle owners may not be willing to be inconvenienced to assist in the resolution of this problem and there may be some legal constraints as well. The mood in the United States today seems to be one of wanting less government control of our lives, not more.

**TECH-14. Please indicate your view of the trend in U.S. federal regulatory and legislative standards over the short term (1996-2000) and long term (2001 to 2005). Also, list any likely new areas of legislative activity.**

**Scale: 1 = much more restrictive 3 = no change 5 = much less restrictive**

| Legislation/Regulatory Activity | Short Term 1996-2000 Mean Rating | Long Term 2001-2005 Mean Rating |
|---|---|---|
| Vehicle emission standards | | |
| Passenger car | 2.0 | 1.7 |
| Light truck | 2.0 | 1.7 |
| Fuel economy standards (CAFE) | | |
| Passenger car | 2.2 | 1.8 |
| Light truck | 2.1 | 1.8 |
| Occupant restraint/interior safety | | |
| Passenger car | 2.2 | 1.9 |
| Light truck | 2.1 | 1.9 |
| Vehicle integrity/crashworthiness | | |
| Passenger car | 2.3 | 2.0 |
| Light truck | 2.2 | 2.0 |
| Alternate fuel/power source | | |
| Passenger car | 2.5 | 2.1 |
| Light truck | 2.6 | 2.1 |
| Antitheft | | |
| Passenger car | 2.7 | 2.4 |
| Light truck | 2.8 | 2.5 |
| Regionalization of nat'l standards | | |
| Passenger car | 2.6 | 2.5 |
| Light truck | 2.6 | 2.5 |
| Product liability | | |
| Passenger car | 2.9 | 2.7 |
| Light truck | 2.9 | 2.7 |

## Short term new areas

Daytime headlights in passenger cars and light trucks: 2

Enhanced vision for passenger cars and light trucks: 2

Global international standards ISO 9000 for cars and light trucks: 2

In use emission performance and recycling: 1

Particulates for passenger car and light truck: 1

Recyclability for passenger car and light truck, both rated 2 (4 responses)

Side impact protection and anti-skid for passenger cars: 2

Side impact protection and anti-skid for light trucks: 3

### Long term new areas

Global international standards ISO 9000 for cars and light trucks: 2

Responsibility for maintenance: 2

Particulates for passenger car and light truck: 1

Recyclability for passenger car and light truck: 1 (2 responses)

Recycled content in passenger cars and light trucks: 1 (3 responses)

Side impact protection and anti-skid for passenger cars: 1

Side impact protection and anti-skid for light trucks: 2

### Selected edited comments

- I'm amazed that the federal government has not done their job of rationalizing and stopping the regionalization of clearly a national responsibility.
- One must ask if the higher (than for passenger cars) import duty on light trucks (including vans) will receive public attention and be reduced. Long term, the public will expect and get some better information and improvement in service cost. Unless there's an industry initiative to respond, an "extremist" movement will arise to push for regulation; that's the least desirable response.
- These issues are very dependent on which direction we go politically. The next two years will be very definitive.

### Discussion

In the short term (1996-2000), panelists forecast more restrictive regulations in fuel economy standards (CAFE), occupant restraint/interior safety, vehicle integrity/crashworthiness, and vehicle emission standards. Regulations and legislative standards for alternate fuel/power source, antitheft, product liability, and regionalization of national standards are forecast to be little changed from present standards.

In the long term (2001-2005), panelists forecast more restrictive standards in all of the above areas with the exception of product liability and regionalization of national standards.

### Manufacturer/supplier comparison

Results for manufacturers and suppliers are in general agreement. Only 6 of the 36 categories had a statistically significant difference, and the greatest difference in the mean ratings was 0.36.

### Comparison of forecasts: MKT-42 and MAT-4

The mean responses of marketing and materials panelists are within 0.2 of the technology panelists responses with the exception of the items noted in the following table.

| SHORT TERM 1996-2000 | | | |
|---|---|---|---|
| **Legislation/Regulatory Activity** | **Tech.** | **Mat.** | **Mkt.** |
| Fuel economy standards (CAFE) | | | |
| Passenger car | 2.2 | 2.6 | — |
| Light truck | 2.1 | 2.5 | — |
| Vehicle emission standards | | | |
| Passenger car | 1.9 | 2.5 | 2.3 |
| Light truck | 2.0 | 2.4 | — |

Technology panelists forecast somewhat more restrictive standards than materials or marketing panelists for the items noted.

## Trend from previous Delphi surveys

The results of the current survey are compared to those of 1994 Delphi VII in the following table.

| | **Short Term Mean rating** | | **Long Term Mean rating** | |
|---|---|---|---|---|
| **Forecast:** | **Delphi VII** | **Delphi VIII** | **Delphi VII** | **Delphi VIII** |
| **Time period:** | **1994-1998** | **1996-2000** | **1999-2003** | **2001-2005** |
| Alternate fuel/power source | | | | |
| Passenger car | — | 2.5 | — | 2.1 |
| Light truck | — | 2.6 | — | 2.1 |
| Antitheft | | | | |
| Passenger car | 2.7 | 2.7 | 2.3 | 2.4 |
| Light truck | 2.8 | 2.8 | 2.4 | 2.5 |
| Fuel economy standards (CAFE) | | | | |
| Passenger car | 1.9 | 2.2 | 1.5 | 1.8 |
| Light truck | 2.0 | 2.1 | 1.5 | 1.8 |
| Occupant restraint/interior safety | | | | |
| Passenger car | 2.1 | 2.2 | 1.8 | 1.9 |
| Light truck | 2.0 | 2.1 | 1.8 | 1.9 |
| Product liability | | | | |
| Passenger car | 2.5 | 2.9 | 2.4 | 2.7 |
| Light truck | 2.5 | 2.9 | 2.4 | 2.7 |
| Regionalization of national standards | | | | |
| Passenger car | — | 2.6 | — | 2.5 |
| Light truck | — | 2.6 | — | 2.5 |
| Vehicle integrity/crashworthiness | | | | |
| Passenger car | 2.1 | 2.3 | 1.8 | 2.0 |
| Light truck | 2.1 | 2.2 | 1.8 | 2.0 |
| Vehicle emission standards | | | | |
| Passenger car | 1.9 | 2.0 | 1.6 | 1.7 |
| Light truck | 1.9 | 2.0 | 1.5 | 1.7 |

Results for the two surveys are quite similar, with a forecast towards less regulation in the current survey compared with the 1994 Delphi VII survey. In no case is the difference in mean rating between the two surveys greater than 0.4. Where no numbers are shown for 1994 Delphi VII, the question was not asked.

## Strategic considerations

Safety and antitheft features or modifications to the vehicle are often introduced prior to legislation because of consumer demand. This is true also of fuel economy improvements as far as they directly affect the customer. Corporate average fuel economy (CAFE) increases may drive model mix change forced by pricing or vehicle downsizing. Both have negative effects on customer choice and are done reluctantly by the manufacturers.

Vehicle emisson standards provide no visible direct benefit to an individual vehicle buyer in spite of his or her knowledge that the overall well-being of society may be enhanced. Cost increases as a result of emission control cannot generally be sold by the manufacturer as a plus to the buyer. Only government legislation can provide the incentive in this case to force change that may be in the best interest of society. The cost/benefit relationship for emissions control is a difficult issue that should be weighed carefully by both government and industry. Everyone is for clean air, but how clean and at what price?

The consumer is faced with an increasing affordability problem relative to automobiles. Increased legislation and the accompanying cost increases will exacerbate this problem. Vehicle sales may be impacted as consumers are forced to drive vehicles longer because they cannot afford a new one. The trend towards leasing is an early sign of the affordability issue. At some point, leasing may become too expensive also.

**TECH-15. Please indicate the expected convergence of federal regulated/legislated standards between passenger cars and trucks by 2000 and 2005.**

| Scale: 1 = identical standards<br>3 = standards more similar than current<br>5 = divergence same as current. |
|---|

| Standard | Mean Rating |
|---|---|
| Product liability | 2.3 |
| Occupant restraint/interior safety | 2.4 |
| Vehicle integrity/crashworthiness | 2.5 |
| Antitheft | 2.7 |
| Vehicle emissions | 2.8 |
| Alternate fuel capability | 3.0 |
| Fuel economy standards (CAFE) | 3.4 |

**New areas:** Global standards: 2; Particulates: 1; Recycled content: 2

## Selected edited comments

- European and U.S. standards will move toward uniformity.
- Federal standards will comprehend the blurring of passenger car vs. sport utility vehicle/light truck usage.
- Frankly we should push for worldwide common standards. . .perhaps only different cars/trucks.
- Light truck will not converge to car if work trucks are regulated the same as carlike trucks such as sport utility vehicles, minivans, etc.
- Standards will become identical where genuine differences in vehicle use and duty cycles and cargo do not exist that dictate unique standards. Good, sound rationale will have to exist to allow varying performance characteristics, especially in the area of crash avoidance/occupant protection.

## Discussion

Federal regulated/legislated standards are forecast to be more similar than now present between passenger cars and trucks, but not identical.

## Manufacturer/supplier comparison

Results for manufacturers and suppliers are in general agreement. There is no significant difference statistically in responses with the exception of fuel economy standards. In this case, the mean rating for manufacturers and suppliers is 3.6 and 3.2, respectively. Even in this area, results are in quite close agreement.

## Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

## Strategic considerations

As passenger cars and light trucks converge from a functional standpoint, it is reasonable to expect that federal regulated/legislated standards will converge also. It is a fine line between a sport utility vehicle, a light van and a station wagon. On the other hand, there is a significant difference in use between a passenger car and a pickup truck used largely to haul lumber, hay, etc. Panelists' comments suggest that standards may be different where use is different and similar where use is similar.

**TECH-16. What new regional regulations/legislation do you anticipate in the next decade that will impact the design of vehicles? Please comment on design changes required and the region affected.**

| Regulation/ legislation | Region | Design Requirement | Number of Responses |
|---|---|---|---|
| Emissions-Total | | | 29 |
| Emissions | Eastern states | | 12 |
| Emissions | | | 7 |
| Emissions | Large cities | | 5 |
| Emissions | Non-attainment areas | | 2 |
| Emissions | Mountain states | | 2 |
| Emissions | County | | 1 |
| Electric vehicles/hybrid vehicles | | | 6 |
| Alternate fuels-Total | | | 4 |
| Alternate fuels | California, Southwest | | 3 |
| Alternate fuels | | | 1 |
| Recycling-Total | | | 5 |
| Recycling (components, plastic, oil) | California, Northeast | | 4 |
| Recycling | | Infrastructure, compatable designs | 1 |
| Noise | | | 2 |
| Safety | | | 2 |
| Anti-theft | | | 1 |
| Electromagnetic capability & emissions | | Circuit design | 1 |
| Exhaust emissions- cold cycle | | | 1 |
| Infant seat sensing | | | 1 |
| Infrastructure changes | | | 1 |
| Interior control standardization | | | 1 |
| Night time lighting | | | 1 |
| Pass-by | | | 1 |
| Speed limits | | | 1 |
| Testing methods | State-by-state | | 1 |
| Vehicle size | Large cities | | 1 |

## Selected edited comments

- Europe has 15 different regional regulations for various things. This drives complexity and high engineering cost.
- I think regional requirements will become more similar to federal standards as older, non-conforming/heavy polluting vehicles are taken out of service or restricted in use.
- The California and Northeast mandates will drive costs sky-high. Changes required include ultra-light vehicles and new infrastructures including: electrical power generation, aluminum/ magnesium production facilities, special traffic lanes.

## Discussion

Emissions regulations are forecast to see the most regional regulations/legislation in the next decade. Recycling is also forecast to be impacted by regional regulation/legislation.

## Manufacturer/supplier comparison

Manufacturer/supplier comparisons are not done for open-ended questions

## Trend from previous Delphi surveys

This question was not asked in a previous survey.

## Strategic considerations

Regional regulation/legislation adds to vehicle design and parts proliferation, and increased cost as a result. The issue of vehicle affordability has been addressed in previous questions and is a grave concern to manufacturers. The federal government must control the ability of regional government to mandate vehicle design change. This has been effectively done in the area of emissions where only two requirements are allowed: federal or California. California rules may be used in other states, but they must be the same as the California rules. Where a region has a unique problem, it may be necessary to allow unique vehicles for that region.

## TECH-17. What is your view of the trend in government direction in regulations?

**Score: 1 = highly likely 3 = somewhat likely 5 = highly unlikely**

| Government Emphasis | Mean Rating |
|---|---|
| Address trade | 2.5 |
| Address torte liability | 2.8 |
| Increase gasoline prices | 2.8 |
| Regulate based on technical considerations | 3.4 |
| Develop a comprehensive energy policy | 3.5 |
| Utilize cost/benefit analysis in setting standards | 3.5 |
| Address foreign domestic investment | 3.7 |

### Selected edited comments

- Acceptance of computers in daily life will increase legislators' faith in technology. "Technical considerations" and "cost/benefit analysis" will come in the more rational legislative environment.
- As long as vehicle regulation agencies exist, they will continue to justify their existence by new regulation rather than letting the marketplace determine content. Government should only intervene in areas of national interest that individual and consumer segments are not motivated to demand.
- Depends on whether the Republicans maintain their hold on Congress.
- I have a low expectation for the government ever acting in a rational manner.
- Permeability standards may eliminate plastic panels.
- Regarding energy policy: The United States government is not capable of doing anything in a "comprehensive" manner.
- The claim of the regulators is that they do this already; I do not agree.
- The lack of a comprehensive energy policy is one of the major shortcomings of U.S. domestic policies.
- The last two trends, which reflect consideration of reality, have historically been ignored, unfortunately.
- Trend has been technology forcing. Expect this to continue.

### Discussion

Panelists rate as somewhat likely that government will address torte liability and trade or increase gasoline prices. They rate as unlikely that government will address foreign domestic investment, develop a comprehensive energy policy, utilize cost/benefit analysis in setting standards and regulate based on technical considerations.

### Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not asked in this form in a previous Delphi survey. In the 1992 Delphi VI survey, an open-ended question addressed these issues. Establishing fair trade policies was the area receiving the largest number of responses (30 percent of panelists). In the 1994 Delphi VII survey, panelists were asked to respond to some issues with a "yes" or "no" as to what the U.S. Congress should do to assist the traditional domestic automotive industry. The results are summarized below.

| The U.S. Congress Should: | Yes | No | No response |
|---|---|---|---|
| Coordinate legislation, government agencies and other policy activities | 91% | 8% | 1% |
| Regulate based on technical considerations | 68 | 27 | 5 |
| Increase gasoline prices | 64 | 32 | 4 |
| Manage trade, foreign domestic investment | 48 | 47 | 5 |

## Strategic considerations

Government regulations play a major role in the success or failure of the domestic automotive industry. The ability of the North American industry to compete globally is greatly influenced by government regulations. Panelists forecast that it is at least somewhat likely the government will regulate in areas and in a manner that could positively influence the industry. In fact, recent events in Washington have shown a more favorable attitude toward the domestic automotive industry than was seen in the recent past. Assistance in establishing fair trade with Japan and a slowing in the establishment of new regulations detrimental to the industry are encouraging signs of a more favorable relationship between Washington and the automotive industry.

For additional insight into government regulation, please refer to the Marketing volume, Question 6.

**TECH-18. Do you anticipate more, less or about the same cooperation among automotive companies in North America over the next decade in working to achieve common interests?**

| Scale: 1 = much more cooperation 3 = about the same 5 = much less cooperation? |
|---|

| Cooperation Among | Mean Rating |
|---|---|
| Traditional U.S. manufacturers and suppliers | 1.7 |
| Traditional U.S. manufacturers | 2.2 |
| Traditional and foreign-owned manufacturers | 2.8 |

## Selected edited comments

- Industry and government will learn more about the meaning and implementation of cooperation. Suppliers will have more voice in the vehicle detailed design and specifications due to outsourcing.
- Note the continued blurring of the distinction between foreign-owned and traditional United States. Note also that outside Detroit, Washington and Wall Street, few know or care.
- Some traditional U.S. manufacturers will increase their cooperation with their supply base while others will go the other way.
- The advancing integration of technologies and systems will require higher levels of cooperation and joint ventures.

## Discussion

Panelists forecast more cooperation between traditional U.S. manufacturers and between traditional U.S. manufacturers and suppliers. They forecast that cooperation between traditional and foreign-owned manufacturers will be almost unchanged from the present.

## Manufacturer/supplier comparison

The mean rating by manufacturers for cooperation among traditional U.S. manufacturers is 2.0 versus 2.4 for suppliers. There is no statistical difference between manufacturers and suppliers in the other two relationships.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. The results of the two surveys are shown in the following table.

| Cooperation Among | 1994 Delphi VII Mean Forecast | 1996 Delphi VIII Mean Forecast |
|---|---|---|
| Traditional U.S. manufacturers | 1.6 | 2.2 |
| Traditional U.S. manufacturers and suppliers | 1.7 | 1.7 |
| Traditional and foreign-owned manufacturers | 3.1 | 2.8 |

Panelists in the current survey are somewhat less optimistic regarding increased cooperation among traditional United States manufacturers than were the panelists in the 1994 Delphi VII survey.

## Strategic considerations

Increased cooperation between traditional U.S. manufacturers and between traditional U.S. manufacturers and suppliers will be important to both manufacturers and suppliers to successfully compete in the future global automotive industry. The leveraging of resources will be critical to contain costs of product development and maximize worker output. The synergy between manufacturers and suppliers will provide an advantage to the companies that learn to most effectively work in a cooperative manner. In many ways it's easier to go it alone than to cooperate.

Cooperation between individuals as well as companies requires a high level of trust if the cooperative relationship is to be optimized. This is a concern today because the values and ethics that underlie trust are fragmented and in many cases not well defined. The problem is exacerbated by at least three factors:

- Rapid personnel turnover
- Increased pace of globalization
- Extreme pressures—e.g.fear of financial failure that can lead to compromising values

This is an important and challenging area for the industry and much needs to be done.

Although panelists do not see a significant increase in cooperation between traditional and foreign-owned manufacturers, this does not mean that there is no cooperation currently. In fact, the many joint ventures between traditional and foreign and foreign-owned manufacturers are examples of the scope of cooperation today.

**TECH-19. What is the anticipated global trend towards sharing of vehicle platforms and technologies in the coming decade?**

| Scale: 1 = significantly more sharing<br>3 = unchanged<br>5 = significantly less sharing |
|---|

| Within same Company: | Mean |
|---|---|
| Sharing of technologies | 1.2 |
| Sharing of vehicle platforms | 1.4 |

| Between Companies: | Mean |
|---|---|
| Sharing of technologies | 2.1 |
| Sharing of vehicle platforms | 2.7 |

## Selected edited comments

- Cost will drive this.
- Information exchange will come by many routes: direct, through databases and through consultants and suppliers—common sources.
- Sharing technologies will become a necessary method to avoid cost for innovation.
- Structural costs will force this.
- Technology sharing is natural result of supplier consolidations.
- The current trend towards platform teams with design autonomy will slow down the trend towards more sharing.
- The trend for increased platform sharing within a manufacturer will be somewhat offset by adaptation of lean product and process development of the most progressive manufacturers.
- This increase will be within the individual auto companies.
- To some extent this increase will be within the individual auto companies, but it will also "diffuse" across OEM and country boundaries. The issue is not *if* there will be significantly more sharing of technologies, but how much. Sharing of vehicle platforms rated "3" with the exception of joint ventures or other limited time affiliations/alliances.
- While there may be some sharing of platforms and technologies between companies (e.g., GM/ Isuzu and Ford/Mazda), I don't see many further partnerships being formed.
- While there may be some ventures to allow sharing of vehicle platforms between companies, this will be mostly an intercompany initiative to reduce development/structural cost. Sharing of technologies between companies may be the only viable way to fund development of some new technologies. The supplier community might become more proactive in leading/coordinating these efforts.
- Will be cost driven and will happen because of this "driver."
- With significant pressure on the tier suppliers for continual cost reduction, suppliers are going to push for reduced numbers of "unique" sub-systems. They will focus on a modular (easily tunable) design approach. The "one-size-fits-all" strategy.

## Discussion

Panelists forecast significantly more sharing of vehicle platforms and technology globally in the coming decade. Sharing of vehicle platforms between companies is forecast to not change significantly. Some increase in sharing of technologies between companies is forecast.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not asked in this format in any previous survey.

## Strategic considerations

Sharing of vehicle platforms and technologies is forecast to increase significantly within companies. As companies have downsized dramatically in recent years, it is essential to eliminate duplication of efforts. As a result, more vehicle and component design will be common on a global basis. This requires considerable communication worldwide and the ability to transmit computer data efficiently between organizations in different parts of the world.

Because of common designs, common sourcing may also increase.

Little change is expected in the sharing of vehicle platforms between companies. Technology sharing between companies is forecast to increase. This may happen through joint venture programs or, as noted in the comments, through common supplier bases.

Clearly where manufacturers and suppliers can share technology or components that the customers don't see, or value, for being unique, there is considerable opportunity for cost reduction. Affordability pressures will undoubtedly accelerate this trend. Already the Big Three are working to standardize electrical connectors, and many more projects are envisioned.

**TECH-20. How important are these elements of competition to the traditional domestic manufacturers?**

| Scale: 1 = most important<br>3 = somewhat important 5 = least important |
|---|

| Key Elements | Mean Rating |
|---|---|
| Cost to the manufacturer | 1.3 |
| Quality/reliability/durability (QRD) | 1.4 |
| Corporate product reputation | 1.6 |
| Reduced lead time | 1.8 |
| Vehicle sales price | 1.8 |
| Styling/fashion | 1.9 |
| Fit and finish | 2.0 |
| Safety | 2.0 |
| Sales and service | 2.0 |
| Performance | 2.2 |
| New technology/product innovation | 2.4 |
| Ride and handling | 2.4 |
| Vehicle ergonomics | 2.4 |
| Fuel economy | 2.6 |
| Environmental responsibility | 2.8 |
| Image of good corporate citizenship | 2.9 |

**Other responses**

Niche/image vehicles: 1; Overall customer satisfaction: 2; Security: 1

## Selected edited comments

- "Least important" does not mean "not important."
- The only thing that really counts is the bottom line.

## Discussion

Of the many elements of competition for the traditional domestic manufacturers, panelists rank cost and quality as the most important.

## Manufacturer/supplier comparison

The elements in the following table were found to have statistically significant differences between manufacturers and suppliers ratings.

| Key Elements | Mean Forecast | |
|---|---|---|
| | Mfr. | Supplier |
| Corporate product reputation | 1.4 | 1.8 |
| Environmental responsibility | 2.5 | 3.1 |
| Image of good corporate citizenship | 2.4 | 3.3 |
| Quality/Reliability/Durability (QRD) | 1.2 | 1.6 |
| Safety | 1.8 | 2.2 |
| Sales and service | 1.7 | 2.3 |
| Vehicle ergonomics | 2.2 | 2.6 |
| Vehicle sales price | 1.5 | 2.0 |

Suppliers rated as less important all elements for which there was a statistical difference. The greatest differences were found in the elements of image of good corporate citizenship and environmental responsibility. In these areas the manufacturers saw themselves as more responsible than did the suppliers.

## Trend from previous Delphi surveys

This question was asked in the current form in the 1994 Delphi VII survey. The current and 1994 surveys are compared in the following table.

| Key Elements | Mean Forecast | |
|---|---|---|
| | 1994 Delphi VII | 1996 Delphi VIII |
| Corporate product reputation | 2.0 | 1.6 |
| Cost to the manufacturer | 1.5 | 1.3 |
| Environmental responsibility | 2.2 | 2.8 |
| Fit and finish | na | 2.0 |
| Fuel economy | 2.2 | 2.6 |
| Image of good corporate citizenship | 2.4 | 2.9 |
| New technology/product innovation | 2.1 | 2.4 |
| Performance | 2.2 | 2.2 |
| Quality/reliability/durability (QRD) | 1.4 | 1.4 |
| Reduced lead time | 2.2 | 1.8 |
| Ride and handling | 2.5 | 2.4 |
| Safety | 1.9 | 2.0 |
| Sales and service | 1.8 | 2.0 |
| Styling/fashion | 2.1 | 1.9 |
| Vehicle ergonomics | 2.5 | 2.4 |
| Vehicle sales price | na | 1.8 |

The elements having the greatest difference between the two surveys are environmental responsibility and image of good corporate citizenship. Both elements were rated as less important by the current panelists.

## Strategic considerations

Although panelists rated cost and quality as most important, many elements of competition must be considered by a vehicle manufacturer in planning, developing and selling the product. All elements are important and must be addressed, and the manufacturer that best addresses the most elements with the best balance will win in the marketplace. While the organization may focus on one or a few elements at any one time, the others are neglected at the peril of the organization.

It should be noted that all elements listed in this question received ratings of less than "3" suggesting they are all considered important competitive factors.

Vehicle discriminators change in the marketplace as manufacturers reach parity or separate in performance on key elements. The manufacturer that can perform well on all elements will not have to worry about what the next discriminator will be. This is certainly one dimension of agility.

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**TECH-21. What percentage of product design and engineering for North American-produced passenger cars is and will be performed in North America and offshore by the traditional domestic vehicle manufacturers?**

| Design/Engineering Site | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| North America | 90% | 80% | 75% | 80/93% | 75/85% | 69/81% |
| Offshore | 10 | 20 | 25 | 8/20 | 15/25 | 19/31 |

## Selected edited comments

- Ford 2000 program is only variable here.
- Ford 2000; GM - Opel design connection.
- Note that percentage of production by foreign (i.e., non-U.S.) manufacturers in Mexico and Canada is higher than in the United States.
- Offshore would be higher without the inclusion of Chrysler.
- The different global organizational structures of Ford, GM and Chrysler seem to make this an apples to oranges question with Ford 2000, GM Opel, etc.
- The movement toward "globalization" will not subside; the offset of more non-North American design and engineering work being done over here could somewhat compensate.
- Trend is indicated by Ford shifting all future small car development to Europe. GM tending that way with some platforms also. This will change further with the need for smaller platform expertise (both car and truck) between 2000 and 2005.
- Trend is toward more global activity.
- World car design will be made more common as improved market information is conveyed faster and more reliably by satellite conferences. Also, better techniques of product definition will lead to commonization.

## Discussion

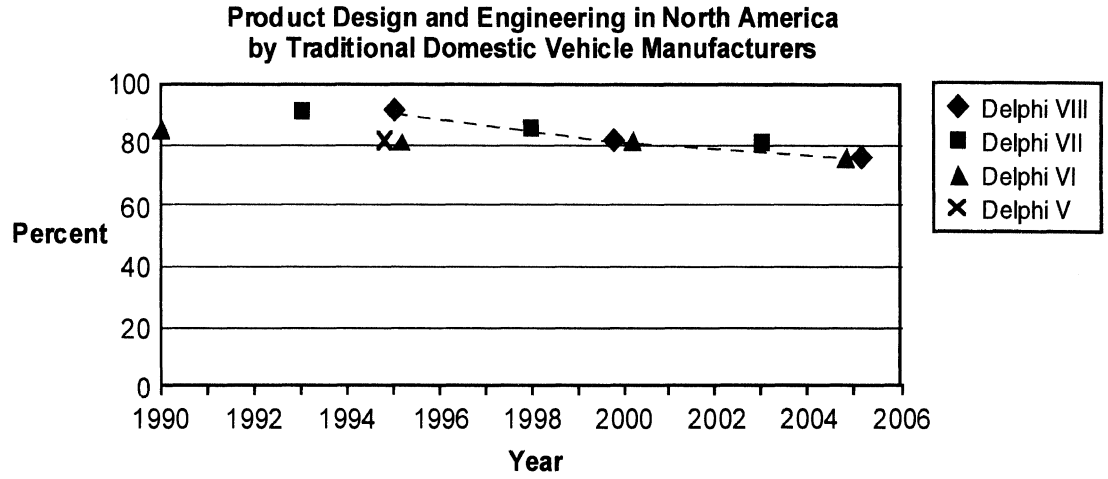
Panelists forecast the vast majority of product design and engineering for North American-produced passenger cars will be performed in North America by the traditional domestic vehicle manufacturers through 2005. The amount performed offshore is forecast to increase significantly, however, from 10 percent currently to 25 percent in 2005.

## Manufacturer/supplier comparison

There is no statistical difference in response between manufacturers and suppliers.

## Trend from previous Delphi surveys

A comparison between this survey and the previous three surveys is summarized in the following chart.




The current survey results fall below those of 1994 Delphi VII but very close to the1992 and 1990 Delphi surveys.

## Strategic considerations

The forecast trend for reduced product design and engineering in North America by the traditional domestic vehicle manufacturers is likely the result of many factors. Among these are an increasing use of offshore suppliers, global organizational structures of the manufacturers and suppliers, increased partnering with foreign manufacturers and the deficiency of some critical skills in North America. Some offshore locations may provide the lowest cost source of product design and engineering. As noted in the comments, both Ford and GM are contributing heavily to the trend with their present organizational strategies.

Some factors to be considered in the expansion of offshore product design and engineering are communications between all areas in the organization, vehicle systems engineering, problem resolution in the production process, and the long-term potential impact on an organization of reducing the in-house level of technical expertise. We live in a rapidly changing world, and a seemingly secure relationship today may be jeopardized tomorrow by political changes.

To retain a significant proportion of design and engineering content in North America, it is crucial to support development of advanced technologies and nurture the development of skilled human resources. Also it is imperative for government policy to support the research and development capability of manufacturers and suppliers. Examples of policy actions include sustainance of strong national laboratories, cooperation with industry, and tax policy supporting research and development.

**TECH-22. What percentage of product design and engineering for North American-produced passenger cars is and will be performed in North America and offshore by foreign owned vehicle manufacturers?**

| Design/Engineering Site | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| North America | 10% | 20% | 25% | 10/20% | 11/30% | 15/40% |
| Offshore | 90 | 80 | 75 | 80/90 | 70/90 | 60/85 |

## Selected edited comments

- If the dollar weakens further then more work will be done here.
- Major tooling sources and European suppliers relocating to Detroit. Ford 2000 impact on small car design in Europe.
- Over time, somewhat more of this activity will move to North America; however, the "cultural barriers" will come down slowly.
- Vehicles will be tailored more for specific markets (i.e., Japan, China, Europe, North America, South America), made possible through reduced lead times and gaining economies of scale through larger suppliers.

## Discussion

The percentage of product design and engineering in North America for North American-produced passenger cars by foreign-owned vehicle manufacturers is forecast to increase from 10 percent currently to 25 percent by 2005.

## Manufacturer/supplier comparison

There is no statistical difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

There is generally good agreement between panelists in the last three surveys regarding the direction and magnitude of product design and engineering in North America for North American-produced passenger cars by foreign-owned vehicle manufacturers.

## Strategic considerations

The forecast increase in product design and engineering in North America for North American-produced passenger cars by foreign-owned vehicle manufacturers is likely the result of many factors. These factors may include an increase in the number of vehicles assembled in North America by foreign-owned manufacturers, an increase in the number of components and sub-assemblies sourced in North America by foreign-owned manufacturers, the relatively low value of the American dollar (and consequently reduced research and development cost), availability of critical technical skills, and government pressure. In spite of these increases, panelists forecast that most of the product design and engineering will remain offshore through 2005.

Foreign manufacturers will use their own resources along with those of suppliers and North American engineering service companies in the design and engineering of their products.

The increase in product design and engineering in North America by foreign-owned vehicle manufacturers will at least partially offset the decrease forecast for the traditional domestic manufacturers.

**TECH-23. What percentage of parts, components and subassemblies do the traditional domestic vehicle manufacturers source from these regions currently, and what percentage will they source in 2000 and 2005, assuming no domestic content legislation? Please use a dollar volume basis in estimating percentages.**

| Sourcing for Traditional Domestic Manufacturing Operations | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| Asia Pacific (except Japan) | 2% | 5% | 8% | 2/5% | 3/10% | 5/15% |
| Eastern Europe | 1 | 2 | 3 | 0/1 | 1/3 | 1/5 |
| Japan | 10 | 10 | 6 | 5/15 | 5/14 | 5/10 |
| North America (United States, Canada, Mexico) | 80 | 76 | 70 | 70/85 | 61/83 | 55/80 |
| South America | 1 | 2 | 4 | 0/3 | 1/5 | 1/5 |
| Western Europe | 5 | 5 | 5 | 3/10 | 3/10 | 3/10 |

## Selected edited comments

- Much is "capacity balancing" by globally integrated manufacturers.
- Asia Pacific growth is anticipated as quality infrastructure develops in places like China, India and Taiwan.
- Electronic content will increase and the sourcing to North American suppliers will maintain North American content.

## Discussion

Panelists forecast a decrease in North American sourcing of parts, components and subassemblies by the traditional domestic vehicle manufacturers. North American sourcing is forecast to represent 70 percent of the total by 2005 compared to the current estimate of 80 percent. Sourcing from Asia Pacific (except Japan) is forecast to increase to 8 percent in 2005 compared to the current estimate of 2 percent.

## Manufacturer/supplier comparison

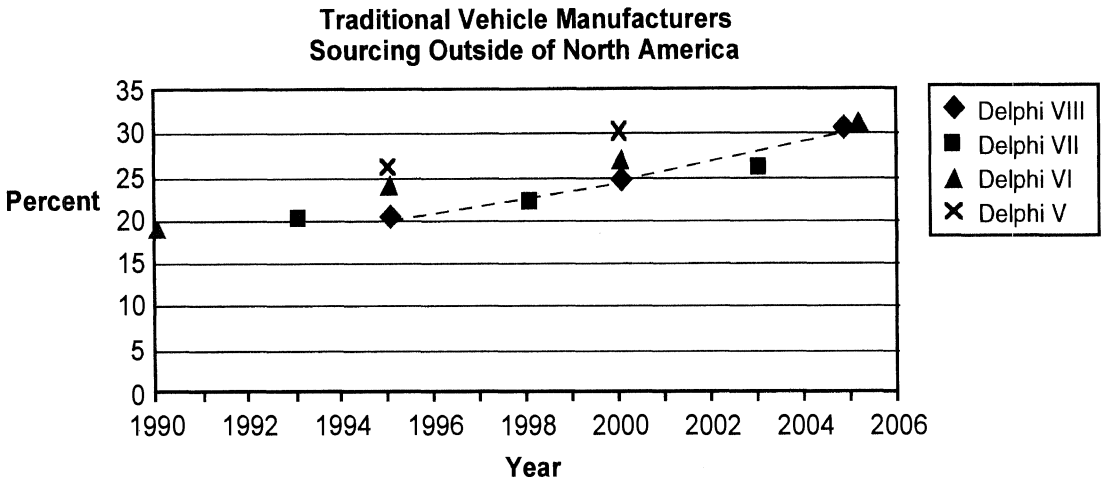
There is no statistical difference in responses between manufacturers and suppliers with the exception of the areas shown in the following chart.

| Sourcing for Traditional Domestic Manufacturing Operations | Mean Response | | | |
|---|---|---|---|---|
| | Current | | 2005 | |
| | Mfrs. | Suppliers | Mfrs. | Suppliers |
| North America (U.S., Canada, Mexico) | 80% | 73% | — | — |
| South America | 1 | 3 | 3% | 6% |
| Western Europe | 4 | 7 | — | — |

Manufacturers forecast greater sourcing from North America and less sourcing from South America and Western Europe than do suppliers.

## Trend from previous Delphi surveys

The percentage of parts, components and subassemblies forecast to be sourced outside of North America by the traditional domestic vehicle manufacturers is summarized in the following chart for this and the previous three Delphi surveys.




This forecast is in line with the 1994 Delphi VII forecast but somewhat below that of the 1989 Delphi V forecast.

## Strategic considerations

Domestic vehicle manufacturers may source parts, components and subassemblies outside of North America for a variety of reasons. Cost is always a major consideration. In spite of the low value of the United States dollar relative to some foreign currencies, primarily Japan and Germany, the dollar has not lost its value relative to currencies of many other countries of the world. As a result, the cost to produce parts in many other countries outside North America remains below costs within North America. Labor cost disadvantages compared to many developing countries is also a factor.

Joint ventures with foreign manufacturers frequently result in the use of many parts and components produced in the country of the foreign partner. This is particularly true of high cost components such as engines and transmissions.

As the domestic manufacturers continue the move to more global organizations and increased sharing of platforms and components between countries, many parts, components and subassemblies designed for use in other countries may be used in vehicles assembled in North America. Many new vehicles are being designed by domestic manufacturers in foreign countries for use and sale around the globe. These vehicles may be assembled in North America, but many components may come from foreign countries.

The loss of sales in North America by domestic suppliers because of industry globalization may be partially or completely offset by the export of components for vehicles designed in North America but assembled elsewhere.

These expectations emphasize the importance of doing everything possible to enhance the competitiveness of the automotive production system in North America. Automotive jobs are critically important to our economy.

It is useful to note that the total trend to sourcing outside North America has followed the same trend for many years but with a significant shift away from Japan to other areas.

**TECH-24. What percentage of parts, components and subassemblies do the North American production operations of foreign-owned vehicle manufacturers source from these regions currently, and what percentage will they source in 2000 and 2005, assuming no domestic content legislation? Please use a dollar volume basis in estimating percentages.**

| Sourcing for Foreign-Owned Manufacturing Operations | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| Asia Pacific (except Japan) | 5% | 9% | 10% | 5/5.3% | 7/10% | 8/12% |
| Eastern Europe | 0 | 0 | 1 | 0/0 | 0/0.5 | 0/3 |
| Japan | 60 | 50 | 40 | 53/60 | 40/50 | 30/40 |
| North America (United States, Canada, Mexico) | 30 | 39 | 40 | 30/35 | 35/40 | 40/48 |
| South America | 0 | 0 | 1 | 0/0 | 0/2 | 0/4 |
| Western Europe | 4 | 5 | 5 | 2/5 | 4/6 | 4/7 |

## Selected edited comments

- As automobile manufacturing and sale and the ownership of companies and producing units become increasingly global and interorganizational relationships more complex, national and geographical distinctions and boundries will become less important and more difficult to perceive and assess.
- Currency exchange rates and political pressures will play a strong role in motivating transplant manufacturers to consider non-traditional suppliers. Improved supplier quality (North America) and competitiveness (North America/Western Europe) will enable more use of these non-traditional sources.
- Currency exchange rates will continue to play a strong role in motivating foreign manufacturers to use non traditional sources.
- Dynamic political pressures have a significant influence on this issue.
- Exchange rates and politics will be forcing functions.
- There's the question of ownership and (R.D.&E) location of North American suppliers of "foreign" manufacturers. Note: This does not address more complex arrangements (e.g., parts made in China by a plant owned partly by a U.S. or Japanese company).

## Discussion

Panelists forecast an increase in North American sourcing of parts, components and subassemblies by the North American production operations of foreign-owned vehicle manufacturers. North American sourcing is forecast to represent 40 percent of the total by 2005 compared to the current estimate of 30 percent. Sourcing from Japan is forecast to decrease to 40 percent in 2005 compared to the current estimate of 60 percent.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the present format in the 1994 Delphi VII. The results of the two surveys are very similar as shown in the following table.

| Forecast for year → | 1993 | 1995 | 1998 | 2000 | 2003 | 2005 |
|---|---|---|---|---|---|---|
| Survey → | Delphi VII | Delphi VIII | Delphi VII | Delphi VIII | Delphi VII | Delphi VIII |
| Year of survey → | 1994 | 1996 | 1994 | 1996 | 1994 | 1996 |
| **Sourced from:** | | | | | | |
| Asia Pacific * (Except Japan) | 5% | 5% | 7% | 9% | 9% | 10% |
| Eastern Europe | 0 | 0 | 0 | 0 | 0 | 1 |
| Japan | 63 | 60 | 55 | 50 | 45 | 40 |
| North America | 25 | 30 | 30 | 39 | 35 | 40 |
| South America | 0 | 0 | 0 | 0 | 2 | 2 |
| Western Europe | 1 | 4 | 2 | 5 | 1 | 5 |

* was Southeast Asia in Delphi VII

## Strategic considerations

The forecast increase in sourcing from North America by the production operations of foreign-owned vehicle manufacturers will provide great opportunities for North American suppliers. At the same time the percentage of parts, components and subassemblies sourced from North America is forecast to increase, the total number of vehicles produced by foreign-owned vehicle manufacturers in North America is expected to increase. The combined effects should provide greatly increased volume for North American suppliers.

Many high cost components such as engines and transmissions are sourced from Japan today. As the volume of vehicles assembled in North America continues to increase, it is likely that these components will be built in North America, and many of the components that go into these engines and transmissions will be sourced in North America.

As noted in the comments, currency exchange rates will play a large part in sourcing decisions. The recent drop in the value of the dollar relative to the yen has certainly provided an incentive for Japanese manufacturers to source in North America.

The forecast increase in sourcing from North America is also likely due in part to the improving quality of products from North American suppliers.

The first comment in the preceeding page is profound and probably accurately defines the future of this industry: "As automobile manufacturing and sale and the ownership of companies and producing units become increasingly global and interorganizational relationships more complex, national and geographical distinctions and boundries will become less important and more difficult to perceive and assess."

**TECH-25. What percentage of components and subassemblies produced in North America do the traditional domestic manufacturers and foreign manufacturers source from each country currently and what percentage will they source in 2000 and 2005? Please use a dollar volume basis in estimating percentages.**

| Components Sourcing | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| **Traditional Domestic** | | | | | | |
| North American (NA) content | | | | | | |
| United States | 75% | 70% | 70% | 70/80% | 65/78% | 60/75% |
| Canada | 15 | 15 | 15 | 10/20 | 10/17 | 10/20 |
| Mexico | 10 | 15 | 20 | 5/10 | 10/20 | 15/20 |
| **Foreign Manufacturers** | | | | | | |
| North American (NA) content | | | | | | |
| United States | 80 | 72 | 70 | 70/88 | 65/85 | 60/80 |
| Canada | 10 | 10 | 10 | 5/15 | 7/15 | 7/15 |
| Mexico | 8 | 13 | 18 | 5/10 | 6/20 | 10/25 |

## Selected edited comments

- I believe foreign manufacturers will evolve toward the sourcing patterns of the traditional manufacturers.
- If the peso continues to slide, more work will go to Mexico.

## Discussion

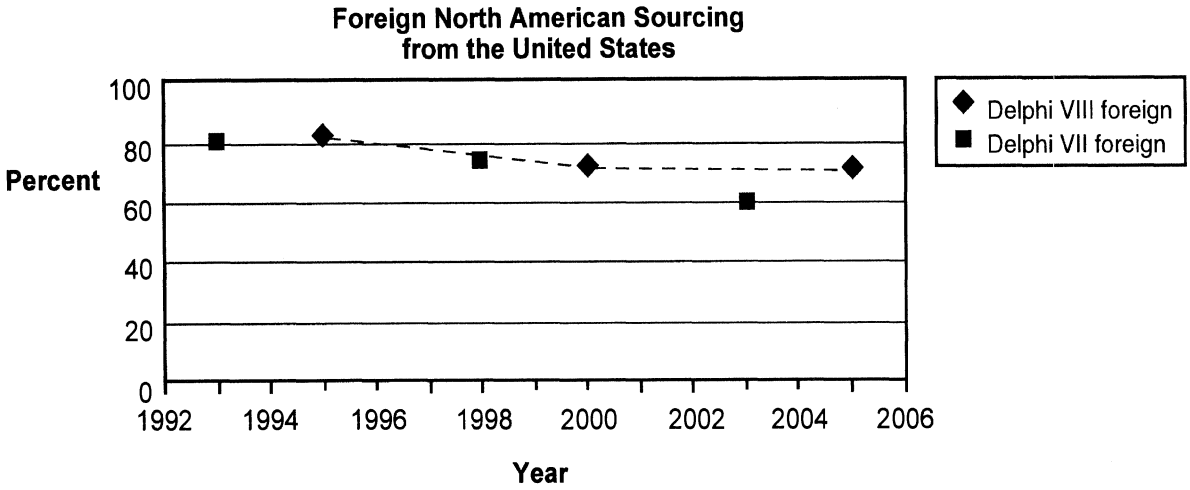
Panelists forecast that both traditional domestic and foreign manufacturers will source a smaller percentage of components and subassemblies produced in North America from the United States and a larger percentage from Mexico in the next decade. Sourcing by traditional domestic manufacturers from the United States is forecast to decrease from 75 percent currently to 70 percent in 2005. Similarly, sourcing by foreign manufacturers from the United States is forecast to decrease from 80 percent currently to 70 percent in 2005.

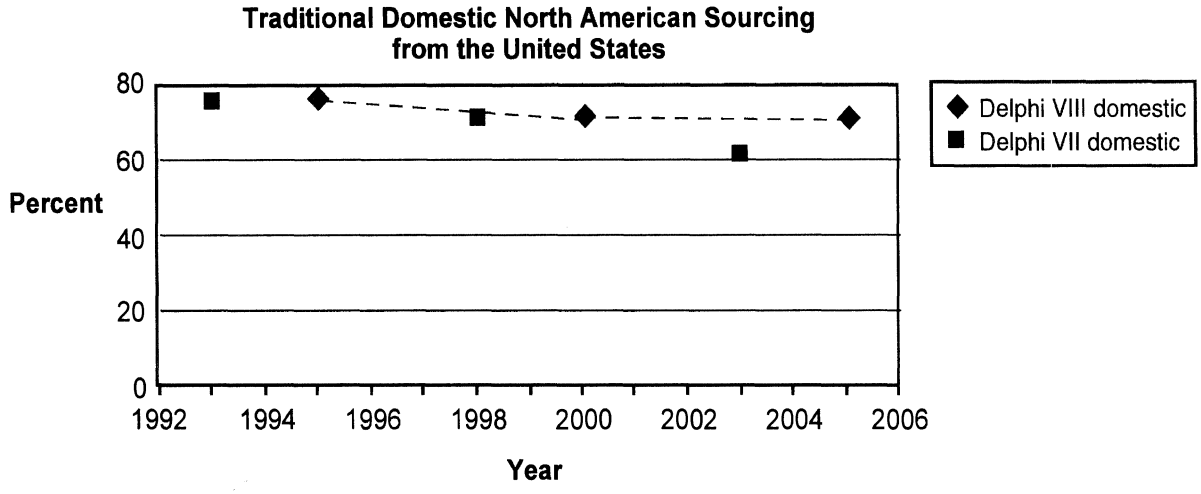
## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the same form in the 1994 Delphi VII. A comparison of the results of the current survey and Delphi VII for sourcing of components from the United States is shown in the following charts .




Current panelists forecast a somewhat lower percent reduction in North American sourcing from the United States than did the panelists of the 1994 Delphi VII.

## Strategic considerations

The recent devaluation of the Mexican peso adds a significant degree of uncertainty regarding sourcing in North America. If the peso remains low there will continue to be strong incentive to source from Mexico. In spite of this devaluation, however, panelists forecast a significant but not dramatic decrease in sourcing from the United States as a percent of North American sourcing in the next decade. Many factors other than piece cost influence sourcing, including transportation cost, delivery time, proximity of the source to the assembly plant for problem resolution and ability of the source to support the design and development process. Furthermore, both manufacturers and suppliers will increasingly try to rationalize production across North America to maximize efficiency. This will certainly be a factor in the location of production. These and perhaps other factors may have been considered by panelists in responding to this question.

**TECH-26. In 2000 and 2005, what percentage of new tooling for North American-produced passenger cars and light trucks will be sourced in North America?**

| New Tooling Sourced in North America | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Passenger cars | 75% | 70% | 60/80% | 60/80% |
| Light trucks | 80 | 75 | 70/85 | 60/85 |

## Selected edited comment

- Asian tool quality is improving quickly. Tool supply from China, Korea, and Southeast Asia will grow faster than component content. Data communications and on-time delivery will facilitate this.

## Discussion

Panelists forecast a decrease in the next decade in the percent of new tooling sourced in North America for both passenger cars and light trucks. North American sourced tooling in 2005 is forecast to be 70 percent and 75 percent for passenger cars and light trucks, respectively.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked (for passenger cars only) in the 1994 Delphi VII survey. The responses for the two surveys were identical at 75 percent and 70 percent, although the 1994 survey asked for forecasts for 1998 and 2003.

## Strategic considerations

The machine tool industry is a critical resource relative to the military security of North America. The forecast reduction in the percent of tooling sourced from North America increases the vulnerability of North America to global political events. One panelist commented that sourcing of tooling from China, Korea and Southeast Asia will increase. These areas of the world are certainly not the most stable politically, nor are the relationships of these areas with the United States totally predictable. The shortsighted benefit of low cost may prove to be detrimental long term to North America.

The tooling industry employs many people in North America. Continued future erosion of this employment base as well as loss of critical skills may result in a reduction of the new automobile consumer base due to lost jobs or jobs that pay lower wages. It may be a valuable study for the automotive industry to ascertain the potential future vehicle sales lost as a result of foreign sourcing of new tooling. Perhaps the lost vehicle sales in the future should be balanced against the short-term cost savings for new tooling. This argument certainly goes beyond the tooling industry and includes all sourced raw materials and components.

## TECH-27. What will be the major design or technology issues between manufacturers and suppliers in the next decade?

| Issues | Number of Responses |
|---|---|
| Full service suppliers | 9 |
| Intellectual properties ownership of jointly developed future products and concepts with stronger Tier 1 suppliers | 8 |
| System and subsystem design/analysis/test | 7 |
| Quality assurance | 6 |
| Computer interfaces—common ( CAD, etc) | 5 |
| Cost reduction—cooperation in implementing | 5 |
| Mass reduction | 5 |
| Environmental compliance | 4 |
| Low cost designs—customer value, VE/VA | 4 |
| Materials (joining of aluminum, recyclability, etc.) | 4 |
| System engineering responsibility transferred to supplier base | 4 |
| Design cost—compensating suppliers | 3 |
| Fuel economy | 3 |
| Supplier—increased design responsibility | 3 |
| Technical capability of suppliers | 3 |
| Time to delivery—tooling and components | 3 |
| Trust (Especially GM & Ford—1 comment) | 3 |
| Data and information sharing | 2 |
| Dealing with geographic spread/colocation of manufacturers and suppliers | 2 |
| Modular assemblies—additional | 2 |
| Precision net-build parts with high strength/integrity | 2 |
| Recycling | 2 |
| Supplier participation in development | 2 |
| Supplier understanding of how subsystems work within vehicle system | 2 |
| Support from second and third tier supply base | 2 |
| Communications—accelerated introduction schedule | 1 |
| Computer modeling to reduce development time | 1 |
| Concurrent engineering | 1 |
| Cooperation throughout supplier tiers | 1 |
| Design coordination | 1 |
| Durability | 1 |
| Electronic controls | 1 |
| Flexibility | 1 |
| Low-cost manufacturing systems | 1 |
| Manufacturing processes | 1 |
| Manufacturing supply chain coordination | 1 |

| | |
|---|---|
| Materials—low-cost, more desireable | 1 |
| Multiplexing signals | 1 |
| New product innovation | 1 |
| Safety | 1 |
| Shared inventories—reduce | 1 |
| Standards and specifications | 1 |
| Supplier investment in new technology | 1 |
| Supplier responsibility to develop/support new features/technology | 1 |
| Suppliers working together to develop new technologies | 1 |
| Tools and methods common | 1 |
| Training of workforce | 1 |
| Warranty/durability | 1 |

## Selected edited comment

- Will the supplier, by early-on extensive funding of participation in the concept, design, development (and to some extent tooling), have assured production percent (100%?) and price (including scheduled learning curve reductions) for the life of the model? The converse "do it and trust me (and my successors)" won't be realistic and effective "teaming."

## Discussion

Panelists have identified many design and technology issues between manufacturers and suppliers in the next decade. The most frequently mentioned are full service suppliers, intellectual property ownership, responsibility for system and subsystem design/analysis/test, and quality assurance.

## Manufacturer/supplier comparison

Manufacturer/supplier comparisons are not made for open-ended questions.

## Trend from previous Delphi surveys

This question was not asked in a previous survey.

## Strategic considerations

As manufacturers downsize and outsource more components, subsystems and design, the relationship between manufacturers and suppliers takes on added importance. True partnering is required to assure a continued reliable supply base that is capable of handling design, test and validation of parts and subsystems. Integration of these parts and subsystems into the vehicle becomes a joint responsibility of manufacturers and suppliers. A clear understanding of these responsibilities and lines of demarcation will be essential to the development of reliable, high-quality vehicles that will satisfy the customer. As in athletics, the team of individuals working towards their own various goals will not succeed as well as the individuals working together as a cohesive team. Words used by panelists describing the required behavior include trust, sharing, cooperation, responsibility, communication, flexibility and innovation. Other relevant phrases might include team spirit, common goals and shared rewards.

**TECH-28. Please give your expectations in months of current and future development cycles from concept approval through Job One for the reskinning of high- and low-volume passenger cars, maintaining current hardpoints.**

| Future Development Cycles Maintaining Current Hardpoints | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| High-volume vehicle (production more than 50,000 units/year) | | | | | | |
| United States | 36 | 30 | 26 | 30/42 | 24/38 | 20/34 |
| Japan | 30 | 25 | 24 | 24/35 | 20/31 | 18/29 |
| Europe | 40 | 36 | 30 | 30/46 | 27/40 | 24/37 |
| Low-volume vehicle (production less than 50,000 units/year) | | | | | | |
| United States | 30 | 28 | 24 | 25/38 | 22/34 | 20/30 |
| Japan | 26 | 24 | 20 | 20/30 | 18/29 | 16/25 |
| Europe | 36 | 30 | 28 | 28/42 | 25/36 | 21/32 |

## Selected edited comments

- Depends if the low-volume vehicles are "variants" of high-volume ones in development and production.
- Note that Japan rarely reskins, maintaining current hardpoints-at least today.
- Technically it will be possible to go 15-20 percent faster but economics (tooling absorption) will limit cycle time reduction.
- Volume does not influence development cycles.
- We need clear definition of when the clock starts—concept approval? Is that program definition, program implementation or program approval?

## Discussion

Panelists forecast reduced development cycle time for vehicles maintaining current hardpoints for all manufacturers. The gap in development cycle time is expected to narrow between manufacturers with a total spread between all manufacturers of only six months for high-volume vehicles maintaining current hardpoints by 2005. A similar trend is forecast for low volume vehicles.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers except for the items summarized in the following table.

| Future Development Cycles Maintaining Current Hardpoints High-volume vehicle | | | | | | |
|---|---|---|---|---|---|---|
| Manufacturer Location | Mean Estimate Current | | Mean Estimate 2000 | | Mean Estimate 2005 | |
| | Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. |
| Japan | 32 | 28 | 28 | 24 | 26 | 22 |
| Europe | 43 | 38 | 38 | 33 | — | — |

For all areas where there is a statistically significant difference in responses manufacturers forecast longer development cycles than suppliers. These responses are four months longer for Japan and five months longer for Europe.

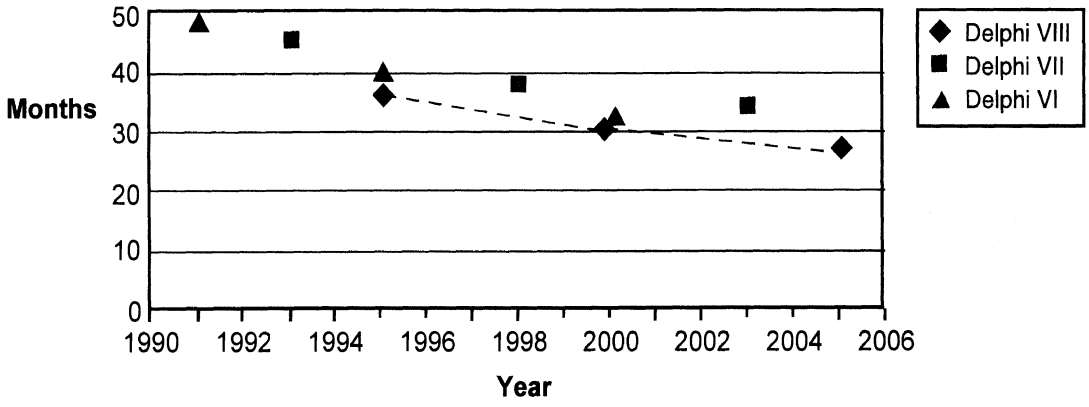
## Comparison of forecast: MKT- 27a

The marketing panel was not asked to differentiate by production volume. The median responses of marketing panelists are two to four months longer for all the years and regions with two exceptions compared to technology panelist responses for high-volume vehicle production. Responses for the two panels were the same for Japan in 2005. For European manufacturers in 2005, the marketing panel forecast 35 months which is five months longer than forecast by technology panelists.

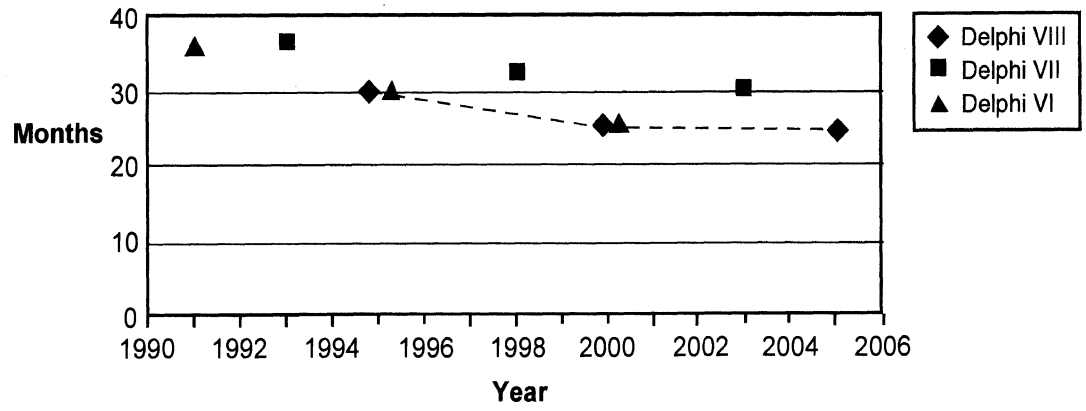
## Trend from previous Delphi surveys

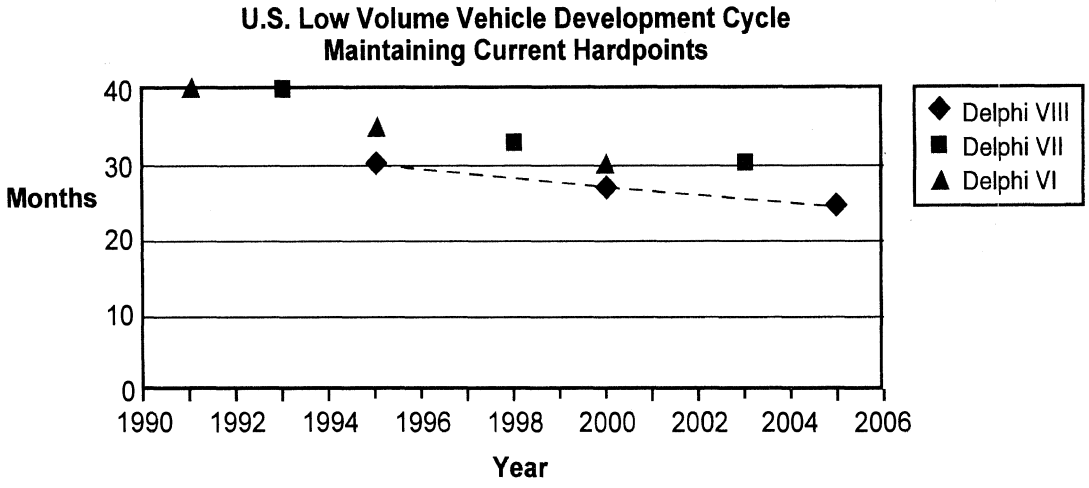
Results for the current and previous two surveys are compared in the following charts.

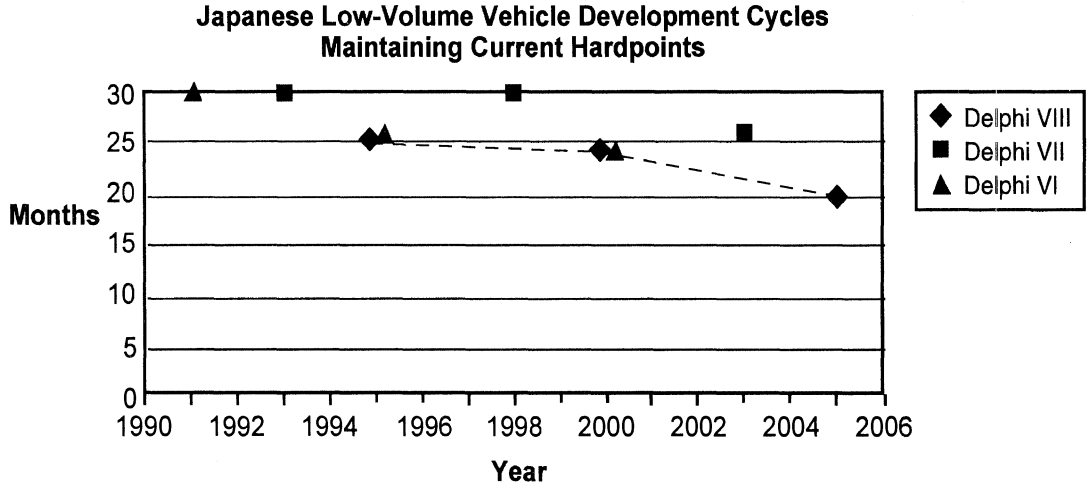
**U.S. High-Volume Vehicle Development Cycles Maintaining Current Hardpoints**




**Japanese High-Volume Vehicle Development Cycles Maintaining Current Hardpoints**






For high- and low-volume vehicles, results of the current survey are on the low end of those from the previous two surveys. In general, the results of all three surveys are in quite close agreement.

## Strategic considerations

Japanese manufacturers currently are viewed as having a significant advantage in time to bring a vehicle to market. Panelists forecast that in the next decade there will be a small difference between Japanese and U.S. development cycle times for a vehicle maintaining current hardpoints. Cycle times for the European manufacturers are forecast to continue to be longer than those of the Japanese or U.S. manufacturers. By 2005, development cycle time will not be a significant factor in marketing of vehicles produced by Japanese or traditional domestic manufacturers. European manufacturers may continue to be at a disadvantage in this area.

Panelists raised the question of definition of starting time for the development cycle. This is a difficult issue. Starting time definition is certainly somewhat different between manufacturers. In fact, for an individual manufacturer the definition is not particularly clear. Manufacturers may have defined criteria for tasks that must be completed prior to starting the clock. In general the key event is management approval of the vehicle for production, including development of a business case and funding. This follows a preliminary design and demonstration of an operational vehicle. In practice, however, all suggested tasks may not be completed at the time of management approval. Furthermore, changes to the approved vehicle are made after approval. As a result, tasks that are to be done at management approval must be done again or modified.

In spite of the ambiguity surrounding when the clock starts, panelists provide a valuable trend in cycle time and the anticipated differences between manufacturers.

**TECH-29. Please give your expectations, in months, of current and future development cycles from concept approval through Job One for new platforms that establish new hardpoints for high and low volume passenger cars.**

| Future Development Cycles Establishing New Hardpoints | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| High-volume vehicle (production more than 50,000 units/year) | | | | | | |
| United States | 48 | 38 | 35 | 40/50 | 36/42 | 30/37 |
| Japan | 36 | 33 | 30 | 33/42 | 28/36 | 24/34 |
| Europe | 49 | 42 | 38 | 42/54 | 38/48 | 32/42 |
| Low-volume vehicle (production less than 50,000 units/year) | | | | | | |
| United States | 42 | 36 | 32 | 36/48 | 30/40 | 24/36 |
| Japan | 35 | 30 | 28 | 28/39 | 24/35 | 22/32 |
| Europe | 45 | 40 | 36 | 36/50 | 32/46 | 30/40 |

## Selected edited comments

- Capability to go fast will be challenged by economic constraints to fully utilize the fast capability at acceptable return on investment.
- Simulation and artificial intelligence design will make big cuts in time-to-market. Gathering market and technology information to define concept will eventually be the biggest block of time.
- This excludes those, like electric vehicles or all-aluminum vehicles or new powertrains, that require or involve completely new product and/or manufacturing technology and facilities.
- Volume does not influence development cycles.
- We need clear definition of when the clock starts—concept approval? Is that program definition or program implementation or program approval? (Same comment as in previous question).

## Discussion

Panelists forecast reduced development cycle time for new platforms establishing new hardpoints for all manufacturers. The gap in development cycle time is expected to narrow somewhat between manufacturers, but Japanese manufacturers are expected to retain a time advantage of eight months for high-volume vehicles and 10 months for low-volume vehicles compared to European manufacturers by 2005. In this same time frame, cycle time for U.S. manufacturers is forecast to be between that of Japanese and European manufacturers.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers except for the items summarized in the following table.

| Future Development Cycles<br>New Platforms—New Hardpoints<br>High-volume vehicle | | | | | | |
|---|---|---|---|---|---|---|
| Manufacturer Location | Mean Estimate Current | | Mean Estimate 2000 | | Mean Estimate 2005 | |
| | Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. |
| Japan | 40 | 36 | 36 | 31 | 32 | 28 |
| Europe | 52 | 47 | 45 | 41 | 41 | 36 |

For all areas where there is a statistically significant difference in responses, manufacturers forecast longer development cycles than do suppliers.

## Comparison of forecast: MKT- 27b

There is no statistically significant difference in responses between Technology and Marketing panels except for the items summarized in the following table.

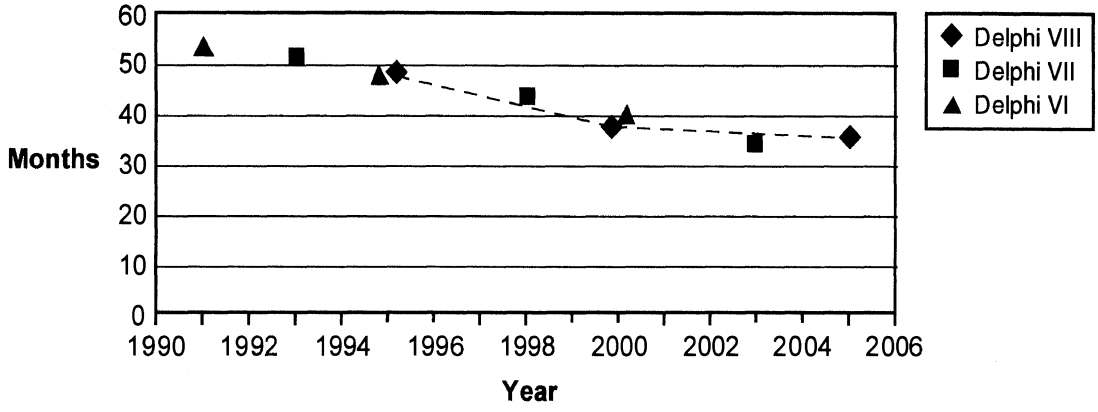
| Future Development Cycles<br>New Platforms—New Hardpoints<br>High-volume vehicle | | | | | | |
|---|---|---|---|---|---|---|
| Manufacturer Location | Mean Estimate Current | | Mean Estimate 2000 | | Mean Estimate 2005 | |
| | Tech. | Mkt. | Tech. | Mkt. | Tech. | Mkt. |
| United States | 46 | 48 | 39 | 42 | 34 | 37 |
| Japan | 37 | 40 | 33 | 36 | 29 | 32 |
| Europe | 49 | 52 | 43 | 47 | 38 | 42 |

Marketing panelists forecast development cycles two to four months longer than technology panelists for the areas where there is a statistically significant difference.

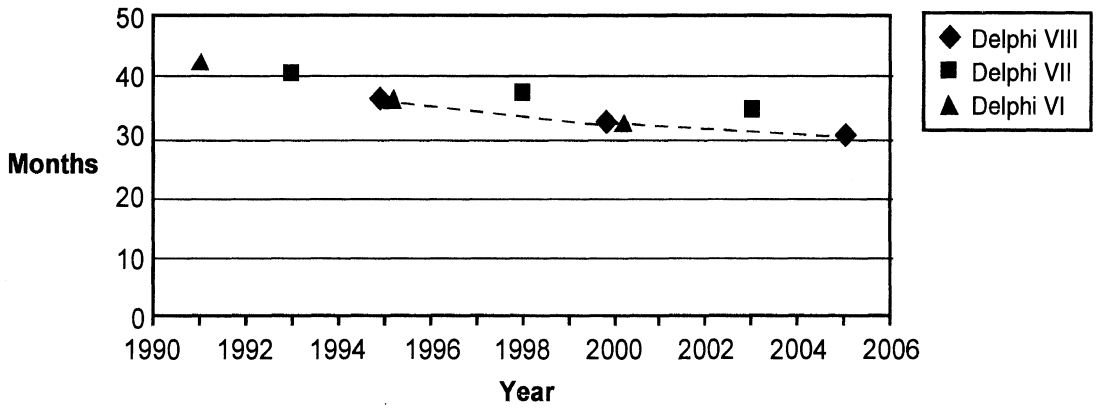
## Trend from previous Delphi surveys

Results for the current and previous two surveys are compared in the following charts.

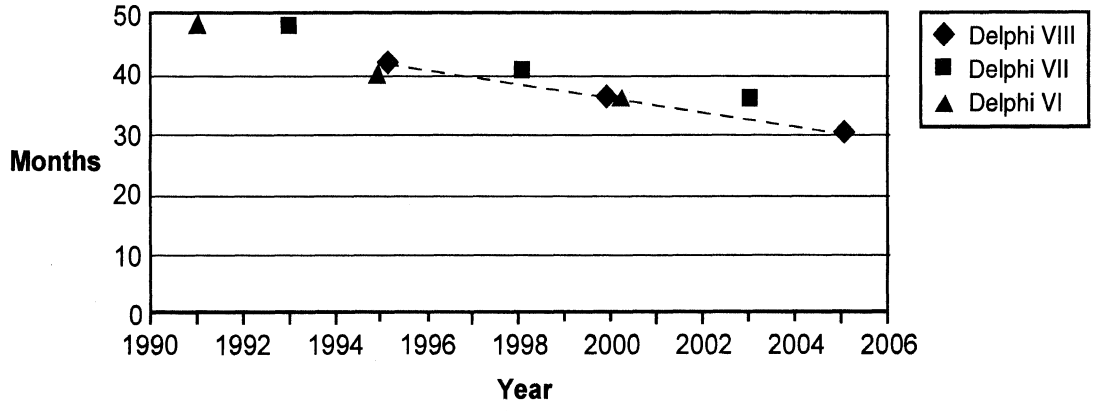
**U.S. High-Volume Vehicle Development Cycles**
**New Platform with New Hardpoints**

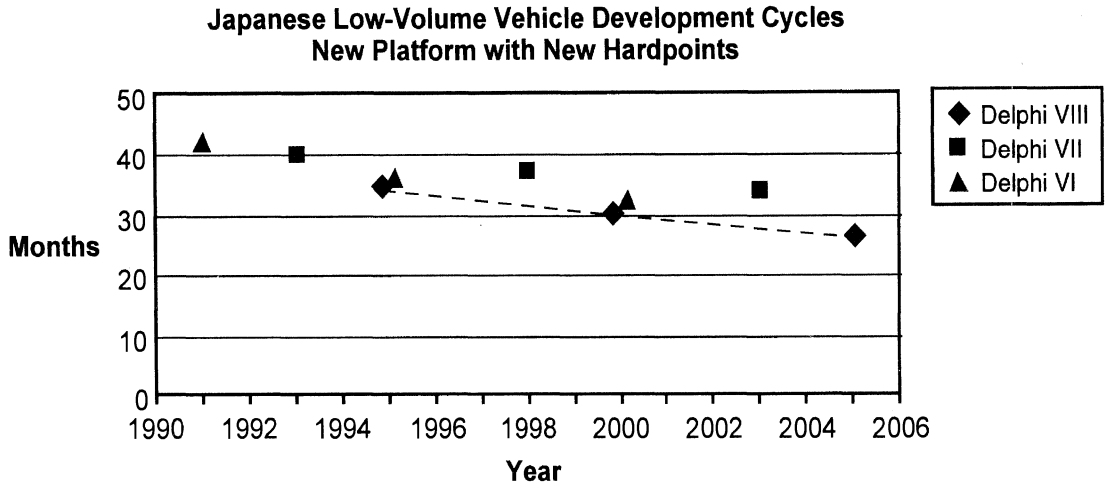



**Japanese High-Volume Vehicle Development Cycles**
**New Platform with New Hardpoints**




**U.S. Low Volume Vehicle Development Cycle**
**New Platform with New Hardpoints**






For high- and low-volume vehicles, results of the current survey are on the low end of those from the previous two surveys. In general, the results of all three surveys are in quite close agreement.

## Strategic considerations

For high-volume vehicles, panelists forecast that by 2005 Japanese manufacturers will retain a five-month cycle time advantage compared to U.S. manufacturers for new platforms establishing new hardpoints. This compares to a current advantage of eight months. This will continue to provide some advantage to the Japanese manufacturers in responding to market changes. As stated in response to the previous question, however, cycle time may be dictated by financial constraints as opposed to cycle development time. Even in this case, there is an advantage in short cycle time in that customer preferences that guide the design can be based on more recent information.

A further advantage in shorter cycle times is the availability of resources to work on other programs. It can not be assumed that the Japanese will use more resources for a shorter time to develop the product. To the contrary, it is likely that they will use the same or fewer resources for a shorter period of time, thus resulting in a cost advantage. Advances in computer-aided design, engineering and manufacturing will reduce the total resources required to execute a program. The manufacturer that best utilizes the advances in these areas will benefit through lower cost and reduced cycle time.

As engineering and product development move to more of a "math based" approach the potential for dramatic development time reduction grows. Virtual prototyping is an example of a key technology. There is opportunity for individual manufacturers and suppliers to gain considerable competitive advantage if they develop or obtain the critical software.

**TECH-30. Where do you see product and process technology leadership currently and in the future?**

**Scale: 1 = technology leader**
**3 = neither technology leader nor follower**
**5 = technology follower**

| Countries | Product Technology | | Process Technology | |
|---|---|---|---|---|
| | Today | 2005 | Today | 2005 |
| United States | 2.1 | 1.7 | 2.3 | 1.8 |
| Europe | | | | |
| Eastern | 4.9 | 4.4 | 4.7 | 4.2 |
| Western | 2.5 | 2.3 | 2.9 | 2.6 |
| Japan | 1.5 | 1.6 | 1.3 | 1.5 |
| Korea | 4.2 | 3.4 | 3.9 | 3.4 |
| South America | 4.7 | 4.4 | 4.6 | 4.3 |

## Selected edited comments

- Technology—What about the Ukraine and Russia? They have some very well trained manufacturing engineers.
- The reawakening of the U.S. industry to its cultural and technologically innovative roots will cause it to regain leadership, especially with strengths in software and control systems.

## Discussion

Panelists rate Japanese manufacturers the highest in both product and process technology today. The United States is forecast to close this gap by 2005 so that the two countries are virtually the same in product technology and quite similar in process technology. Western Europe is ranked third today, and is forecast to retain that position in 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII. Results of that survey are shown in the following table.

| Countries | Product Technology | | Process Technology | |
|---|---|---|---|---|
| | Today | MY 2003 | Today | MY 2003 |
| United States | 2.0 | 1.7 | 2.3 | 1.8 |
| Europe | 2.4 | 2.1 | 2.6 | 2.4 |
| Japan | 1.6 | 1.6 | 1.5 | 1.5 |
| Southeast Asia | 3.8 | 3.1 | 3.7 | 3.1 |
| South America | 4.1 | 3.8 | 4.1 | 3.7 |
| Eastern Europe | 4.5 | 3.8 | 4.5 | 3.8 |

Current panelists rate Japan and the United States nearly the same as did panelists in the 1994 Delphi VII survey. The relative ranking for all areas of the world was the same in the two surveys.

## Strategic considerations

As the automotive industry moves further toward a global industry, technology leadership will play an increasing role in determining which manufacturers succeed. The role of technology is expanding rapidly in both product and process development and products. Panelists forecast that the United States will be essentially on par with the current leader in this area, Japan, by 2005. This is good news for domestic manufacturers and suppliers, as the implication is that they will be competitive on a global basis.

There are many specific areas of technology in which the United States excels. Computer software is one of these. The U.S. military and aircraft industries also have tremendous technological capabilities. The Partnership for a New Generation of Vehicles and other relationships with federal laboratories may be a conduit for development and transfer of technology to the automotive industry.

**TECH-31. Using current vehicles as a baseline, what is your expectation for the change in vehicle design efficiency in the next decade.**

| Scale: 1 = dramatic improvement 3 = somewhat improved 5 = unchanged |
|---|

| Vehicle Design | Mean Rating |
|---|---|
| Stiffness efficiency (stiffness/mass) | 2.1 |
| Noise reduction efficiency (dB reduction/mass added) | 2.1 |
| Packaging efficiency (interior vol./plan view area) | 2.6 |

## Selected edited comments

- Improvement in stiffness efficiency will come partially through design and largely through materials. Not a high emphasis on noise reduction for the average vehicle.
- Noise reduction and improved overall NVH will occur but mass will not be added to accomplish this.
- Noise source reduction vs. treatment will receive considerable attention.
- Simulation and more user-friendly software applied more regularly to problems will bring the improvement.
- There is an inverse relationship between noise and stiffness.
- Worldwide platforms being designed by U.S. companies will force competition to match performance. Also, holistic system's view of vehicles will encourage greater efficiency.

## Discussion

Panelists forecast improved design efficiency for packaging, vehicle stiffness and noise reduction.

## Manufacturer/supplier comparison

Responses for manufacturers and suppliers are in agreement.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Strategic considerations

With increasing fuel economy requirements, there will be increased incentive to improve design efficiencies in the areas of packaging, stiffness and noise reduction. At the same time that fuel economy requirements are expected to rise, the customer will increasingly demand improved packaging, reduced noise, and improved vehicle ride and handling, which is improved by increasing vehicle stiffness.

The most cost-effective way to reduce the mass of the vehicle is to decrease its size. The customer, however, is not willing to accept reduced interior size or luggage space. Improved packaging efficiency can allow the reduction in overall vehicle size without loss of vehicle functionality.

Past methods of improving vehicle stiffness and reducing noise have generally resulted in added vehicle mass through larger component sections, added braces, or stiffening members. The challenge for the future is to obtain the benefits without paying a mass penalty. Our panelists forecast that there will be improvements in this area. Increased use of computers and advanced software in the design process will be a major contributor to improved design efficiencies.

**TECH-32. Considering the recent trend toward standardization of electrical connectors, what additional components do you anticipate will be standardized by 2005?**

- Airbag modules and related devices; OBD II sensors.
- All components that are not necessary to be differentiated for appearance or performance reasons as perceived by final customers. Fluid line couplings, fittings, fasteners, etc.
- Alternator/compressor/starter.
- Anything a driver/passenger can't see is fair game.
- Brake fluid, valves, mechanical connectors (bolts/nuts).
- Brake lining compounds.
- Brakes, fuel pumps, steel wheels, mufflers, transmissions, HVAC modules, alternators.
- Closures (gas, radiator); not much else.
- Communication algorithm for AHS.
- Diagnostic modules, fittings, fluids and adhesives.
- Door closures; hydraulic pneumatic fill up; battery connections; fuel system connections; wheel mounting fasteners.
- Electrical distribution/connectors, diagnostics for servicing, repair materials (paints, sealers, etc.).
- Fasteners (both threaded and non-threaded) and exterior/interior lighting.
- Fasteners, hydraulic fittings.
- Filters, bolts.
- Filters, spark plugs.
- Fluid and fiber optic connections.
- Fuel fittings, lighting, brake fluids, coolant.
- Fuel vapor emission system components; alternators (2 sizes), air conditioner compressors/ dryers; materials and coatings. This is assumed to be per manufacturer. In general, any complex and/or expensive-to-tool components will be standardized. Other components are being optimized for their particular applications (i.e., headlights, driver controls, door handles, etc.).
- Hose connections, non-threaded fasteners.
- I would like to see car/light truck standardize on many components like the heavy truck industry has. This includes engines, transmissions, axles, suspensions, air ride systems and some lighting and mirrors. Virtually anything under the skin could be standard, with the visible item and restyling cues unique to the manufacturer.
- Ignition modules, fuel gas caps, electric motors.
- Just completing and implementing connectors will be a big job. The older I get, the longer time lines seem to become.
- Material specifications.
- Material standards between companies; bulbs, motors, alternators.
- Multiplex units.
- O2 sensors, map sensors.

- Other non-visible items like door hinges and latches, electric motors, mufflers and fasteners, brackets, bearings, batteries, etc.
- Screws, attachment plastics and metals.
- Sensor outputs (each will have a designated output).
- Serial data bus, address format/convention; lots of replacement parts; lamps.
- Standard fuel filler caps; standard brake tube and hose connectors.
- Standardize vehicle electrical repair/diagnosis—all regions.
- Switches, computer modules.
- Transmissions, engines, controls.
- Vehicle computer data stream information.
- Wheel nuts/bolts, brake lining materials.

## Discussion

Panelists noted many components or systems that are candidates for standardization by 2005. In general, anything that is transparent to the customer is a candidate.

## Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

## Trend from previous Delphi surveys

This question was not asked in a previous survey.

## Strategic considerations

Standardization can result in significant cost savings. With tremendous pressure to reduce or maintain vehicle cost today, the incentive for standardization is very strong. Manufacturers can start this process internally and then expand to other organizations or the entire industry. This area is one where organizations like the Society of Automotive Engineers, Automotive Industry Action Group and United States Council on Automotive Research can provide a very useful function.

This issue has profound competitive implications, particularly when extended to the global arena. Suppliers need to take special note of this trend if their components are not evident to the ultimate consumer. The customer wants all hidden components to have world class functionality at minimum cost.

**TECH-33 Please rate your organization's current use of "systems engineering" on a scale of 1-5.**

| Scale: 1 = excellent/high 3 = moderate 5 = none |
|---|

| | Median |
|---|---|
| Management's use/embrace of systems engineering | 2.6 |
| Middle/senior management's understanding of "systems engineering" | 2.7 |
| Effectiveness of systems engineering in your organization | 3.0 |
| Number of systems engineers in your organization | 3.1 |

## Selected Edited Comments:

- Systems engineering not used for technical cost/benefit but for advertising benefit.
- There are currently many definitions of "systems engineering" in industry–same buzzword, but different meanings.
- Although not yet there, we are making big gains daily–everything is now vehicle level requirements-driven, but do not yet always get the best balance of requirements roll out to all the subsystems. I support management's use/embrace of systems engineering, but they don't always understand that their personal goals must give in to the best solution for the higher level system!
- Concern for "Lust to Rust" or systems engineering is the most highly leveraged process available to OEMs and suppliers.
- Systems engineering is very effective where used. More training/experience is required. Processes are continually improving.
- Systems impact even being felt in prototype world where our customer base is changing dramatically to first tier sourcing from OEMs with tremendously increased need for engineering, marketing support.
- Our business has both types of engineers–systems and traditional mechanical engineers. The systems engineers got no respect from the traditional ones.
- This must be the next popular buzzword among senior and middle level management. They will soon discover that engineers are already doing it.
- We need good computer software to effectively manage the systems engineering process.

## Discussion

Panelists rate the understanding, embrace, effectiveness and staffing of systems engineering as moderate within their organizations.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Strategic considerations

As manufacturers rely increasingly on suppliers for the design and validation of components, subsystems and systems, systems engineering becomes increasingly important. Manufacturers must combine diverse components and systems into a vehicle that satisfies the customer and is reliable throughout the life of the vehicle.

Manufacturers must develop vehicle specifications and roll these down into system, subsystem and component specifications against which the product of the supplier can be measured. Suppliers must be an integral part of the development of the specifications for the component or system which they supply.

Panelists rate the understanding, embrace, effectiveness and staffing of systems engineering within their organizations as moderate. Organizations that are able to improve this rating to excellent will produce products that are superior to those of organizations that maintain a moderate level of systems engineering.

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**TECH-34. Please indicate in what year the following technologies will see limited application (<5 percent) in passenger cars or light duty trucks, and what year the technology will see a 25 percent application rate.**

| Technology | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | First application | 25% application | First application | 25% application |
| Electrorheological fluids | 2000 | 2010 | 1998/2005 | 2005/2020 |
| Electrochromatic glass | 2000 | 2010 | 1998/2001 | 2005/2010 |
| Low heat rejection engine | 2003 | 2010 | 2000/2005 | 2005/2020 |
| Stratified charge spark ignited engine | 2000 | 2005 | 1997/2002 | 2005/2010 |
| Two-stroke spark ignited engine | 2001 | 2010 | 1998/2003 | 2006/2020 |
| Miller cycle engine | 1995 | 2005 | 1994/1998 | 2003/2010 |
| Active/semi-active engine mounts | 1999 | 2005 | 1997/2000 | 2005/2010 |

## Selected edited comments

- 25 percent application for electrorheological fluids, stratified charge spark ignited engine, two-stroke spark ignited engine, Miller cycle engine: never.
- Application of a low heat rejection engine will never happen assuming you mean something like the NASA space engine. All engines have some amount of stratification in the charge. I interpreted the stratified charge spark ignited engine to mean a D.I. gasoline engine.
- Electrochromatic glass, Miller cycle engine, and active/semi-active engine mounts will never see 25 percent application.
- Electrorheological fluids includes magnetorheological fluids.
- ER and MR fluids have a long way to go to fit the automotive environment. Two-stroke is still emissions limited.
- Low heat rejection engine is a matter of degree. It's already underway. Miller cycle, too, is a matter of degree.
- Miller cycle and stratified charge have already been introduced (Mazda 1994/5 and Honda CVCC circa 1975). We've just about given up on ER fluids, but what about magneto-rheological (MR) fluids?
- Stratified charge spark ignited engine, two-stroke spark ignited engine and Miller cycle engine will never have a 25 percent application and two-stroke spark ignited engine will never have a first application.

## Discussion

Panelists forecast that a number of emerging technologies will see limited application by the turn of the century and an application rate of 25 percent or more by 2010. Comments from some panelists state that they never expect the technologies in question to reach an application rate of 25 percent. Two panelists commented that the two-stroke spark ignited engine will never see a first application because of exhaust emission problems. Responses from panelists who stated that the technology would never have a first application or 25 percent application were not entered into the numerical analysis of the table above.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This is the first time that this question has been asked in this format.

## Strategic considerations

Successful application of an emerging technology can provide a competitive advantage to the manufacturer or supplier that first introduces it. One or more panelists comment that each of the technologies considered will never have a significant application rate. On the other hand, the median year for limited application of each of these technologies is well within the next decade. It is possible that some panelists have knowledge of promising work in these areas that is not widely known within the industry. Conversely, panelists that have negative views of these technologies may indeed have knowledge and know they may not see applications, at least in the next 10-15 years.

Some emerging technologies may be technically feasible but not economically viable for large volume application. These technologies may see limited application on niche vehicles and provide a positive technology image for the manufacturer. Of course, as we have seen in the past, some technologies that initially appear to be excessively costly respond to technical development and become affordable.

**TECH-35. What types of batteries will likely be used in electric or hybrid vehicles in 2000 and 2005?**

| Types of Batteries | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Lead-acid | 80% | 60% | 75/90% | 50/77% |
| Lithium-polymer | 0 | 10 | 0/0 | 0/10 |
| Nickel-cadmium | 6 | 10 | 2/10 | 3/15 |
| Nickel-hydride | 8 | 20 | 5/10 | 10/25 |

**Other responses:**
Flywheels: 2000 - .1 percent; 2005 - 5 percent; Lithium-ion: 2005 - 20 percent; TBD: 2005 - 70 percent; Unknown: 2005 - 10 percent

## Selected edited comments

- Breakthrough in next five years could change percentages, but you can't plan for breakthrough.
- For 2000, only lead-acid is really viable. The 2005 electric vehicle battery-of-choice will hinge on yet unknown (and unpredictable) breakthroughs.
- High temp batteries won't make it.
- I have no idea but they must be low-cost long-lived and provide competitive range.
- If they happen, it will be lead-acid: only real existing business in place; almost every alternative has very serious environmental consequences; no battery technology that meets a real competitive business case exists, including lead-acid (cost, performance, mass, "green," etc.).
- It is clear that any near term EV will be lead-acid; too early to pick "winner" of second generation batteries.
- It looks like a wide portion of the people are not in tune with what is going on in batteries and the state of production readiness of some of the alternatives especially lithium-polymer.
- Lead-acid is heavy and will be superseded—no good alternatives yet. Would expect some breakthrough in seven years.
- Lead-acid only choice for 2000-2005; pull the plug!
- Lithium-polymer battery development will be accelerated to meet mandate requirements. Nickel-metal-hydride will be forced into use to meet customer expectations of electric vehicles.
- More important is the fraction of vehicles that are electric and the applications. If it's a low fraction and short range, lead-acid will probably stay the overwhelming choice because the driving force for introduction of a new system in volume production will be lacking.
- Nickel-iron: 2000 - 10 percent; 2005 - 15 percent The wild fluctuations in the price of cadmium and its horrible environmental reputation will prevent its widespread use.
- No proven alternative to lead acid yet and question forcing function to develop alternative source in today's climate.
- Requires a breakthrough. The use of hybrids will slow incentive to replace lead-acid.
- There may be a new source by 2005.

- Unless a significant breakthrough is achieved, the lead acid battery will dominate and, as such, will restrict electrical vehicle growth. Secondly, someone will value the cost and pollution to generate electricity (coal and nuclear power) versus gasoline engines. It is shifting pollution from one place to another.
- Which is best depends on the application but the dominant application is likely to drive the choice. Still uncertain which will prove the selected one, but one will emerge as "selected" and then steadily be improved so its position will be solidified as was the case for the gasoline engine in 1900-2000.

## Discussion

Panelists forecast that lead-acid batteries will be used on 80 percent of electric vehicles in 2000 and 60 percent in 2005. Nickel-hydride batteries are forecast to be used in 20 percent of vehicles in 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII. Results of the current survey are compared to those of 1994 Delphi VII in the following table.

| Forecast for year → | 1998 | 2000 | 2003 | 2005 |
|---|---|---|---|---|
| Survey → | Delphi VII 1994 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Type of Batteries** | | | | |
| Lead-acid | 80% | 80% | 50% | 60% |
| Lithium-polymer | 0 | 0 | 5 | 10 |
| Nickel-cadmium | 5 | 6 | 5 | 10 |
| Nickel-hydride | 0 | 8 | 10 | 20 |
| Sodium-sulfur | 1 | — | 10 | — |

The two surveys are in close agreement, although the current survey forecasts a somewhat higher penetration of nickel-hydride batteries for 2005.

## Strategic considerations

In the near term, the lead-acid battery appears to be the only candidate for electric vehicles. In spite of the shortcomings of this battery, including low energy and power density and long recharge time, it is the best developed candidate. An electric vehicle with lead acid batteries will have limited range, cost greater than that of a gasoline engine powered vehicle, long recharge time, and a battery life of only a few years. Such a vehicle will not be saleable without subsidies. These subsidies may be derived from the total vehicle fleet. This will raise the cost of the total fleet, further exacerbating the increasing affordability problem. Total vehicle sales may fall as a result.

Of course new technology could change things (e.g. recent progress with the nickel metal hydride battery could change the forecast significantly). However, even if breakthroughs occur in battery technology, the energy and power density available with petroleum-based fuels are probably not approachable.

In the longer term, panelists forecast that other alternatives such as the nickel-hydride battery will emerge. The large amount of activity currently in the area of battery development may provide a breakthrough that will change the outlook for electric vehicles.

The environmental issue of disposal of large numbers of batteries must also be addressed.

**TECH-36 Research consortia provide effective, efficient means to accomplish specific research goals. In 1994, consortia existed to further knowledge in electric batteries, composite materials, recycling and others. In the future, in what other areas does it make sense to consider joint automotive research activity?**

| Issues | Number of Responses |
|---|---|
| Safety—crash standards, restraints, injury reduction, etc | 11 |
| Intelligent vehicle highway systems (messages, guidance, etc) | 9 |
| Emissions | 8 |
| Materials—high strength, light weight, low cost (one grade?), low risk | 8 |
| Fuel cells | 5 |
| Recycling & remanufacturing, commonizing plastic parts materials | 5 |
| Tires—low rolling resistance, handling & ride technology | 5 |
| Driver behavior | 4 |
| Manufacturing processes (modular assembly, etc.) | 4 |
| Power plant technology | 4 |
| Two stroke engines—development, emissions, etc | 4 |
| Alternative fuels—improving efficiency, safety, etc | 3 |
| Fuel economy | 3 |
| Noise reduction | 3 |
| Reliability, quality, durability methodology, measures and projections | 3 |
| Air conditioning refrigerant, new concepts | 2 |
| Batteries—advanced propulsion | 2 |
| Composite material—frames, engine components | 2 |
| Crash avoidance—sensors, etc. | 2 |
| Data communication protocol—efficient via compatible architecture | 2 |
| Environmentally friendly manufacturing (casting, paint, machining) | 2 |
| Hybrid electric vehicles | 2 |
| Transmissions | 2 |
| Weight reduction | 2 |
| "Green" activities beyond recycling | 1 |
| Aerodynamics | 1 |
| All areas where customer demands are for function and they don't care who makes it | 1 |
| Brakes | 1 |
| CAD/CAE/CAM data exchange | 1 |
| Ceramic casting dies | 1 |
| Ceramic engine components | 1 |
| Connector technology | 1 |
| Corrosion protection | 1 |
| Crash safety with alternative fuels and batteries. | 1 |

| | |
|---|---|
| Diesel engine combustion/emission technology. High pressure & direct injection | 1 |
| Distribution networks—process to get vehicles sent anywhere in the world | 1 |
| Electric motors | 1 |
| Electrical signal transmission technology | 1 |
| Electronic modal control | 1 |
| End use customer wants and needs | 1 |
| Energy storage devices | 1 |
| Evaporative control systems | 1 |
| Friction | 1 |
| Fuels development, distribution, infrastructure standards and technologies | 1 |
| High-cost equipment technologies | 1 |
| Highway design and construction | 1 |
| Integrated vehicle structure | 1 |
| Lubrication | 1 |
| Manufacturing locations (commonize or distribute over work force, materials availability, markets) | 1 |
| Modeling techniques | 1 |
| Non-proprietary technology issues | 1 |
| Paint—environmentally friendly | 1 |
| Pre-competitive technology—reciprocating engine, etc | 1 |
| Professional development of engineers | 1 |
| Propane/hydrogen containers—safety, weight | 1 |
| Purchasing | 1 |
| Revise emissions deterioration procedure—let manufacturers select to achieve in-use compliance | 1 |
| Structural adhesives | 1 |
| Structures | 1 |
| Suspensions | 1 |
| Theft protection | 1 |
| Vehicle assembly | 1 |
| Waste disposal | 1 |

## Selected edited comments

- I don't think generally that consortia are effective.
- There is a role for SAE TECH Standards cooperation in this.
- USCAR now has 14 consortia. They cover most powertrain issues.
- I don't agree with the premise. So far the effectiveness of consortia is minimal.

## Manufacturer/supplier comparison

Manufacturer/supplier comparisons are not made for open-ended questions.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Discussion/Strategic considerations

The greatest number of responses for areas in which research consortia would be beneficial are safety, intelligent vehicle highway systems, emissions and materials. Numerous other areas are noted. Consortia in areas of interest to all manufacturers and many suppliers can provide cost savings to all involved. Although some panelists question the effectiveness/efficiency of consortia, others have noted a positive benefit.

The new wave of partnering is in its early stages and certainly not all will be effective. But increasingly we are learning how to partner—no easy task for an industry and culture that has thrived with a "Lone Ranger" mentality.

It should be noted that consortia can only be used by law for precompetitive areas.

**TECH-37. As quality, reliability and durability continue to improve, what new technologies will be used, or current techniques enhanced, to measure and validate the level of product quality, reliability and durability?**

| Issues | Number of Responses |
|---|---|
| Better, on-line databases of customer "real world" experiences | 6 |
| Real-time on-line process control | 6 |
| Modeling—greater accuracy, solid | 5 |
| Onboard diagnostic systems—improved, greater use | 5 |
| Artificial intelligence, fuzzy logic, neural systems, "alias" type software | 4 |
| Customer/dealer feedback to engineering—wants and problems | 4 |
| Laser scanning for dimensions | 4 |
| Design of experiments—greater use | 3 |
| Vision systems to oversee build | 3 |
| Build it right the first time | 2 |
| CSI information, J.D. Powers, etc | 2 |
| Design for manufacturing/assembly—greater use | 2 |
| Focus group trials | 2 |
| QSR-9000 with external certified auditing to industry-wide standards | 2 |
| Quantifying customer wants, market analysis | 2 |
| Robots—more for assembly/quality checks | 2 |
| Automated inspection, data management—greater use | 1 |
| Accelerated durability—overload conditions | 1 |
| Automated checking/prompting in design and manufacturing | 1 |
| CAE | 1 |
| Complete vehicle electrical function check | 1 |
| Complex mechanical components and subsystems—scrapped, not fixed | 1 |
| Computer simulated durability tests | 1 |
| Correlated testing | 1 |
| Cross-functional training of development team—more | 1 |
| Database logging of design details to date | 1 |
| Dealership training improved | 1 |
| Design/assembly techniques—new ( Ex: one piece body side ) | 1 |
| Discipline and more effective use of what we have today | 1 |
| Durability testing enhanced—computer and real world | 1 |
| Engine-hour measure—miles or hours without service | 1 |
| Environmental test chambers | 1 |
| Environmentally safe fluids | 1 |
| Fleet/rental vehicles—better tracking | 1 |
| Focus on no malfunction for 10 years or 150,000 miles | 1 |

| | |
|---|---|
| Integrated computer design engineering and manufacturing with statistical based validation and simulation for quality, reliability and durability | 1 |
| Life cycle cost | 1 |
| Life cycle testing correlated to customer experience | 1 |
| Measure: high mileage function and high mileage durability—establish criteria to measure high mileage test results | 1 |
| Microprocessing, miniaturization | 1 |
| Pre-control of manufacturing variables | 1 |
| Process—mistake proofing | 1 |
| Process controls of manufacturing system related to product design/warranty impact | 1 |
| Rapid prototyping | 1 |
| Reduced service intervals ( sealed hood for 100,000 miles ) | 1 |
| Remote sensing of vehicle and plant emissions | 1 |
| Robust design tools | 1 |
| Squeak and rattle devices | 1 |
| Things gone wrong percentage | 1 |
| Time until scheduled maintenance | 1 |
| Vision systems for build-tied to computer design models | 1 |
| Warranty | 1 |

## Selected edited comments

- Long term reliability (200,000+ miles) is very difficult to prove. Test correlations and life cycle testing are difficult and expensive. Need technology to simplify the task.
- I expect to see the application of Statistical Quality Measurement to durability, serviceability and maintenance/service cost even out to 100,000 miles and 10 years. This involves long-time feedback. It also requires projection of past experience to the service costs of vehicles currently being designed and produced. In time we will see an average or standard service cost number on the window of the car that is like the EPA mpg number.
- Design dimensions can be improved if product consistency is improved. Simultaneously, the only way to improve consistency is to continuously measure the production process and use those data to make the process more consistent.

## Discussion

The list of technologies and ideas is impressive. It is worth noting all of them, including those with a single response. Clearly there are many opportunities and methods to continue improvements in quality, reliability and durability.

## Manufacturer/supplier comparison

Manufacturer/supplier comparisons are not made for open-ended questions.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Strategic considerations

Improving quality, reliability and durability from current levels is difficult and will become more difficult as improvements continue. Panelists have identified numerous areas to enhance product validation. The most frequently mentioned involve greater use of computers in design, manufacturing, customer feedback and service diagnostics. It will be critical to use all available technologies, enhance development of skilled employees and in general improve the culture of QRD.

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**TECH-38. Please forecast the materials content change in percentage for the average North American-produced passenger car for 2000 and 2005, given the indicated CAFE scenarios. Leave blank any materials with which you are unfamiliar. (Use plus and minus, e.g., +5 percent, -3 percent etc.) Please reference all percentage changes to base year.**

| Materials | 1993* | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|---|
| | | 2000 | 2005 | 2005 | 2000 | 2005 | 2005 |
| | | 27.5 mpg | 30 mpg | 35 mpg | 27.5 mpg | 30 mpg | 35 mpg |
| Aluminum | 182.0 | 10% | 15% | 20% | 5/10% | 9/20% | 10/30% |
| Cast iron | 406.0 | -5 | -10 | -15 | -3/-10 | -20/-5 | -30/-8 |
| Copper | 42.0 | -1 | -5 | -5 | -5/0 | -10/0 | -15/0 |
| Glass | 89.0 | 0 | 0 | 0 | -1/1.25 | -3/.5 | -4/0 |
| Magnesium | 5.0 | 5 | 10 | 15 | 2/20 | 4/30 | 7/40 |
| Plastics/composites | 245.5 | 5 | 10 | 15 | 5/10 | 6/15 | 10/25 |
| Powdered metals | 27.0 | 4 | 5 | 5 | 0.5/10 | 2/10 | 3/15 |
| Rubber (including tires) | 134.0 | 0 | 0 | 0 | -1/0 | -5/0 | -5/0 |
| Steel | 1739.0 | -5 | -10 | -15 | -10/-3 | -15/-5 | -23/-8 |
| Zinc (include coatings) | 33.0 | 0 | 0 | 0 | -3/2 | -5/2 | -6/2 |

*** Source:** *Ward's Automotive Yearbook 1994 (Materials Section)*

## Selected edited comments

- "Plastic glazing" will displace traditional glass.
- Copper usage depends on multiplexing. Alcoa is putting major resources behind its continuing push for extended use of aluminum. The all-aluminum van body might be in one or two vehicles about 2005, though such a radical change will probably not come until after that.
- Current recognition of aluminum as a lightweight material will result in increased use over the near term. However, cost issues and the optimized use of iron and steel will ultimately regain many of the powertrain, chassis and body panel applications that are "lost" over the next three to five years. In addition to the low cost of ferrous metals, the excellent recyclability of iron relative to aluminum will also favor iron and steel as environmental pressures and fully accounted "cradle-to-grave" material life cycle analyses are considered.
- Powdered metals will be used for manufacturing enhancement rather than CAFE (i.e., near net shape).
- Re: Rubber (including tires)—no spare tires at 35 mpg in 2005.
- Recycling of glass, plastics, and rubber makes no sense economically, so it won't happen.
- Steel—no change in 2000. Aggressive CAFE requirements will ultimately result in less steel and more aluminum/Mg usage. Styling will result in more glass coverage area, and the glass manufacturers will be challenged to provide mass offsets via laminates and improved materials. Multiplexing will allow some copper wiring mass reductions in spite of increasing electrical content.
- We will see higher grades of steel for more structural strength in lighter sections, more composite aluminum/iron engine blocks—other castings. Crash energy management is a big design plus for steel.

## Discussion

Panelists forecast an increase of up to 20 percent in the use of lightweight materials such as aluminum, magnesium and composite materials by 2005. Conversely, the use of cast iron and steel is forecast to decrease by as much as 15 percent in the same time frame. The shift to lightweight materials is highly dependent on future CAFE standards. For example, the use of aluminum is forecast to increase by 20 percent by 2005 at a CAFE standard of 35 mpg, but only 15 percent at a 30 mpg CAFE.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of aluminum in 2005 at a CAFE of 35 mpg. For this scenario a few very high forecasts (6 responses between 100 and 300 percent) greatly affected the mean forecast upon which the test for statistical significance is made. In this case the mean value is 49 percent for manufacturers and 22 percent for suppliers. Both means are above the median forecast of 20 percent.

## Comparison of forecast: MAT-15

The following table includes all materials and years for which the median responses for technology and materials panels do not agree.

| Materials | Passenger Cars | | | | | |
|---|---|---|---|---|---|---|
| | Median Response 2000 | | Median Response 2005 30 mpg | | Median Response 2005 35 mpg | |
| | Tech | Mat | Tech | Mat | Tech | Mat |
| Aluminum | — | — | — | — | 20 | 25 |
| Cast iron | -5 | -10 | -10 | -15 | -15 | -20 |
| Copper | — | — | — | — | -5 | -10 |
| Magnesium | 5 | 50 | 10 | 100 | 15 | 200 |
| Powdered metals | — | — | 5 | 10 | 5 | 13 |
| Steel | -5 | -3 | -10 | -6 | -15 | -10 |

The responses between the two panels were in good agreement on all materials with the exception of magnesium. The materials panel forecast a tripling of the use of magnesium by 2005 as compared to only a 15 percent increase for the technology panel. It should be noted that 13 of the technology panelists forecast an increase in the use of magnesium by 2005 at a CAFE of 35 mpg in excess of 100 percent. It should be further noted that the total magnesium used in a passenger vehicle in 1993 was only five pounds.

## Trend from previous Delphi surveys

This question was asked in a different format in previous surveys. In previous surveys the change was expressed in pounds. In the following table, the results from the 1994 Delphi VII survey have been converted to percentages and compared to the current survey.

| Material | 1993 | Median Response | |
|---|---|---|---|
| | | Delphi VII 2003 35 mpg | Delphi VIII 2005 35 mpg |
| Aluminum | 182 | 57% | 20% |
| Cast iron | 406 | -30 | -15 |
| Copper | 42 | -18 | -5 |
| Glass | 89 | -8 | 0 |
| Magnesium | 5 | 233 | 15 |
| Plastics/composites | 245 | 31 | 15 |
| Powdered metals | 27 | 17 | 5 |
| Rubber | 134 | -5 | 0 |
| Steel | 1739 | -18 | -15 |
| Zinc | 33 | -14 | 0 |

Forecasts for long-term material changes to meet a CAFE standard of 35 mpg are significantly lower in the current survey than in the previous survey. This is most notable for magnesium where current panelists forecast a 15 percent increase versus 233 percent for Delphi VII panelists. On an absolute weight basis the difference is not great since only 5 pounds of magnesium are present on the current car. The difference in forecasts between panelists may be a result of the manner in which the question was asked as opposed to differences in opinion between panelists.

## Strategic considerations

The primary factor influencing material selection in the next decade is the required corporate average fuel economy. Mass reduction is one of the most significant tools available to reduce fuel consumption in the near term. Unfortunately, low-mass materials cost more than the materials that they replace. Since fuel economy standards have not been established for 2005, manufacturers are reluctant to commit to increased cost. Estimates of material usage in 2005 are therefore tied to the expected CAFE. A forecast of future CAFE standards was addressed in TECH-2. The results of that question forecast a CAFE in 2005 of 32 mpg, or about midway between the two scenarios addressed in this question.

Increased vehicle cost caused by greater use of lightweight materials may negatively impact total vehicle sales. Many studies indicate that more and more customers are being priced out of the new car market today.

Recycling is another factor that may influence future material selection. While aluminum and ferrous metals are relatively easy to recycle, plastics and composite materials pose a much more difficult problem, at least at the present time. It would not be surprising to see major strides in the recycling of materials that are difficult to recycle today.

Finally, progress is being made in the reduction of mass with steel and cast iron by improved materials, design and manufacturing process techniques. Lightweight materials are shooting at a moving target.

Additional considerations regarding mass reduction are included in TECH-41.

**TECH-39. Indicate the percentage of North American production for these automotive exterior components that will be steel, plastic or aluminum.**

| Automotive Components | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | 2000 | | | 2000 | | |
| | Steel | Plastic | Aluminum | Steel | Plastic | Aluminum |
| **Outer** | | | | | | |
| Doors | 90% | 5% | 5% | 90/90% | 5/7% | 2/5% |
| Front fenders | 80 | 10 | 5 | 80/88 | 10/15 | 5/8 |
| Hood (exterior) | 80 | 10 | 10 | 80/85 | 7/10 | 5/10 |
| Rear deck | 80 | 10 | 10 | 80/85 | 5/10 | 5/10 |
| Rear quarter panels | 90 | 5 | 5 | 85/95 | 4/10 | 2/5 |
| Roof | 95 | 4 | 3 | 90/95 | 1/5 | 2/5 |
| **Other** | | | | | | |
| Floor pan | 98 | 0 | 2 | 95/100 | 0/1 | 0/3 |

| Automotive Components | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | 2005 | | | 2005 | | |
| | Steel | Plastic | Aluminum | Steel | Plastic | Aluminum |
| **Outer** | | | | | | |
| Doors | 80% | 10% | 10% | 75/85% | 9/15% | 5/10% |
| Front fenders | 75 | 15 | 8 | 70/80 | 10/20 | 5/10 |
| Hood (exterior) | 70 | 15 | 15 | 70/75 | 10/20 | 10/20 |
| Rear deck | 70 | 15 | 12 | 70/75 | 10/20 | 10/20 |
| Rear quarter panels | 80 | 10 | 5 | 75/90 | 5/15 | 5/10 |
| Roof | 90 | 5 | 5 | 80/94 | 3/10 | 3/10 |
| **Other** | | | | | | |
| Floor pan | 90 | 2 | 5 | 90/97 | 0/5 | 2/5 |

## Selected edited comments

- CAFE/guzzler requirements will result in less steel, more aluminum and plastic applications for exterior body panels over time. Specific application decisions will continue to reflect mass tradeoffs against piece cost, tooling cost, quality and other risk factors. Steel will continue to be the most used material for high-volume products.
- Cosmetic surfaces will not likely be aluminum due to low yield strength in trim sections. Use of aluminum is likely to be as hidden structure (space frame) with plastic as cosmetic surface.
- Cost/performance of new lightweight materials and development will be important as well as methods of joining dissimilar types of materials.
- Future CAFE direction will significantly drive the movement toward lower mass alternative materials.
- I do not see aluminum roofs and rear quarters as specific panels—need total aluminum body.
- Moving away from steel is primarily a cost decision. We could be 100 percent aluminum today. Already 100 percent plastic in some cases.

- North American manufacturers will not change within a five-year span. Normalcy must exist before next generation should/can happen and be trusted.
- Note the Alcoa strategic initiative. Note with drivetrain life being significantly extended there will be motivation for longer life body panels, particularly in rust-prone regions.
- Plastic and aluminum will be increased for weight reduction. However, recyclability is a big factor for plastic body parts.
- Since manufacturing costs will be the overriding concern in the automotive industry, the expected increase in aluminum use will be slowed down significantly. Iron and steel are beginning to fight back with numerous very cost-effective solutions.

## Discussion

Plastic and aluminum are forecast to be used increasingly for exterior body components through 2005. However, steel is expected to remain the dominant material for these applications.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

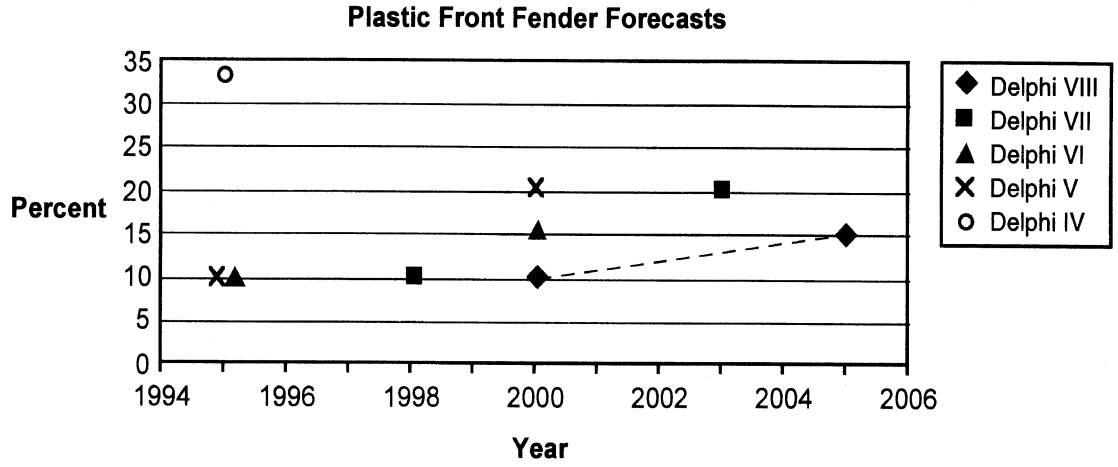
## Trend from previous Delphi surveys

The forecast use of plastic and aluminum in exterior body components in the current survey is compared to previous surveys in the following tables. Aluminum was not addressed prior to the 1992 Delphi VI survey. Floor pans were not addressed in a previous survey.

| ***Plastic* Exterior Outer Body Component Forecasts** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **For year →** | **1995** | | | **1998** | **2000** | | | **2003** | **2005** |
| **Date of Forecast →** | **1987** | **1989** | **1992** | **1994** | **1989** | **1992** | **1996** | **1994** | **1996** |
| | **Delphi IV** | **Delphi V** | **Delphi VI** | **Delphi VII** | **Delphi V** | **Delphi VI** | **Delphi VIII** | **Delphi VII** | **Delphi VIII** |
| **Body Component** | | | | | | | | | |
| Doors | 25% | 5% | 5% | 8% | 10% | 10% | 5% | 15% | 10% |
| Front fenders | 33 | 10 | 10 | 10 | 20 | 15 | 10 | 20 | 15 |
| Hood | 30 | 10 | 10 | 10 | 15 | 15 | 10 | 15 | 15 |
| Rear deck | 40 | 10 | 10 | 10 | 15 | 15 | 10 | 15 | 15 |
| Rear quarter panels | 30 | 5 | 5 | 5 | 10 | 10 | 5 | 14 | 10 |
| Roof | 15 | 5 | 5 | 3 | 5 | 8 | 4 | 5 | 5 |

The forecasts for the current survey are for the same or less plastic exterior body components compared to previous surveys. The 1987 Delphi IV survey forecast significantly higher use of plastic than more recent surveys, and significantly overestimated the amount of plastic actually used in 1995.

The forecasts for front fenders are shown in the following graph as an example of a typical plastic component forecast.




The expected use of plastic for front fenders has decreased for each of the last five surveys. A use rate of 33 percent was forecast for 1995 in the 1987 Delphi IV survey.

| *Aluminum* Exterior Outer Body Component Forecasts | | | | | | |
|---|---|---|---|---|---|---|
| For year→ | 1995 | 1998 | 2000 | | 2003 | 2005 |
| Date of Forecast→ | 1992 | 1994 | 1992 | 1996 | 1994 | 1996 |
| | Delphi VI | Delphi VII | Delphi VI | Delphi VIII | Delphi VII | Delphi VIII |
| **Body Component** | | | | | | |
| Doors | 1% | 5% | 5% | 5% | 10% | 10% |
| Front fenders | 1 | 5 | 5 | 5 | 10 | 8 |
| Hood | 2 | 10 | 7 | 10 | 15 | 15 |
| Rear deck | 2 | 5 | 5 | 10 | 15 | 12 |
| Rear quarter panels | 1 | 5 | 5 | 5 | 7 | 5 |
| Roof | 1 | 2 | 2 | 3 | 5 | 5 |

The current forecast is in general agreement with previous forecasts for the use of aluminum for exterior outer body components. Forecasts of the current survey are somewhat below those of previous surveys for the 2005 time frame for front fenders, rear deck and rear quarter panels.

## Strategic considerations

The use of plastic and aluminum for exterior body components is forecast to increase. However, forecasts for the current survey are below those of previous surveys. Cost of these alternate materials, manufacturing concerns and improvements with steel are the likely reasons for the lower forecast usage. Without definite fuel economy regulations for the future, manufacturers are reluctant to commit to higher cost materials to reduce vehicle weight.

The GM APV has plastic outer panels. These will be replaced with steel to reduce vehicle cost in the next generation van. The benefits of corrosion resistance and resistance to denting were not worth the added cost according to surveys of customers. As vehicle costs increase due to mandated emissions and safety requirements, customers are looking increasingly at the value of optional alternatives on the vehicle. On the other hand, Saturn has found strong acceptance from customers for plastic fenders and doors. Consequently, they are likely to remain plastic for the foreseeable future.

Recycling is an issue for plastics that may be influencing the forecast for the future.

Aluminum body panels offer significant challenge for manufacturing and vehicle repair. In addition to high cost, aluminum may have the disadvantage of less resistance to dents.

With the high level of activity on materials technology and the development of creative approaches to both body design and manufacturing, one must be prepared for surprises in this area. Some very interesting projects are under way around the world.

**TECH-40. What percentage of gasoline-fueled North American-produced passenger cars and light trucks will have gas tanks made from steel or plastic in the indicated years?**

| Gas Tank Materials | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| **Passenger Cars** | | | | |
| Steel | 70% | 50% | 60/70% | 40/60% |
| Plastic | 30 | 50 | 30/40 | 40/60 |
| **Light Trucks** | | | | |
| Steel | 80 | 60 | 70/80 | 50/70 |
| Plastic | 20 | 40 | 20/30 | 30/50 |

## Selected edited comments

- Due to vapor permeation regulation, the industry will be converting from plastic.
- Enhanced evaporation requirements killed plastic tanks—three-day test can't tolerate any leaks. Unaware of suitable plastic technology. Plastic tanks can be formed to irregular voids unlike steel.
- I've heard of some problems with plastic tanks but assume they can be resolved economically.
- No big driver for change.
- Packaging and mass advantages, combined with a proven track record, will establish plastic as the material of choice for new vehicle designs—assuming evaporation emissions/permeation "fixes" work out.
- Packaging density will result in the selection of plastic tanks as vehicles are redesigned, assuming the vapor permeation concern is resolved.
- Trucks will lag behind passenger cars. Foil-lined bags in plastic tanks could be used for evaporation regulations.
- Vapor permeation still a problem.
- Weight saved using plastic is a myth (burn test laws require extra thickness (weight) to meet)—only advantage is shape (more gallons).

## Discussion

The use of plastic in gas tanks for both passenger cars and light trucks is forecast to increase significantly by 2005 to represent about half of all gas tanks in that time frame, but clearly there are questions over vapor permeability with plastic.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not previously asked for light trucks. The results of the current survey are compared to those of previous surveys in the following table.

| Passanger Car Gas Tank Material Forecasts | | | | | | |
|---|---|---|---|---|---|---|
| For year→ | 1995 | 1998 | 2000 | | 2003 | 2005 |
| Date of Forecast→ | 1992 Delphi VI | 1994 Delphi VII | 1992 Delphi VI | 1996 Delphi VIII | 1994 Delphi VII | 1996 Delphi VIII |
| **Gas Tank Material** | | | | | | |
| Steel | 80% | 80% | 65% | 70% | 60% | 50% |
| Plastic | 20 | 20 | 33 | 30 | 40 | 50 |

The results of the current survey are in agreement with those of previous surveys.

## Strategic considerations

Weight reduction and ability to form into complex shapes are the incentives to the use of plastic in gas tanks. Fuel permeation is a concern for evaporative emissions but may be controllable by the use of coatings. Recycling of plastics and cost are additional considerations in the selection of gas tank material.

Panelists forecast that the use of plastics will increase when the above factors are considered.

**TECH-41. What percentage change in total vehicle weight do you anticipate by 2000 and 2005? Please indicate plus or minus.**

| Vehicle Type | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Passenger car | -5% | -10% | -10/-2% | -15/-5% |
| Light truck | -5 | -8 | -5/0 | -12/-3 |

## Selected edited comments

- Accelerated reductions in base vehicle weight will be largely offset by added features and content.
- Interesting equation as the CAFE/performance pressure to reduce mass encounters increased emission/safety requirements, increasing customer content demands and affordability constraints.
- This will occur mainly through better design and material changes in 2000, downsizing in 2005.
- Weight reduction needs to occur through design optimization and attention to detail—flange length, radius, reduced "flanges", etc.—not by buying exotic materials.

## Discussion

Panelists forecast reductions in vehicle weight of 10 percent and 8 percent for passenger cars and light trucks, respectively, by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers with the exception of light trucks in 2000. For this case, mean forecasts for manufacturers and suppliers are -1.6 percent and -4.8 percent respectively.

## Trend from previous Delphi surveys

In previous surveys, panelists were asked to forecast the percentage change in vehicle weight without regard to passenger cars or trucks. A comparison of the current survey and the past two surveys is shown in the following chart.

| Median Forecast Change in Vehicle Weight | | | | | | |
|---|---|---|---|---|---|---|
| | Base Year | 1995 27.5 mpg | 1998 | 2000 | 2003 | 2005 |
| 1996 Delphi VIII * | 1995 | — | — | -5 | — | -10 |
| 1994 Delphi VII | 1993 | — | -3 | — | -8 | — |
| 1992 Delphi VI | 1990 | -4.6 | — | -11.4 (35 mpg) | — | — |

* Passenger car specific

Panelists in the current survey forecast slightly larger decreases in vehicle weight five and 10 years after the base year than did panelists in the 1994 Delphi VII survey. They are in good agreement with panelists in the 1992 Delphi VI forecast for five- and 10-year forecasts. It must be noted, however, that the baseline weight changed less than 1 percent from 1990 to 1993. It appears that the expected weight reduction of 5 percent and 10 percent is always five and 10 years away. This is likely the result of forecast CAFE increases that have been in the future for at least the last five years but to date have not materialized.

## Strategic considerations

For a midsized passenger car, reducing vehicle weight by one EPA test weight class, or 125 pounds, results in an EPA combined fuel economy savings of approximately 0.5 mpg. If CAFE standards increase, as is forecast in TECH-2, weight reduction will be one of the more significant tools that manufacturers can use to increase fuel economy. For a vehicle that is already in production, replacing components with lighter weight components results in the fuel economy savings stated above.

If a new vehicle is being designed, the fuel economy improvement for using lightweight materials may be significantly greater than stated above. This is because weight savings can cascade into numerous other parts of the vehicle. For example, if the decision is made in the design of a new vehicle to use an engine with an aluminum cylinder block rather than a cast iron cylinder block, it is likely that many other components can be made lighter. These may include the engine cradle, front suspension, brakes, tires and possibly integral frame sections. As these additional components are made lighter, the fuel economy of the vehicle increases, thus possibly allowing a smaller fuel tank which saves additional weight. A total analysis of the vehicle is thus required to determine the total weight savings obtained by substituting a lightweight material for a heavier material. Only after this total analysis is made can the actual cost per pound of weight savings be determined.

As stated in the previous question, however, manufacturers are hesitant to commit to higher cost materials when the fuel economy standards for the future have not been established. Vehicle cost is an ever increasing problem for manufacturers.

History tells us that most developments that add measurably to vehicle cost don't happen as quickly as expected. This is certainly in part due to accelerated improvements in the present technology because of the competitive threat and our tendency to be overly optimistic on the application of new technologies.

**TECH-42. Assuming CAFE requirements at 27.5 mpg in 2000 and 30 or 35 mpg in 2005, what is the value today, in current dollars, per pound of weight saved to a vehicle manufacturer? What will it be in 2000 and 2005? Please do not adjust for inflation.**

| Median Response | | | |
|---|---|---|---|
| **1995 Current Value CAFE = 27.5 mpg** | **2000 CAFE = 27.5 mpg** | **2005 CAFE = 30 mpg** | **2005 CAFE = 35 mpg** |
| $1.00 | $1.00 | $2.00 | $3.00 |
| **Interquartile Range** | | | |
| **1995 Current Value CAFE = 27.5 mpg** | **2000 CAFE = 27.5 mpg** | **2005 CAFE = 30 mpg** | **2005 CAFE = 35 mpg** |
| $1.00/$1.00 | $1.00/$1.50 | $2.00/$2.18 | $2.50/$4.00 |

## Selected edited comments

- A great deal of the "willingness to pay" is predicated on whether the vehicle can stay in its EPA class without weight reduction!
- Added cost must add other benefits, not just weight savings (performance, part consolidation, manufacturing, etc.).
- Each company may be in a different situation if 30 or 35 mpg is required.
- In addition to weight reduction for fuel economy and performance reasons, ease of use for the customer will be an added incentive for the future (i.e., hood easier to open, spare tire easier to handle, etc.).
- It has no value unless it keeps the vehicle in its current test weight class (offsets other increases) or drops it to a lower class.
- OEMs will not share the increased costs of the lighter weight components with their Tier One suppliers.
- Paying for weight is not the answer unless up against a gas guzzler tax. We must hold cost—need optimization to save weight.
- Regulatory discontinuities tied to the different EPA test weight classes distort the behavior of the car manufacturers. Logically, there should be a certain "willingness-to-pay" for weight reductions given that weight reductions translate into some non-negligible fuel savings for the car owner.
- The economic customer would not pay $1.00/pound unless fuel went to $2 to $3/gallon. So this is CAFE-driven.
- The above question depends on whether you are buying or selling.
- The real value only functions at the EPA test weight break points. There it is high.
- There is no "average" paying for weight reduction; it depends on getting into a lower weight class.
- This answer significantly depends on the vehicle's CAFE status and corporate status and gas guzzler legislation and/or European vehicle weight tax limits. The $2/lb. number commonly heard rarely applies, e.g., if a vehicle is 10 lbs. from the gas guzzler penalty, we would pay up to the penalty!
- This will be a tradeoff of what the market will tolerate for vehicle cost vs. reduced performance as interpreted by the manufacturer.

- Ultimately the value must balance with lifetime fuel cost savings to the customer and/or CAFE fine avoidance for the vehicle producer.
- Value may be directed at CAFE requirements but as vehicles get lighter there will be greater need for emphasis on vehicle harmonics. Unless we are at a class limit, weight reduction will yield to vehicle harmonics.
- Values become real when you miss a test weight class.
- Varies depending on how close you are to meeting target and how badly you need it to make target.
- Vehicle manufacturers quote $1.00/lb. saved; however, they are really not willing to pay it unless the actual weight saved drops the vehicle a full class.
- We keep quoting the Delphi estimates, but so far no OEM buyers have been willing to give us a PO for any lighter but more expensive items.
- While greatest value exists at the test weight class "default points", there is still generic value in keeping mass down. For some vehicles, the mass tradeoff value might be greater at one end of the vehicle than the other, reflecting factors other than just fuel economy (i.e., brake/axle capacity, mass distribution, etc.)

## Discussion

Panelists forecast that the value per pound of weight saved to a vehicle manufacturer will increase from $1.00 currently to $2.00-$3.00 in 2005, depending on CAFE requirements.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Comparison of forecasts: MAT-13

Median responses from the technology and materials panelists were the same.

## Trend from previous Delphi surveys

The results of the current survey are compared to those of the previous survey, 1994 Delphi VII, in the following table. In surveys prior to 1994, CAFE standards were not stated.

| Value of a Pound of Weight Savings (1995 Dollars) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1993 | 1995 | 1998 | 2000 | 2003 | 2003 | 2005 | 2005 |
| | 27.5 mpg | 27.5 mpg | 27.5 mpg | 27.5 mpg | 30 mpg | 35 mpg | 30 mpg | 35 mpg |
| 1996 Delphi VIII | — | $1.00 | — | $1.00 | — | — | $2.00 | $3.00 |
| 1994 Delphi VII | $2.06 | — | $2.06 | — | $3.09 | $4.12 | — | — |

Panelists forecast in the current survey significantly lower values per pound of weight saved than was forecasted in the previous survey.

## Strategic considerations

The value of a pound of weight saved in a vehicle is forecast to increase significantly as CAFE fuel economy standards increase. A fundamental problem is that manufacturers do not know when CAFE increases will come. It is therefore difficult to justify spending money to meet an objective that is not known. This is particularly true as vehicle affordability is becoming an increasing problem.

Emission and safety requirements continue to add cost to the vehicle as increasing fuel economy requirements loom on the horizon.

In many areas of the vehicle, cost is being added to decrease weight. An example is the increasing use of aluminum in engine cylinder heads and blocks. Most engines are used across several vehicle lines. It is therefore not possible to make a decision regarding weight on the basis of whether a model of a vehicle is near the top of an EPA test weight class. The manufacturers are making this change assuming that it is going to be needed in the future, since such a change is a long lead time item. This same logic is being applied to many components that are used across several vehicle lines.

The value to the manufacturer of increasing vehicle fuel economy was addressed in TECH-6. In that question, panelists responded that one mile per gallon will be worth $120 in 2005 for a CAFE of 30 mpg. Decreasing the weight of a midsized vehicle by one EPA test weight class, or 125 pounds, will increase EPA weighted fuel economy by about 0.5 mpg. A 250-pound reduction will increase fuel economy by 1 mpg. From TECH-6, this would be worth $120 in 2005 at 30mpg CAFE. From the current question, the panelists forecast that manufacturers would pay $2 per pound in 2005 at 30 mpg CAFE, or $500 for the 250-pound weight saving for 1 mpg. There is quite a large discrepancy between responses to the two questions.

The above comparison may point out that what a manufacturer is willing to pay to save weight or fuel economy has not been developed to the point of an exact science. Manufacturers may set guidelines, but each case is taken on its own merit and many other factors enter into the decision. As evidenced by one of the comments to this question, this leads to some frustration by suppliers that come to manufacturers with weight savings proposals.

This is the first time that the question regarding the value of 1 mpg fuel economy increase has been included in a Delphi survey. Perhaps the above discussion will stimulate some discussion within the manufacturers and suppliers organizations on this subject, and hopefully lead to a more analytical approach to decision-making with regard to both the value of mass reduction and fuel economy improvement.

**TECH-43. How likely are federal or state government legislation and regulations to require the recyclability of automotive materials in 2000 and 2005?**

**Scale: 1 = extremely probable 3 = somewhat probable 5 = not at all probable**

| Regulatory Issues | Mean Rating 2000 | Mean Rating 2005 |
|---|---|---|
| Ban on some current automotive materials | 3.1 | 2.3 |
| Establishment of uniform identification/coding standards for materials to facilitate separation | 2.5 | 1.8 |
| Financial penalties/incentives based on recycled content | 3.6 | 2.8 |
| Minimum recycled content | 3.3 | 2.6 |
| Specific regulation for the following | | |
| Disposal of automotive fluids | 2.4 | 1.7 |
| Disposal of used tires | 2.5 | 1.7 |
| Recyclability of plastics/polymers | 2.8 | 2.1 |
| "Take back"' regulations making manufacturers responsible for final product disposition | 3.9 | 3.1 |

**Other:** Recycling automotive fluids and used tires: 2000 - 2; 2005 - 1

## Selected edited comment

- Whether there are regulations will depend to a substantial extent on whether there is establishment and general adherence to voluntary consensus standards and levels. SAE can and should be the vehicle for those.

## Discussion

Panelists forecast that many areas of recycling are at least somewhat probable of having federal or state government legislation and regulations in the next decade. Legislation and regulations in the areas of identification/coding, disposal of automotive fluids, disposal of used tires and recyclability of plastics/polymers are forecast to be highly probable.

## Manufacturer/supplier comparison

There is no statistical difference in responses of manufacturers and suppliers with the exception of the establishment of uniform identification/coding standards for materials to facilitate separation in 2005. For this case, mean ratings from manufacturers and suppliers are 1.6 and 2.0, respectively.

## Comparison of forecast: MAT-7

There is no statistically significant difference in responses between the technology and materials panelists except for the items noted in the following table.

| Regulatory Issues | Mean Response 2000 | |
|---|---|---|
| | Tech. | Mat. |
| Specific regulation for the following: | | |
| Disposal of automotive fluids | 2.3 | 2.8 |
| Recyclability of plastic/polymers | 3.0 | 3.4 |

## Trend from previous Delphi surveys

The results of the current and past two surveys are presented in the following table. Results for the current survey are for 2005, since past surveys asked for probability in the next decade.

| Regulatory Issues | Mean Forecast 1-5* | | |
|---|---|---|---|
| | Delphi VI | Delphi VII | Delphi VIII |
| Establishment of uniform identification/coding standards for materials to facilitate separation | 2.3 | 1.9 | 1.8 |
| Financial penalties/incentives based on recycled content | 3.4 | 3.0 | 2.8 |
| Disposal of automotive fluids | 1.7 | 1.9 | 1.7 |
| Disposal of used tires | 2.2 | 2.0 | 1.7 |
| Recyclability of plastics/polymers | 2.5 | 2.3 | 2.1 |
| "Take back" regulations making manufacturers responsible for final production disposition | 3.5 | 3.2 | 3.1 |

* **Scale:** 1= Extremely probable, 5= Not at all probable

Current panelists forecast in all categories that federal or state government legislation and regulations are as probable or more probable than was forecasted by earlier panelists.

## Strategic considerations

The single edited comment states well the industry responsibility currently with regard to recycling. A proactive role will assure that the most efficient approaches to recycling are utilized in the future. A cooperative approach between government and industry will provide the best overall solution for all involved.

Considerable effort is being expended by industry today to find the best solutions for the future. This is an area where consortia could maximize the benefit for the expenditure made. Industry today is earning the right to participate in future rule making.

It is almost certain that recycling must be considered in the future in determining the life cycle cost of a given material.

**TECH-44. What modifications to used vehicles will be required in the next decade to accommodate non-CFC refrigerants and what will be the approximate cost to the customer for these modifications in today's dollars? Select only the most likely scenario and enter only one cost.**

| Modifications | Median Response | Interquartile Range | Number of responses |
|---|---|---|---|
| | Cost (in today's dollars) | Cost (in today's dollars) | |
| Minor—change refrigerant, some seals and hoses | $100 | 50/200 | 43 |
| Medium—new compressor, evaporator | $400 | 200/675 | 25 |
| High level—replace most system components | $1000 | 425/1150 | 16 |

## Selected edited comments

- At high level of modification, vehicle would be scrapped or driven without air conditioning because cost would exceed vehicle value.
- I don't think anyone will modify.
- Minor modifications—45 percent; Medium modifications: 55 percent; High level modifications: 5 percent of cars on road.
- Modification requirements will vary (by system) as future non-CFC refrigerant compatibility was not factored into the design of many older air conditioning systems. May be partially subsidized?
- None required.
- The most likely scenario is always the cheapest.

## Discussion

The majority of panelists (51 percent) forecast that minor changes would be required to used vehicles to accommodate non-CFC refrigerants. The median forecast for these modifications is $100. Some panelists (19 percent) forecast that high levels of modification would be required with a median cost of $1,000.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was asked as an open-ended question in the last survey, 1994 Delphi VII. The responses from that survey are summarized in the following table.

| Responses | Percent of Responses |
|---|---|
| Minor modifications required | 15 |
| Medium level of modification required | 15 |
| High level of modification required | 11 |

As in the current survey, the greatest percent of respondents forecast that a minor or medium level of modification would be required.

## Strategic considerations

There is no consensus between panelists as to the modification required to repair the air conditioning system on older vehicles when CFC refrigerants are no longer available. The majority forecast that the repair cost will be in the range of $100. Many, however, (19 percent) forecast that repair may cost $1,000. One of the panelists commented that the level of modification will depend on the system originally installed on the vehicle and will vary between vehicles.

As the value of the vehicle decreases with age, the customer will be more and more reluctant to spend large sums of money to repair the air conditioning system. The first result if the cost is large will be that customers will not have the air conditioning system repaired when it fails. Finally, it is likely that vehicles will be scrapped at an earlier age because it is not economical to repair the air conditioning system. This applies particularly to southern portions of the United States.

Vehicle durability fleets are currently running with non-CFC refrigerant installed in systems that were designed for CFC refrigerant. In the near future it will become more clear as to the significance of this issue as these vehicles accumulate substantial mileage and failures are evaluated.

The comment related to "the most likely scenario being the cheapest one" is profound and probably accurate. This panelist has been around a while and understands the reality of the market-place.

The politics of this issue are still complicated and will probably remain so for some time.

**TECH-45. What percentage of North American-produced passenger cars will use an integral frame or other designs in 2000 and 2005?**

| Frame Construction | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| **Passenger Cars** | | | | | |
| Integral body/frame or unibody | 91% | 92% | 91% | 90/94% | 88/95% |
| Separate body/frame | 5 | 3 | 2 | 3/5 | 1/4 |
| Space frame | 4 | 4 | 5 | 3/6 | 2/10 |
| Total | 100% | | | | |
| **Sport Utility Vehicle** | | | | | |
| Integral body/frame or unibody | 19% | 25% | 30% | 20/25% | 25/38% |
| Separate body/frame | 81 | 75 | 70 | 73/80 | 55/75 |
| Space frame | 0 | 0 | 0 | 0/0 | 0/5 |
| Total | 100% | | | | |
| **Pickup** | | | | | |
| Integral body/frame or unibody | 0% | 0% | 3% | 0/5% | 0/10% |
| Separate body/frame | 100 | 100 | 96 | 95/100 | 90/100 |
| Space frame | 0 | 0 | 0 | 0/0 | 0/0 |
| Total | 100% | | | | |
| **Minivan** | | | | | |
| Integral body/frame or unibody | 58% | 64% | 70% | 60/70% | 61/76% |
| Separate body/frame | 31 | 25 | 20 | 20/30 | 11/27 |
| Space frame | 11 | 10 | 10 | 9/13 | 5/15 |
| Total | 100% | | | | |

***Source:** *Ward's Automotive Reports*, December 26, 1994

## Selected edited comments

- For passenger cars: Body-on-frame construction will become extinct, and space frame construction will start to emerge as the manufacturing/joining technology develops and costs come down.
- It's assumed that space frame includes a partial one with more plastic panels.

## Discussion

Panelists forecast that integral body/frame or unibody will be used on almost all passenger cars and most minivans through 2005. Separate body/frame is forecast to be used on most pickups and sport utility vehicles.

## Manufacturer/supplier comparison

Results for manufacturers and suppliers are in close agreement.

## Comparison of forecast: MAT-29

There is no statistically significant difference in responses between the technology and materials panelists.

## Trend from previous Delphi surveys

Results of the current survey and the most recent survey, 1994 Delphi VII, are in very close agreement for passenger cars. Other types of vehicles were not addressed in previous surveys.

In the 1987 Delphi IV survey it was forecasted that 7 percent of North American-produced passenger vehicles would be space frame by 1995. Space frames were used on 4 percent of passenger cars in 1994.

## Strategic considerations

The use of space frames in passenger cars will be more enticing in the future to help facilitate styling change. Current design however may have a fuel economy penalty because of higher weight. This could change dramatically with some design concepts under development. The experience with the Saturn will also provide a comfort level with this design for high-volume vehicles.

Advances in design and manufacturing technology will continue to improve the integral body/frame. The primary disadvantage continues to be the high cost for vehicle changes that affect major body panels.

Separate body/frame will continue to be used in pickup trucks and sport utility vehicles which are designed to carry large loads and haul heavy trailers.

**TECH-46. What percentage of North American-produced passenger cars will incorporate the following suspension features currently and in 2000 and 2005?**

| Suspension Features | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current | 2000 | 2005 | Current | 2000 | 2005 |
| **Front Suspension Configuration** | | | | | | |
| MacPherson struts | 75% | 71% | 70% | 75/80% | 70/75% | 65/75% |
| Twin A-arm | 25 | 29 | 30 | 20/25 | 25/30 | 25/35 |
| **Rear Suspension Configuration** | | | | | | |
| Independent | 60 | 65 | 70 | 50/60 | 60/70 | 65/75 |
| Non-independent | 40 | 35 | 30 | 40/50 | 30/40 | 25/35 |
| **Springs** | | | | | | |
| Air | 2 | 4 | 5 | 2/9 | 2/9 | 2/10 |
| Oil/fluid | 1 | 1 | 2 | 0/5 | 0/5 | 0/8 |
| Composites | 2 | 5 | 8 | 3/10 | 3/10 | 4/15 |
| Steel | 94 | 87 | 80 | 85/96 | 80/94 | 71/89 |
| **Self leveling** | 5 | 6 | 9 | 2/10 | 5/7 | 6/10 |

## Front suspension other:

Multilink: Current Est. .2 percent; 2000 - 1 percent; 2005 - 2 percent

Shock/spring separate: Current Est. - 14; 2000 - 11; 2005 - 10

## Springs other:

Electromagnetic: 2005 - 3 percent

Titanium: 2005 - 15 percent

## Selected edited comments

- Assuming vehicle mass will be trending down, and payload (being a customer driven requirement) holds relatively constant, there will be increased usage of leveling to cope with the greater percentage of mass change from curb to GVW.
- I believe other types of front suspension will be used in 2000 and 2005.
- I disagree with the comment that mass requirements will drive more consideration/usage of composite springs and that cost pressures will constrain air spring usage and leveling system market growth. Coil springs is where the industry is going.
- Independent rear suspension (RWD) percentages will not change; moves to FWD may increase IRS rates.
- Mass requirements will drive more consideration/usage of composite springs. Cost pressures will constrain air spring usage and leveling system market growth.
- Twist beam rear axle not considered as independent.

## Discussion

Panelists forecast the following trends in the next decade for suspension features:

**Front suspensions:** MacPherson struts will continue to dominate with some increase in the use of twin A-arms.

**Rear suspensions:** The use of independent suspensions is forecast to increase.

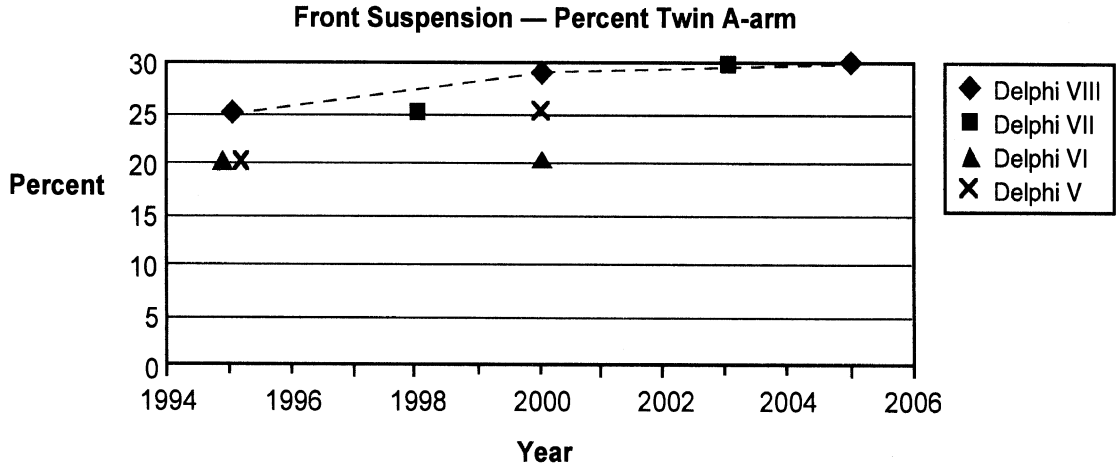
**Springs:** Steel springs will continue to be used on most vehicles, but the use of composites and air springs will increase.

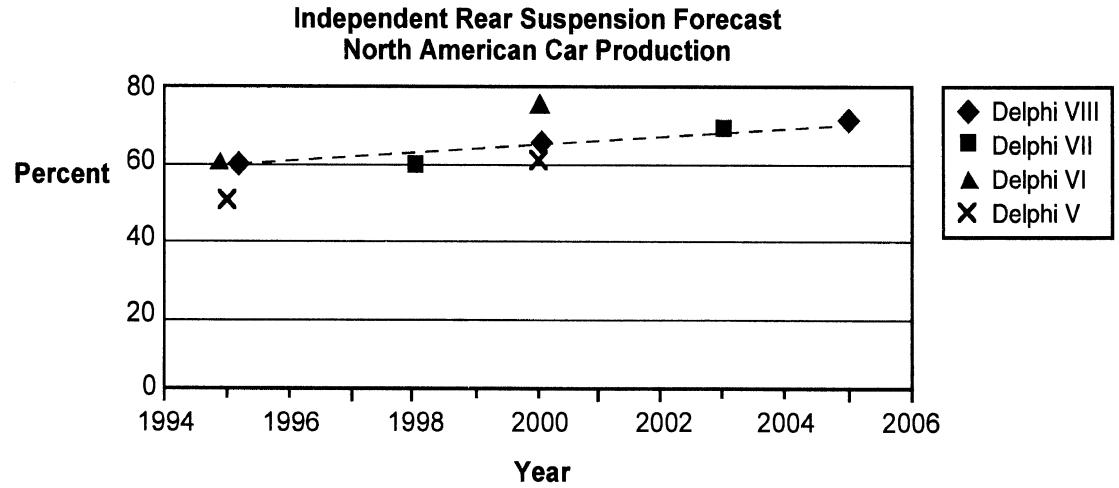
## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Comparisons of the current and previous surveys are shown in the following graphs.




The forecast for twin A-arm front suspensions in the current survey is on the high side of past surveys. The current forecast for independent rear suspensions is in line with past surveys.

## Strategic considerations

Cost pressures will cause manufacturers to look closely at the cost/benefit of all systems of the vehicle. This is particularly true of suspension systems. On vehicles designed primarily to provide basic transportation, the lowest cost system will be selected. This may impact the trend toward twin A-arm front suspensions and independent rear suspensions. One key question today is how customers are doing their cost/value trade-off analysis. Frankly, the way most people use cars and light trucks, the simplest and lowest cost systems have high functionality when well designed. In spite of cost pressures, however, our panelists forecast increases in the use of these design concepts.

Composite springs will be increasingly attractive as manufacturers attempt to reduce vehicle weight to improve fuel economy. Cost will limit overall application, however, as indicated by the relatively low (8 percent) forecast penetration for 2005.

**TECH-47. What percentage of North American-produced passenger cars will have the following chassis/suspension features in 2000 and 2005?**

| Chassis/Suspension Features | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| **Steering** | | | | | |
| Power | | | | | |
| Electrical with electronic control | 0% | 1% | 5% | 0/5% | 1/10% |
| Hydraulic with electronic control | 0.5 | 5 | 10 | 2/10 | 5/20 |
| Traditional hydraulic | 98 | 92 | 81 | 84/96 | 66/91 |
| Non-power | 2 | 2 | 1 | 0.1/2 | 0/2 |
| Total | 100% | | | | |
| **Speed-sensitive power steering** | n/a | 10 | 20 | 5/15 | 9/30 |
| **Active four-wheel steering** | 0 | 0 | 1 | 0/1 | 0/2 |
| **Ride/Handling** | | | | | |
| Passive control (present system) | n/a | 90 | 80 | 85/97 | 70/92 |
| Passive-driver selected | n/a | 5 | 5 | 1/5 | 1/13 |
| Semi-active (damping controls) | n/a | 4 | 8 | 1/5 | 3/10 |
| Active (springs & damping control) | 0 | 1 | 2 | 0/2 | 0.4/5 |

***Source:** *Ward's Automotive Reports*, December 26, 1994

**Other responses:**
Stability augmentation (yaw control).

## Selected edited comments

- 1994 estimate of 0.5 percent for hydraulic steering with electronic control seems to be much higher in '94/'95, assuming you count speed-sensitive systems as "electronic controlled."
- Active suspension is too heavy for CAFE requirements. Trend will be to electrical P/S for weight—but it will come slowly.
- Active suspension will never be cost-effective, but it will be a gimmick with a niche market.
- Fuel economy considerations will drive more use of alternatives to traditional hydraulic power steering. Cost/affordability considerations, and lack of value over a well-designed conventional suspension will decrease usage of smart suspensions in spite of their continued evolution.

## Discussion

Hydraulic power steering is forecast to be used on most passenger cars for the next decade. Electronic control of hydraulic systems is forecast to increase in use (8 percent in 2005). Some application of a fully electric power steering system is expected.

Active four-wheel steering is not forecast to have any significant application rate by 2005 (1 percent).

Passive suspensions are forecast to dominate through 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in response between manufacturers and suppliers with the exception of the items shown in the following chart.

| Chassis/Suspension Features | | | | |
|---|---|---|---|---|
| | Mean Forecast | | | |
| | 2000 | | 2005 | |
| Power Steering | Mfr. | Suppliers | Mfr. | Suppliers |
| Hydraulic with electronic control | — | — | 17% | 11% |
| Traditional hydraulic | 86% | 91% | 71 | 81 |
| Speed-sensitive | 14 | 8 | 31 | 17 |

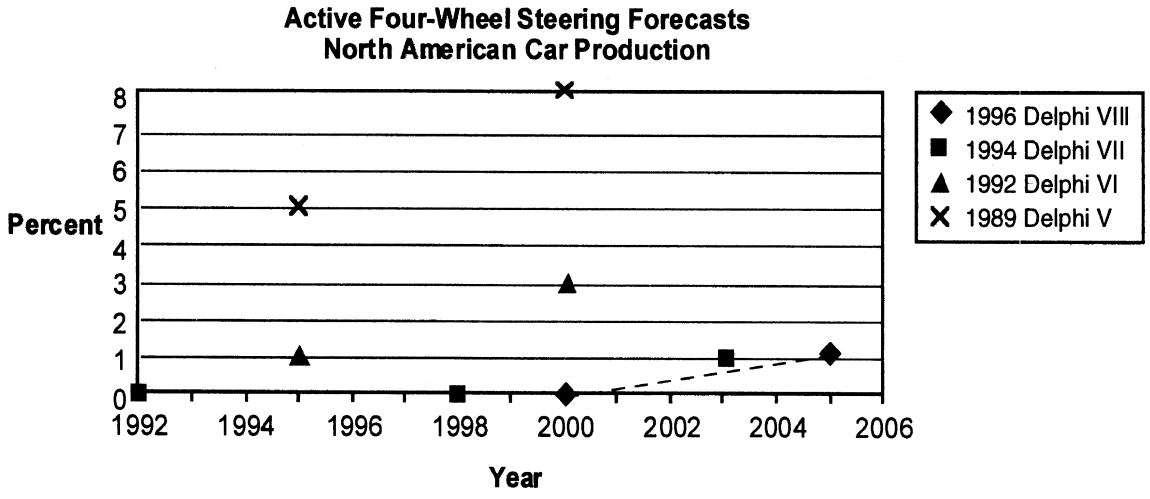
## Trend from previous Delphi surveys

**Electrical/electronic power steering:** Forecasts for 2000 and 2005 in the current survey are identical to the forecasts for 1998 and 2003 in the previous survey, 1994 Delphi VII. This question was asked in a different format prior to 1994 Delphi VII.

**Hydraulic with electronic control power steering:** Forecasts for 2000 and 2005 in the current survey are identical to the forecasts for 1998 and 2003 in the previous survey, 1994 Delphi VII. This question was asked in a different format prior to 1994 Delphi VII.

**Non-power steering:** The previous survey, 1994 Delphi VII, forecast a 2 percent use of non-power steering in 2003 versus 1 percent forecast for 2005 in the current survey.

**Active four-wheel steering:** Results of the current survey are compared to those of previous surveys in the following graph.




Panelists forecast that the interest in active four-wheel steering is diminishing significantly compared to previous forecasts.

**Ride/handling Systems:** The current survey and the 1994 Delphi VII survey are in close agreement. Results of the 1992 Delphi VI survey are shown in the following table.

| 1992 Delphi VI Forecast<br>Percent Penetration of Ride/Handling Systems | | |
|---|---|---|
| **System** | **1995 MY** | **2000 MY** |
| Passive control | 88% | 78% |
| Passive-driver selected | 5 | 10 |
| Semi-active (damping control) | 5 | 8 |
| Active (springs & damping ) | 2 | 4 |

Current panelists forecast lower penetration of passive-driver selected and active suspensions than panelists of the 1992 Delphi VI survey.

## Strategic considerations

Interest in high-cost, high-tech features such as active suspensions and four-wheel steering appears to be diminishing. Such features will likely see application in high-cost niche vehicles in the future, but our panelists do not forecast any significant penetration in the next decade. The trend in forecasts appears to be that the customer is expected to be more cost/value-conscious than previously forecast in past surveys. This again highlights the issue of vehicle affordability and the need to control and contain vehicle cost.

There are some very interesting developments underway in power steering technology that could alter the forecast significantly. As in most areas addressed in this overall Delphi forecast, one must be prepared for surprises.

**TECH-48. Please forecast the total domestic and import U.S. market in percent of the following brake system technologies in 2000 and 2005.**

| Brake Systems | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| **Passenger Car** | | | | | |
| Antilock brake system | 55.8% | 75% | 90% | 70/80% | 80/100% |
| Four-wheel disc brakes | 6.1 | 10 | 20 | 10/18 | 15/30 |
| Traction (anti-spin) control | 7.7 | 15 | 25 | 10/20 | 15/35 |
| **Light Truck** | | | | | |
| Two-wheel antilock brakes | 53.8 | 50 | 30 | 30/60 | 15/70 |
| Four-wheel antilock brakes | 32.1 | 50 | 70 | 40/59 | 50/90 |

*** Source:** Cars: *Ward's Automotive Reports* "Factory Installations", December 26, 1994
Trucks: *Ward's Automotive Reports* "Factory Install Trucks", January 16, 1995

## Selected edited comment

- ABS is compelling for control. Traction control will follow ABS.

## Discussion

Panelists forecast significant increases in the use of antilock brake systems and traction control on passenger cars by 2005. On light trucks, an increase in four-wheel antilock brakes and a decrease in the use of two-wheel antilock brakes is forecast.

## Manufacturer/supplier comparison

Statistically significant differences in responses are noted for the items shown in the following table.

| Passenger Car Brake Systems | | | | |
|---|---|---|---|---|
| System | 2000 | | 2005 | |
| | Mfr. | Supplier | Mfr. | Supplier |
| Antilock brake system | 77% | 73% | — | — |
| Four-wheel disc brakes | 21 | 13 | — | — |
| Traction control | 19 | 14 | 35% | 22% |

Manufacturers forecast a higher penetration for the systems that were statistically different than did suppliers.

## Comparison of forecast: MKT-44

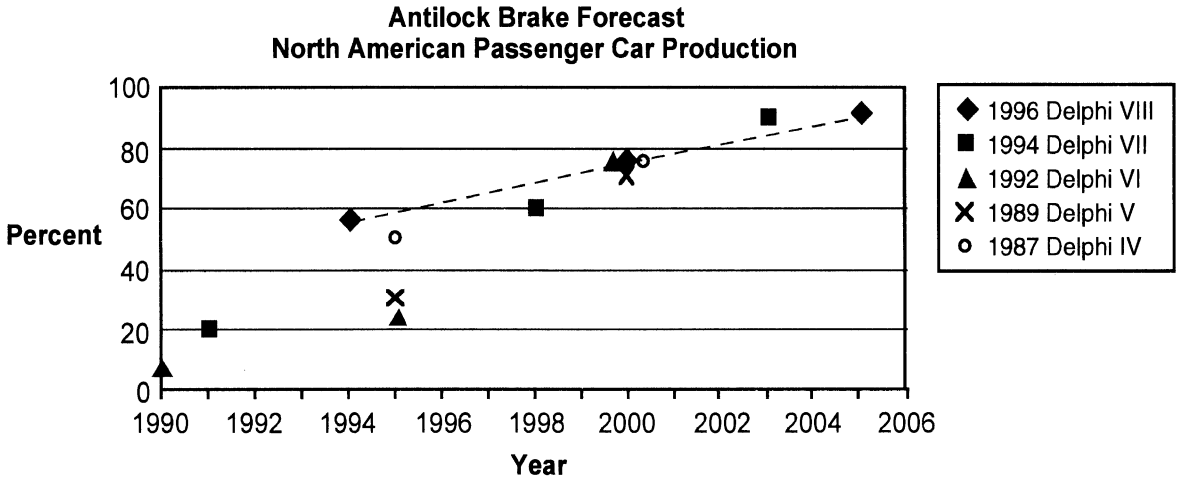
There is no statistically significant difference in responses between the technology and marketing panelists except for the items noted in the following table.

| Brake Systems | Mean Response 2000 | | Mean Response 2005 | |
|---|---|---|---|---|
| | Tech. | Mkt. | Tech. | Mkt. |
| **Passenger Car** | | | | |
| Antilock brake system | — | — | 89.1% | 85.6% |
| Four-wheel disc brakes | 17.1% | 10.6% | 25.6 | 16.0 |
| **Light Truck** | | | | |
| Four-wheel antilock brakes | 48.9 | 43.5 | 67.2 | 54.7 |

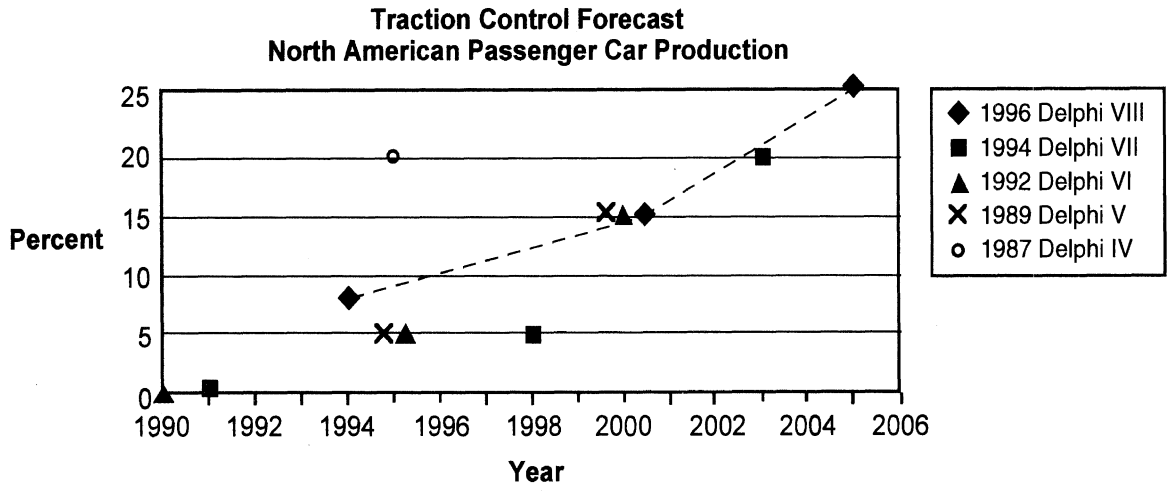
Technology panelists forecast higher penetrations of the brake systems noted.

## Trend from previous Delphi surveys

This question was asked in a different format for light trucks in past surveys. Comparisons to past surveys for passenger car antilock brakes are summarized in the following graph.




The forecasts for antilock brakes in the current survey are in line with those of past surveys. The actual penetration in 1994 is significantly higher, however, than forecasted in the 1989 and 1992 surveys for 1995.




The long-term forecast for traction control in the current survey is in line with past forecasts. The actual 1994 estimate is higher, however, than forecasted in the 1992 or 1994 surveys.

## Strategic considerations

The current use of antilock brakes and traction control exceed that forecasted in earlier surveys. These features are recognized by customers as safety features for which they are willing to pay more money. Antilock brakes are currently installed on many vehicles as standard equipment. In this case the customer is not choosing to pay more for that one feature. Like airbags, however, manufacturers' marketing surveys find that the customer wants these features installed as standard equipment. In spite of the safety reason for the addition of these features, the net result is to increase the cost of the vehicle. The accumulation of many such features over the years has caused a significant increase in vehicle cost.

Some recent studies of accident rates have failed to show the safety benefit of antilock brakes. This is a surprising result, with no well accepted explanation. There can be no question regarding the superior control in braking on icy surfaces with this feature. Stopping distances may be increased in some situations, however.

A basic traction control system can be added for minimal cost once antilock brakes are available. This system includes engine power control during acceleration. The more sophisticated traction control system that includes brake application is significantly more effective and costly. This system will generally be used on luxury or performance vehicles. Traction control is most beneficial on rear-wheel drive vehicles. Since rear-wheel drive is used in a small fraction of passenger cars, there is little incentive to add a sophisticated traction control system to most passenger cars.

Four-wheel disc brakes are used on many performance and luxury passenger cars as well as some family passenger cars. For most driving conditions and most customers, this feature is of little or no benefit. The feature may be more one of image than substance for the bulk of driving in this country. Rear disc brakes are more costly than drum designs, and with the affordability concerns of today, rear disc brakes could be a tough sell on most vehicles.

Perhaps the industry has been overly responsive to the buff magazines that seemingly have little regard for the affordability issue and how most people drive.

**TECH-49. What percentage of North American-produced passenger cars will incorporate the following tire features?**

| Tire Features | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Airless spare | 5% | 7% | 0/10% | 2/20% |
| Failure sensing devices | 5 | 10 | 1/10 | 5/20 |
| Puncture resistant/self-sealing | 10 | 15 | 2/20 | 5/30 |
| Run-flat | 5 | 10 | 2/10 | 5/20 |
| No spare tire for vehicle | 2 | 8 | 0/10 | 2/20 |

## Selected edited comments

- Mass/packaging pressures will encourage manufacturers to selectively opt for no spare (vs. 1-800 service coverage, in combination with physical failure mitigation measures).
- No spare is a marketing/consumer issue of vehicle confidence.
- Spare tires and jacks are important to the female driver. I always request a real jack and have an extra tire for emergencies. I realize that both the jack and tire (actual/useful) are eliminated from the vehicle for weight reduction.

## Discussion

A number of new tire features are forecast to see limited application by 2005, including elimination of the spare tire.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results of the previous three forecasts are compared to the current survey in the following table.

| Tire Features | 1995 | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|
| | Delphi V 1989 | Delphi VI 1992 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| Airless spare | — | — | 0% | — | — | 5% | 1% | 7% |
| Failure sensing | 2% | 1% | 2 | 8% | 5% | 5 | 10 | 10 |
| Puncture resistant/ self sealing | — | 5 | 5 | — | 10 | 10 | 15 | 15 |
| Run-flat | 5 | 1 | 2 | 10 | 5 | 5 | 10 | 10 |
| No spare tire | 5 | 0 | 0 | 10 | 3 | 2 | 2 | 8 |

Results of the current survey are in line with past surveys for failure sensing, puncture resistant/self-sealing and run-flat. The current survey forecasts generally higher penetration of airless spare and no spare.

## Strategic considerations

An increase in legislated fuel economy requirements will increase the interest in eliminating the spare tire for weight savings. Side benefits of the elimination of the spare tire would be increased luggage space and reduced cost. The breakthrough required for this to happen, however, is the virtual elimination of flat tires or the ability to drive on a flat tire. Both of these technologies are forecast to have some application by 2005. The customer will be very reluctant to give up the spare tire until he/she has had considerable experience with these technologies to prove their capability.

Removing the spare tire and providing 1-800 service will be of little comfort to the customer who drives on rural roads far from service.

New technology could significantly alter the forecast considering the compelling advantages of eliminating spare tires: weight, packaging and cost.

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**TECH-50. What percentage of North American-produced passenger cars and light trucks will incorporate driver, front passenger and rear seat airbags in 2000 and 2005?**

| Airbag Applications | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| **Passenger Cars** | | | | | |
| Rear seat occupants | 0% | 2% | 6% | 0/5% | 3/20% |
| Side airbags | 0 | 5 | 20 | 2/15 | 10/40 |
| **Light trucks** | | | | | |
| Passenger side | 9.1% | 50% | 90% | 40/70% | 80/100% |
| Rear seat occupants | 0 | 0 | 3 | 0/0 | 0/6 |
| Side airbags | 0 | 2 | 10 | 0/5 | 5/15 |

* **Source:** Various OSAT estimates

## Selected edited comments

- Airbag "customer sensing," occupant in the seat? —occupant size? —baby seat installed?
- Consumer safety expectations will increase usage faster.
- Customer expectations will be more significant than real safety requirement for side impact bags.
- I don't think truck owners are as safety-conscious as car owners. Volvo marketing really plays up their tanklike properties.
- I see passenger side bags being required by both government and competition.
- In recent months there has been a significant move in passenger cars toward side impact airbags.
- Per FMVSS 208 all light trucks sold in the United States must have passenger airbags after model year 1999.
- Unless mandated by the government, side airbags won't be seen outside of Volvos and not in trucks of any types.
- Vans, APVs and sport utility vehicles will get rear seat bags. Will not be offered in pickups even with extended cabs.
- Volvo's bold move to use side airbags has acted as a catalyst for others to follow.
- With much light truck usage as a passenger car alternative, similar market pressures/safety concerns will drive passenger side airbag incorporation.

## Discussion

Panelists forecast some application of side airbags and airbags for rear seat occupants in passenger cars and side airbags and airbags for rear seat occupants in light trucks by 2005. They also forecast that most light trucks will have passenger side airbags in that same time frame.

## Manufacturer/supplier comparison

There is no statistical difference in responses between manufacturers and suppliers except for the items for light trucks shown in the following table.

| Light Truck Airbag Applications | Mean Response | | | |
|---|---|---|---|---|
| | 2000 | | 2005 | |
| | Mfr. | Supplier | Mfr. | Supplier |
| Passenger side | 62% | 51% | 92% | 82% |
| Side airbags | — | — | 14 | 9 |

Manufacturers forecast higher penetration of passenger side and side airbags than suppliers forecast.

## Trend from previous Delphi surveys

| Airbag Applications | 1994 | 1995 | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|
| | Delphi VIII 1996 | Delphi V 1989 | Delphi VI 1992 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Passenger Cars** | | | | | | | | | |
| Rear seat occupants | 0% | 0% | 0% | 2% | 2% | 3% | 2% | 10% | 6% |
| Side airbags | 0 | — | 1 | 1 | — | 10 | 5 | 5 | 20 |
| **Light trucks** | | | | | | | | | |
| Passenger side | 9.1 | — | — | 20 | — | — | 50 | 50 | 90 |
| Rear seat occupants | 0 | — | — | 0 | — | — | 0 | 0 | 3 |
| Side airbags | 0 | — | — | 0 | — | — | 2 | 0 | 10 |

The current survey forecasts significantly higher penetration of side airbags than previous surveys. Certainly this forecast has been impacted by the recent introduction of side airbags on the Volvo. Other airbag application rates are in general agreement with past surveys.

## Strategic considerations

Customers equate airbags with safe vehicles and are expected to demand them in future vehicles. Front seat driver and passenger airbags for passenger cars and front seat driver side airbags on light trucks were not included in this question because of the near term anticipated 100 percent application rate. Panelists forecast a significant penetration of side airbags in passenger cars by 2005, and some application in light trucks. Proliferation of airbags in the next decade will continue to increase the pressure on vehicle cost containment as the money spent on these features competes with other features.

Increased airbag application also will add weight to the vehicle which runs counter to the desire to reduce weight for fuel economy.

Some field studies suggest an actual increase in injuries in low-speed collisions with airbags. This is a result of abrasions and lacerations from the airbag deployment. Vehicle repair costs increase also on vehicles with deployed airbags. It is still true that the best protection in low-speed

collisions is a belted occupant without an airbag. In high speed collisions, however, the safest combination is a belted occupant with an airbag.

Other specific situations have raised concern relative to the safety of airbags. These include rear facing restrained children, and passengers in near proximity to the dashboard. Design modifications are under consideration to remedy these situations.

Recycling of vehicles with airbags will become an increasing problem as the airbag must be deactivated or removed prior to vehicle recycling.

In spite of the above concerns, panelists forecast that the trend is toward more airbags. Important progress is being made in airbag cost reduction which is certainly a factor in the growing optimism for this technology.

**TECH-51. What percentage of vehicles produced in North America will have the following Intelligent Transportation Systems America (formerly known as IVHS) by 2005?**

| ITS Systems | Median Response 2005 | Interquartile Range 2005 |
|---|---|---|
| Adaptive cruise control | 10% | 5/24% |
| Collision warning systems | 5 | 3/20 |
| Automatic toll collection | 6 | 2/20 |
| Navigation | 10 | 5/20 |
| In-vehicle message system | 10 | 5/20 |

**Other responses:**
Blind spot detection: 5 percent: Emergency services communication: 20 percent; On-board interactive PC: 20 percent

## Selected edited comments

- Automatic toll collection will result from legislative mandate.
- Collision warning systems are already on some thousands of vehicles–depends on complementary widespread installation of infrastructure. Automatic toll collection can be retrofit rather than OEM-installed, and that's likely to be the case.
- Fear of litigation will slow collision avoidance technology introduction. Affordability (for cars) and infrastructure costs vs. other budget priorities will slow IVHS.
- More and more vehicle owners spend a great deal of time commuting. In-vehicle message systems coupled with telecommunications would be the next generation for drivers in urban areas. It would essentially allow work to be done during commutes.
- These technologies will catch on fast when introduced. Note acceptance of cellular phones. Customers accept the high level of reliability of electronic systems especially when they are self-diagnostic and have default-limited capability.

## Discussion

Panelists forecast that several Intelligent Transportation Systems will have limited application (5-10 percent) by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the present format in the 1994 Delphi VII survey. A comparison of the 1994 Delphi VII survey and the current survey is shown in the following table.

| ITS Systems | 1994 Delphi VII for the year 2003 | 1996 Delphi VIII for the year 2005 |
|---|---|---|
| Adaptive cruise control | 5% | 10% |
| Collision warning systems | — | 5 |
| Automatic toll collection | 5 | 6 |
| Navigation | 5 | 10 |
| In-vehicle message system | 10 | 10 |

Considering the wide quartile range for each of the systems, the two surveys are in general agreement.

## Comparison of forecast: MKT-45

There is no statistically significant difference in responses between the technology and marketing panelists.

## Strategic considerations

By customer demand, cost is being added in several areas of the vehicle to improve vehicle safety. It is likely only a matter of time before the ITS technologies in consideration here will be adopted in significant numbers. Panelists forecast that the initial applications will occur in the next decade. The demand for these items may very well surprise the industry in the next decade, as did airbags and antilock brakes in the 1990s. Again, however, cost is an increasingly important concern for future vehicle sales, and the customer will be looking for the greatest value in new features.

Technical developments in this rapidly emerging area could alter the forecasts significantly. Developments from the automotive electronics community should no longer be surprising.

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**TECH-52. What percentage of North American-produced passenger car and light truck engines will be equipped with the following number of cylinders in 2000 and 2005?**

| Passenger Cars | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| Number of Cylinders | 1994* | 2000 | 2005 | 2000 | 2005 |
| 3 | 1.3% | 2% | 2% | 1/2% | 1/3% |
| 4 | 45.5 | 47 | 50 | 45/50 | 45/55 |
| 6 | 39.4 | 40 | 42 | 40/44 | 35/45 |
| 8 | 13.6 | 10 | 8 | 9/12 | 5/10 |
| 10/12 | 0.1 | 0 | 0 | 0/0.1 | 0/0.1 |
| Total | 100% | | | | |

| Light Trucks | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| Number of Cylinders | 1994* | 2000 | 2005 | 2000 | 2005 |
| 3 | 1.3% | n/a | n/a | n/a | n/a |
| 4 | 13.6 | 15% | 16% | 13/15% | 10/20% |
| 6 | 52.9 | 55 | 55 | 53/56 | 51/60 |
| 8 | 33.3 | 30 | 28 | 30/34 | 20/31 |
| 10/12 | 0.1 | 0.1 | 2 | 0/0.2 | 0/0.2 |
| Total | 100% | | | | |

***Source:** Cars: *Ward's Automotive Reports*, December 19, 1994;
Trucks: *Ward's Automotive Reports*, January 2, 1995

## Selected edited comments

- Interacts with use of low inertia turbocharging or supercharging.
- It is quite possible that engine displacement can be reduced while maintaining the power output of current generation engines. This can be realized through improved timing and fuel injection, and also through the adoption of stronger materials which can carry a heavier workload. Some European manufacturers are already investigating the replacement of four-cylinder engines by three-cylinder engines, and similarly, five-cylinders replacing six-cylinders while maintaining output. A key component in this is a stronger engine block material of which compacted graphite cast iron can provide significant advantages while maintaining the cost and environmental profiles of cast iron.
- Not much change foreseen unless the United States gets serious about an energy policy.
- Passenger cars will increase from 46 percent to 48 percent in four-cylinder applications due to sheer economics and volume of cars sold at the low end.

## Discussion

Panelists forecast a decrease in the number of eight-cylinder engines and an increase in the number of four- and six-cylinder engines by 2005 for both passenger cars and light trucks. However, the number of eight-cylinder engines in light trucks will remain significant in the forecast time frame (28 percent).

## Manufacturer/supplier comparison

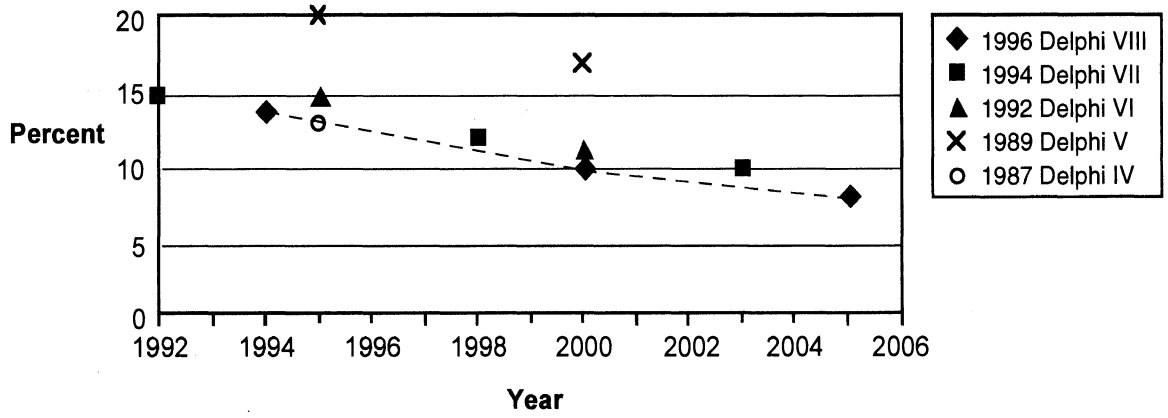
There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results from the current survey are compared to those of the last four surveys in the following table and graphs.

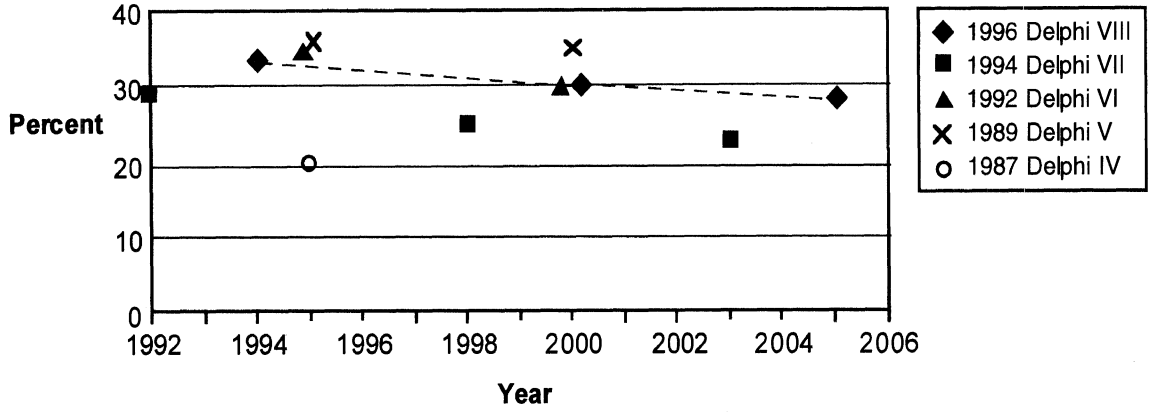
| For year→ | 1995 | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|
| Date of Forecast→ | 1987 | 1989 | 1992 | 1994 | 1989 | 1992 | 1996 | 1994 | 1996 |
| | Delphi IV | Delphi V | Delphi VI | Delphi VII | Delphi V | Delphi VI | Delphi VIII | Delphi VII | Delphi VIII |
| **Number of Cylinders** | | | | | | | | | |
| Passenger Cars | | | | | | | | | |
| 3-Cylinder | 2% | 0% | 0% | 1% | 1% | 3% | 2% | 2% | 2% |
| 4-Cylinder | 50 | 50 | 45 | 42 | 47 | 51 | 47 | 44 | 50 |
| 6-Cylinder | 35 | 30 | 40 | 42 | 35 | 35 | 40 | 43 | 42 |
| 8-Cylinder | 13 | 20 | 15 | 12 | 17 | 11 | 10 | 10 | 8 |
| 10-Cylinder | n/a | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| Light-duty Trucks | | | | | | | | | |
| 4-Cylinder | 45% | 14% | 15% | 13% | 15% | 20% | 15% | 0% | 16% |
| 6-Cylinder | 35 | 50 | 50 | 60 | 50 | 50 | 55 | 60 | 55 |
| 8-Cylinder | 20 | 36 | 35 | 25 | 35 | 30 | 30 | 23 | 28 |
| 10/12-Cylinder | — | — | — | 0 | — | — | 0.1 | 0 | 0 |

**Eight-Cylinder Passenger Car Engine Forecasts**



The eight-cylinder passenger car estimate for 1994 and the forecasts for 2000 and 2005 from the current survey are on the low side of previous forecasts, but little changed from the 1994 Delphi VII survey. The higher estimates for the 1989 Delphi V survey may be due to the fact that baseline estimates were not given with that survey. It is interesting to note that the 1994 estimate provided with the current survey (13.6 percent) is very close to the 1995 forecast from the 1987 Delphi IV survey (13 percent). The 1985 estimate provided for that survey was 27 percent.

**Eight-Cylinder Light Truck Engine Forecasts**




The current forecast for eight-cylinder truck engine penetration is in line with previous forecasts. The 1987 survey forecasted a significantly lower penetration of eight-cylinder engines (20 percent) than is actually estimated for 1994 (33.3 percent). It is interesting to note that, although the long-term trend is for lower penetration for eight-cylinder engines, the actual estimate increased from 1992 to 1994. The estimate for 1985 was 45 percent.

## Strategic considerations

The anticipated legislated demand for improved fuel economy is driving the trend away from eight-cylinder engines to six- and four-cylinder engines, particularly in passenger cars. This trend is forecast to continue as fuel economy requirements become more stringent. The horsepower improvements in four- and six-cylinder engines from four-valve-per-cylinder designs and port fuel injection have facilitated this move. The smoothness of an eight-cylinder engine will assure its continued use in larger luxury cars for the foreseeable future.

For light trucks, the move away from eight-cylinder engines is not as dramatic as in passenger cars. Larger eight-cylinder engines are still desirable for trailer towing and hauling heavy loads in the vehicle. Panelists forecast that eight-cylinder engines will be used in more than one-fourth of all light trucks in 2005, as opposed to only 8 percent of passenger cars.

The move away from eight-cylinder engines will have a minor impact on suppliers of engine components such as pistons and spark plugs, assuming a constant size vehicle market.

Of course, standardization and deproliferation could have an important impact on suppliers.

**TECH-53. What percentage of six-cylinder engines in North American-produced passenger cars and light trucks will be 60° V-6, 90° V-6 and what percentage will be In-line (IL-6)?**

| Six-Cylinder Engines | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2000 | 2005 | 2005 |
| Passenger Cars | | | | | |
| 60° V-6 | 57.2% | 60% | 65% | 60/65% | 60/70% |
| 90° V-6 | 42.8 | 40 | 35 | 35/40 | 25/40 |
| IL-6 | 0.0 | 0 | 0 | 0/1 | 0/3 |
| Light Trucks | | | | | |
| 60° V-6 | 19.8 | 25 | 30 | 20/30 | 25/40 |
| 75° V-6 | 2.3 | 2 | 2 | 2/3 | 0/3 |
| 90° V-6 | 60.0 | 60 | 55 | 55/63 | 40/63 |
| IL-6 | 17.9 | 15 | 10 | 10/18 | 5/16 |

***Source:** Cars: *Ward's Automotive Reports*, December 19, 1994;
Trucks: *Ward's Automotive Reports*, January 2, 1995

**Other:** Light trucks 1L-5: 2000 - 5 percent; 2005 - 5 percent
Passenger cars 1L-5: 2000 - 1 percent; 2005 - 5 percent
Narrow (15° V6) flat 6: <1 percent for 2000 and 2005.

## Selected edited comments

- For passenger cars, the increase in 60° V-6 is related to the consumer perception of a smoother running engine. For light trucks, the smooth-running engine is not that important, thus the increase of the 90° V-6.
- Hoodlines vs. crush space and balance characteristics will continue to be traded off. The inherent cost and balance advantages of the line 6 will be rediscovered.
- IL-6 for passenger cars percentages include new BMW and Mercedes-Benz plants in the United States.
- Light trucks will share more engines with passenger cars.

## Discussion

Panelists forecast that six-cylinder engines in passenger cars will be predominantly a 60° V-6 configuration, whereas in light trucks they will be predominantly a 90° V-6 configuration for the foreseeable future. Use of in-line six-cylinder engines in light trucks is forecast to decrease, and their use in passenger cars is expected to be almost nonexistent.

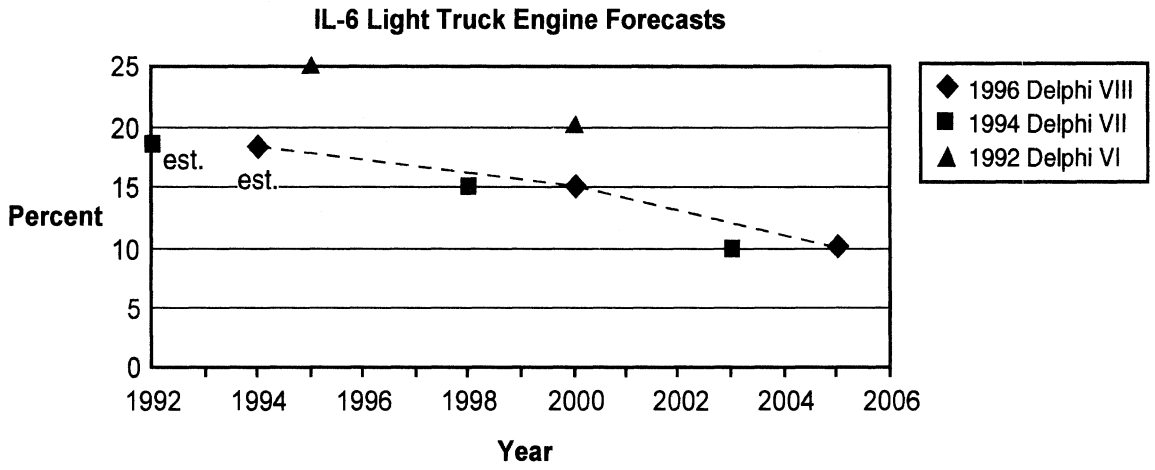
## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Past surveys have asked only whether six-cylinder engines will be in-line or V-6. For passenger cars, both the current survey and the 1994 Delphi VII survey, forecast no use of in-line six cylinder engines. The 1992 Delphi VI survey forecasted a 10 percent penetration of IL-6 engines in 1995 and 2000.

The forecasts for use of IL-6 cylinder engines in light trucks is summarized in the following graph.




Results of the current survey are in line with the previous survey, in 1994, but somewhat below the 1992 survey, Delphi VI. A current estimate was not given with Delphi VI which may explain the difference in results.

## Strategic considerations

In passenger cars, packaging is the primary disadvantage of an IL-6 engine. Crush distance from the front of the vehicle is also a concern for longitudinally mounted IL-6 engines. Packaging is less of a problem in full-size light trucks but is a problem in small trucks. A consideration in designing a new engine is the number of different vehicles in which the engine can be packaged. The IL-6 engine certainly is at a disadvantage in this regard.

The primary advantage of the IL-6 design is the outstanding balance characteristics. Cost is also an advantage, depending on the valvetrain configuration. These advantages are outweighed by packaging considerations for most applications.

The superior balance characteristics of the 60° V-6 as compared to the 90° V-6 are the primary reason for the trend to that configuration. A balance shaft is required in a 90° V-6 to provide satisfactory smoothness at low speeds. This adds cost, weight and complexity to the engine that is not required with the 60° V-6 design, but there are advantages in the 90° design in terms of lower profile and the possibility of deriving it by chopping two cylinders off a V-8.

**TECH-54. What percentage of North American-produced passenger car engines will incorporate the following number of valves per cylinder in 2000 and 2005?**

| Valve Configurations | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Two valves per cylinder | 69.3% | 60% | 50% | 60/65% | 40/60% |
| Three valves per cylinder | 0.0 | 0 | 0 | 0/5 | 0/10 |
| Four valves per cylinder | 30.7 | 38 | 45 | 35/40 | 40/53 |
| Five valves per cylinder | 0.0 | 0 | 1 | 0/1 | 0/3 |

* **Source**: *Ward's Automotive Reports*, December 19, 1994

## Selected edited comment

- The current trend is two valves per cylinder and with most future engine designs this is the trend, as well.

## Discussion

Panelists forecast an increase in the number of passenger car engines with four valves per cylinder. This design is expected to be represented in nearly half of all passenger car engines by 2005. Minimal or no application of three or five-valves-per-cylinder designs are forecast.

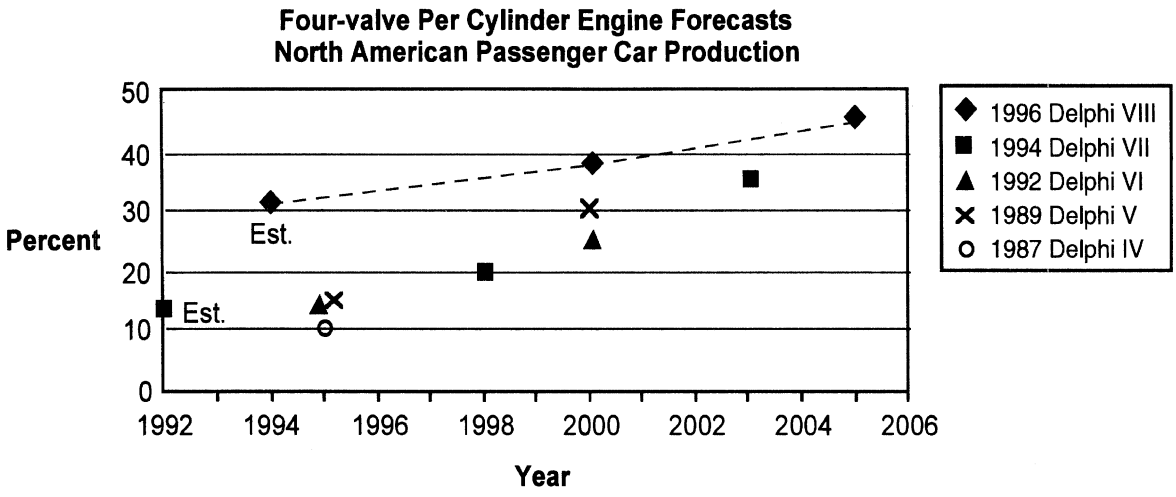
## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results from the current survey are compared to those of past surveys in the following table and graph.

| Valve Configurations | 1994 | 1995 | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Delphi VIII 1996 | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1991 | Delphi VII 1993 | Delphi V 1989 | Delphi VI 1991 | Delphi VIII 1994 | Delphi VII 1993 | Delphi VIII 1996 |
| Two valves per cylinder | 69% | 70% | 80% | 76% | 80% | 60% | 65% | 60% | 60% | 50% |
| Three valves per cylinder | 0 | 20 | 5 | 5 | 0.5 | 10 | 5 | 0 | 1 | 0 |
| Four valves per cylinder | 31 | 10 | 15 | 14 | 20 | 30 | 25 | 38 | 35 | 45 |
| Five valves per cylinder | 0 | — | — | 5 | 0 | — | 5 | 0 | 0 | 1 |




## Strategic considerations

Panelists forecast a significant increase in the number of passenger car engines that will use a four-valve-per-cylinder design. The advantage of this design is that a smaller engine can be used to provide adequate performance, thereby improving fuel economy. However, the increased fuel economy from a smaller engine is somewhat offset by the higher valvetrain parasitic loads, higher RPMs at a given power, increased weight and higher axle ratio used with a four-valve configuration.

If engine size is not reduced when a choice is made between two and four valves per cylinder, performance will be improved at the expense of fuel economy.

Suppliers of valves and associated valvetrain components will certainly benefit from the increase in the total number of valves used.

Key questions are cost and potential of older two-valve designs to be improved. The low-tech (two-valve) engines are significantly lower cost than high-tech designs which is very important today. Furthermore, great strides are being made in increasing the specific power of low-tech engines through better design.

**TECH-55. What percentage of North American-produced passenger car engines will utilize the following valvetrain configuration in 2000 and 2005?**

| Valvetrain Configurations | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| **"V" Engine Configurations** | | | | | |
| Push rod | 68.5% | 60% | 50% | 50/64% | 35/56% |
| Single overhead cam | 24.0 | 30 | 30 | 25/30 | 25/40 |
| Dual overhead cam | 7.5 | 10 | 15 | 10/15 | 12/21 |
| No cam (electromagnetic actuation) | 0.0 | 0 | 1 | 0/0 | 0/5 |
| Total | 100% | | | | |
| **"In-Line" Engine Configurations** | | | | | |
| Push rod | 15.6% | 10% | 5% | 10/13% | 0/10% |
| Single overhead cam | 46.7 | 49 | 47 | 45/50 | 40/50 |
| Dual overhead cam | 37.7 | 40 | 45 | 38/40 | 40/50 |
| No cam (electromagnetic actuation) | 0.0 | 0 | 0 | 0/0 | 0/4 |
| Total | 100% | | | | |

***Source:** *Ward's Automotive Reports*, December 19, 1994

**Other:** "In-Line" engine configurations: 2 stroke - 2000 - 1 percent; 2005 - 2 percent

## Selected edited comment

- Cost pressures will drive to SOHC rather than DOHC.

## Discussion

Panelists forecast a significant decrease in the number of passenger car engines that will utilize a push rod valvetrain configuration in the next decade. The push rod design will be replaced by a combination of single and dual overhead cam designs in in-line engines. Push rods are forecast for 50 percent of "V" engines in 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

In past surveys there was no differentiation between V and in-line engine configurations. The results are therefore not directly comparable. The results of past surveys are summarized in the following table.

| Valvetrain configurations | 1995 | | | 1998 | 2000 | | 2003 |
|---|---|---|---|---|---|---|---|
| | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1991 | Delphi VII 1993 | Delphi V 1989 | Delphi VI 1991 | Delphi VII 1993 |
| Push rod | 30% | 60% | 45% | 49% | 60% | 30% | 35% |
| Single overhead camshaft | 50 | 30 | 45 | 35 | 30 | 50 | 40 |
| Dual overhead camshaft | 20 | 10 | 10 | 15 | 10 | 18 | 20 |
| No camshaft (e.g. electromagnetic) | — | — | 0 | 0 | — | 2 | 1 |

The 1987 Delphi survey forecasted that 50 percent of engines would have a push rod valvetrain design by 1990 and 30 percent by 1995. This compares to an actual penetration of 55 percent in 1992.

The current survey is in agreement with past surveys with regard to the trend to replace the push rod design with single or dual overhead cam designs.

## Strategic considerations

Overhead cam designs provide improved engine breathing through more rapid opening and closing of the valves. This is possible because of the lower mass of the valvetrain, resulting in lower inertia loads. Combustion efficiency may also be improved because of more optimum placement of the spark plug and combustion chamber shape.

For a "V" engine configuration, the push rod design offers some advantages compared to overhead cam designs. The most obvious is the number of camshafts required—one for the push rod versus two or four with the overhead cam design. Dual overhead cams with a "V" engine add considerable cost, weight and packaging difficulty as compared to the push rod design. As a result, engine designers are working hard to improve the power output of push rod engines. Considerable gains have been made in recent years through the use of steel camshafts which allow greater valve acceleration rates for improved engine breathing. Advances in fuel injection techniques have also contributed to increased output. As a result, the push rod design is forecast to be used in half of all "V" engines in 2005.

For in-line engines, the above disadvantages of overhead cams are not present, and panelists forecast that push rods will nearly disappear by 2005.

Cost advantage of the push rod engine can be very significant in this day of affordability concerns. Many customers are not interested in how power is developed but more with getting the power smoothly at the lowest possible cost.

For trucks, in particular, the high displacement, high torque, inexpensive push rod engine is tough to beat.

**TECH-56. What percentage of current North American-produced engines will undergo major redesign (> 30 percent of the investment cost of a new engine) by 2000 and 2005?**

| North American-Produced Engines | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Four-cylinder engine | 30% | 50% | 25/34% | 40/60% |
| V-6 engine | 30 | 50 | 30/30 | 50/60 |
| V-8 engine | 20 | 35 | 20/30 | 25/50 |

## Selected edited comments

- A lot of engines (Ford's Modular Vs) have already been converted. These were not counted because they will not have another change before 2000.
- Engines will go through redesign cycles of about 10 years, allowing incorporation of new technology (both component design and process improvements).
- Ford just redesigned their V6, in-line 4. GM needs a new 4-cylinder engine. Chrysler needs a new V8–puts most investment in engines because they have the oldest.
- Fuel economy, mass and noise requirements will keep many powertrain engineers busy.
- Fuel economy, mass, packaging and noise "opportunities" will continue to play against the substantial investment and manpower required to execute new engines.
- If the European trend of increasing diesel share should spread to the United States, major redesigns would be required.
- If the U.S.-Japan trade agreement leads to more Japanese/transplant engine plants in North America and those engines are counted as major re-design as the investment criteria could dictate, these numbers will be biased upwards by maybe 10 percent (not the V-8s).
- Major work needed to meet more rigorous fuel economy goals.
- Modular engines accelerate capacity for change.
- Most current engines will be replaced by completely new engines by 2005.
- New technology will have to be incorporated.

## Discussion

Panelists forecast that nearly half of all engines will undergo major redesign by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results of the current survey are compared to those of previous surveys in the following table.

| Engines Undergoing Major Redesign | | | | |
|---|---|---|---|---|
| **By the year→** | **2000** | | **2003** | **2005** |
| **Survey year→** | **1989** | **1992** | **1994** | **1996** |
| | **Delphi V** | **Delphi VI** | **Delphi VII** | **Delphi VIII** |
| **Engine** | | | | |
| 4-Cylinder engine | 70% | 65% | 50% | 50% |
| V-6 engine | 65 | 60 | 60 | 50 |
| V-8 engine | 60 | 50 | 40 | 35 |

Comparisons to past surveys are difficult for this question in that it is not known how much redesign has been done since each of the past surveys. On a relative basis it can be stated, however, that current panelists expect slightly less major engine redesign in the next decade than did panelists of previous surveys.

## Strategic considerations

Major redesign of nearly half of all engines in the industry in a 10-year period is a major undertaking. It will require a large expenditure of dollars and human resources. At the same time that engines are being redesigned, major calibration and development work will be required to comply with more stringent emissions and fuel economy standards. The demand for experienced personnel will be substantial.

The brand character of many vehicles has been established by the engine in the past. The organization that does the best job in the major redesign of engines in the next decade may well have a significant marketing advantage assuming a proper balance between cost and perceived value to the customer.

Also, as we learn more about the details of engine design, significant improvements may be possible in older designs.

**TECH-57. What percentage of North American-produced passenger cars and light trucks with spark-ignited engines will incorporate the following types of fuel management systems in 2000 and 2005?**

| Passenger Cars | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| Fuel Injection: | 1994* | 2000 | 2005 | 2000 | 2005 |
| Direct cylinder injection | 0.0% | 1% | 5% | 0/2% | 1/10% |
| Port or multipoint | 94.7 | 95 | 95 | 95/99 | 90/97 |
| Single point with individual tubes to ports | 0.0 | 0 | 0 | 0/0 | 0/0 |
| Throttle body (single point) | 5.3 | 2 | 0 | 0/4 | 0/2 |
| Total | 100% | | | | |

*Source: Cars: *Ward's Automotive Reports*, December 19, 1993; Trucks: *ard's Automotive Reports*, January 2, 1995

| Light Trucks | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| Fuel Injection: | 1994* | 2000 | 2005 | 2000 | 2005 |
| Direct cylinder injection | 0.0% | 5% | 6% | 1/5% | 5/10% |
| Port or multipoint | 56.4 | 70 | 80 | 70/80 | 80/85 |
| Single point with individual tubes to ports | 5.6 | 0 | 0 | 0/0 | 0/0 |
| Throttle body (single point) | 39.7 | 20 | 10 | 15/25 | 5/15 |
| Total | 100% | | | | |

*Source: Cars: *Ward's Automotive Reports*, December 19, 1993; Trucks: *Ward's Automotive Reports*, January 2, 1995

## Selected edited comments

- Current technology is headed in the direction of single point with individual tubes.
- Direct cylinder fuel injection systems will be incorporated into more engines if the two-stroke engine becomes a significant light truck engine.
- GM's new Sequential Central Port Injection (SCPI) is going in all their '96 V-8s (except their big blocks HD truck) and is already on their 4.3L V-6. This accounts for at least 30 percent of North America truck volume and, thus, this must be at least 30 percent in 2000. There is no way that direct cylinder injection will be a measurable amount in trucks by 2000!
- GM trucks 4.3L engine in production today with single point/individual tubes system. Suspect it's a lower cost solution to multiport performance.
- LDT and passenger cars will share features.
- Port or multipoint is the trend and will continue to increase due to the simple control and cost.

## Discussion

Port or multipoint fuel injection is forecast to be the predominant fuel system in both passenger cars and trucks in the next decade.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not asked for light trucks in previous surveys. Results from the current forecast for passenger cars are compared to those of previous forecasts in the following table.

| Forecast for year→ | 1994 | 1995 | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Delphi VIII 1996 | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1992 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Fuel-Management Systems** | | | | | | | | | | |
| Throttle body | 5% | 40% | 35% | 30% | 10% | 25% | 10% | 2% | 2% | 0% |
| Port (multipoint) | 95 | 58 | 60 | 70 | 88 | 75 | 90 | 96 | 95 | 95 |
| Carburetion | 0 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The demise of throttle body injection has occurred much more rapidly than expected by panelists in past surveys. The estimate of 5 percent for 1994 is far below forecasts of 30-40 percent from previous surveys for 1995. In fact, the 1989 Delphi V survey forecasted a penetration of throttle body injection of 25 percent in 2000. The proven superiority of port injection for emissions control, power and driveability have resulted in an early elimination of throttle body injection.

## Strategic considerations

The rapid increase in the use of port injection was not accurately forecast by past panelists. This is likely a result of a late recognition that only port injection could meet future emission standards. Port injection is a significantly higher cost system than throttle body injection but is virtually required to meet more stringent emissions standards. Because of cost, the industry will continue to explore lower cost designs.

Panelists forecast some use of direct cylinder injection in passenger cars by 2005. This is tied in part to the possible introduction of the two-stroke engine in that time frame. Also, there are some important advancements being made in direct cylinder injection, stratified charge and four-stroke engines. The forecast use of direct cylinder injection in light trucks is unexplained, but may also be tied to the use of two-stroke engines or stratified charge four-stroke engines.

**TECH-58. What percentage of North American-produced spark-ignited engines for passenger cars will be either supercharged or turbocharged in 2000 and 2005?**

| Spark-Ignited Engines | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Supercharged | 0.3% | 1% | 2% | 0.4/2% | 0.5/5% |
| Turbocharged | 0.2 | 0.5 | 1 | 0.2/1 | 0.25/3 |

***Source:** *Ward's Automotive Reports*, December 19, 1994

## Selected edited comments

- Consider charged diesels, as well. Also, it's likely that either the super or turbo will achieve a lead and then dominate. I favor the super.
- Not much change unless these systems come down sharply in price.
- Smaller future engines (for fuel economy) may rekindle turbocharger demand.
- Supercharger is a more likely accessory on two-stroke engines.
- Will meet much resistance in face of increased fuel economy goals.

## Discussion

Panelists forecast penetrations of 2 percent and 1 percent for superchargers and turbochargers, respectively, in 2005.

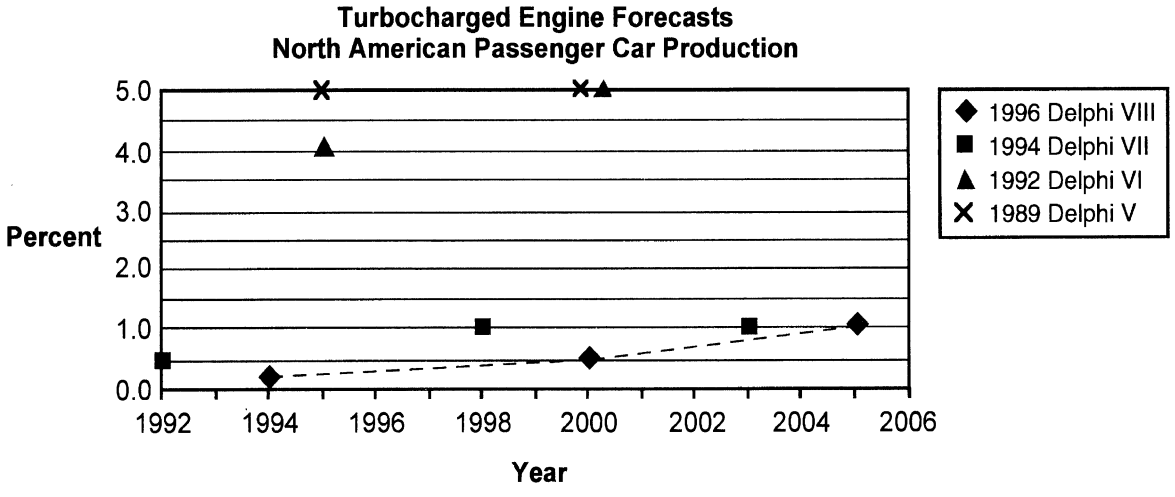
## Manufacturer/supplier comparison

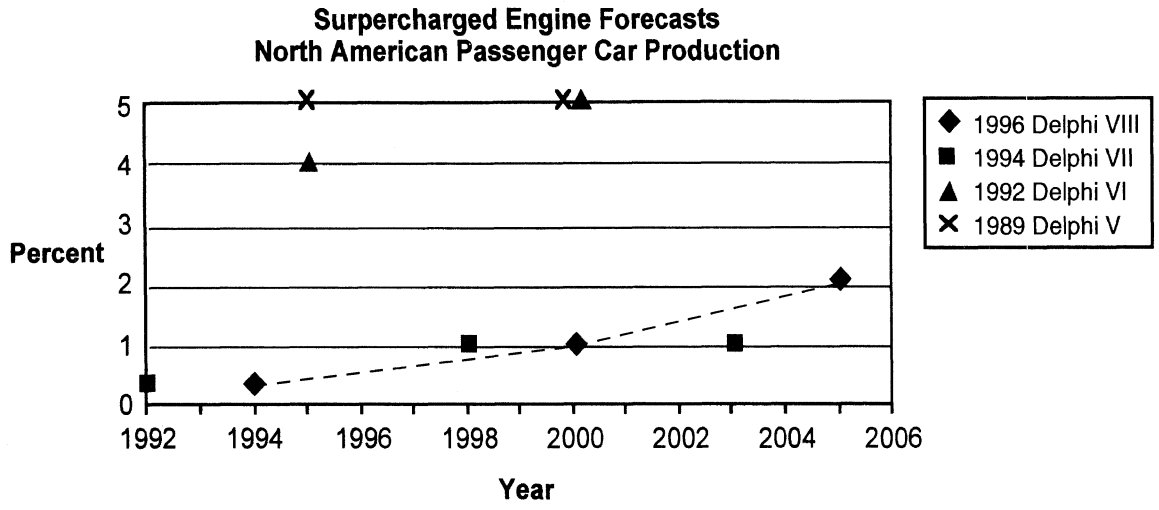
There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

In 1979, Delphi I panelists forecasted that by 1990, 25 percent of spark-ignited engines in U.S.-produced light-duty vehicles would be turbocharged. The 1981, 1984 and 1987 Delphi panelists all forecast 10 percent penetration of turbocharging by 1990.

The forecasts of current panelists are compared to those of the previous three surveys for turbocharging and supercharging in the following graphs.






The current forecasts for turbocharged and supercharged engines are similar to the previous survey, 1994 Delphi VII, but substantially less than the 1992 Delphi VI and 1989 Delphi V forecasts.

## Strategic considerations

Engine design features such as four valves per cylinder, port fuel injection and steel camshafts have dramatically increased power output. Although turbochargers and superchargers can provide greater power output for a given engine, they do this at great expense, added complexity and increased packaging problems compared to the alternatives.

Superchargers do provide the advantage of greatly increased low-speed torque compared to the alternatives. This gives the engine the characteristics of a much larger engine.

Turbochargers and superchargers offer the potential of using a small engine in place of a larger engine for improved fuel economy. In spite of this potential, panelists forecast that the disadvantages of these systems will limit their application to very low levels in the next decade.

**TECH-59. What percentage of North American-produced passenger cars and light trucks with spark-ignited engines will incorporate the following ignition system features in 2000 and 2005?**

| Passenger Cars | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| Ignition System Features | 1994* | 2000 | 2005 | 2000 | 2005 |
| Coil-on-plug designs | n/a | 5% | 10% | 1/10% | 5/21% |
| Cylinder pressure control of ignition | 0.0% | 0.5 | 3 | 0/3 | 0/10 |
| Distributorless ignition systems | 46.2 | 60 | 75 | 50/68 | 60/80 |
| Individual cylinder control of ignition timing | 0.0 | 2 | 9 | 0/5 | 2/20 |
| Knock/adaptive control | 44.9 | 55 | 70 | 50/60 | 56/80 |
| Two spark plugs per cylinder | 0 | 0 | 0 | 0/1 | 0/3 |

| Light Trucks | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| Ignition System Features | 1994* | 2000 | 2005 | 2000 | 2005 |
| Coil-on-plug designs | n/a | 3% | 10% | 0/10% | 1/25% |
| Cylinder pressure control of ignition | n/a | 0 | 0.3 | 0/1 | 0/4 |
| Distributorless ignition systems | n/a | 46 | 60 | 30/60 | 40/80 |
| Individual cylinder control of ignition timing | n/a | 0 | 5 | 0/3 | 5/10 |
| Knock/adaptive control | n/a | 40 | 50 | 30/58 | 40/80 |
| Two spark plugs per cylinder | 4.3% | 0 | 0 | 0/1 | 0/2 |

* **Source:** *Ward's Automotive Reports*, December 19, 1994

## Selected edited comments

- All Ranger L-4 engines have 2 plugs/cylinder.
- Passenger car and light truck engine technologies will converge as we approach 2005.
- There may also be a readout, based on the weighted-average timing for knock, advising the operator if the optimum fuel octane is being used. That will require both engineering and user education.
- Unless emission regulations are tightened, most of these items are too expensive.

## Discussion

Panelists forecast that distributorless ignition systems and knock/adaptive control of ignition will be used on approximately 75 percent of all passenger car engines and on more than half of all light truck engines by 2005. Coil-on-plug designs are forecast to be used on 10 percent of passenger cars and light trucks in the same time frame.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not previously asked for light trucks.

Results of the current survey for passenger cars are compared to those of the last four surveys in the following table.

| Forecast for the year→ | 1994 | 1995 | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|
| Forecast→ | Delphi VIII 1996 | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1992 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Ignition Systems** | | | | | | | | | | |
| Closed-loop timing | — | — | 10% | — | 1% | 25% | — | — | 5% | — |
| Coil-on-plug designs | n/a | — | 5 | 5% | 5 | 15 | 10% | 5% | 10 | 10% |
| Cylinder pressure control of ignition | 0% | — | — | — | 1 | — | — | 0.5 | 5 | 3 |
| Distributorless ignition systems | 46.2 | 50% | 40 | 50 | 60 | 75 | 75 | 60 | 80 | 75 |
| Individual cylinder control of ignition | 0 | 20 | 40 | 40 | 5 | 75 | 60 | 2 | 15 | 9 |
| Knock/adaptive control | 44.9 | 55 | 30 | 40 | 40 | 60 | 65 | 55 | 60 | 70 |
| Two spark plugs per cylinder | 0 | — | — | — | — | — | — | 0 | — | 0 |

Results of the current survey generally agree with those of past surveys with the exception of individual cylinder control of ignition timing. On this item there is reasonable agreement with the last survey, 1994 Delphi VII. The previous three surveys, however, forecasted significantly higher applications of this technology. Panelists in the 1992 survey, Delphi VI, commented that this technology was patented and that application might not be used until the expiration of those patents.

## Strategic considerations

Increasingly stringent emissions standards and expected fuel economy standards will continue to push the application of more sophisticated ignition systems. This is particularly true of distributorless ignition systems and knock/adaptive control.

Distributorless ignition systems remove the requirement of setting ignition timing and the potential for this timing to be incorrect on vehicles in the field.

The benefits of coil-on-plug, cylinder pressure control, individual cylinder control and two spark plugs per cylinder apparently are not expected to justify the cost and complexity of their use on lower priced vehicles. The forecast for several is not insignificant, suggesting there is substantial development activity under way.

**TECH-60. What percentage of engines produced in North America by traditional domestic manufacturers will employ the following valvetrain technologies in 2000 and 2005?**

| Valvetrain Advances | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Variable timing control | 5% | 15% | 3/10% | 10/25% |
| Variable lift control | 1 | 5 | 0/5 | 2/10 |
| Lighter valves (20% or more) | 10 | 20 | 5/20 | 10/55 |

**Other:** Electric valve actuation: 2005 - 5 percent

## Selected edited comment

- Will be paced by rate of development of new engines.

## Discussion

The use of variable valve timing control is forecast to be used on 15 percent of engines by 2005. Twenty percent of engines are forecast to have valve weight reduction of 20 percent or more in that same time frame. Limited use of variable lift control is expected.

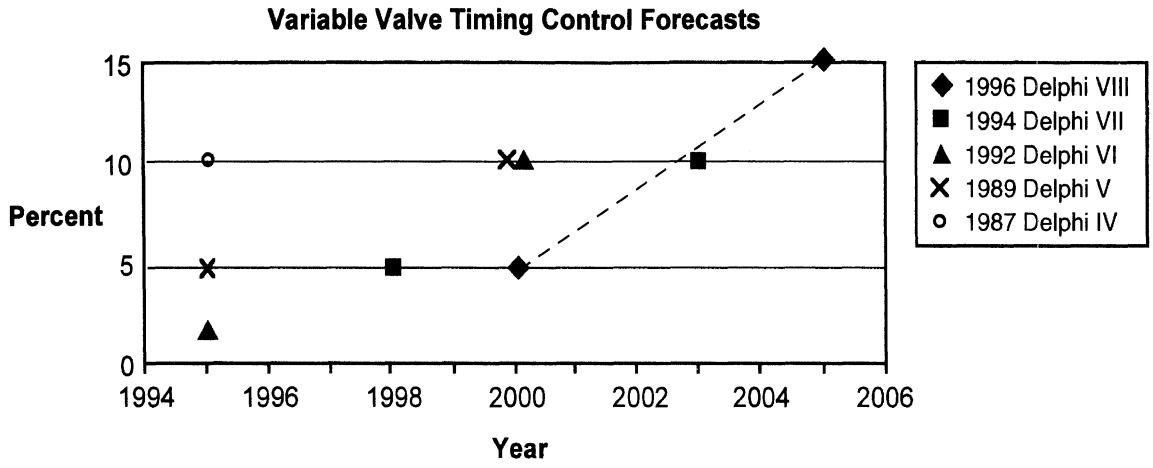
## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

The issue of lighter valves was not addressed in previous surveys. Results of the current survey are compared to previous surveys in the following table.

| Forecast for the year→ | 1995 | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|
| Forecast→ | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1992 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Valvertrain Advances** | | | | | | | | | |
| Variable timing control | 10% | 5% | 2% | 5% | 10% | 10% | 5% | 10% | 15% |
| Variable lift control | — | 1 | 1 | 1 | 5 | 5 | 1 | 10 | 5 |




Variable valve timing was forecasted to have a penetration of 5 percent by 1990 in the 1984 Delphi III survey and the 1987 Delphi IV survey. For each of the previous five surveys, variable valve timing has been forecast to have a penetration of about 5 percent in the next 5-8 years and 10 percent in the next 8-12 years. The current survey forecasts higher penetration in 10 years (15 percent).

The continued delay of higher fuel economy standards may partially explain the delay in implementation of this technology. Cost and reliability concerns are other potential causes for the delay in implementation.

## Strategic considerations

This technology continues to show promise for improved engine performance, fuel economy and idle quality, but has not lived up to the forecast penetration of past surveys.

The relatively large spread in interquartile range for variable valve timing may indicate uncertainty regarding the application of this technology as well as the different strategies of the various manufacturers.

Variable valve timing control and variable lift control will be readily accomplished with the introduction of electromagnetic valve actuation. This technology is not forecast to see significant application in the next decade, however (TECH-55).

As in most areas of the vehicle, one must be prepared for breakthroughs that could dramatically alter the application rate of new technology.

**TECH-61a. What percentage of North American-produced passenger car and light truck engines in 2000 and 2005 will utilize cast iron or aluminum cylinder heads and blocks?**

| Passenger Cars | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| **Material** | **1994*** | **2000** | **2005** | **2000** | **2005** |
| **Heads** | | | | | |
| Cast iron | 22% | 15% | 10% | 12/20% | 5/15% |
| Aluminum | 78 | 85 | 90 | 80/88 | 85/95 |
| Total | 100% | | | | |
| **Blocks** | | | | | |
| Cast iron | 87% | 80 | 65 | 75/82 | 50/75 |
| Aluminum | 13 | 20 | 33 | 16/25 | 25/50 |
| Total | 100% | | | | |

| Light Trucks | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| **Material** | **1994*** | **2000** | **2005** | **2000** | **2005** |
| **Heads** | | | | | |
| Cast iron | 80% | 70% | 53% | 60/75% | 50/66% |
| Aluminum | 20 | 30 | 47 | 25/40 | 34/50 |
| Total | 100% | | | | |
| **Blocks** | | | | | |
| Cast iron | 95% | 90 | 85 | 85/93 | 70/90 |
| Aluminum | 5 | 10 | 15 | 7/15 | 10/30 |
| Total | 100% | | | | |

***Source:** *Ward's Automotive Reports*, December 19, 1994
** Various OSAT Estimates

## Selected edited comments

- 2005 is CAFE-dependent.
- Heads will continue to trend toward aluminum for passenger cars while cost considerations will keep light truck heads in gray iron. In the near term, aluminum blocks will increase slightly, but cost pressures and improvements in cast iron technology will undoubtedly lead to a reversion to cast iron. Each of the Big Three and some 30 other automotive companies in America, Europe and Asia are now evaluating compacted graphite cast iron. This material is substantially stronger than gray iron and can provide weight reduction opportunities in today's gray iron blocks at a cost per pound saved of less than $2.00.
- In general, vehicles are moving towards lighter weight components.

## Discussion

Panelists forecast that aluminum will be used for 90 percent of cylinder heads and 33 percent of cylinder blocks on passenger car engines by 2005. The number of aluminum cylinder heads and cylinder blocks on light trucks is forecast to increase to 47 percent and 15 percent, respectively, in the same time frame.

## Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers for those categories shown in the following table.

| Passenger Car Engine Cylinder Head and Block Material Forecast | | | | |
|---|---|---|---|---|
| | Mean Response | | | |
| | 2000 | | 2005 | |
| Material | Mfr. | Supplier | Mfr. | Supplier |
| **Heads** | | | | |
| Cast iron | — | — | 6.8% | 9.9% |
| Aluminum | — | — | 92.8 | 89.4 |
| **Blocks** | | | | |
| Cast iron | 72.8% | 78.7% | 53.4 | 68.8 |
| Aluminum | 27.0 | 20.9 | 45.9 | 30.4 |

For the items for which there is a significant difference, suppliers forecast more use of cast iron and less aluminum than do manufacturers.

## Comparison of forecasts: MAT-20

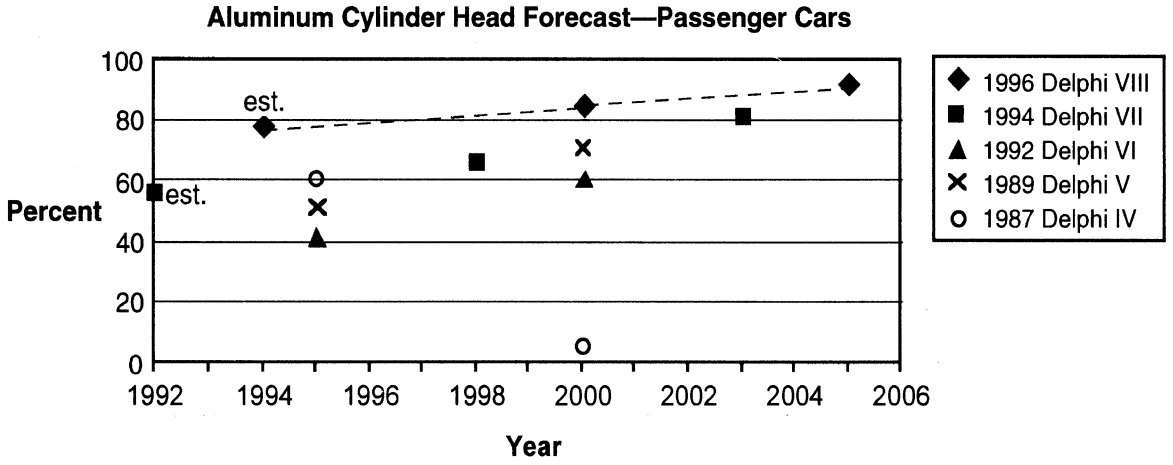
There is a statistically significant difference in responses between the technology and marketing panelists for the items shown in the following table.

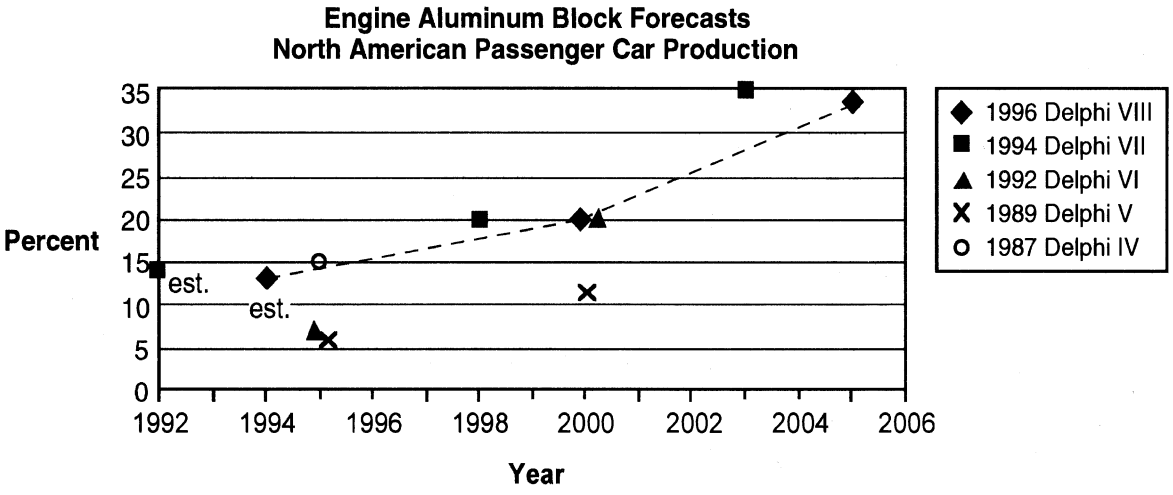
| Material | Passenger Cars | | | | Light-Duty Trucks | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean Response 2000 | | Mean Response 2005 | | Mean Response 2000 | | Mean Response 2005 | |
| | Tech. | Mat. | Tech. | Mat. | Tech. | Mat. | Tech. | Mat. |
| **Heads** | | | | | | | | |
| Cast iron | 16% | 12% | 9% | 5% | 68% | 53% | 53% | 38% |
| Aluminum | 84 | 88 | 89 | 94 | 33 | 47 | 47 | 63 |
| **Blocks** | | | | | | | | |
| Cast iron | 74 | 67 | 56 | 43 | — | — | — | — |
| Aluminum | 26 | 33 | 42 | 56 | — | — | — | — |

Materials panelists forecast a higher use of aluminum than is forecast by technology panelists.

## Trend from previous Delphi surveys

This question was not asked for light trucks in previous Delphi surveys. Comparisons of the current survey to previous surveys are summarized in the following graphs.




## Strategic considerations

In spite of advances in thin wall casting of cast iron, panelists forecast that aluminum will be used in higher volumes in the future. The weight savings with thin wall casting of cast iron have not been able to match the large weight savings obtained by the use of aluminum. The large cost penalty for aluminum, however, is significant. As a result, manufacturers will continue to pursue other alternatives.

Engine cylinder heads and blocks add significant weight to the front end of the vehicle. Reducing the weight of these components can result in weight savings in other components such as engine cradles, front suspension systems, brakes and tires. Future increases in fuel economy requirements will make this weight reduction more attractive from a cost standpoint than it is today.

One consideration in the use of aluminum is the energy used in producing the aluminum. The energy used is considerable and somewhat offsets the fuel saved through vehicle weight reduction. At least one technical author has noted that the energy saved through vehicle weight reduction may be completely offset by the energy used in the production of aluminum. Of course there are significant advantages to aluminum from an energy perspective when recycled.

An additional offsetting factor to the weight savings obtained with aluminum is the superior noise damping characteristics of cast iron. Engine or accessory drive mounting weight may have to be added in order to provide satisfactory engine noise reduction. However, many vehicles in production today prove that quiet vehicles can be obtained using aluminum cylinder heads and blocks.

All of the above factors must be considered in making a decision to select aluminum over cast iron for engine cylinder heads and blocks.

Panelists forecast a significantly larger use of aluminum for cylinder heads and blocks in passenger cars than in light trucks. Increasing light truck fuel economy standards will be a future incentive to use more aluminum in light trucks. Synergistic weight savings from engines in light trucks may not translate to other components such as suspension components because of the large load carrying capability required of light duty trucks.

**TECH-61b. What percentage of aluminum blocks forecast in TECH-61a will be sleeved, unsleeved and coated, and unsleeved?**

| Aluminum Block Engines | Est. 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Sleeved | 100% | 98% | 90% | 92/100% | 75/96% |
| Unsleeved and coated | 0 | 2 | 10 | 0/10 | 2/20 |
| Unsleeved | 0 | 0 | 0 | 0/0 | 0/1 |
| Total | 100% | | | | |

*Source: OSAT

## Selected edited comment

- Depends on the field experience and coating/process development.

## Discussion

Panelists forecast that aluminum blocks will be sleeved on 90 percent of applications by 2005 compared to 100 percent currently.

## Manufacturer/supplier comparison

There is a statistically significant difference in responses for manufacturers and suppliers for 2005. These differences are summarized in the following table.

| Aluminum Block Engines for 2005 | | |
|---|---|---|
| | Mean Forecast | |
| | Manufacturers | Suppliers |
| Sleeved | 79.4% | 89.3% |
| Unsleeved and coated | 18.9 | 9.1 |

Suppliers forecast that more engines with aluminum blocks will be sleeved in 2005 than do manufacturers.

## Comparison of forecasts: MAT-21a

In the materials survey, this question was asked only for 2005. There is no statistically significant difference in responses between the technology and materials panelists for that year.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi technology survey.

## Strategic considerations

Unsleeved and coated cylinder blocks are forecast to be used in 10 percent of aluminum blocks by 2005. As confidence with this system is developed, the penetration will increase to take advantage of the weight and cost savings.

An unsleeved, uncoated design was used on the Chevrolet Vega in the 1970s. The design encountered problems in the field that were remedied through design changes. By the time the Vega went out of production, the design was very durable. This experience might indicate, however, that a sleeved design is less design sensitive and with today's warranty and customer satisfaction concerns, manufacturers are reluctant to take chances.

**TECH-62. What percentage of North American-produced passenger car engines will incorporate the following technical features currently and in 2000 and 2005?**

| Advanced Engine Features | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current Est. | 2000 | 2005 | Current Est. | 2000 | 2005 |
| Roller lifters | | | | | | |
| % of DOHC engines | 15% | 25% | 35% | 15/20% | 20/30% | 30/50% |
| % of push rod engines | 50 | 65 | 80 | 50/60 | 40/75 | 65/90 |
| % of SOHC engines | 20 | 30 | 40 | 20/30 | 25/41 | 34/60 |
| Balance shaft (% of four-cylinder engines) | 20 | 35 | 45 | 20/20 | 30/40 | 35/50 |
| Balance shaft (% of 90° six-cylinder engines) | 25 | 40 | 50 | 20/25 | 30/48 | 38/60 |
| Hollow camshaft | 5 | 15 | 30 | 5/5 | 10/20 | 20/35 |
| Powdered metal cam and gears | 5 | 10 | 20 | 5/5 | 10/15 | 15/25 |

## Selected edited comments

- Hollow camshaft should be popular—going toward lighter weight components.
- Hydroformed camshafts being integrated by several major suppliers.
- No change in percentage of roller lifters on push rod or SOHC engines if the fuel economy law is not changed.
- Powdered metal may not be the low cost solution for lobes.
- What about hydroformed camshafts?

## Discussion

Panelists forecast that most (80 percent) push rod engines will have roller lifters by 2005, whereas 35 percent and 40 percent of DOHC and SOHC engines, respectively, will have roller lifters in that time frame. By 2005, about half of four-cylinder and 90° six-cylinder engines are forecast to have balance shafts. Hollow camshafts are forecast on 30 percent and powdered metal cam and gears on 20 percent of engines.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

In previous surveys roller lifters were not addressed by engine type. Also, balance shafts on six-cylinder engines were not differentiated by engine configuration.

Results of the current survey are compared to those of previous surveys for questions that were common in the following table. If the questions were not common, this is noted by n/a (not applicable).

| Forecast for year→ | 1995 | | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Technical Features** | | | | | | | | | | |
| Balance shaft (% of 4-cylinder engines) | 25% | 20% | 25% | 20% | 20% | 40% | 30% | 35% | 25% | 45% |
| Balance shaft (% of 6-cylinder engines) | 10 | 20 | 20 | n/a | 35 | 20 | 30 | n/a | 40 | n/a |
| Hollow camshaft | 15 | 10 | 10 | 5 | 10 | 20 | 15 | 15 | 15 | 30 |
| Powdered metal cam and gears | 20 | 10 | 10 | 5 | 3 | 20 | 20 | 10 | 10 | 20 |
| Roller lifters | 50 | 40 | 50 | n/a | 55 | 60 | 70 | n/a | 70 | n/a |

Results of the current survey are in general agreement with past surveys for four-cylinder engine balance shafts, although the 1994 Delphi VII forecast was low for 2003 compared to the other forecasts.

The forecasts for hollow camshafts and powdered metal cam and gears are lower in the current survey for 1995 and higher or the same in 2005 than forecasted in previous surveys. The forecasts for 1995 decreased with each survey. The timing of the expected use of these design features is delayed with each new survey.

## Strategic considerations

**Roller lifters:** Roller lifters provide a significant reduction in valvetrain friction and a significant increase in vehicle fuel economy (2 percent). They are more easily packaged in push rod engines than overhead cam engines. In four-valve-per-cylinder engines, roller lifters add significantly to cost, weight and packaging difficulty. In spite of these problems, the application rate is forecast to increase significantly on engines of all configurations due to the increasing requirements for fuel economy.

**Balance shafts, four-cylinder engines:** Panelists in the current survey forecast a significant increase in the use of balance shafts in four-cylinder engines by 2005. Panelists in the 1994 survey, Delphi VII forecasted only a modest increase by 2003. There are a number of conflicting considerations with regards to this technical feature. Engine vibration and noise at high engine speed is significantly reduced by the addition of balance shafts to four-cylinder engines. These balance shafts are counter rotating at twice engine speed. The addition of this feature increases engine cost, weight and complexity, reduces vehicle fuel economy and may reduce reliability. As engine size is reduced, unbalance decreases and the benefit of a balance shaft is reduced. Also, reduced piston weight reduces unbalance and the benefit of a balance shaft. Consideration of all of these factors may introduce some uncertainty regarding the application of this feature to future engines.

**Balance shafts, six-cylinder engines:** In-line six cylinder engines are inherently balanced. 60 degree V-6 engines have first and second order moment unbalances, but the magnitude of the unbalance is small. 90 degree V-6 engines have a significant first order moment unbalance, which can be reduced by the addition of a balance shaft running at engine speed. Panelists forecast that 50 percent of 90 degree V-6 engines will have balance shafts in 2005. Because of the slower rotating speed of the balance shaft in a V-6 engine compared to a four cylinder engine, the concerns relative to lower fuel economy and reliability are reduced in this application.

**Hollow camshaft:** This feature has not been introduced as rapidly as forecast in previous surveys. The requirements for increased fuel economy will be a driving force to apply this weight saving feature. The uncertainty regarding future fuel economy requirements may be the reason for the delay in the application of hollow camshafts.

## TECH-63. What percentage of North American-produced passenger cars will use lean burn technology with a NOx catalyst by 2005?

| Lean Burn Technology | Median Response | Interquartile Range |
|---|---|---|
| With NOx catalyst to meet: | | |
| Federal standards | 25% | 20/30% |
| California standards | 40 | 25/50 |

### Selected edited comments

- By 2005, federal and California emission standards should converge (except for ZLEV provisions).
- California NOx standards are much lower.
- California's very low NOx standards will cause manufacturers to reduce the percentage of vehicles using lean burn in that state. Same is true for the Northeast states (i.e., New York et al) if they adopt the California standards.
- Depends on catalyst development.
- Diesels likely the only application.
- Diesels might not be able to use NOx catalyst!
- Federal and California standards: 20-80 percent.
- There are some claims of this being achieved.
- Wide range depends on available catalysts that survive lean operation. If developed, transition will be rapid.

### Discussion

Panelists forecast that about one-fourth of passenger cars meeting federal emissions standards and 40 percent of those meeting California emission standards will use lean burn technology with a NOx catalyst by 2005.

### Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

### Trend from previous Delphi surveys

The previous survey, 1994 Delphi VII, forecasted a 10 percent use of lean burn with a NOx catalyst to meet both federal and California emission standards in 2003. Previous forecasts did not differentiate between federal and California standards. The results of these earlier surveys are shown in the following table.

| Lean Burn Technology | 1995 | | | 2000 | |
|---|---|---|---|---|---|
| | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1991 | Delphi V 1989 | Delphi VI 1991 |
| | 20% | 5% | 5% | 15% | 8% |

The 1987 survey, Delphi IV, forecasted a 20 percent use of lean burn by 1995. The development of a lean burn NOx catalyst has not progressed as rapidly as expected at the time of that survey.

## Strategic considerations

Lean burn offers the potential for significantly improved fuel economy (7-10 percent). This is a large improvement compared to other fuel economy improving technologies under consideration.

The use of lean burn technology is dependent upon the development of a catalyst that has adequate durability under lean operation. This development is progressing rapidly and may be dependent on sophisticated fuel control strategies. Panelists forecast a significant application of this technology by 2005, which means that they expect the development to be successful in that time frame.

Development of this technology may allow diesel engines to meet federal emissions standards. One panelist commented that this may be the only application of this technology. Diesel engines offer a potential fuel economy improvement of approximately 20 to 30 percent over current spark ignited engines. Diesel engines have a disadvantage in the areas of cost, weight, noise, odor and performance, however.

**TECH-64. What percentage of passenger cars will use the following catalytic converter features to meet federal and California standards?**

| Catalytic Converter Types | Median Response | | | | Interquartile Range | | | |
|---|---|---|---|---|---|---|---|---|
| | To Meet Federal Standards | | To Meet California Standards | | To Meet Federal Standards | | To Meet California Standards | |
| | 2000 | 2005 | 2000 | 2005 | 2000 | 2005 | 2000 | 2005 |
| Electrically heated | 5% | 10% | 10% | 20% | 2/5% | 10/15% | 5/15% | 10/25% |
| Fuel heated | 1 | 2 | 5 | 5 | 0/2 | 0/5 | 0/10 | 0/10 |
| Start-up catalyst with bypass | 5 | 5 | 5 | 5 | 0/5 | 0/5 | 0/5 | 2/8 |
| Start-up catalyst w/o bypass | 10 | 25 | 20 | 40 | 10/15 | 20/30 | 15/30 | 25/50 |
| Metal substrate | 10 | 15 | 10 | 20 | 10/10 | 10/20 | 10/20 | 15/25 |

**Other:** Close coupled UB: Fed. Stds.: 2000 - 50; 2005 - 20; CA Stds.:2000 - 10

## Selected edited comments

- "Start-up catalyst without bypass" will be mainly used for engines of less than three liters. "Electrically heated" will be used for engines of more than three liters.
- Federal and California cars will not differ greatly as car makers try to standardize.
- Figures for 2005 federal standards assume full Tier 2 standards (1/2 Tier 1) in 2004.
- Fuel heated: assumed to fail.
- I really think federal and California standards will be the same by 2005.
- I think the federal and California standards will merge by 2000.
- Start-up catalyst w/o bypass: as little as three months ago I would have had this at about 50 percent and had increased electric and fuel heat converters by 10 percent each (i.e., 34 percent and 11 percent, respectively). However, every day the development engineers are learning how to reduce the emissions with better start-up A/F control and better converter wash coats and loadings; thus, the need for supplementally heated converters is going away quickly!
- While fuel-heated catalysts may be more efficient than electric heat, the small emissions and cost penalties may be too much if EPA CAFE and evaporation regulations tighten.
- With close coupled UB systems, assumes no additional total catalyst.

## Discussion

Panelists forecast that electrically heated catalyst and metal substrate converters will be used on 20 percent of vehicles meeting California standards in 2005. Start-up catalyst without bypass is expected on 40 percent of those same vehicles.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers except for start-up catalyst w/o bypass. The responses for this item are summarized in the following table.

| Start-up Catalyst w/o Bypass—Mean Response | | | | | | | |
|---|---|---|---|---|---|---|---|
| To Meet Federal Standards | | | | To Meet California Standards | | | |
| 2000 | | 2005 | | 2000 | | 2005 | |
| Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. |
| 22% | 10% | 36% | 23% | 34% | 19% | 44% | 33% |

Manufacturers forecast a higher use of start-up catalyst without bypass than do suppliers for both federal and California standards.

## Trend from previous Delphi surveys

This question was first asked for heated catalysts in the previous survey, 1994 Delphi VII. Start-up catalysts and metal substrates were not covered in a previous survey.

The results of the current survey are compared to the previous survey in the following tables.

| Heated Converters to Meet Federal Standards | | | | |
|---|---|---|---|---|
| For year → | 1998 | 2000 | 2003 | 2005 |
| Survey → | Delphi VII 1994 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| Electrically heated | 1% | 5% | 5% | 10% |
| Fuel heated | 3 | 1 | 10 | 2 |

| Heated Converters to Meet California Standards | | | | |
|---|---|---|---|---|
| For year → | 1998 | 2000 | 2003 | 2005 |
| Survey → | Delphi VII 1994 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| Electrically heated | 10% | 10% | 20% | 20% |
| Fuel heated | 5 | 5 | 20 | 5 |

Panelists in the previous survey were split on the application of electrically or fuel-heated converters. Current panelists strongly favor electrically heated catalysts.

## Strategic considerations

The application of electrically heated catalysts will require larger batteries and increased charging capability. This will add weight and cost to the vehicle in addition to the added weight and cost of the converter itself. In many vehicles the space to mount larger batteries and alternators is not available. Major repackaging of underhood components may be required.

California emission standards are being adopted by a number of Eastern states and will require the application of emission control devices required in California.

Start-up catalysts are expected to be used in nearly half of all vehicles meeting California emission standards. These devices will also add weight and cost to the vehicle and cause packaging problems.

Metal substrate converters reduce warm-up time of the converter.

The comment with regard to recent development activity is very important. This industry has demonstrated an amazing ability to find lower cost solutions to problems when confronted with tough challenges, particularly high cost challenges.

Some panelists expect federal and California standards to be similar or the same by 2005. If this is the case, the application numbers for California will apply nationwide.

**TECH-65 What percent of passenger cars will incorporate the following emission control devices in 2000 and 2005 to meet the federal and California emission requirements?**

| Catalytic Converter Types | Median | | | |
|---|---|---|---|---|
| | Federal Requirements | | California Requirements | |
| | 2000 | 2005 | 2000 | 2005 |
| Particulate controls | 1% | 3% | 2% | 5% |
| Lean NOx trap | 1 | 5 | 5 | 10 |
| Start-up HC trap | 2 | 5 | 5 | 10 |

| Catalytic Converter Types | Interquartile Results | | | |
|---|---|---|---|---|
| | Federal | | California | |
| | 2000 | 2005 | 2000 | 2005 |
| Particulate controls | 0/5 | 0/10 | 0/10 | 0/15 |
| Lean NOx trap | 0/5 | 0/20 | 0/10 | 3/20 |
| Start-up HC trap | 0/5 | 2/15 | 1/10 | 5/23 |

## Selected Edited Comments:

- 2005 major unknown in California in light of most recent health effects studies of particulates.
- Assume modest use of diesel engines by 2005.
- Gasoline powered (and other) particulate matter could be subject to control by 2005 (particulate matter less than 10 microns–possibly less than 5 if test procedure can be developed.)
- Lean NOx may or may not be a trap configuration. It might just be a converter that can reduce NOx in a lean atmosphere.
- Mostly seen as temporary/band-aid emission fixes. Competitive pressures will minimize the applications of generally unnecessary emissions equipment.
- Particulate controls percentages depends on the share of diesels.

## Discussion

Panelists forecast limited use (10 percent or less) of particulate controls, lean NOx traps or start-up HC traps by the year 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers except for particulate controls. Responses for manufacturers and suppliers are compared in the following table.

| Particulate Controls—Mean Response | | | | | | | |
|---|---|---|---|---|---|---|---|
| To Meet Federal Standards | | | | To Meet California Standards | | | |
| 2000 | | 2005 | | 2000 | | 2005 | |
| Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. | Mfr. | Sup. |
| 3% | 12% | 6% | 18% | 5% | 17% | 8% | 21% |

Manufacturers forecast lower use of particulate controls than suppliers forecast for both federal and California requirements.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Strategic considerations

Particulate controls, lean NOx and start-up HC traps have been under development for some time. At this point, panelists apparently do not believe that particulate controls will be required. Panelists also apparently believe that there will be better methods of controlling NOx and HC than lean NOx traps and start-up HC traps. It is possible, also, that these devices are not expected to be developed to a production status by 2005.

**TECH-66. What new components, fuels or technologies not previously covered in this survey will be introduced in the next decade for North American-produced passenger cars to help meet new emission standards?**

- Advanced self diagnostics. Separate A/F mixture and spark control for each cylinder.
- Air gap pipe, air gap or sheet metal manifolds, hydrocarbon traps.
- Better sensors for control and monitoring.
- Combustion control—measuring flame front propagation and variation to control mixture and timing.
- Compacted graphite iron is an improved cast iron which is on the horizon of adoption by the world automotive industry. Series production will very likely begin at several companies before 2000, including one of the Big Three. The current level of interest and the profitability of implementation are simply too high to neglect.
- DI diesels with catalyst/particulate traps.
- DI diesels; lean start with improved ignition.
- Don't know in what form it will come, but continuing advances in refining technology will undoubtedly bring on lower emissions petroleum-based fuels.
- Drive-by-wire; air/fuel control.
- Fuel and injector improvements; cylinder pressure control.
- Lean NOx trap (not considered a catalyst) but probably not for North America.
- Lean-burn two-stroke engines; new fuels; new sensor technologies like NOx, $O_2$, lean $O_2$ sensors. Low HC-permeation fuel lines, seal, vapor lines, tanks, etc. Also ORVR (refueling vapor recovery) systems. Hydraulic cooling fan drives will be more common. To meet emissions regulations, more engines will have controls and components allowing them to go 100,000 miles without outside adjustment or service.
- Modified chemical makeup of fuels to increase burn efficiency and reduce pollution.
- Natural gas will grow; gasoline will be even more reformulated.
- New type igniters.
- On-board vapor recovery; OBD II.
- Particulate controls (all fuels) less than 10 microns.
- Permeation treatments for plastic fuel tanks.
- Significantly increased amounts of EGR to meet 0.2g/Mi NOx at 100,000 in-use; new sensors and systems to better meet OBD II requirements such as converter diagnostics and all loads and speeds misfires.

- While components may not change so dramatically, materials will. One potentially important material, compacted graphite cast iron, is currently being evaluated by the Big Three and other American diesel engine manufacturers as a stronger material that will provide new weight reduction opportunities while not requiring any changes in foundry or machining line equipment. The stronger mechanical properties of compacted graphite iron not only allow for weight reduction but also provide operating benefits including:
  - 20-30 percent improved cylinder bore dimensional stability. The reduced expansion of cylinder bores improves ring matching, reduces friction, and also reduces oil consumption.
  - 10-20 percent increase in torsional vibrating frequency is realized due to the 35 percent increase in elastic modules (stiffness) relative to gray iron. This greatly contributes to NVH objectives.

## Discussion

Panelists note a number of new technologies or refinements in current technologies that are expected to be used in the next decade.

## Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Strategic considerations

Many new business opportunities will result from the introduction of new components or technologies to assist in compliance with new emissions standards. Suppliers should stay abreast of these technologies as they develop. A single panelist's comment in this area may be a clue to a large business opportunity or, conversely, a major threat.

**TECH-67. What percentage of North American-produced passenger car engines will incorporate components that are polymer-based in 2000 and 2005? Please provide your estimate for current vehicles.**

| Polymer-Based Components | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current Est. | 2000 | 2005 | Current Est. | 2000 | 2005 |
| Fuel rails | 5% | 20% | 30% | 5/5% | 10/25% | 23/35% |
| Intake manifold | 10 | 25 | 50 | 10/10 | 20/30 | 40/60 |
| Oil pan | 3 | 10 | 15 | 2/5 | 5/10 | 10/20 |
| Piston skirts | 0 | 1 | 2 | 0/10 | 0/1 | 0/5 |
| Valve covers | 10 | 30 | 50 | 10/10 | 25/40 | 40/60 |

**Other:** Throttle body: 2000 - 2 percent; 2005 - 10 percent

## Selected edited comments

- Composites must be cost-effective and also provide NVH benefit which has value (e.g., offset costs in body insulation, etc.).
- Fuel rails will be incorporated gradually.
- Lighter weight components are going to be popular.
- One sees molded plastic manifolds and valve covers on many of the new or redesigned engines. There may be plastic-containing coatings on piston skirts for scuff control, tighter fit and less noise.

## Discussion

Panelists forecast that the use of polymer-based materials will increase significantly by 2005 for a number of engine components. Half of intake manifolds and valve covers are expected to be polymer-based in that time frame.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Comparison of forecasts: MAT-22

There is no statistically significant difference in responses between the technology and materials panelists except for the items noted in the following table.

| Polymer-Based Components | Mean Response Current | | Mean Response 2005 | |
|---|---|---|---|---|
| | Tech. | Mat. | Tech. | Mat. |
| Fuel rails | 5.1% | 7.2% | — | — |
| Intake manifold | 10.0 | 13.3 | — | — |
| Oil pan | — | — | 15.6% | 29.4% |

## Trend from previous Delphi surveys

Fuel rails were not addressed in a previous survey. Results for the other components in the current survey are in general agreement with past surveys.

## Strategic considerations

Polymer-based materials offer the advantage of weight reduction and the ability to be formed in complex shapes. Also, for some components, the surface smoothness is important as well as the ability to produce very complex shapes. The move from steel or aluminum to polymer-based materials will impact many suppliers, providing new business to some and taking away business from others.

The issue of recycling may influence the use of polymer-based materials in the future. Steel and aluminum are more readily recycled.

**TECH-68. What percentage of spark-ignited engines in North American-produced passenger cars will use these ceramic engine components in 2000 and 2005?**

| Ceramic Engine Components | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| Exhaust manifold/port liner | 2% | 5% | 0/5% | 0.3/15% |
| Piston crown | 0.5 | 5 | 0/3 | 0/10 |
| Piston rings, coating | 1 | 5 | 0/6 | 2/16 |
| Seals | 2 | 5 | 0/5 | 0.6/15 |
| Turbocharger turbine/rotor (based on % of engines equipped with turbochargers) | 15 | 28 | 2/30 | 5/52 |
| Valvetrain components (includes valves, inserts, guide seats, tappets, cam, etc.) | 5 | 15 | 1/10 | 5/25 |
| Wrist pins | 0 | 2 | 0/2 | 0/9 |

## Selected edited comments

- Ceramic applications will accelerate as manufacturing technology gets developed, cost drops and durability gets proven.
- Hopefully we can drive this, as I understand ceramics reduces heat rejection to the coolant which may allow us to reduce other components' costs/weight.
- In valvetrains the issue is the average extent of use rather than the percentage of engines that have one ceramic component.
- MMC for upper ring groove! This is a ceramic part that is then cast into the piston.

## Discussion

Panelists forecast limited use of ceramic for engine components by 2005. Valvetrain components are forecast to include ceramics in 15 percent of applications by 2005.

## Manufacturer/supplier comparison

There is a statistically significant difference in responses between manufacturers and suppliers regarding piston rings and coatings. A comparison of responses is shown in the following table.

| Ceramic Engine Components | | | | |
|---|---|---|---|---|
| Components | Mean Forecast | | | |
| | 2000 | | 2005 | |
| | Mfrs. | Suppliers | Mfrs. | Suppliers |
| Piston rings, coatings | 1.3 | 13.2 | 4.3 | 19.9 |

Suppliers forecast a significantly higher use of ceramic piston rings and/or coatings than manufacturers forecast.

## Comparison of forecasts: MAT-23

There is no statistically significant difference in responses between the technology and materials panelists.

## Trend from previous Delphi surveys

The results from the current survey are compared to those of the previous three surveys in the following table.

| Ceramic Engine Components | 1995 | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|
| | Delphi V 1989 | Delphi VI 1991 | Delphi VII 1993 | Delphi V 1989 | Delphi VI 1991 | Delphi VIII 1996 | Delphi VII 1993 | Delphi VIII 1996 |
| Exhaust manifold/port liner | 3% | 1% | 1% | 10% | 5% | 2% | 5% | 5% |
| Piston crown | 2 | 0 | 0 | 8 | 2 | 0.5 | 2 | 5 |
| Piston rings, coating | 0 | 0 | 0 | 0 | 5 | 1 | 2 | 5 |
| Seals | 2 | 2 | 5 | 10 | 5 | 2 | 10 | 5 |
| Turbocharger turbine/rotor (based on percent of engines equipped with turbochargers) | 5 | 10 | 10 | 15 | 20 | 15 | 30 | 28 |
| Valvetrain components (includes valves, inserts, guide seats, tappets, cam, etc.) | 2 | 2 | 2 | 10 | 10 | 5 | 10 | 15 |

The current survey is in general agreement with past surveys.

## Strategic considerations

Ceramic components internal to the engine are viewed with caution because a fracture of the ceramic component may cause catastrophic engine failure. This includes components in the exhaust manifold or ports because a failed component in the exhaust manifold or port can lead to material being ingested into the combustion chamber. This results because of the simultaneous opening of inlet and exhaust valves during overlap.

In spite of this concern, panelists forecast some application of ceramic components internal to the engine by 2005. Validation of durability of these components may lead to a rapid expansion of their use.

One panelist commented that metal matrix composite (MMC) ring grooves will be cast into the piston. A resulting strengthened upper ring groove allows the top piston ring to be placed closer to the top of the piston. This reduces the crevice volume above the top ring, and reduces hydrocarbon emissions.

The fundamental virtues of ceramics remain attractive and prompt continuing hope for breakthroughs. In most cases the benefits are attractive but expectations have deminished over the past few years. Of course, the reality of a breakthrough could change the game dramatically.

**TECH-69. Please estimate the mix of transmissions for passenger cars and light trucks manufactured in North America in 2000 and 2005. Total manual plus total automatic should equal 100 percent.**

| Passenger Cars | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| **Transmission Mix** | **1994*** | **2000** | **2005** | **2000** | **2005** |
| **Manual** | | | | | |
| Four-speed | 0% | 0% | 0% | 0/0% | 0/0% |
| Five-speed | 11.9 | 10 | 10 | 10/12 | 6/12 |
| Six-speed | 0.3 | 0.5 | 1 | 0.3/1 | 0.3/3 |
| Total manual | 12.2 | | | | |
| **Automatic** | | | | | |
| Three-speed | 17.4% | 10% | 5% | 9/15% | 0/10% |
| Four-speed | 70.4 | 72 | 72 | 70/75 | 64/77 |
| Five-speed | 0 | 2 | 5 | 0/5 | 2/15 |
| Continuously variable (CVT) | 0 | 0 | 1 | 0/1 | 0/5 |
| Total automatic | 87.8 | | | | |
| Total | 100% | | | | |

| Light Trucks | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| **Transmission Mix** | **1994** | **2000** | **2005** | **2000** | **2005** |
| **Manual** | | | | | |
| Four-speed | 0.0% | 11% | 10% | 5/15% | 1/14% |
| Five-speed | 21.6 | 7 | 10 | 5/18 | 8/17 |
| Six-speed | 0 | 0 | 0 | 0/0 | 0/1 |
| Total manual | 21.6 | | | | |
| **Automatic** | | | | | |
| Three-speed | 5.5% | 3% | 0% | 1/5% | 0/2% |
| Four-speed | 72.9 | 75 | 75 | 72/77 | 70/76 |
| Five-speed | 0 | 0 | 4 | 0/3 | 2/5 |
| Continuously variable (CVT) | 0 | 0 | 0 | 0/0 | 0/0 |
| Total automatic | 78.4 | | | | |
| Total | 100% | | | | |

* **Source:** Cars: *Ward's Automotive Reports* "Factory Installations", December 26, 1994 p.1 (insert)
Trucks: *Ward's Automotive Reports*, January 16, 1995

## Selected edited comments

- CVT may gradually be spread from the viewpoint of fuel economy and drivability.
- In the next 10-20 years, the distinction between automatic and manual transmissions will fade, differing only in the controls and actuators.
- Increasing traffic density and better automatics will decrease the manual transmission market.
- Manuals per se will be replaced by manually shiftable automatics.

- Re: Total automatic: See Question 4 and 82 - How do you classify an automatic without torque converter?
- Should be trend to six-speed manual transmission and more five-speed automatic transmissions.
- Standard manual transmissions with clutch and stick will increasingly be replaced by "finger-shift" (Tiptronic) transmissions.
- You might consider and ask about an automatic with clutches and electronic control but no torque converter, incorporating a viscous "vibrating" damper. Use with five-speeds would do about all a CVT would but with less parasitic losses.

## Discussion

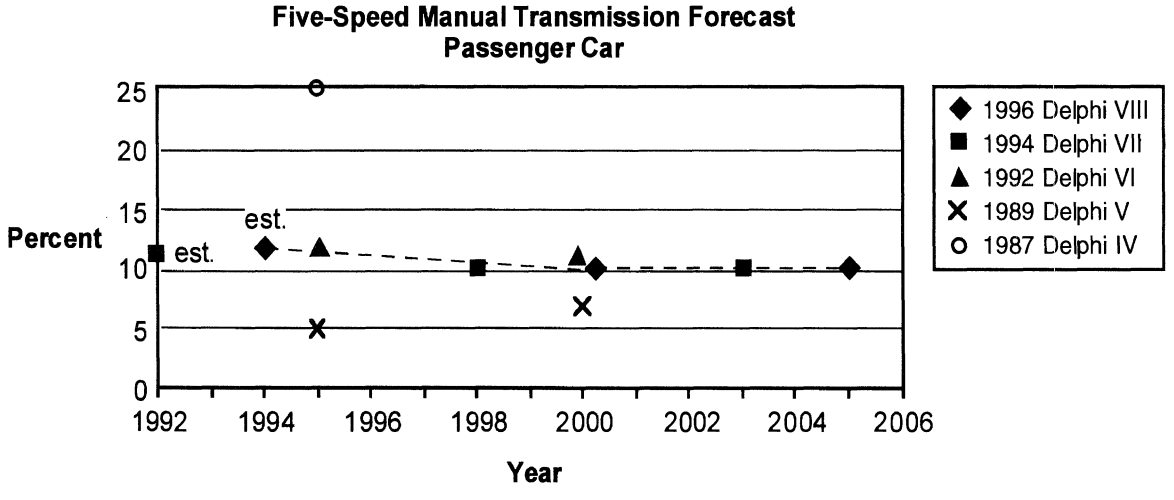
Panelists forecast some application (5 percent) of five-speed automatic transmissions and six-speed manual transmissions (1 percent) by 2005 in passenger cars. Some application (4 percent) of five-speed automatic transmissions is expected in light trucks by 2005. No application of three-speed automatic transmissions in light trucks is expected in 2005. Other transmission configurations are forecast to be little changed by 2005. Four-speed automatic transmissions are forecast to continue their domination in both passenger cars and light trucks.

## Manufacturer/supplier comparison

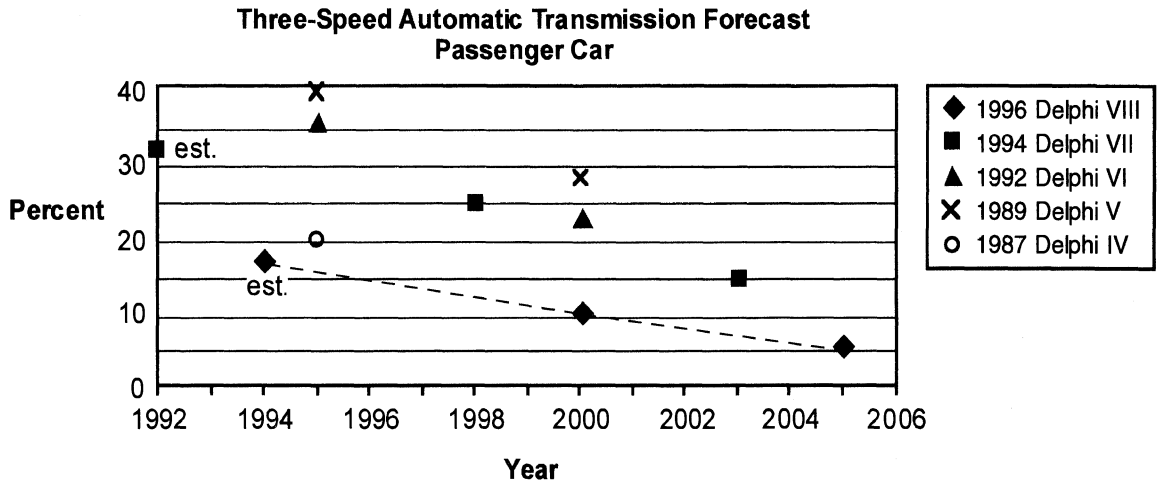
There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Light trucks were not included in previous forecasts. Results of the current survey for passenger cars are compared to those of previous surveys in the following graph.




The results of the current survey for five-speed manual transmissions are similar to results of the previous two surveys. The 1987 and 1989 Delphi forecasts for 1995 were substantially different than the estimated actual penetration for 1994.




The penetration of three-speed automatic transmissions has decreased at a rate faster than forecasted in previous surveys, as evidenced by the estimate for 1994. The current forecast penetration for 2005 is in line with previous forecasts.

## Strategic considerations

Increasing demands for improved fuel economy and performance have driven the trend to increased number of forward speeds in transmissions. Transmissions are one of the many components whose increased cost for improved performance leads to increasing vehicle costs relative to income of the average consumer. Increasing vehicle cost will continue to be a problem for the industry as more customers are not able to afford to buy a new vehicle. Over the life of a vehicle, however, the transmission with a higher number of forward gears will likely return the initial investment, not including lost interest, through reduced fuel consumption

Increasing the number of forward speeds will be one of the tools used by manufacturers to meet future higher fuel economy standards.

A number of panelists commented on an automatic transmission without a torque converter. This design direction warrants watching closely.

**TECH-70. What percentage of North American-produced passenger cars with front engine, front drive will have fore-aft or transverse engine orientation in 2000 and 2005?**

| Engine Orientation | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Fore-aft | 4% | 4% | 4% | 3/5% | 1/8% |
| Transverse | 96 | 96 | 96 | 95/97 | 92/99 |
| Total | 100% | | | | |

*Source: Delphi VII & Estimated guess from Dec. 19, 1994 *Ward's Automotive Reports* (LH output)

## Selected edited comments

- N-S engine front-wheel drive inherently more costly/heavier!
- Reasoning for maintaining fore-aft layout would be passenger cars with a four-wheel drive option.
- While longitudinal may offer some attractive technical benefits, the high investment cost involved in rotating the powertrain would be very difficult to rationalize.

## Discussion

Panelists forecast that the predominant configuration for engine mounting in front-wheel drive passenger cars will continue to be transverse for the next decade.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. Results of the current and preceding surveys are compared in the following table.

| Fore-aft Engine Mounting Forecast—Passenger Cars | | | | | | |
|---|---|---|---|---|---|---|
| | | | Median Forecast | | | |
| | 1992 | 1994 | 1998 | 2000 | 2003 | 2005 |
| 1996 Delphi VIII | — | 4% | — | 4% | — | 4% |
| 1994 Delphi VII | 0% | — | 3% | — | 6% | — |

The use of fore-aft engine mounting by many popular Chrysler models followed the year 1992 which was used as a base for the 1994 survey, Delphi VII. Panelists in that survey forecasted an increasing use of this mounting configuration. Panelists in the current survey do not forecast an increase in use in the next decade.

## Strategic considerations

Advantages for fore-aft mounting of the engine noted in comments in the 1994 Delphi VII survey include compatibility with SLA front suspension, packaging of PUP converters, equal length exhaust, reduced exhaust manifold noise transmission to front of dash and improved front of dash thermal environment. A comment in this survey also notes an advantage for four-wheel drive. Disadvantages noted in the comments in this survey are increased cost and weight.

The tooling cost to convert from transverse to fore-aft mounting would be prohibitive in an existing vehicle. The cost in an all new vehicle with a new transmission may be acceptable.

Considering the advantages and disadvantages of the two mounting configurations, panelists in the current survey forecast no change in future design direction.

**TECH-71. What percentage of North American-produced passenger cars will use the following drivetrain configurations in 2000 and 2005?**

| Drivetrain Configuration | 1994* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Front engine, front drive | 89.6% | 90% | 92% | 90/92% | 89/95% |
| Front engine, rear drive | 10.0 | 9 | 6 | 7/10 | 5/10 |
| Front engine, four-wheel drive | 0.4 | 0.7 | 1 | 0.4/1 | 0.4/2 |
| Total | 100% | | | | |

***Source:** *Ward's Automotive Reports*, Dec. 26, 1994

**Other:** Mid-engine, RWD: 2000 - 0 percent; 2005 - 2 percent; Mid-engine-rear drive: <1 percent for 2000 and 2005.

## Selected edited comment

- CAFE/mass pressures and the lack of benefit over traction control will curtail all-wheel drive except for dedicated off-road and rally usage. Traction control will enable some expansion of the rear drive market (for geographic areas previously dominated by front-wheel drive).

## Discussion

Panelists forecast that front engine, front drive will be the overwhelmingly dominant drivetrain configuration for passenger cars through 2005.

## Manufacturer/supplier comparison

Responses for manufacturers and suppliers are in agreement, with the exception of front engine, four-wheel drive. The results for this combination are shown in the following table.

| Front Engine, Four-Wheel Drive | | | |
|---|---|---|---|
| Mean Forecast | | | |
| 2000 | | 2005 | |
| Mfrs. | Suppliers | Mfrs. | Suppliers |
| 0.8 | 1.6 | 1.3 | 3.9 |

Suppliers forecast a higher penetration of this combination than manufacturers.

## Trend from previous Delphi surveys

Results of the current survey are compared to those of previous surveys in the following table.

| Drivetrain Configuration | 1994 | 1995 | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Delphi VIII 1996 | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1992 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Front Engine:** | | | | | | | | | | |
| Front drive | 89.6% | 76% | 79% | 88% | 88% | 80% | 87% | 90 | 89% | 92% |
| Rear drive | 10.0 | 17 | 18 | 11 | 10 | 15 | 10 | 9 | 9.9 | 6 |
| **Front Engine** | | | | | | | | | | |
| Four-wheel drive | 0.4 | 5 | 3 | 1 | 1 | 5 | 3 | 0.7 | 1 | 1 |

The current and previous two surveys are in close agreement on the rear drive configuration. The 1987 and 1989 surveys, Delphi IV and Delphi V, however, forecasted significantly higher penetration of the rear drive configuration.

The forecast for four-wheel drive declines with each survey.

## Strategic considerations

High-performance vehicles continue to favor the rear drive configuration because of the superior traction available on acceleration on dry pavement due to the shift of weight to the rear wheels. Some large passenger cars also use a rear drive configuration. This configuration is superior for trailer towing because of weight on the rear wheels and higher capacity transmissions available with rear drive. The number of vehicles using this configuration is forecast to decline in the next decade. This is in spite of the improved traction on wet or ice-covered roads available to rear drive vehicles through the use of traction control.

Improved fuel economy with front drive vehicles is a significant driving force to this configuration. Vehicles designed with front-wheel drive have a lower weight per unit of interior volume compared to rear-wheel drive vehicles. This is partially due to the lower weight of the combined transmission, differential and drive shafts. Interior packaging efficiency is also enhanced due to the absence of the driveshaft tunnel.

Traction on wet or ice covered pavement is also a positive factor in the use of front-wheel drive.

The forecast for four-wheel drive continues to decline with each new survey. The popularity of sport utility vehicles may explain this, in that this is an option available to the customer that wants four-wheel drive. For the customer that wants a passenger car with four-wheel or all-wheel drive, the only option today is to buy a Japanese or European car. In areas of the country that have large snowfall and hills, these vehicles sell well. Traction control offers improvement on slippery roads over non-traction control, but cannot match the performance of all-wheel drive.

**TECH-72. What percentage of North American-produced passenger car transmissions will incorporate electronic control (excluding automatic lock-up torque converter) in 2000 and 2005?**

| | | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | 1994* | 2000 | 2005 | 2000 | 2005 |
| Transmissions Incorporating Electronic Control | 65% | 80% | 95% | 75/85% | 85/100% |

*Source: OSAT estimates, *Ward's Automotive Report*, December 26, 1994

## Selected edited comments

- Change will come with every new design/retool program.
- Electronic control may include manual transmission feedback for clutch/gear position.
- Every car manufacturer is moving towards transmission control with engine control.

## Discussion

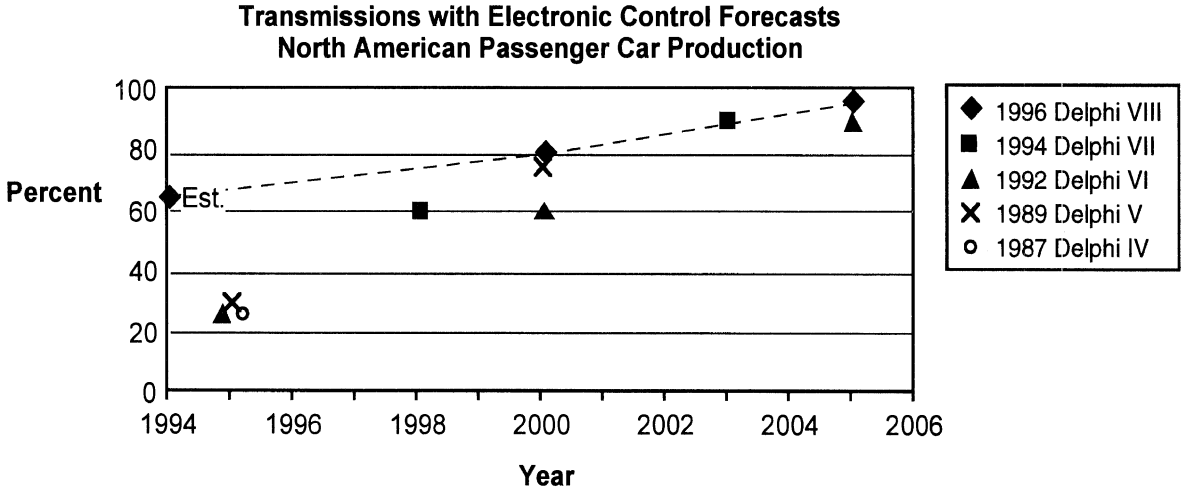
Panelists forecast that almost all transmissions will incorporate electronic control by 2005 as compared to 65 percent in 1994. This trend is driven by the requirement for improved fuel economy, improved shift quality and the desired integration of engine and transmission controls.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results of the current and past surveys are compared in the following graph.




The estimate for 1994 is significantly higher than forecasted in previous surveys. This is the first survey for which an estimate was provided. The forecasts from the current survey for 2000-2005 are in agreement with previous surveys, however.

## Strategic considerations

Electronic transmission control is forecast to be nearly a standard feature on passenger cars by 2005. Improved fuel economy, improved shift quality and integration of engine and transmission control are driving factors for electronic control.

The cost of this feature will decline as the cost of electronics in general declines.

**TECH-73. What percentage of total vehicle cost of North American-produced passenger cars will electronic componentry comprise currently and in 2000 and 2005?**

| | Median Forecast | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current Est. | 2000 | 2005 | Current Est. | 2000 | 2005 |
| Electronic componentry as percentage of total vehicle cost | 15% | 18% | 20% | 10/20 | 14/25 | 17/30 |

## Selected edited comments

- Content will increase, but functional integration and electronics learning curve will keep cost from rising.
- Entertainment; safety—crash sensing, airbag intelligence; modal control and control limit sensing of vehicle; fuel economy and emissions control of engine and transmission; improved control algorithms—neural networks, fuzzy logic will add convenience and effectiveness.
- Includes wires, connectors, etc.
- More electronic content, but price will come down.
- This tends to be supplier-produced.

## Discussion

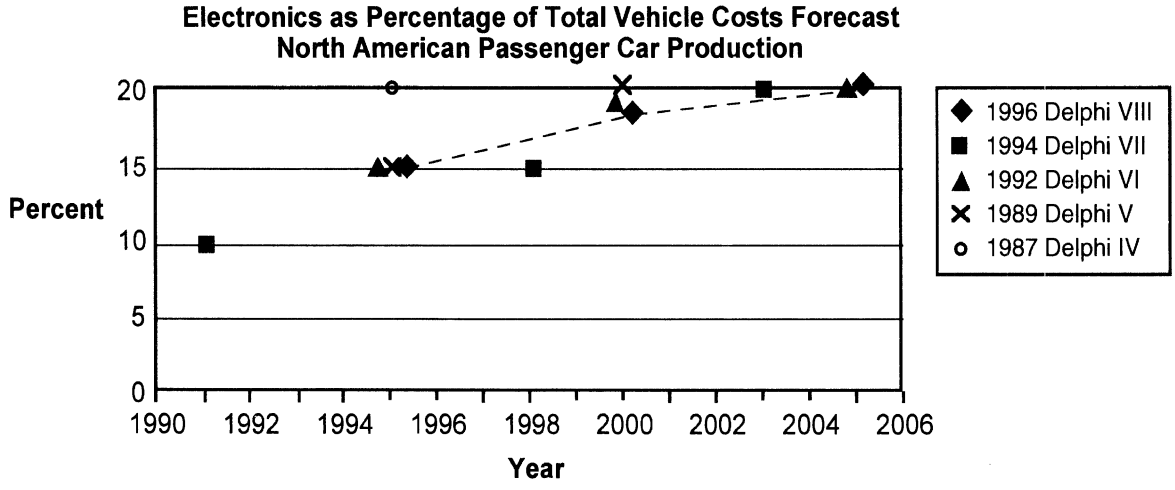
The cost of electronic componentry as a percentage of total vehicle cost is forecast to increase to 20 percent by 2005 compared to a current estimate of 15 percent.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

The results of the current forecast are compared to previous forecasts in the following graph.




There is generally good agreement between the current and past surveys, although the forecast for 1995 made by the 1987 Delphi IV survey substantially exceeds the actual level.

## Strategic considerations

The cost of electronics as a percentage of total vehicle cost is forecast to increase from 15 percent currently to 20 percent in 2005. This is in spite of the general decline in the cost of electronic components. The expected increase in electronic content, therefore, is greater than the forecast for decreased cost.

Expected added electronic systems and features are summarized in the selected edited comments.

The electronics industry has done a truly remarkable job in reducing cost while adding to capability. Wouldn't it be nice if the same were true for mechanical components? The affordability problem would be insignificant. Unfortunately, there is a huge difference between managing electrons and making parts.

**TECH-74. What percentage of North American-produced passenger cars will utilize at least one multiplexed (MPX) power subsystem by 2000 and 2005? Please estimate for current vehicles.**

| Passenger Car | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current Est. | 2000 | 2005 | Current Est. | 2000 | 2005 |
| Multiplexed power sub-system utilization | 3% | 10% | 20% | 1/5% | 5/20% | 10/40% |

## Selected edited comments

- Cost of sensors and actuators will determine usage.
- Driven by wire weight and cost reduction. Limited by cost of interfaces.
- Multiplexing will catch on.

## Discussion

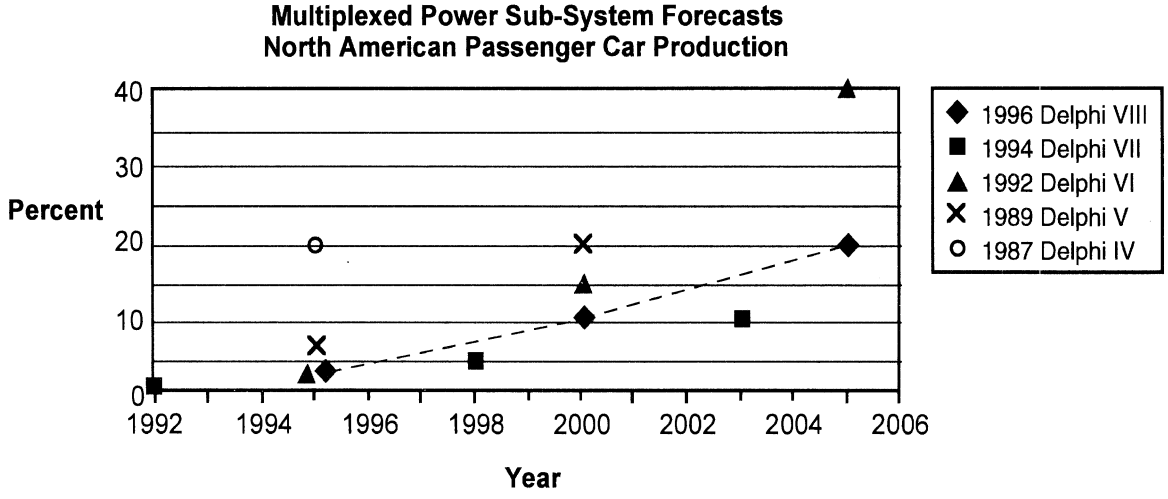
The number of vehicles incorporating multiplexed power subsystems is forecast to increase from 3 percent currently to 20 percent in 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers except for the current estimate. The current mean estimate for manufacturers is 7.8 percent versus 4 percent for suppliers.

## Trend from previous Delphi surveys

Results of the current survey are compared to past surveys in the following graph.




Forecasts for the current survey are on the low side of previous surveys.

## Strategic considerations

As noted in the selected comments, this technology is currently limited by the cost of interfaces. As these costs decrease, application rates will grow, assuming that reliability can be proven. The advantages of weight reduction and reduced space requirements are major incentives for development of the technology.

This is another example where the forecast has not lived up to expectations because of two key factors:

- Moving target of current technology
- Problems with new technology

This is all too common a story when dealing with complex vehicle systems and technologies.

**TECH-75. What percentage of multiplexed systems will utilize a fiber optic control bus technique rather than wire control bus by 2005?**

| | Median Response | Interquartile Range |
|---|---|---|
| Multiplexed systems fiber optics | 8% | 2/19 |

## Selected edited comments

- It will be one step at a time, but these will be in engineering prototypes.
- Mostly between control modules.
- Transfer of TV cable technology is limited by inter-industry communication. It could grow fast about 2010.

## Discussion

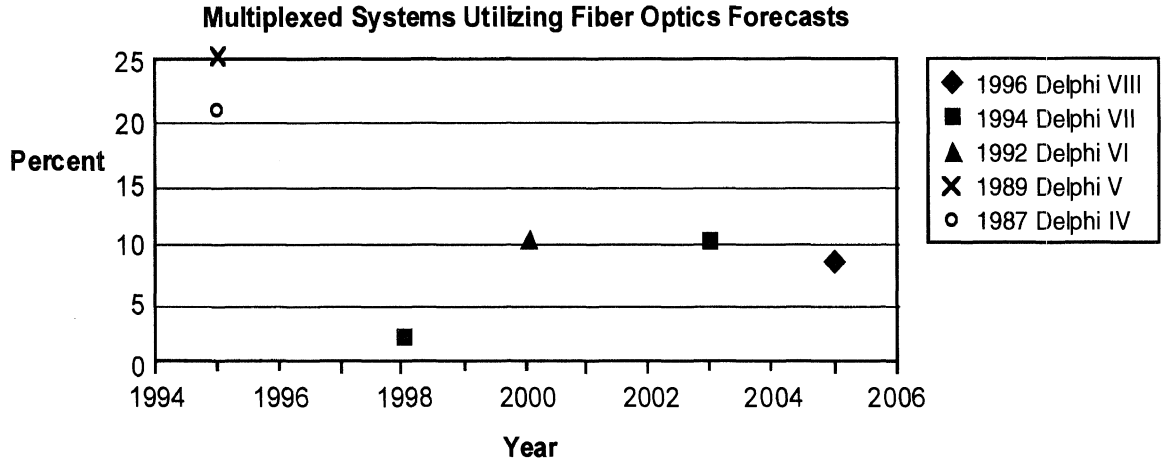
Panelists forecast an 8 percent use of fiber optics in multiplexed systems by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results of the current survey are compared to those of previous surveys in the following graph.




The current forecast is in general agreement with the preceding two forecasts but is well below the forecasts of Delphi IV (1987) and Delphi V (1989).

## Strategic considerations

Application of this technology is much delayed from forecasts in early Delphi surveys. Delays of application will continue until the technology is validated for reliability and cost to the satisfaction of manufacturers. Current panelists forecast that this will begin to take place by 2005.

**TECH-76. How likely will the integration of computer hardware and software be between powertrain, chassis and body in the next decade?**

| Scale: 1 = highly likely 3 = somewhat likely 5 = highly unlikely. |
|---|

| | Mean Rating |
|---|---|
| Computer integration | 2.2 |

## Selected edited comments

- Assumed to apply to onboard systems. This is more a matter of degree than likelihood. The likelihood depends on the degree.
- Computing will remain distributed.
- Concept of totally integrated vehicle system design is still climbing the foothills.
- Desire to reduce cost, mass and assembly hours would tend to strongly drive up integration.
- Distributed control with smart sensors and actuators will be the next generation system so hardware will not be integrated but controls will act as one integrated system.
- It's happening.
- There will be some integration between similar systems, such as ABS/traction control/stability control, or fuel management and ignition, or consolidation of body related items such as security, HVAC, etc. I don't see one central processor for everything, ever.
- Will have separate modules to handle complexity issues. Modules will back up each other to ensure performance is maintained.

## Discussion

Panelists forecast that the integration of computer hardware and software between powertrain, chassis and body in the next decade is likely. Several comments, however, indicate that there will continue to be special purpose hardware and software for some time to come, if not indefinitely.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Strategic considerations

Cost of computer hardware could be reduced and packaging space minimized if the computers used for all systems of the vehicle could be integrated. Panelists state that this integration is likely. Some comments suggest, however, that this integration is in its infancy and may never be complete.

The data could also be interpreted to suggest that while electronics integration is likely, the system could be distributed around the vehicle.

**TECH-77. What percentage of North American-produced passenger cars will employ the following electronic/electrical features as factory-installed equipment in 2000 and 2005?**

| Electronic/Electrical Features | 1993* | Median Response | | Interquartile Range | |
|---|---|---|---|---|---|
| | | 2000 | 2005 | 2000 | 2005 |
| Antitheft | 9.8% | 15% | 25% | 12/20% | 20/40% |
| CD player | 3.8 | 10 | 20 | 5/15 | 10/40 |
| Cellular phones | 0.1 | 5 | 10 | 1/7 | 4/20 |
| Cruise control | 74.8 ** | 80 | 85 | 76/80 | 80/90 |
| Digital audio tape (DAT) | 0 | 1 | 4 | 0/2 | 0/6 |
| Drive-by-wire (electronic throttle control) | 0 | 2 | 5 | 0.5/5 | 2/20 |
| Electronic keyless entry | 16.3 | 25 | 40 | 20/28 | 30/50 |
| Onboard diagnostic via expert systems (AI) | 0 | 5 | 10 | /10 | 5/25 |
| Voice activated/interactive controls | 0 | 1 | 3 | 0/2 | 1/10 |

* **Source:** *Ward's Automotive Yearbook*, 1994
** *Ward's Automotive Reports*, December 26, 1994

**Other:** Brake by wire: 2005 - 30%; Fax: 2000 - 3%; 2005 - 5%; Message systems: 2000 - 5%; 2005 - 10%; Electronic rear view mirror: 2000 - 5%; 2005 - 10%; Navigation systems: 2000 - 2; 2005 - 4.

## Selected edited comments

- CDs will have more information than just music. Electronic gadgetry is highly accepted.
- Cellular phones are increasingly important and a safeguard for emergency situations. Urban areas will be the primary users of cellular phones.
- Factory-installed cruise control will come as a result of drive-by-wire.
- Onboard diagnostic via expert systems (AI) excludes emission OBD-II systems.
- Re: Cruise control—Some will be "smart."

## Discussion

Panelists forecast that the application of many electronic/electrical features as factory-installed equipment will significantly increase by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers for all features except those shown in the following table.

| Electronic/Electrical Features Forecast | | | | |
|---|---|---|---|---|
| Features | Mean Forecast | | | |
| | 2000 | | 2005 | |
| | Mfr. | Supplier | Mfr. | Supplier |
| CD Player | — | — | 36% | 22% |
| On-board diagnostic via expert systems (AI) | 20% | 7% | 29 | 17 |

Manufacturers forecast higher application of CD players and onboard diagnostic via expert systems than suppliers.

## Trend from previous Delphi surveys

Results of the current survey are compared to those of past surveys in the following table.

| Electronic Features | 1993 | 1995 | | | 1998 | 2000 | | | 2003 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Delphi VIII 1996 | Delphi IV 1987 | Delphi V 1989 | Delphi VI 1992 | Delphi VII 1994 | Delphi V 1989 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| Anti-theft | 9.8% | — | — | — | 15% | — | — | 15% | 25% | 25% |
| CD player | 3.8 | — | — | — | 6 | — | — | 10 | 15 | 20 |
| Cellular phones | 0.1 | 15% | 5% | 10% | 5 | 15% | 25% | 5 | 10 | 10 |
| Cruise control | 74.8 | — | — | 70 | 75 | — | 90 | 80 | 80 | 85 |
| Digital audio tape (DAT) | 0 | — | — | — | 2 | — | — | 1 | 5 | 4 |
| Drive-by-wire (electronic throttle control ) | 0 | 5 | 1 | 2 | 2 | 5 | 10 | 2 | 7 | 5 |
| Electronic keyless entry | 16.3 | 15 | 5 | 10 | 20 | 15 | 25 | 25 | 25 | 40 |
| On-board diagnostic via expert systems-AI | 0 | — | — | 5 | 2 | — | 15 | 5 | 10 | 10 |
| Voice activated/ interactive controls | 0 | 10 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 3 |

Results of the current survey are similar to those of previous surveys except as follows:

**Cellular phones**: Current and 1994 surveys lower than previous surveys

**Electronic Keyless entry**: Current survey higher than previous surveys

## Strategic considerations

Vehicle cost increases for application of new required emissions and safety features will compete with consumers' dollars for new discretionary electronic features. In spite of cost increases in other areas, however, panelists forecast a significant increase in application rates of many electronic/electrical features. This increase will provide excellent business opportunities for suppliers of electronic components in the next decade. Fortunately the trend to unit cost reduction of electronics could mitigate some affordability concerns.

In the rapidly changing field of electronics, it is likely that a number of new features that are unknown today will see significant application in the next decade.

**TECH-78. What percentage of passenger cars produced in North America will utilize the following systems voltages by 2005?**

| Voltage level | Median Response | Interquartile Range |
|---|---|---|
| 24V | 5% | 0/10% |
| 36V | 0 | 0/0 |
| 48V | 0 | 0/0 |
| 12/24V | 10 | 5/20 |
| 12/36V | 0 | 0/7 |
| 12/48V | 0 | 0/5 |

## Selected edited comments

- Benefit of higher voltage, permitting smaller conductors, will be hindered by current support infrastructure.
- Don't see much movement away from 12V. High cost to revise impacted systems and the lack of clear, credible benefits for higher voltage; tends to imply status quo will prevail.
- Good subject for a USCAR consortium project.
- If it allows accessory downsizing—weight save/fuel gain.

## Discussion

Panelists forecast a 5 percent application of 24V systems and a 10 percent application of 12/24V systems by 2005. The driving forces to higher voltage systems are more efficient electrical systems due to lower current flow, smaller alternators for ease of packaging and smaller wires for packaging.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the present form in the 1994 Delphi VII survey. There were no alternatives to the present 12V system that received a median response greater than zero.

## Strategic considerations

A rapid change in system voltage is unlikely because of the many components that must be changed to accommodate the higher voltage. This will be a very complex process requiring significant coordination. A gradual change to another voltage is likely, with interim vehicles having a multiple voltage system such as the 12/24V system. In this manner, tooling can be changed one component at a time over a period of time.

The advantages of higher efficiency and improved packaging will continue to keep this issue under consideration.

**TECH-79. How many rotating and linear electric motors will standard and upscale North American-produced passenger cars have in 2000 and 2005? Include door locks, mirrors and trunk lid actuators. Please provide your estimate for current vehicles.**

| Passenger Cars Having Rotating and Linear Electric Motors | Median Response | | | Interquartile Range | | |
|---|---|---|---|---|---|---|
| | Current Est. | 2000 | 2005 | Current Est. | 2000 | 2005 |
| Standard <$25,000 | 10 | 15 | 20 | 6/16 | 8/24 | 10/25 |
| Upscale >$25,000 | 20 | 25 | 30 | 15/29 | 15/35 | 20/40 |

**Other responses:**

- Door locks - 4
- Drivers door - 1
- Drivers seat - 5
- External mirrors - 4
- Fuel pump - 1
- Hood - 1
- Massagers - 2
- Moon roof - 1
- Passenger seat - 4
- Radiator fan - 1
- Radio antenna - 1
- Rear seat - 2
- Rear view mirror - 2
- Tire pump - 1
- Trunk - 1; HVAC fan - 1
- Windows - 4

## Selected edited comments

- I see piezoelectric actuators replacing some electric motors by 2005. These will probably be for locks, mirrors and low force devices.
- Seat and window motors largest contributors to $25,000 vehicle. Hopefully pneumatic/hydraulic power distribution could cut down on cost and weight.
- Somewhat constrained by affordability/income growth considerations.

## Discussion

The number of electric motors is forecast to increase by 100 percent for vehicles costing less than $25,000 and 50 percent for vehicles costing more than $25,000 by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

Results from the current survey are compared to those of the previous two surveys in the following table.

| Passenger Car Rotating and Linear Electric Motors Forecasts | | | | | | | |
|---|---|---|---|---|---|---|---|
| For the year → | 1995 | | 1998 | 2000 | | 2003 | 2005 |
| Vehicle Type | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| Standard <$25000 | 10 | 10 | 12 | 12 | 15 | 15 | 20 |
| Upscale >$25000 | 20 | 20 | 20 | 25 | 25 | 24 | 30 |

The current and previous two surveys are in reasonably close agreement.

## Strategic considerations

The results of this survey imply that future vehicles will have added cost and weight as a result of an increased number of electric motors. The features that these motors drive will also add cost and weight. The vehicle affordability issue and the anticipated requirements for weight reduction for improved fuel economy are in opposition to the addition of more features requiring more electric motors.

Larger alternators may also be required to drive these additional motors. Current alternators are already near their limits of packaging capability.

For suppliers of electric motors, the forecast portends good things to come in the next 10 years, but the technology could shift to other types of actuators.

**TECH-80. What percentage of North American-produced passenger cars will be equipped with these electric motor-driven devices by 2000 and 2005?**

| Electric Motor-Driven: | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| A/C compressor | 1% | 3% | 0/5% | 0/10% |
| Air pump | 5 | 10 | 1/15 | 3/30 |
| Power brakes | 2 | 5 | 0/10 | 2/15 |
| Power steering pump | 2 | 10 | 1/6 | 3/16 |
| Water pump | 0 | 1 | 0/5 | 0/8 |

## Selected edited comments

- A/C compressor and power steering pump will depend upon electric vehicle production.
- Alternators are already maxed out; new technologies for alternators must come first.
- If the power steering pump is electric, it is likely to go all-electric power steering. Requires attention to alternator efficiency. This is likely to become all or none.
- This trend would be driven by electric and hybrid vehicles.

## Discussion

Electric motor-driven air pumps and power steering pumps are forecast to have penetrations of 10 percent or less by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1992 survey, Delphi VI. The results of the current survey are compared to those of previous surveys in the following table.

| Electric Motor-Driven Devices Forecasts | | | | | | |
|---|---|---|---|---|---|---|
| For the year→ | 1995 | 1998 | 2000 | | 2003 | 2005 |
| Motor Driven Device | Delphi VI 1992 | Delphi VII 1994 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| A/C compressor | 0% | 0% | 5% | 1% | 5% | 3% |
| Air pump | 3 | 3 | 10 | 5 | 5 | 10 |
| Power brakes | — | 0 | — | 2 | 5 | 5 |
| Power steering pump | — | 1 | — | 2 | 5 | 10 |
| Water pump | 0.5 | 0 | 3 | 0 | 3 | 1 |

The results of the current survey are in general agreement with previous surveys except:

**Air pump:** Delphi VI (1992) had a higher forecast for 2000.

**Power steering pump:** Current survey is higher for 2005.

## Strategic considerations

Electric motor-driven accessories can be controlled to run only when they are required. This provides a fuel economy advantage compared to engine-driven devices that have a parasitic power draw when not in use.

Alternator capacity may be a problem with additional electric motor-driven devices. Many vehicles today cannot package larger alternators. Load management may be able to control these requirements.

Electric motor-driven devices may be an advantage for under-hood packaging.

**TECH-81. What percentage of North American-produced passenger cars will utilize noise cancellation technologies by 2000 and 2005?**

| Technologies | Median Response | | Interquartile Range | |
|---|---|---|---|---|
| | 2000 | 2005 | 2000 | 2005 |
| **Electronic Interior Noise Cancellation** | | | | |
| Digital signal processing (DSP) systems integrated into audio systems | 1% | 5% | 0.5/4% | 2/10% |
| **Electronic Exhaust Noise Cancellation** | | | | |
| "Electronic" muffler | 1 | 4 | 0/3 | 1/8 |

## Selected edited comments

- Do not see electronic muffler being cost effective. DSP and active sound are not effective unless speakers are close to ears–in headrests or headsets.
- DSP is a gimmick item that might sell on some luxury cars. Electronic muffler could improve engine efficiency.
- May enable reducing mass of conventional noise reduction measures, reduced glass thickness, etc.
- Noise control is increasingly important. Automotive carpet manufacturers are introducing carpets to reduce NVH in vehicles. Masland Industries has devoted two labs to the study of interior noise.

## Discussion

Panelists forecast 5 percent or less application of electronic noise cancellation technology by 2005.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the 1992 survey, Delphi VI. A comparison of the current survey to previous surveys is shown in the following table.

| Electronic Noise Cancellation Forecast | | | | | |
|---|---|---|---|---|---|
| For the year→ | 1998 | 2000 | | 2003 | 2005 |
| | Delphi VII 1994 | Delphi VI 1992 | Delphi VIII 1996 | Delphi VII 1994 | Delphi VIII 1996 |
| **Technology** | | | | | |
| Electronic Interior Noise Cancellation | 1% | 10% | 1% | 5% | 5% |
| Electronic Exhaust Noise Cancellation | 1 | 10 | 1 | 5 | 4 |

The 1992 survey, Delphi VI, forecasted significantly higher penetration for both technologies (10 percent) than did subsequent surveys. The last two surveys are in agreement.

## Strategic considerations

Electronic noise cancellation is forecast to have limited application through 2005 in spite of the potential to reduce vehicle weight by reducing the amount of sound-absorbing materials. Cost is a prohibiting factor. This technology may be used to a limited extent on some niche luxury vehicles.

Electronic mufflers offer the potential of increased performance by reducing exhaust back-pressure.

A breakthrough in the area of cost could change the outlook for this technology.

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**TECH-82. What new technologies that have not been previously covered in the questionnaire are likely to emerge in the next decade that will have significant impact on the following vehicle systems?**

## Responses: Engine

- Alloys other than steel/aluminum/ceramic.
- APU for hybrids.
- Coolant management, lightweight crank, rods and pistons (and pins), better ignition system.
- Electromagnetic valve actuation.
- Improved cold start emissions to avoid use of electric. Heated catalysts and particulate controls (all fuels); completely sealed engines.
- Improved fuel control during crank, start-up, and transients; lean burn two-stroke engine.
- Low mass, high efficiency modular design, simplicity, low cost manufacturing.
- New internal combustion engine configurations—hydrogen powered Wankel perhaps? Infinite variable induction systems.
- OBD II; very high mileage warranty and tuneup intervals.
- On-board diagnostic systems will have an overwhelming impact.
- Synthetic lubricants; flex manufacturing; package size reduction.
- The adoption of compacted graphite cast iron. In some material tables it would be preferable to separate cast iron into "gray iron" and "compacted graphite" since the adoption of compacted graphite could have a substantial impact on the current trend toward light metals. Compacted graphite's improved properties will be better able to withstand the competitive pressures of aluminum and magnesium than does conventional gray iron.
- Cylinder cut-out.
- Wider use of hydraulic engine mounts, variable tuning devices for engine mounts.

## Responses: Transmission

- Adaptive electronic control (Porsche Tiptronic-type).
- CVTs.
- Improved efficiency, less weight.
- Infinitely variable.
- Maintenance-free automatics.
- Material development; electronics.
- More combination of functions to reduce weight and cost.
- New actuation methods for automatics, pedalless clutches for manuals.
- Single speed for electric.
- Smaller package; integrated with engines.
- Transmission and engine control electronics combined (integration).

## Responses: Body

- Adhesive bonding with spot-welding.
- Body panels that can be easily swapped to change color or appearance of vehicle. Extreme would be a change from a minivan to a pickup by swapping upper rear body unit.
- Fasteners and other design advances to allow increased use of nonsteel materials.
- Low mass, low manufacturing cost, smaller, weld bonding technology.
- More combination of functions to reduce weight and cost.
- Reduced front overhang vs. crash energy.
- Speech recognition.
- Structural composites.

## Responses: Chassis

- Active roll stabilization.
- Aluminum.
- Aluminum/composite frame and structural products.
- Composite rotors.
- Electric and/or electric-hydraulic brakes.
- Electronic controlled suspension, modularized systems, low mass, low manufacturing cost.
- Fasteners and other design advances to allow increased use of nonsteel materials.
- Hydraulic high damping bushings, electrorheological or variable tuning of engine mounts.
- Hydroformed structures, composite frames.
- Integration of batteries (for electrics/hybrids as structural members). Hydroformed frames/ subframes for optimum strength/weight.
- Mass reduction; drag reduction (brakes, bearings, steering loads, yaw control); stability augmentation.
- Materials/composites.
- Softer riding multi-link suspensions.
- Total vehicle stability systems via ABS sensing and single wheel or axle-by-axle brake manipulating.
- Trend to fixed-piston caliper brakes and improved brake cooling.

## Responses: Electrical

- Electric traction motors and controllers.
- Electrical load reduction/management; electrical power availability.
- Electronic (real time guidance).
- Electronic multiplexing of data in the vehicle; three-volt logic, 32-bit micro's.
- Embedded "one piece part" electronics including software for piece part customization.
- Greater use of HID headlights. Minimization of electro-mechanical devices, for reliability's sake.
- Head up displays, radar detection, reduced power consumption via microprocessor controls.

- Interactive architecture, modularized, low mass, fiber optic introduction as common feature.
- Piezoelectric actuators.

## Responses: Safety

- Adaptive airbag systems which will respond to crash, temperature and occupant characteristics.
- Bilaminate and trilaminate to replace tempered glass applications (for safety).
- Collision avoidance; emergency calling.
- Continued trend to more responsive, predictable vehicle handling. I hope and pray for stricter driver's license requirements. Better windshield cleaning system.
- Handling parameters incorporated into ABS system.
- Homing devices ("Lo-Jack") for anti-theft.
- Integrated child seats will have to conform to increasingly tougher standards. The use of colors and labels will have to adhere to world safety standards.
- Night vision.
- Occupant-sensing, programmable air bags, seat belt pretensioners, lidar/radar/ultrasonic collision-sensing, vehicle armament (yes, bulletproofing).
- Occupant sensors.
- Passive antitheft systems.
- Rollover and rear collision protection; integrated child seats and adult seats.
- Aspheric mirrors, alternate airbag propellant, single point sensing.
- Smart airbag deployment controls.
- Structure of vehicle will be fitted around occupant–perhaps fixed seats and moveable controls.

## Responses: Comfort/convenience

- Automatic climate control more widespread. Continued trend to more ergonomic and better feeling switches/controls.
- Automatic/smart wipers.
- Hot/cold beverage keepers.
- Individualized HVAC controls and systems, adjustable rear seats, elimination of ash trays.
- Load-sensitive seating
- New focus as human factors expand to intellectual comfort; pseudo-exercise systems will come in—especially when automated highway is implemented.
- Occupant sensing (smart key or smart card) for vehicle comfort/convenience/entertainment programmability.
- Personality enhancements; electronic noise cancellation.
- Power sliding door on vans.
- Seats.

### Responses: Glass

- Antichip, thinner, lighter.
- Auto light sensing and darkening, auto antifogging and anti-icing, power-off opaque for security.
- Better insulation.
- Electronic tint control.
- Glare reduction coatings. Less distortion in compound curves.
- Mass reduction (thin but strong, plastic laminates); glass alternatives; more impact/tamper resistant.
- Plastic glazing hard coated polymers.
- Side safety glass, plastic glazing, structural glass electrochromic glass/coatings.
- Solar, thick or bilaminate.
- Thinner laminates, plastic composites for side windows.
- Tint change with light.

### Responses: Vehicle interior

- Adaptive seating, climate controlled seats, reconfigurable displays (old vs. young requirement).
- More fire resistant.
- New seat suspensions.
- Panels that can be replaced to change color by owner. Further integration of components (i.e., heater ducts formed in structure of dashboard). Improved use of space, either for occupants or storage, by using more coordinated, integrated design efforts.
- Passenger security while in the vehicle.
- Seat cushion with air controls.
- The starting point of vehicle design.

### Responses: Other

- "Green" issues become marketing/merchandising driver.
- Continued push on vehicle durability.
- Cut off of A/C and alternator for short duration, accelerations (or other power demands) to reduce engine size while maintaining vehicle performance, in order to improve mpg.
- Occupant entertainment and support of business activity will create new systems.
- Software–necessary for the adaptation of new electronic features/functions. New software development programs that are "engineer friendly." Gender/age customization of vehicle features.

### Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

### Trend from previous Delphi surveys

This question was not asked in a previous Delphi survey.

## Discussion/Strategic considerations

Numerous technologies, materials, components or systems have been noted by panelists as items that are likely to emerge in the next decade that will have significant impact on the vehicle. Some of the items are expansions or improvements of current technologies. Others are new ideas and new technologies. Many of these items offer the opportunity for a manufacturer to develop a competitive edge through the early introduction of the item or technology if, of course, customers value them.

**TECH-83. Considering the technical changes in vehicles, please forecast the trend in service activity for dealerships over the next 10 years (1995-2005).**

| Scale: 1 = sharply increase 3 = no change 5 = sharply decrease. |
|---|

| Dealership Service Activity | Sharply Increase |
|---|---|
| Electrical/electronics | 1.6 |
| Non-CFC refrigerant conversion | 2.0 |
| Body shop | 3.0 |
| Mechanical | 3.0 |

**Other responses:**

Emissions diagnostics: 2. Driven by IM240 -type tests. Fixes will be easy-diagnostics to find the root cause. Will require new skills and tools.; Engine: 1 - due to 100,000 miles emissions requirements.; Non-dealer service and higher dealer prices: 5; Preventive maintenance: 2.

## Selected edited comments

- Consider the possibility of the trends in OEM-dealer relations continuing or changing abruptly; also consider the trends driven by special service outlets and rising costs of service. Consider further the possibility that by 2005 the sales/lease contract will leave more or all responsibility and costs for service on the OEM-dealer combination. One sees signs that some discontinuous changes in responsibility for service are on the horizon. They might be combined with or driven by mandatory junking of vehicles that are unsafe or environmentally unfriendly.
- Increased content in electrical/electronics area must be offset by improved QRD!
- Less non-CFC refrigerant conversions because new cars will be non-CFCs, and cost to convert older cars will become less attractive as the vehicle values decrease.
- No change in dealership body shop activity but will require new skills.
- OBD II and increasing emission requirements/more sophisticated emissions hardware will result in increased dealership (vs. other) service activity.
- Service from dealerships is extremely difficult and time-consuming. The end user will look for more convenient ways for repair. Snap in/snap out modules for electronics. Simple components that can be fixed by someone other than the dealer.

## Discussion

Panelists forecast an increase in service activity for dealerships in the next 10 years in the areas of electrical/electronics and non-CFC refrigerant conversion. Body shop and mechanical repair activities are forecast to not change in that time frame.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Trend from previous Delphi surveys

This question was first asked in the same format in the 1994 survey, Delphi VII. Results of the two surveys are compared in the following table.

| Dealership Service Activity | Mean Rating | |
|---|---|---|
| | 1994 Delphi VII | 1996 Delphi VIII |
| Body shop | 2.9 | 3.0 |
| Electrical/electronics | 1.6 | 1.6 |
| Mechanical | 3.7 | 3.0 |
| Non-CFC refrigerant conversion | 1.8 | 2.0 |

Mean ratings were very similar for the two surveys, with the exception of the mechanical area. Panelists in the current survey rate this area as no change, whereas those of the 1994 survey, Delphi VII, rated this area as decreasing somewhat.

## Strategic considerations

Some very thought-provoking comments are offered by the panelists. The issue of leasing may very well impact service and where it is performed. Since vehicles are generally leased from dealerships, it is very reasonable that the service on these vehicles will be done in dealerships almost exclusively. As the number of leased vehicles increases, it is likely that the amount of service done by dealerships will increase also. This affects new vehicles but may have little impact on vehicles more than three years old.

The increasing complexity of vehicles, particularly in the area of electronics, makes service by dealerships more likely in this area. Special testing equipment and training will be more and more required to service vehicles in the future.

Two trends that are counter to each other with regard to service are the increasing reliability of vehicles and the increasing complexity and contenting of vehicles. In recent years, overall vehicle reliability has improved even as vehicles have become more complex. If this trend continues–and it is likely that it will–the size of the total service pie may decrease.

Increased use of on-board diagnostics will facilitate faster, more reliable service. Major advances in this area are expected in the next few years.

**TECH-84. Please indicate your estimate of supply deficiencies for the following skill areas and job functions.**

| Scale 1 = extremely severe 5 = not at all severe |
|---|

| Occupation/Training | Current Rating | 2005 Rating |
|---|---|---|
| Engineer | | |
| Chemical | 3.5 | 3.2 |
| Electrical | 2.8 | 2.5 |
| Industrial | 3.4 | 3.2 |
| Manufacturing | 2.6 | 2.5 |
| Materials | 3.0 | 2.8 |
| Mechanical | 3.0 | 2.8 |
| Systems | 2.4 | 2.3 |
| Designer | 2.9 | 2.8 |
| Software writer/designer | 2.6 | 2.5 |
| CAD/CAM/CAE | 2.6 | 2.6 |
| Electronics technician | 2.7 | 2.4 |
| Service technician | 2.8 | 2.5 |
| Skilled trades | 3.1 | 2.7 |

**Other responses:**

Efficient engine managers: Current - 1; 2005 - 2; Executive and Electronic Engineer: Current - 2; 2005 - 2; Process metallurgy engineers: Current - 2; 2005 - 2; Project/Program Managers: Current - 1; 2005 - 1

## Selected edited comments

- Engineering is becoming an ever increasing global profession. This will continue to drive down salaries in North America; however, China, India and other countries will fill the void.
- If we are to provide better materials, we must have more engineers who not only understand the materials but also the production processes and how these affect the ultimate properties of the materials. It is not only industrial engineers (logistics, queuing theory, etc.) and manufacturing engineers (equipment, productivity, quality). We must also have process engineers who can measure and control the process itself.
- Level of technical expertise is increasingly demanding on the resource base. The current level of staff is slim due to the experience base in the resource pool. Not enough awareness is placed on engineering and technical positions as a viable career option. Many students that aspire to the career option often do not have the economic means to go to school. Project/program managers will be an emerging profession due to OEMs moving toward full service supply base.
- Mechanical engineers that understand electronics and electrical engineers that understand mechanical engineering.
- Quality and skill level and continual extensive updating and advancement of each engineer's capabilities are more important than numbers. Also, enhancements of productivity will reduce demand. All this interacts with supply.

- The shift to electronic controls will strain electrical engineering resources unless the transition from military continues. Biggest strain is on management to make mechanically-based engineers adapt to electronic control of integrated vehicle system.
- The skill deficiencies are brought about, mostly, by resource allocation restrictions at each company. The talent is being developed or available. Systems and software writer/designer areas are truly deficient.

## Manufacturer/supplier comparison

There is no statistically significant difference in responses between manufacturers and suppliers.

## Discussion/Strategic considerations

Panelists forecast that the deficiency in skilled personnel will change little by 2005 from what it is today. For all areas listed, the current supply deficiency is rated as somewhat severe.

Several excellent comments are noted. Of particular interest is the comment related to the globalization of engineering resources. There is considerable evidence of this trend today. It is apparent in industry and education today that many, if not most, of the highly technical people working and studying in the United States are not originally from the United States. Many of the brightest students from the United States are choosing other fields of study that offer greater monetary rewards. Eager students from other countries are filling the void.

**TECH-85 What new skills will be required in your organization in the next decade, and what educational changes should be made to provide these skills?**

## Computer:

- Structured initiatives for training in software design methods and practices, and the use of information technology are essential.
- Validation by analysis.
- Virtual reality applications of 3D CAD.
- Rapid prototyping.
- Interdisciplinary with superior computer base.
- Engineer and designer functions are merging into one. Need new graduate engineers trained in CAD and CAE tools. Robust design/parametric design needs to be taught and experimental design/test methods to support.
- Continued growth of analysis capability.
- CAM skills acquired in college.
- Virtual prototyping.
- Better understanding of micro processors by mechanical and chemical engineers (I think this is progressing).
- More predictive/analysis skills for CAE (FEA, etc.).
- Structural mechanics; more emphasis on statistical experiments, quality tools and structural mechanics in engineering courses.
- Computer modeling.
- Enhanced (engineering type) skills of our product designers; enhanced computer modeling skills of vehicle systems and vehicles as a whole; companies must provide more educational skill type training in the future.
- Computer skills for correspondence with suppliers, managing programs and SPC will need enhancement.
- Much greater emphasis on electronic prototyping, CAD metal flow simulations.
- Manufacturing assembly and process simulation via computer.
- Modeling capabilities to evaluate parameter variations.
- Higher level of computer modeling capability.
- Even more CAD/computer skills, interconnectivity (Internet, WWW) to get more information for internal use.
- CAD and simulation tools at both product and system level.

## Continuing Education:

- There must be much greater time, money and management, and individual professional attention and effort devoted to intensive and customized career-long development of the engineering and technology capabilities of every individual engineer, engineering leader and technician. It must yield additional intellectual capability, knowledge and skill that is equivalent to what one would expect from 100 hours per year "in class" plus twice that much preparation. That learning must be customized to the next two-to-five years of each individual's likely career path and the organization's/automotive industry's likely needs and opportunities. That's a big challenge and opportunity and one that's not being met anywhere or adequately. Given the attention to total life

cycle, and the progress being made and likely to be made in longer life (years and miles) parts and cars, the impact of this factor on the car market should be assessed!

- Continued education throughout employment will become even more important. "Broader picture" engineers that can develop a specialty and also look beyond it to the entire manufacturing system.
- Solid modeling; computer simulated durability; CAE; reliability analysis.
- Training must be a regular part of the program. Training skills must be learned by all leadership levels. Leadership must be actively involved in all training activities.
- A dedication to continued learning.

### Culture:

- Ways to change the culture, break the molds and get faster, more nimble.
- Understanding the Japanese mindset.
- Understanding of global requirements and needs; ability to work in teams.
- People skills–collaborative decisions–teamwork.
- Language skills (particularly Japanese) as our market becomes more global.
- Global awareness of markets and cultures; interacting with people from many cultures on their turf.

### Design/development processes:

- A greater understanding and definition of the engineering/product development cycle and the systems and processes involved will be needed. QS-9000 certification will help to force this issue to upper management's attention.
- Greater emphasis on the process of engineering.
- A much better understanding of the engineering process must be developed and executed. This entails training on who does what, interdependencies, and relative timing and coordination required to efficiently execute the project. I do not see enough focus on how engineering is done from concept through launch.

### Economics and Cost/value:

- Economics are as important as functional requirements today. Engineers need to understand constraints better–not just forces and materials. The days of unlimited resources are long gone.
- Engineers with understanding of cost/value; introduce cost/value concepts to engineers at undergraduate level.

### Manufacturing:

- Manufacturing engineers with detailed metal working knowledge and experience.
- Need more intelligent manufacturing organization.
- Logistics and sequencing.
- Engineers will need to understand lean manufacturing and design to manufacturing process capabilities.
- Manufacturing.
- Manufacturing engineers; manufacturing methods must be added to the design engineers process.

- More skilled trade personnel with tooling development capability.
- Understanding of ergonomic stressors on the assembly line; more emphasis on industrial engineering and productivity gains.

### Materials:

- Need highly skilled specialists who can understand and implement new process and material technologies.
- Materials are changing so rapidly and can be tailored to specific tasks. We need a lot more materials/M.E.s/manufacturing of new materials types of people.
- Ceramic engine.
- Greater specialization in materials.

### Project Management/Organization:

- Improved project/program management skills.
- Better managers, less engineers, greater marketing expertise.
- We will need training in matrix management and in operating "virtual" organization.
- Program management expertise and more program managers.
- Management skills to use resources to reduce product development time.
- Engineers will be expected to be total project manager. Managers, skills in program management, product development, process management, quality management, and customer management will be expected. Cross-functional training will be critical—universities need to push total program management.

### Quality/Reliability/Durability:

- More DFMA, error proofing and involvement in process engineering—both for suppliers and internal manufacturer.
- Reliability prediction techniques.
- More statistical training for engineers (this is not progressing satisfactorily).
- Reliability engineering.
- Better knowledge of TQM is required.
- Continued emphasis on reliability/durability of vehicles over the intended useful life—will require knowledge of reliability techniques.
- Understanding of reliability/quality parameters and techniques for increasing these in every product.

### Personal Development:

- Training, management championing and mentoring, consistent usage and measurement.
- Higher sense of "make it happen" and "self confidence" (motivational).

### Systems Engineering:

- Systems engineering.
- More emphasis on systems engineering vs. "widget" engineering.
- More system engineers.

- Systems engineering combined with rapid decision making skills. Requires more "soft science" skills in technical organizations.
- Formal "systems engineering" skills will be absolutely essential at the OEMs and first and second tier suppliers. "Systems engineering" skills require in-house training and senior management buy in to be effective.
- Systems simulation.
- Skills on new and advanced area of current automobile technologies will be required. Skills on system engineering based on new technology will be needed. Example: laser technologies incorporated into vehicle systems.
- System integration skills; greater technical skills to absorb the greater role of supplier engineering requirements.
- Mechanical/electrical/electronics integration engineering; offer courses which require cross discipline integration.
- Major shift to systems engineering thinking/deployment; continued/expanded use of electronics to control mechanical devices—mechanical/electrical engineering skills must merge.
- Ability to clearly define system requirements.
- Design automation skills becoming crucial along with system/sub-system engineering. Educational institutions should offer more courses addressing the above. As the use of electronics increase, skills related to electronic systems engineering and software will be critical.
- Systems engineering and vehicle integration are growth areas; better linkage of packaging/ requirements engineering/design/analysis is an area of growth and opportunity.

### Miscellaneous:

- Visualization skills—solid model creation skills; engineers who can do everything required to complete a program.
- We need to find easier and faster methods to translate "voice of the customer" in reliable product with perceived value.
- Scope of workers' jobs will be much greater—more tools and resources available, but greater accountability will be a key—will polarize the workforce. Including people in overall corporate direction information and rewarding them for their contributions to corporate goals.
- Math and science, even for production line jobs.
- Ability to visualize detail design and how to evaluate strength and weakness before prototype build.
- Greater knowledge of customer direction on new models.
- More knowledge of control systems and tools.
- Electronics is involved in everything.

## Strategic considerations

Panelists have noted a wide range of new skills and improvements in current skills that will be required in the next decade. These comments cover virtually all aspects of engineering and business including people skills, understanding diverse cultures, materials, processes (engineering and manufacturing), design, computer applications, prototyping, reliability, organizational development, new technologies, cost/value relationships, manufacturing, customer requirements, project management, cross-functional requirements and systems engineering.

Many of the comments relate to changes required in engineering and business colleges at the undergraduate or graduate level. Many others, however, relate to ongoing education required to keep engineers and managers up-to-date on rapidly changing technology and organizational philosophies.

The comments should be reviewed by both business and universities to see what areas require attention for the future.

All businesses will be required to assure that the skills noted are present and current in their organizations in order to be competitive in an increasingly competitive global market. The universities must be ready to provide up-to-date ongoing education in all of the areas mentioned.

The effective management of knowledge is a strategic imperative for all manufacturers and suppliers. In addition, winners will be able to "do what they know."

## DEFINITIONS

**FOREIGN NAMEPLATES.** Refers to all non-U.S.-headquartered vehicle manufacturers or dealership networks regardless of production location (i.e., Honda's U.S. production should be combined with its import vehicles).

**LIGHT TRUCK.** Includes sport utilities, small vans and pickup vehicles.

**TRADITIONAL DOMESTIC OR BIG THREE.** Refers to all United States-headquartered (parent company) manufacturers or dealership networks regardless of production location (i.e., forecast for General Motors should include NUMMI-produced Prizms and imported Metros).

Note: "Year" refers to Model Year unless otherwise specified.

## KEY WORD INDEX

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| Materials | 10,43 | - | - |
| Materials change | 38 | - | - |

| Key Words | Question Number | | |
|---|---|---|---|
| | Technology | Marketing | Materials |
| Message system | 51 | - | - |
| Metal matrix composite | - | - | 21b,22,35,40,44 |
| Metal substrate | 64 | - | - |
| Miller cycle | 34 | - | - |
| Modle niches | - | 8 | - |
| Motors, electric | 79,80 | - | - |
| Multiplexed | 74,75 | - | - |
| Nameplate offerings | - | 4 | - |
| Natural gas | 11,12 | 42 | 4 |
| Navigation | 51 | - | - |
| Nickel-cadmium | 35 | - | - |
| Nickel-hydride | 35 | - | - |
| Nodular iron | - | - | 35 |
| Noise cancellation | 81 | - | - |
| NOx catalyst | 63 | - | - |
| Nylon | - | - | 16,18 |
| Occupant restraint | 14,15 | - | - |
| Oil pan | 67 | - | 17,22 |
| Outsourcing | - | 54 | - |
| Owner loyalty | - | 22 | - |
| Ownership | - | 19,26,35 | - |
| Paint | - | - | 9,18,27,31,38-40,44 |
| Particulate controls | 65 | - | - |
| Parts | 23,24 | - | - |
| PC/PBT | - | - | 16 |
| Performance | 20 | - | 28,40,44 |
| Phenolic | - | - | 16 |
| Piston | 67,68 | - | 18,22,23,28,35 |
| PNGV (Partnership for a New Generation Vehicle) | 7,8,9,10 | - | - |
| Political trends | - | 1 | - |
| Polycarbonate | - | - | 16,34 |
| Plastic/composite | 38,39,40,67 | - | 5,7,9,15,16,18,19,22, 25-28,30-36,39-44 |
| Platforms | 19 | 29 | 5,29 |
| Polyester elastomer | - | - | 16 |
| Polyester thermoplastic | - | - | 16 |
| Polyester thermoset | - | - | 15,16 |
| Polyethylene | - | - | 16 |
| Polymer based | 38,67 | - | - |
| Polypropylene | - | - | 15,16,18,19,40 |
| Polyurea | - | - | 16 |
| Powdered metal | 38,62 | - | 15,21b,22,24 |
| Powertrain material applications | - | - | 5,10,12,18,24,28 |
| PPO/nylon | - | - | 16 |
| PPO/styrene | - | - | 16 |
| Prices | - | 13,14,25 | 11 |
| Procurement | - | 55 | - |
| Product design | 21,22 | - | - |
| Product liability | 14,15 | - | 6 |
| Production, volumes | - | 5,36,37,38 | - |

| Key Words | Question Number | | |
|---|---|---|---|
| | Technology | Marketing | Materials |
| Production development | - | 27a,27b,28 | - |
| Production process | 10 | - | - |
| Propane | 11,12 | - | 4 |
| Push rod | 55,62 | - | - |
| PVC | - | - | 16,40 |
| QRD | 20,37 | - | 28,31,40 |
| Quality | - | 23 | |
| Recyclability | 43 | 49 | 5,7,8,16,31,40-44 |
| Redesign | 56 | 29,30 | 12,20 |
| Reformulated gasoline | - | - | 2 |
| Regionalization | 14,16 | - | - |
| Regulation | 13,14,15,16,17,43 | 6,9 | 3,5-8,16,35,38,42,44 |
| Repair | - | 19,21,22 | 9 |
| Research consortia | - | 7 | - |
| Retail prices | - | 13 | - |
| Retail sales | - | 18,30,31 | - |
| Ride and handling | 20 | - | - |
| Ride/handling | 47 | - | - |
| Roller lifters | 62 | - | - |
| Rolling/resistance | 4,9 | - | - |
| Rubber | - | - | 15 |
| Safety | 20 | 7,24,25 | 5,6,8,28,31,33, 36,40,44 |
| Sales | - | 2,5,18,30,32,33,34 | - |
| Sales personnel | - | 19,22 | - |
| Sales procedures | - | 19,22 | - |
| Seals | 68 | - | 23 |
| Selection criteria materi-als | - | - | 8,22 |
| Selling | - | 18,19 | - |
| Service | 83 | - | 19,28 |
| Sharing | 19 | - | - |
| Skills | 84,85 | - | - |
| SMA | - | - | 16 |
| Social factors | - | 2 | - |
| Spark plugs | 59 | - | - |
| Springs | 46 | - | 33 |
| Stainless Steel | - | - | 22,27 |
| Standardization | 32 | 7 | - |
| Standards | 14,15 | - | - |
| Start-up catalyst | 64 | - | - |
| Steel | 38,39,40 | - | 5,8,9,15,16,18,29, 31,32,33,35,36,41,42 |
| Steering | 47,80 | - | 17-19,40 |
| Strategic planning | - | 1 | - |
| Stratified charge | 34 | - | - |
| Styling | - | 22,29,30,52a,b | - |
| Sub-assemblies | 23,24,25 | - | - |
| Supercharged/ Super-charger | 58,4 | - | - |
| Suppliers | - | 53-57 | - |
| Suspension | 46 | 43,48 | 5,15,18,20,33,40 |

| Key Words | Question Number | | |
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| | Technology | Marketing | Materials |
| Systems engineering | 33 | - | - |
| Taxes | 1,12 | 9 | 1 |
| Technology leadership | 30 | - | - |
| Thermoplastic | - | - | 9,15,18,31,32,33, 40-42,44 |
| Thermoset | - | - | 9,15,16,18,31,32, 42,44 |
| Tires | 4,9,49 | 51 | 7,15,20 |
| Titanium | - | - | 18,40 |
| Toll collection | 51 | - | - |
| Tooling | 26 | - | 5,9,25,31,40 |
| Torte liability | 17 | - | - |
| TPO | - | - | 8,15,16,40 |
| Traction control | 48 | 44,48 | - |
| Trade | 17 | 39,40,41 | - |
| Transaction prices | - | 14 | - |
| Transmission | 4,72,69 | - | 17-19,24,25,28 |
| Transverse | 70 | - | - |
| Trends | - | 1,2 | - |
| Truck attributes | - | 11,12,25 | - |
| Turbocharger | 4,58 | - | 23 |
| Two-stroke engine | 34 | - | - |
| Urethane | - | - | 16,18,37,40 |
| Value of 1 mpg improvement | 6 | - | 14 |
| Value of pound saved | 42 | - | 13 |
| Valve covers | 67 | - | 18 |
| Valves per cylinder | 54 | - | - |
| Valvetrain | 55,60,68 | - | 23,24 |
| Vehicle attributes | - | 10-12,25,48 | - |
| Vehicle demand | - | 2,31 | - |
| Vehicle features | - | 50 | - |
| Vehicle integrity | 14,15 | - | - |
| Vehicle production | - | 5 | - |
| Vehicle servicing | 83 | 19,21,23 | - |
| Vehicle use | - | 26 | - |
| Vinylester TS | - | - | 16 |
| Voice activated | 77 | - | - |
| Voltage, system | 78 | - | - |
| Water pump | 80 | - | - |
| Weight reduction/weight | 4,5,9,41,42 | - | 5,7-9,12-14,16,18, 40,44 |
| Wheels | - | 51 | 17,18,33,36 |
| Wrist pins | 68 | - | - |
| Zinc | - | - | 15,18,41 |