Volume 3: Materials

DELPHI VI

Forecast and Analysis of the U.S. Automotive Industry Through the Year 2000

- *Marketing*
- *Technology*
- *Materials*

The University of Michigan

DELPHI VI FORECAST AND ANALYSIS OF THE U.S. AUTOMOTIVE INDUSTRY

VOLUME 3: MATERIALS

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FOREWORD

INTRODUCTION

Delphi VI is a detailed analysis of forecasts by three separate panels of automotive industry executives, directors, managers, and engineers who are expert in the areas of automotive technology, materials, and 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 the sixth 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, and Delphi V in 1989.

The Office for the Study of Automotive Transportation (OSAT) is the data, analyzes, presents, and interprets the results. Since the forecasts are those of the panelists, Delphi VI 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 with regard to the Delphi forecast is that it presents a vision of the future. It is obviously not a precise statement of the future but rather what the industry thinks the future will likely be.

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 from these experts.

The Delphi method is dependent upon the judgement of knowledgeable experts. This is a particular strength of this method 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, realize 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 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 the panelist to freely express his or her opinion. 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 faculty/staff and representatives of the automotive industry. Lists of prospective expert panelists were assembled: one each for Technology, Marketing, and Materials. Panel 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 227 member panels are as follows: 10% of the Technology Panel were composed of CEOs, presidents, or vice presidents; 22% were directors; 23% were managers or supervisors; 42% were engineers (chief, assistant chief, and staff); and 3% of the panel were made up of academic specialists and consulting technical-engineering specialists. The Marketing Panel was composed of 29% CEOs, presidents, or vice-presidents; 22% directors; 39% managers; 3% engineering specialists; and 7% academic and consulting marketing specialists. Among Materials panelists, 14% were CEOs, presidents and vice presidents; 12% were directors; 51% managers and supervisors; 16% engineering specialists; and 7% academic and consulting materials specialists. Approximately 34% of the Delphi VI panelists were employed by vehicle manufacturers; 56% by components and parts suppliers; and 10% were specialists, consultants, and academics.

PRESENTATION OF DELPHI FORECASTS AND ANALYSES

Data Tables. When a question calls for a response in the form of a number, the 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% and the IQR 35-45%. This means that one-quarter of the respondents answered 35% or less, another one-quarter chose 45% or more, and the middle half of all responses ranged between 36% and 44%, with 40% 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%, but with an interquartile range of 20-70%, 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, where necessary, 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 VI 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 between the opinions of these two groups.

Comparison of Panels. The three groups of Delphi panelists (Technology, Marketing, and Materials) are asked questions that specifically focus on their respective area 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 its relevance and importance to strategic planning, because it reflects 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 VI 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, but rather they are points that the reader might consider useful.

MATERIALS CONTENTS

EXECUTIVE SUMMARY

The Delphi VI Forecast and Analysis of the U.S. Automotive Industry Through the Year 2000 Materials Volume identifies, describes, and provides strategic analyses of new developments and trends in the areas of automotive materials and processes and their applications and impact on overall vehicle design. Analysis of the competition between polymers, steel, aluminum, and other materials for a variety of body, chassis, and powertrain components are presented as are recycling/environmental, energy, and sourcing issues. Although many materials innovations are not visible to the consumer, their effects on future vehicle design and the automotive supplier industry may be profound. The wide range of issues developed in *Delphi VI Materials* provides broad indication of the major automotive materials developments and trends through the year 2000 and, in some cases, beyond.

Delphi VI Materials is divided into seven major sections:

- **Fuels:** covering retail gasoline fuel prices, alternative fuels, the role of reformulated gasoline, and expected future oil change intervals.
- **Emerging materials issues and business environment:** highlighting a number of issues including government regulatory expectations, corrosion trends, and a number of the important issues connected with recycling and life-cycle management.
- **Body and chassis materials applications:** including specific forecasts in the areas of materials use for vehicle frames, structures, and body panels.
- **Materials applications:** forecasting total vehicle materials expectations, specific component composition, and the introduction of new materials such as magnesium, metal matrix composites, and glass substitutes.
- **Powertrain materials applications:** covering materials applications for engine components, aluminum as an engine material, and the consideration of ceramics and powdered metals.
- **Brake and wheel materials:** highlighting these subsystems' materials considerations.
- **Manufacturing and paint technologies:** forecasting body joining and adhesive technologies as well as future paint technologies.

Delphi VI Materials panelists' forecasts of automotive materials applications and related processes and systems on one hand are quite cautious, and on the other hand they indicate a significant rate of change in critical areas of the vehicle. The industry is going through a period of fundamental change in which total customer satisfaction is the objective of every manufacturer. Advanced materials applications and process technologies will become increasingly important in the cost and quality of future products.

Section I—Fuels and Lubricants

The Materials panelists generally forecast a reasonably stable energy future with only modest fuel price increases through the year 2000. Of course, some still recognize the possibility of an energy shock within the next decade. About 75% of future gasoline demand is expected to be unleaded regular, approximately 15% mid-grade unleaded, and 10% premium for 2000. In the year 2000, 50% of the gasoline sold in North America could be considered a reformulated gasoline. In regard to alternative fuels, legislation is viewed as a key driving factor by the year 2000. Materials panelists forecast about 10% of the vehicles will use flexible or variable fuel (gasoline/methanol blends), 2% natural gas, and 2% propane. This is generally in line with past *Delphi* forecasts.

We revisited the issue of oil-change interval in Delphi VI, and found that the expectations for oil changes are in line with the present technology. Panelists expect approximately an 8,000-mile change interval by the year 2000.

Section II—Materials and the Business Environment

Materials panelists believe that assembly, manufacturing, and materials processing innovation for vehicle weight reduction will present the most significant challenges and opportunities to the North American industry in the coming decade. Furthermore, they tend to agree with other panels in their forecast of increased regulatory action across a wide range of areas, from fuel economy to crashworthiness and vehicle emissions. Corrosion is still viewed by some as a significant automotive problem, but more than 60% believe that this issue has been satisfactorily resolved. With emphasis on future weight reduction, the Materials panel believes that the value of a pound of vehicle weight saved will expand from a current estimate of $2.00 per pound to $3.00 per pound by the year 2000. Public policy is viewed as an important area, and panelists believe that government should regulate based on technical merit and become more involved in managing trade and controlling foreign investment. There is a very strong feeling that government should not arbitrarily create regulations without regard to market factors, cost, or technical feasibility.

Recycling is viewed as an increasingly important issue, which will prompt future regulation. Expected regulations include requiring manufacturers to address recycling of plastics, uniform identification standards to facilitate separation, and appropriate recycling of used tires. Economics, identification, and separation of materials are viewed as the primary challenges in the recycling arena.

Section III—Body and Chassis Materials

The Material panelists generally believe that the integral body frame design will remain the predominate technology through the year 2000, but that the space frame will modestly erode the position by 2000, attaining about 10% penetration. Steel is expected to remain the dominant frame and structural material; plastic composites and aluminum are envisioned to grow in application by the end of the decade, securing 11% and 7%, respectively, of the year 2000 market. We may see the first production vehicle with a polymer-based composite intensive structure by the year 2000. Thermoplastics continue to be viewed as slightly more favorable for vertical external panels, whereas thermosets are the choice in horizontal applications. Steel is envisioned to continue its dominance in sheet applications, but is forecast to fall to 60% for vertical and 70% horizontal panels by 2000. Aluminum is expected to increase penetration to about 5% for both types of panels.

Relatively speaking, steel will remain dominant in structural applications, but with a growing role for thermosets, thermoplastics, and aluminum.

Section IV—Total Vehicle Materials Applications

Following our past practice, we look at representative vehicle components to determine expectations for various materials. Components include the hood, roof, fuel tank, suspension, and others. As an example, for the model year 2000, 60% of the outer hoods are expected to remain as steel, but with 10% of higher strength steels, 10% aluminum, and 20% reinforced plastic composites. For the fuel tank, 55% are expected to be made from steel, 5% from reinforced plastics, and 40% from non-reinforced plastics. All responses are suggestive of intense materials competition. Materials panelists expect continuing weight reduction, particularly if higher level CAFE standards are imposed. Steel and cast iron use is forecast to be reduced with reasonably significant increases of aluminum and plastics and even significant percentage applications of magnesium and powdered metals. Metal matrix composites and magnesium alloys are considered in individual questions. Magnesium is envisioned for engine blocks, transmission housings, and wheels. Metal matrix composites are expected to be used in 10% of pistons and 3% of connecting rods by the year 2000. Although glass is expected to remain the dominant material, polycarbonate materials are forecast to replace glass in windshields and side windows by the year 2000.

Section V—Powertrain Material Applications

Delphi VI Technology panelists forecast major powertrain redesign during the next decade. Manufacturing precision will be increased and these engines are expected to incorporate a variety of new advanced features. Commensurate with this change, new materials are forecast to be an integral part of engine innovation. For most engine components, competition between various materials will intensify. In some cases, three or four different materials are viewed as likely candidates for application. Dramatic increases in the use of aluminum for engine cylinder heads and blocks are forecast; 70% of the cylinder heads and 20% of the blocks are expected to be aluminum in the year 2000. The role of powdered metals is forecast to expand dramatically in various powertrain components, including connecting rods, valve seats, and valve guides. The trend to aluminum in radiators is expected to continue to the point where 80% of the radiator cores are forecast to be aluminum by the year 2000.

Section VI—Brakes and Wheels Materials Application

Materials competition for friction surfaces, brakes, and clutches will be intense as various ceramic- and kevlar-based materials, fiberglass, and carbon-based compounds receive serious consideration. Although it appears that traditional asbestos-based materials will still be used in significant volumes.

The same magnitude of competition is evident with wheels. By 2000, 60% of styled wheels are forecast to be made from aluminum, 25% from steel, and even some from application of composites and magnesium.

Section VII—Manufacturing and Paint Technologies

Significant changes are envisioned in body joining technology with increased use of adhesives, laser welding, and mechanical fasteners. Resistant spot welding is expected to be used in approximately 50% of applications by the year 2000. Where adhesive bonding is used, urethanes and epoxies are forecast to be the dominant technologies. Water-based paints are forecast to become the dominant paint technology by the year 2000 with lower application rates for both high solids and powdered coatings. As with many different materials areas, the pursuit of product differentiation, quality, durability, customer value, and manufacturer profit will create intense competition.

I. FUELS/LUBRICANTS

MAT-1. **Please estimate U.S. retail fuel prices (per gallon) for the following years. (Please use constant 1990 dollars, without adjusting for inflation.)**

Unleaded Gasoline	1991 Estimate*	Median Response			Interquartile Range		
		1995	2000	2005	1995	2000	2005
Unleaded regular	$1.38	$1.35	$1.60	$1.90	$1.30/1.40	$1.45/1.70	$1.70/2.20
Unleaded premium	$1.54	$1.55	$1.80	$2.00	$1.42/1.60	$1.55/1.80	$1.90/2.25

*Source: American Automobile Association

SELECTED EDITED COMMENTS

- This is a Catch-22 situation. The Middle East needs increased income. New CAFE standards drive fleet economy up. Net results after Middle East stabilization will be increased fuel costs at rates in excess of inflation.
- Electric vehicles and competitive alternate fuels are in the future.
- Price increases will be due to a significant change in gasoline tax.
- The United States consumer will "bid" for oil as Eastern Europe/Latin America compete with U.S. for supplies held artificially in short supply.
- The government will compensate for low fuel prices and assure that gasoline is not undervalued.
- We are effectively at 1995 prices now. Prices for the years 2000 and 2005 are unpredictable because of Middle Eastern instability. There will be some upward pressure to raise fuel taxes as a means of reducing the deficit.
- Electric and competitive alternative fuels are in the future.
- I still find this item the most difficult to put any sensible prediction on since the prices are governed by emotion.
- The most likely increase will be due to federal tax.
- Prices will tend to stabilize over the short term and rise again as regional resources dwindle.
- The CAFE requirements will be significantly higher by the year 2000. The car buyer will benefit but the oil companies will only partially benefit. There will be government fuel surcharges to foster conservation, retard use, and affect balance of payments.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panels' predictions are within ten cents of each other over each forecast period. Where there are differences, the suppliers tend to predict higher prices.

COMPARISON OF FORECASTS: TECH-1 and MKT-8

The forecasts of each panel are within ten cents of each other for each period and fuel type, except the 2005 unleaded regular gasoline forecast. Materials panelists forecast unleaded regular gasoline at $1.90 per gallon versus $1.75 and $1.72 for Technology and Marketing panelists, respectively. Given the number of variables and length of forecast, this difference does not appear to represent any major variation in strategic direction among the panels.

TREND FROM PREVIOUS DELPHI SURVEYS

Fuel price expectations have increased since the Delphi V survey (1989). Using the CPI-adjusted forecast, the 1991 panelists estimated prices of both unleaded regular and premium gasoline for the year 2000 to be at least 14% higher than prices estimated by the 1989 panel. Although current estimates are higher than the 1989 survey, the unleaded regular forecast (the only grade forecast in 1987) is significantly below 1987 forecast. The following two tables present these results.

Unleaded Regular Gasoline	Forecast for 1995			Forecast for 2000		
	1987 Delphi IV	1989 Delphi V	1991 Delphi VI	1987 Delphi IV	1989 Delphi V	1991 Delphi VI
Price*	$1.70	$1.20	$1.35	$2.00	$1.30	$1.60
1990 CPI Adjusted**	1.83	1.26	1.35	2.16	1.37	1.60

* Dollars at time of survey.

** Adjusted to 1990 consumer price index (CPI).

Unleaded Premium Gasoline	Forecast for 1995		Forecast for 2000	
	1989 Delphi V	1991 Delphi VI	1989 Delphi V	1991 Delphi VI
Price*	$1.35	$1.55	$1.50	$1.80
1990 CPI Adjusted**	1.42	1.55	1.58	1.80

* Dollars at time of survey.

** Adjusted to 1990 consumer price index (CPI).

STRATEGIC CONSIDERATIONS

Generally, forecasts for future gasoline prices are modestly higher than forecasts in Delphi V. However, no significant or sharp increases are anticipated by the Materials panelists. Recent events in the Middle East, which failed to result in substantial increases in energy pricing, appear to support a moderate, long-range forecast. Despite the popular belief that we will face short and midterm international energy uncertainty, the energy future is likely to be reasonably stable and predictable and not likely to force major dislocations in the design of future vehicles. On the other hand, policy actions, such as much more stringent CAFE standards or a significant increase in fuel taxes, could have a substantial effect.

A series of statements from our previous forecast, Delphi V, with some updating, is worth repeating with regard to expectations of energy price stability:

1. Even with the occurrence of a major Middle East war (and the loss of supply from several key nations), real energy prices actually decreased, indicating that, at least for the foreseeable future, there is significant global petroleum supply. Furthermore, no matter how unpredictable energy-producing countries might be, in most cases, petroleum still manages to find its way to markets throughout the world.
2. Increased cash-flow requirements on the part of energy-producing nations necessitate pumping increasingly larger quantities of petroleum.
3. Progress in alternative fuel technology, particularly the use of methanol and natural gas, seems to be causing concern within the major energy-producing nations that any significant disruption of petroleum supplies could accelerate the move toward alternative fuels and thereby diminish the value of their petroleum resources.
4. Continued improvement in overall fleet-fuel economy limits increases in transportation's petroleum usage.
5. Increased stability and reliance on market-oriented economies in formerly communist countries should promote worldwide political and, therefore, economic stability.

Even with this stable energy forecast in mind, it is clear that automotive engineers must be cognizant of all issues related to energy pricing and availability and be prepared for challenging surprises.

Clearly, acceleration of petroleum demand is likely as less-developed countries become increasingly affluent and needs for individual mobility expand. Furthermore, environmental concerns such as global warming, disappearance of polar ozone, and other factors may require shifts in our thinking as our knowledge of environmental issues improves. Finally, and perhaps most important, our political system is fully capable of creating a "worst-nightmare" scenario for the industry with regard to policy actions, particularly with very aggressive fuel economy or emission regulations.

Energy, its availability, and its pricing, will clearly be fundamental factors shaping the characteristics of future motor vehicles, material selection, and the automotive market.

MAT-2. Please estimate the allocation of gasoline sales for the light-duty vehicle fleet for 1995 and 2000.

Unleaded Gasoline	Median Response		Interquartile Range	
	1995	2000	1995	2000
Regular unleaded	75%	75%	70/80%	70/80%
Midgrade unleaded	15	15	15/15	12/15
Premium unleaded	10	10	8/10	5/10

SELECTED EDITED COMMENTS

- Assumes only the gasoline-operated fleets.
- Midgrade and premium use is more a function of marketing efforts than actual vehicle needs. In the interest of reduced crude consumption this practice of "overselling" octane requirements should be discontinued.
- By 2000, the energy content per gallon will be the most important consideration.
- Factors driving premium fuels are 1) petroleum companies typically market their fuel system cleaning additives in premium fuel grades; 2) electronic spark control systems that are not individual cylinder sensitive cause driveability problems; and 3) the ongoing market for performance engines and generally higher operating temperatures of those engines.

MANUFACTURER/SUPPLIER COMPARISON

The panels are in agreement except the 2000 forecast where manufacturers forecast a greater share of regular unleaded gasoline (80% versus 74%) and the suppliers forecast twice the share for premium unleaded (10% versus 5%). These variations do not appear to represent any significant strategic differences.

TREND FROM PREVIOUS DELPHI SURVEYS

Expectations for midgrade unleaded gasoline as a percentage of the total unleaded gasoline mix have grown over the last two years. Delphi IV (1987) asked for forecasts of only regular versus premium grades. The forecast for the 1995 regular proportion is constant: 75% regular and 25% premium. The following table presents the trend between Delphi V and Delphi VI.

Unleaded Gasoline Mix	Forecast for 1995		Forecast for 2000	
	1989 Delphi V	1991 Delphi VI	1989 Delphi V	1991 Delphi VI
Regular unleaded	75%	75%	75%	75%
Midgrade unleaded	5	15	5	15
Premium unleaded	20	10	20	10

STRATEGIC CONSIDERATIONS

The forecast for regular unleaded fuel has remained relatively constant since the past Delphi. The real surprise is growth in expectations for a midgrade unleaded gasoline and reduced use of premium fuels. One interesting issue related to the three grades of gasoline is where an alcohol-based fuel such as M85 might fit. This suggests that perhaps four different and separate distribution systems might be required to handle the multiple grades, which indeed would add considerable complexity to the distribution and sales operations of the various energy companies.

In the past few years, there has been a significant increase in vehicles requiring higher-octane fuels. Of course, some important developments have been made to control octane requirement even as compression ratios have been increased. Improved ignition control, combustion chamber design, mixture motion and EGR control, and numerous other factors have led to a lower octane requirement at a given compression ratio.

Further technologies such as individual cylinder combustion optimization, variable valve timing and lift, and other features could further reduce octane requirement; and if compression ratio or ignition timing advance is limited, a trend to reduce fuel octane levels is possible. The role of reformulated gasoline (please see the following question) with regard to fuel octane is uncertain although the oxygenates and more careful composition control may yield some interesting results.

The reduced expectations for premium fuels may be due to the assumption that a more value-oriented customer tends to be less enthused about high-performance vehicles. Furthermore, better customer education will help consumers select the octane required by their vehicle. There is no fuel economy advantage for premium fuels if spark knock or detonation does not occur with lower-grade fuels (unless knock sensor control of ignition timing is used).

Another factor that could have an influence on fuel octane is the development of additives that off-set increased octane requirement of spark-ignited engines. This is a problem that is all too common in modern day engines. Any development of this type could certainly influence the ratio between regular and premium fuel.

MAT-3. **By the year 2000 what percentage of national gasoline sales will be considered "reformulated"?**

Percent "Reformulated" Gasoline by the year 2000	
Median Response	Interquartile Range
50%	30/70%

SELECTED EDITED COMMENTS

- Automotive and fuel companies indicate reformulated gas is how they will meet clean air requirements through 2000.
- Marketing issues by "big oil" could determine percentage of mix, not actual fleet requirements.
- Reformulated gas is the quickest and cheapest of alternate fuels.
- The oil companies have been absent from these discussions far too long. Their time will come and reformulations will be their contribution.
- The Clean Air Act amendment of 1990 calls for reformulated gasoline, even though the latter part is being defined only now. Environmental benefits are not yet known and may be more public relations than fact.
- CAFE outcome will influence percentage of reformulated gas.
- Most passenger cars will use some type of reformulated gas to pass emission requirements.
- There will be continuing pressure to reduce hydrocarbon emissions. This is a relatively easy way to make significant incremental improvements.

MANUFACTURER/SUPPLIER COMPARISON

There are no differences between the two panels' forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

There is no question that the motor-vehicle-fuel issue will be very exciting in the decade ahead. The interest in reformulated gasoline is a rather recent development associated with the new Clean Air Act. In areas of the country that are not in compliance with clean-air standards, more carefully controlled fuel composition requirements will insure that future fuels will be sophisticated hydrocarbon-based fuels. Panelists' expectations are high for reformulated gasoline by the year 2000, which suggests substantial changes will be required in refineries and perhaps in the overall fuel distribution system. The comments section of this question is particularly noteworthy and should be reviewed carefully. Clearly, the introduction of this new concept of gasoline will have a significant impact on a number of energy and vehicle issues, including retail price.

It will be interesting to observe whether the general public reacts with acceptance or rejection. If consumers have problems, policy makers are likely to be influenced by a negative reaction. If a new gasoline is not viewed as a cost-effective means of achieving emissions reduction, one can only speculate what the political system might do.

MAT-4. **What is the likelihood of federal legislation mandating some degree of alternative fuel capability in the total fleet by the year 2000.**

Likely: 95%	Not Likely: 5%

SELECTED EDITED COMMENTS

- Alternate fuel vehicles will be primarily commercial fleets with limited geographical range.
- Congress is motivated by propaganda, not facts.
- One major producer has demonstrated ability. California will set the trend through the California Air Resources Board (CARB).

MANUFACTURER/SUPPLIER COMPARISON

Both panels are unanimous that federal legislation is likely.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

Panelists conclude that alternative-fuel legislation will be in place by the year 2000. In fact, legislative actions are already well underway with numerous initiatives around the country concerning alcohols, natural gas, and electric vehicles. Developments in this area will be extremely interesting as many of the manufacturers have decided to take advantage of what they increasingly believe are business opportunities with regard to various alternative fuels. With this general shift in attitude, we would not be surprised to see rapid development of technology at an even faster pace with some alternative fuels.

MAT-5. **What percentage of North American-produced passenger vehicles (NAPPVs) will be produced with alternative fuel capability in the years 1995, 2000, and 2005?**

Alternative Fuels	Median Response			Interquartile Range		
	1995	2000	2005	1995	2000	2005
Flexible or Variable fuel	5%	10%	15%	2/10%	5/20%	10/30%
Natural gas	1	2	4	1/1	1/3	3/5
Propane	1	2	3	1/1	1/2	1/3

SELECTED EDITED COMMENTS

- All of our design work for liquid fuel systems requires methanol capability. These projects are for 1995-1997 car programs. Capability will begin to spread. Average life expectancy of a car is 11 years. By the year 2005 the majority of vehicles will be methanol capable.
- Methanol will lose favor to compressed natural gas and propane.
- Most alternative fuels have range and distribution problems that will limit their marketability unless legislated.
- Pending legislation could dramatically drive methanol above fuel percentages.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturer and supplier forecasts through 2005 are essentially the same for natural gas and propane-fueled vehicles. However, there are significant differences in flexible or variable fuel vehicles. The manufacturers forecast exactly twice the penetration for each year: 8% versus 4%, 20% versus 10%, and 30% versus 15% in 1995, 2000, and 2005, respectively. These differences may result in significant differences in R&D and production capacity requirements and provisions between the two groups. Although development of flexible fuel vehicles may be viewed as a proprietary, competitive advantage, it appears that if the manufacturers expect 30% NAPPV production to be so equipped then they should better link suppliers into the product development effort.

COMPARISON OF FORECASTS: TECH-6

Materials panelists are significantly more optimistic towards alternative fuel penetration for NAPPVs. The following table presents this comparison. Although it would be more assuring if these two panels were in agreement, given that many alternative fuel usage barriers (fuel system corrosion, fuel distribution infrastructure, and others) are in the Materials-panel area of influence and control, it appears that the Materials experts believe these concerns will be appropriately addressed to achieve their aggressive market share rates.

Alternative Fuels	Technology Panel			Materials Panel		
	1995	2000	2005	1995	2000	2005
Flexible or variable fuel	1.0%	6%	10%	5%	10%	15%
Natural gas	0.5	2	3	1	2	4
Propane	0.5	1	2	1	2	3

TREND FROM PREVIOUS DELPHI SURVEYS

Given current regulatory requirements and advancements in sensor technology, Delphi VI Materials panelists predict a greater production share of flexible fuel vehicles from 1995 to 2005. These predictions are not driven by a temporary fuel crisis but regulatory and market demand. Equivalent questions covering natural gas or propane were not asked in previous Delphi surveys.

Percentage of NAPPVs with Flexible Fuel Capability					
1989 Delphi V Median Responses			1991 Delphi VI Median Responses		
1995	2000	2005	1995	2000	2005
1%	5%	10%	5%	10%	15%

STRATEGIC CONSIDERATIONS

As noted in the comparison with the Technology forecast, material specialists are forecasting a greater role for the various alternative fuels than the Technology panelists. By the year 2000, more than one million vehicles are expected to be produced with some hybrid- or alternative-fuel capability.

From an automotive industry perspective, we have several concerns associated with the movement toward alternative-fuel capability in motor vehicles. First of all, we are faced with uncertainties with regard to the human resources and capital required to develop and then produce vehicles with these capabilities. Critical skill and capital issues are of particular concern today because of increasing shortages of both on a world scale. It must be remembered that a vehicle with alternative fuel capabilities must meet all of the technical and regulatory standards, as well as customer expectations that have been established for gasoline-fueled vehicles. These standards and expectations may increase as characteristics of alternative-fuel technology become better understood. We do believe that advances in alternative-fuel capability will encourage energy-producing areas of the world to use restraint in petroleum pricing and availability. Propane, since it is a petroleum derivative, will probably be very much tied to the overall petroleum situation and could move from the point today where it is in excess supply as a by-product to a supply that is constrained if propane demand rises too aggressively for motor vehicles.

A second general area of concern is customer acceptance. We believe consumers will expect parity with today's vehicles in terms of cost per mile, convenience, safety, and travel range, areas where alternate fuels may come up short in the minds of customers. Benefits of alternate fuels will have to be clearly defined, and public policy will have to be used to induce use.

Based on the new Clean Air Act, fleets will be particularly affected and, indeed, the auto industry is moving aggressively to develop new alternative fuel capable vehicles. Natural gas appears promising as a fleet-vehicle fuel, particularly where operating range is defined and central, high-pressure refueling pumps may be practical.

Finally, present day spark-ignited, internal-combustion engines can be readily adapted to use alternate fuels being evaluated for future utilization (e.g., hydrogen). No fundamental technological barriers exist and current challenges should be resolvable with appropriate development. In some cases, such as with natural gas or propane, engines would be cleaner, potentially more durable, and would require less maintenance. The on-board energy storage concerns are more significant and will require compromises in such factors as travel range and packaging.

Obviously, developments with alternate fuels must be followed closely by the industry. Of course, all who are engaged in powertrain and fuel system activities will be impacted, but other suppliers and service providers will be affected as well. Still, it must be kept in mind that petroleum-based fuels are a well-known and cost efficient means to store energy and supply is not in doubt for many years to come.

MAT-6. What average oil-change interval do you expect for NAPPVs in MYs 1995 and 2000?

Oil Change Interval	Median Response		Interquartile Range	
	1995	2000	1995	2000
	7,500 miles	8,000 miles	6,000/7,500 miles	5,000/10,000 miles

NO COMMENTS

MANUFACTURER/SUPPLIER COMPARISON

Suppliers believe that shorter oil-change intervals will be the standard: 6,000 miles in 1995 (compared with the manufacturers' forecast of 7,500 miles) and 8,000 miles in 2000 (compared with the manufacturers' forecast of 10,000 miles).

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi III (1984) panelists forecast 1992 interval ranges to be at 12,000 miles. This survey was conducted at a time when a big push was occurring to lengthen oil change intervals. Engine technology and durability issues have significantly shorter interval forecasts.

STRATEGIC CONSIDERATIONS

It has been several Delphi forecasts since we addressed the issue of oil-change intervals. The results of this forecast are significantly lower than those in the past and indicate that relatively little change from today's standards is envisioned over the next few years. This is important considering the significant changes expected in engine technology, lubricants, and lubricant additives. To some extent, there may be an offsetting effect. New engines that are designed to operate at higher speeds and greater specific power, are being produced with a higher level of microprecision. This trend, in addition to improvements in additive and base-lubricant technology, may further offset some of the problems associated with greater internal stress levels.

Additional factors in oil-change intervals may be the concerns with reliability, durability, and unpredictable driving patterns, as well as the extended warranties. Consequently, there may be reluctance to pursue longer oil-change intervals than are already practiced.

Of course, it is useful to reflect upon where we were 15 to 20 years ago when oil changes were required approximately every 1,000 miles. The gains made to date give testimony to the tremendous improvements in both engine and lubricant technology. An emerging technology that is already being applied, to some extent, is measurement of lubricant degradation which could lead to oil-changes on a basis of lubricant condition rather than a fixed interval. A common approach today is to look at the engine speed, load history, and other variables, and from this infer lubricant degradation. This is a reasonable approach with present computer based-technology, but still not equivalent to actual sensing of lubricant degradation. In a general sense, modern diagnostics will probably lead to more service based on need rather than service to schedule.

II. EMERGING MATERIALS ISSUES AND BUSINESS ENVIRONMENT

MAT-7. What technology, materials, or manufacturing issues do you feel will present the most significant challenges or opportunities to the North American automotive industry in the coming decade?

Automotive Material Challenges	Percent of Responses
Assembly, manufacturing, and material processing innovation	23%
Vehicle weight reduction	21
Recyclability	13
Application of composite materials	11
Regulatory compliance	9

Other responses include: balancing conflicting demands, supplier support capabilities, vehicle systems integration, and profitability.

REPRESENTATIVE RESPONSES

- Low investment tooling (epoxy and aluminum). Modular design, supplier capabilities, and the UAW.
- Manufacturing issues: 1) availability of skilled workforce, 2) relationship of assemblers and suppliers, and 3) integration of process "know how" with information management "know how" to bring customer, assembler, and suppliers closer together.
- The need to reduce vehicle weight and continuing the improvements in durability will require development of new lightweight materials and technology. However, the cost of developing new materials, technology, and manufacturing productivity improvement must be drastically reduced.
- High-strength, lightweight composite materials for body, chassis, and powertrain will be used for weight reduction.
- Elimination of waste in whatever form (scrap, time, motion, assembly) is key to improving North American competitiveness. We need to conduct more R&D to match Japanese. Less emphasis on "home run" technology and more effort to incremental improvements.

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 Materials forecast.

STRATEGIC CONSIDERATIONS

Industry challenges involving materials suppliers and processors bring significant opportunities as well as risk for individual groups within the automotive industry. Some materials suppliers gain value-added sales opportunities through assembly, manufacturing, and processing innovation; weight reduction; recyclability; advanced composites; and regulatory compliance issues. On the other hand, these same opportunities may mean materials substitution or result in product obsolescence, creating a corresponding risk for established suppliers. As societal demands and engineering challenges increase, innovation will be required in each of these technology, materials, and manufacturing issues.

A materials supplier can not view itself as simply a commodity supplier. There are too many suppliers pursuing the same market for all to survive with this strategy. A materials supplier must offer, or have access to, capabilities addressing each of the identified issues. A supplier may maintain or increase sales by offering the customer an advantage, or by emphasizing its own given advantage against weaknesses, in each of these areas.

The second comment highlights many interesting points. First, companies need to be concerned with the available skills for manufacturing as well as managerial activities. Skills required for traditional trades are in short supply and new skills (such as CAD/CAM operators) are increasingly in demand. Second, each identified challenge requires the support of a value-based—not a transactional—cost-based customer-supplier relationship. Third, information, knowledge, and process-based strategies will determine future competitive advantages.

MAT-8. What is your view of the trend in U.S. federal regulatory standards over the 1992 - 2000 time frame. Also list any likely new areas of legislative activity.

Legislative/Regulatory Activity	Percent of Panelists		
	More restrictive	Standard	Less restrictive
Vehicle emission standards			
Passenger car*	75%	25%	0%
Light truck	91	9	0
Fuel economy standards			
Passenger car	100	0	0
Light truck	100	0	0
Vehicle integrity/crashworthiness			
Passenger car	69	31	0
Light truck	81	19	0
Occupant restraint/interior safety			
Passenger car	84	16	0
Light truck	91	9	0
Lemon laws			
Passenger car	41	56	3
Light truck	38	59	3
Product liability			
Passenger car	34	63	3
Light truck	37	63	0

*Beyond new Clean Air Act

Other single responses include: recycling of scrap vehicles and used fluids; limiting vehicle usage in high emission regions; laws enforcing recyclability; OEMs responsible for recycling; recycling of components; recycling requirement for old vehicles; thermal load to environment; buy-back of vehicles to dismantle and recycle; disposal of scrapped cars; alternative-fueled vehicles; collision avoidance features; disassembly designs; and bar coding of components by material.

SELECTED EDITED COMMENTS

- I find it a dichotomy that in a free market economy such as the United States, fuel economy standards are regulated, whereas in Western Europe with more government control, the market itself dictates fuel economy usage.

MANUFACTURER/SUPPLIER COMPARISON

The two panels agree on the direction of regulatory action for all categories. Some differences in magnitude do exist. Manufacturers view vehicle integrity/crashworthiness, occupant/interior safety, and lemon laws receiving more restrictive attention than suppliers. A larger percentage of suppliers than manufacturers forecast more restrictive vehicle-emissions and product-liability activity.

COMPARISON OF FORECASTS: TECH-8 AND MKT-6

In general, a significantly smaller percentage of Technology and Materials panelists expect more restrictive federal regulatory standards over the 1992-2000 time frame than the Marketing panelists. This is particularly evident in the areas of passenger-car-emissions standards, crashworthiness, and occupant safety. The three panels, however, express a good consensus when addressing these issues as they relate to increased standards for light trucks. There is one obvious common area of agreement: fuel economy (CAFE) standards. Every one of the Materials panel respondents expects to see more CAFE regulatory activity directed at both passenger cars and light trucks. This is matched by both the Technology and Marketing panelists, with more restrictive responses in the 90% plus or very high 80% range.

There are differing perspectives between the three panels regarding regulatory activity directed at passenger-car-emissions standards, crashworthiness, and occupant safety. The following table presents these differences. Many factors may cause these differing opinions. Technology panelists may expect that there are emerging automotive technologies that will negate the necessity for legislation. The Marketing panelists, perhaps being more responsive to consumer and political considerations, expect to see more legislation regardless of new technology utilization.

The observation that a majority of respondents from all three panels does not anticipate increased regulatory activity in the areas of "lemon laws" and product liability may be a reflection of increased product quality and improved customer handling by dealerships.

Regulation	Regulatory Activity Materials vs. Technology and Marketing Comparisons Percentage of Total Respondents					
	Materials Panel		Technology Panel		Marketing Panel	
	More restrictive	Same	More restrictive	Same	More restrictive	Same
CAFE						
Passenger car	100%	0%	90%	10%	88%	12%
Light trucks	100	0	89	11	92	8
Emission standards						
Passenger car	75	25	65	34	91	9
Light trucks	91	9	81	19	100	0
Crashworthiness						
Passenger car	69	31	55	44	75	25
Light truck	81	19	77	22	85	15
Occupant safety						
Passenger car	84	16	58	41	77	23
Light truck	91	9	78	22	83	10
Lemon laws						
Passenger car	41	56	36	64	45	52
Light truck	38	59	35	64	44	53
Product liability						
Passenger car	34	66	27	67	42	52
Light truck	37	63	30	64	43	51

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

Although lemon law and product liability initiatives are forecast to remain constant over the next eight years, the major federal regulatory efforts (vehicle emissions, fuel economy, vehicle integrity/crashworthiness, and occupant restraint/interior safety) are expected to become more restrictive. These expectations are consistent with forecasts throughout Delphi VI's three panels. It is evident that materials and product technology will play a critical role in advancing each of these social agendas while operating under the consumer satisfaction, market, and political constraints established by the Marketing panel.

More panelists forecast restrictive regulatory activity for light trucks than for passenger cars. This trend may provide some suppliers and manufacturers with engineering and manufacturing economies of scale. However, it also creates a whole new set of engineering challenges for light-duty truck designs. The blurring of commercial and personal use requires that passenger vehicle-oriented regulations (such as air bag passive restraint, roll-over protection, and lighting) be applied to trucks without losing any utility or function.

Recycling issues (please see MAT-12 through MAT-15) are the most frequently mentioned new regulatory area. Emissions, safety, and fuel economy pressures will require material specification changes and innovation. Material changes must consider future recycling demands and any possible legislated material bans. These material concerns must be addressed early in the design and product development cycle. Recycling concerns impact all materials because make-versus-buy, cost and weight budgets, and engineering and quality-performance objectives are met through the cumulative sum of all material applications. The interaction across component systems requires materials optimization that may require interesting strategic alliances among competing material industries. For example, structural components may benefit from a combination of aluminum and plastic that each by itself may not have been competitive against steel. Material suppliers and processors need to proactively seek out these opportunities to protect markets and develop new ones.

MAT-9. **Please indicate significant new materials application/technologies that are likely to emerge within the next decade for each of the following vehicle systems.**

Engine	% Responses
Increasing application/utilization of light weight materials, structures, and coatings in engines	77%
Within this category the following technologies were specified:	
Ceramics	30%
Plastics/composites	25
Aluminum	20
Magnesium	10
Other, unspecified	15
Two-cycle engines	8
Increased electronics	4

Other single responses include: multi-valve engines, higher compression engines, and new induction systems.

REPRESENTATIVE RESPONSES

- Aluminum, magnesium, and plastics/composite applications will emerge.
- Coatings technologies will be used for lower emissions. Metal alloy systems will be used for lighter weight.
- Lighter weight blocks will be used to lower weight.

Transmission/Final Drive	% Responses
Increasing application/utilization of lightweight materials as follows:	
Magnesium	25%
Plastics	19
Aluminum	13
Ceramics	6
Electronically controlled transmissions	13%
Continuously variable transmission (CVT)	6
Others: T-Drives, clutchless manual transmission, new lubricants, and increased electronics.	18

REPRESENTATIVE RESPONSES:

- Torque converter turbine assemblies will probably begin to change over from stamped steel to plastic.
- I expect ceramics and plastics to grow.
- Magnesium housings and synthetic "tailored" lubricants will be used.

Body	% Responses
Increasing utilization of:	
High strength steel	28%
Plastics/composites	28
Prepainted steels	16
Aluminum	11
Increased space-frame usage	11
Increased in mold-in-color	6

REPRESENTATIVE RESPONSES

- There will be increased use of lightweight higher strength steels. Some vehicles will have aluminum panels; some composite panels.
- There will be some integration of composites into the structure.
- Space frames with hang on panels, prepainted steel will be used.

Chassis	% Responses
Increased use of aluminum	50%
Within this category the following were specified:	
Aluminum space frame	40%
Aluminum suspension components	29
Increased use of plastics/composites	36
Increased application of high strength steel	14

REPRESENTATIVE RESPONSES

- There will be applications of aluminum space frames.
- Rectangular extrusions such as on 4-wheel drive Ford Contour may appear.
- Aluminum chassis and suspension components will increase in use.

Interior	% Responses
Increased use of plastics (with mold-in color)	38%
Increased modularization of IP	38
More fabric	12
New flame retardant materials	12

REPRESENTATIVE RESPONSES

- Use of mold-in color for new plastic components.
- Lightweight integrated functions rather than separate parts.

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 Materials forecast.

STRATEGIC CONSIDERATIONS

Materials selection will become more complex as powertrains, bodies, chassis, and interiors evolve to meet challenging customer, environmental, fuel economy, safety, design, packaging, and cost reduction demands. Materials substitution and product technology, and processing innovation are forecast to occur in each surveyed area.

While there are differences in the areas considered requiring individual strategic action, two themes are common throughout. First, materials traditionally considered "high priced" or "exotic" will be more seriously considered. Ceramics, magnesium, and composites are receiving increased attention as fuel economy and other regulatory pressures increases the value of a pound of weight saved (see MAT-11) and value-based material specification becomes the norm. By value-based specification we mean not simply looking at material cost per pound or the piece price of the component, but total system costs (can additional weight or cost be taken out elsewhere?), total processing costs (can assembly time or quality be improved?), and total systems complexity (can individual part numbers be removed from work-in-process and service-parts inventory bins?). Also, these materials are advancing on the engineering and processing learning curve such that costs fall, quality rises, and confidence increases.

Second, with most systems, radical technology innovation may bring fundamental changes. Two-cycle engines—for specific market segments—will significantly change design parameters of horse power to litre displacement and horse power to weight ratios. In conjunction with a vehicle designed for a two-cycle engine (with better aerodynamics and lighter weight systems), make/buy, value of weight saved, and other specification criteria may change dramatically. With transmissions, expectations of continuously variable transmissions and T-drive configurations offer similar shifts in design philosophy. For body systems, space-frame usage and sheet and structural composites could result in significant changes relative to current practices.

MAT-10. **It has been suggested by a number of automotive industry experts that the issue of material degradation (corrosion) has been satisfactorily resolved. Do you agree or disagree with that analysis?**

Agree: 63%	**Disagree:** 37%

If you disagree, please comment on the present status and the issues that remain to be resolved.

SELECTED EDITED COMMENTS

- Although technical solutions have been identified, implementation has not been achieved in all cases. Body corrosion should not be an issue but some of the solutions (i.e., zinc/nickle-coated steel) are not yet proven by field experience. I believe, for example, that zinc/nickel will prove to be inadequate.
- Aluminum wheels corrode.
- Degradation has been solved for the body but not underhood or underbody.
- Current issues are fairly minor and deal with optimization.
- Current methods are too expensive and limit quality. Problems exist with recycling capability.
- I agree the issue has been resolved technically, but at what cost, and what else was given up in weight, formability, and surface quality?
- Five to ten year-old vehicles still show rust.
- Material degradation is not limited to corrosion. Composites are subject to ultraviolet attack (the cracking dashboard syndrome). Composites add ultraviolet stabilizers and inhibitors, steel adds zinc. Both classes of material have solved their degradation problems.
- The problem has been addressed with coatings. But, coatings still get chipped off, scratched, or other damage and corrosion results.
- There are still large differences in geographical areas of the United States. In the Northeast it is still an issue.
- Time is the issue—we have not seen the latest materials in the field long enough.

MANUFACTURER/SUPPLIER COMPARISON

There are no significant differences between the responses of the two panels.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

Corrosion continues to be a concern in modern vehicles, as indicated by the tremendous efforts that have been undertaken by the industry to minimize the cause and effects of a variety of corrosion problems. We sense there is a somewhat diminished feeling of confidence with regard to the control of corrosion since a few years ago. Clearly, two thirds of our panel agree that the corrosion problem has generally been dealt with appropriately. Of course, the one third that does not believe that this is true is a strong minority voice, which deserves to be considered.

Many factors are important in this issue. For example, just what is corrosion, as noted by one comment related to general material degradation of any form, may be considerably broader than the classical forms of corrosion.

Another issue is the longevity of the vehicle. If one views 10 years without panel penetration as acceptable performance, this would be deemed worthy of saying the problem is solved. On the other hand, a materials expert might focus on some other area. For example, he might consider the chipping or degradation of the normal coating to be unacceptable.

In general, we believe the cost/benefit dimensions of corrosion control are important with appropriate balancing of the value of material/component degradation control against cost. One interesting issue, of course, is the fact that the new vehicle purchaser may not value 10-or 15-year protection. The real benefit is received by the downstream owner of the vehicle. This may have a positive impact on resale value, which is a benefit to the new car owner but is difficult to quantify. All in all, this is a very complicated issue, and we must concur that there still is significant work to be done in the corrosion area. Any materials or component supplier as well as manufacturer must carefully consider this issue in the design of future products.

MAT-11. What is the dollar value per pound of weight saved? What will it be by MYs 1995 and 2000? (Please use current dollars, i.e., do not adjust for inflation.)

Value Per Pound Saved	Median Response			Interquartile Range		
	Current Value	1995	2000	Current Value	1995	2000
	$2.00	$2.50	$3.00	$0.50/$3.00	$2.00/$3.00	$3.00/$5.00

SELECTED EDITED COMMENTS

- Dollar value per pound of weight saved is a function of inertia weight classes, opportunities for additional synergistic weight savings, and other benefits such as increased performance and efficiency of powertrain components.
- The sizeable increase of value in the future is due to the cost of higher technology components and slower cycle times.
- It depends on what the weight savings translates into in terms of engine and vehicle performance. Fuel economy standards and magnitude of penalties imposed by legislative requirements will determine the value.
- Weight savings is not always used by OEMs in justification of the cost they will pay. I have seen no case where a higher price was paid for a lower weight component.
- Weight savings will mean nothing to the OEM until vehicle program managers get serious about meeting weight targets. CAFE requirements will truly force some unpleasant marketing requirements on the OEMs. Design-responsible engineers and decision makers at the OEMs will have to take a macro look at the product and product-systems.

MANUFACTURER/SUPPLIER COMPARISON

The panels agree that the current value of per pound weight savings is $2.00 today and will be $2.50 in 1995. For 2000, because of differing expectations of fuel-economy standards, strategies to meet regulatory standards, and consumer demand, manufacturers estimate a pound of material saved in 2000 will be $4.00; the suppliers estimate $3.00. This may signal an opportunity for high-value, low-weight, high-strength materials. The customer may be willing to pay a premium to achieve greater vehicle utility.

COMPARISON OF FORECASTS: TECH-21

Although the Technology and Materials panelists agree on the most distant forecast, the Materials panel estimates the value per pound saved 25% higher ($2.50 versus $2.00) in 1995 and a full 100% higher ($2.00 versus $1.00) today. This may imply significant strategic differences in that the Technology panel may be viewed as representing the market demand (e.g., platform engineers) and the Materials panel represents the supply. In the near term there is an apparent significant difference of opinion over material value and customer needs.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was asked in Delphi IV (1987) but not Delphi V (1989). Coming off of a record sales year, with little regulatory activity and stable fuel prices, the panelists forecast 1995 value per pound saved at $0.75. This forecast is 30% of the current 1995 forecast. It is interesting that the 1987 comments are similar to Delphi VI comments: value of weight reduction is a function of weight class and pure weight reduction has no value to the manufacturers.

STRATEGIC CONSIDERATIONS

It is difficult to evaluate the value per pound saved. The calculation is dependent on the specific vehicle platform, weight and cost objectives and status, proximity to an inertia weight class, and the regulatory environment. Many panelists' comments highlight these considerations. Even given these uncertainties, it is clear that the value per pound of weight saved will increase dramatically over the next eight years.

As discussed in previous questions, changes in this valuation can significantly alter the use potential of a given material and therefore impact materials suppliers. For example, a current materials supplier may believe potential competition is excessively expensive to warrant substitution. However, regulatory pressures or customer expectations may increase the effective cost of the existing material, making the alternative price competitive. It is critical for suppliers to maintain ever improving targets of cost, quality, and customer value. Suppliers and manufacturers must improve the effectiveness and their relationship through enhanced communication, educational activities, and joint manufacturer/supplier development programs. Purchasing decisions should be moved toward value- or systems-based purchasing and away from cost- or transaction-based purchasing. Improvements in this process will certainly lessen the potential shocks associated with shifts in automotive materials.

MAT-12. **What do you believe that the U.S. Congress should do, or should not do, to assist the traditional, domestic automotive industry? (Consider the "automotive industry" to include both OEMs and suppliers).**

The U.S. Congress should:	Percentage of Responding Panelists
Regulate based on technical merit	31%
Manage trade, foreign direct investment	23
Coordinate legislation, government agencies, and other policy activities	11
Increase gasoline prices	11

Other responses include: provide R&D incentives, provide government-backed loans, facilitate cooperation between companies, and provide tax incentives for alternative fuels and recycling.

REPRESENTATIVE RESPONSES: U.S. Congress **Should**

- Congress should better understand technical challenges before creating regulations. Reward companies for development of technology that improves the environment, increases CAFE, etc.
- CAFE should be frozen at 27.5 and the impact of higher gasoline taxes should be evaluated.
- Congress should give government-backed loans to automakers. It should back off of gas mileage requirements.
- A more level field for competition against the Japanese, (i.e., loosen Japanese OEMs' "Keiretsu" system) should be established. More traditional OEM and supplier alliances should be encouraged.

The U.S. Congress should not:	Percentage of Responding Panelists
Arbitrarily set regulations with out regard to market, costs, and technical feasibility	71%

Other responses include: promote protectionism, require auto makers to take back vehicles for recycling, set methods of attainment as well as objectives, and enforce strict ant-trust regulation.

REPRESENTATIVE RESPONSES: U.S. Congress **Should not**

- CAFE standards should not be arbitrarily established without knowledge of available materials and technology to meet goals.
- An aura of protectionism should not be created for suppliers who can not manage efficient businesses.
- Congress should not try to direct the marketplace.

MANUFACTURER/SUPPLIER COMPARISON

These comparisons are not made for open-ended questions.

COMPARISON OF FORECAST: TECH-88

Materials panelists top four "should do" responses match four of the Technology panelists' top six responses. While Materials suppliers are more interested in broader policy mechanics (i.e., regulating based on technical merit and coordinated legislation) Technology panelists appear more action oriented (i.e., establish fair trade policies, develop a national manufacturing policy, and relax legislated regulations). Both perspectives have particular advantages. The two panels' responses are precisely the same regarding what Congress should not do: pass legislation without regard to technical feasibility.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATION

Relations between Detroit and Washington are threatened by the theme that is implicit in the consensus of these responses and inherent in the relationship to date: adversarial product regulation based on political processes. Materials panelists desire significantly improved processes, focused objectives, optimized solutions, and realistic timetables for development of regulation. There is also a desire to expand the Detroit-Washington relationship beyond just product issues to encompass manufacturing competitiveness, trade, and other public-sector-controlled factors of production. Only through improved relations, understanding, and cooperation will industry be able to leverage Washington's public-sector-controlled resources, and effectively meet competitive pressures in an increasingly global environment. Through the same improved relations, government should be better able to leverage the industry's ability to provide improved economic conditions, safer roads, cleaner air, and other social and economic future in one economy.

To ensure that future government policies consider market and, economic forces, and technical feasibility, the auto industry (manufacturers, suppliers, and others with direct economic ties) must develop a more credible and comprehensive public policy communication effort.

MAT-13. **The recyclability of automotive materials and related environmental concerns will be significant issues confronting the entire industry (OEMs and suppliers) in the upcoming decade. With regard to recycling, what factors do you think are, or will become, important regarding the utilization of materials within the following categories? Please specify material where appropriate. (Where 1 = most important, 5 = least important)**

Recycling Factors	Plastics/Polymers			Non-Ferrous metals			Ferrous Metals
	Unreinforced Thermoplastics	Reinforced Thermoplastics	Thermosets	Aluminum	Copper	Zinc	
Limited reapplication potential of recovered material	2.4	2.2	2.0	3.0	3.2	3.3	3.4
Recycling infrastructure	1.7	2.6	1.7	3.1	3.4	3.1	3.3
Energy required to process raw material	3.1	3.2	3.1	2.1	2.9	3.1	2.4
Energy required for recovery	3.1	3.0	1.5	2.9	2.9	2.9	2.6
Economics of reclamation/recycling process	1.5	1.5	3.0	2.9	2.7	2.3	3.1
Scrap value	2.8	2.8	2.6	3.3	3.2	3.2	3.4
Labeling/Identification	1.8	2.2	2.1	3.8	4.0	2.6	4.1
Dismantling/Disassembly	2.1	1.8	2.3	3.1	3.2	3.0	3.3
Ease of materials separation	2.3	2.0	2.9	2.7	2.7	2.4	3.6
Lack of design for disassembly	2.8	2.7	2.8	3.1	3.0	3.1	3.5
Industrial environment/Health issues	3.1	3.0	2.7	3.9	3.8	2.8	4.0
Alloy content/ contamination	2.3	2.3	1.8	2.7	2.7	2.7	3.4
Environmentally safe disposal	2.0	1.9	1.8	3.3	3.0	2.8	3.6

SELECTED EDITED COMMENTS

- Europe leads on plastic recycling. North America and Japan are behind and North America is slipping further behind. This issue is not really on the Big Three's agenda.
- Recycling will not be a major factor until the economics are right.

MANUFACTURER/SUPPLIER COMPARISON

Across all these variables there are numerous differences between the suppliers and manufacturers. One way of capturing potential differences between the groups is to look at the top perceived recycling barriers across all materials. This indicates potential customer requirements and materials or materials supplier advantages. For manufacturers, the most significant perceived barriers are economics of reclamation/recycling process, ease of materials separation, dismantling/disassembling, energy required for recovery, and environmentally safe disposal. For suppliers, the major barriers are environmentally safe disposal, alloy content/contamination, ease of materials separation, economics of reclamation/recycling process, and the recycling infrastructure.

COMPARISON OF FORECASTS: TECH-24

It is difficult to make a direct comparison across so many variables. Analyzing the top four responses within each material category, the Materials and Technology panels are in agreement on three out four for each material except thermosets and ferrous materials. Although the differences appear minor, perceptions of the barriers and advantages facing these two materials groups do vary.

For thermosets, the Technology panel believes that the top recycling issues are recycling infrastructure and economics of reclamation (tie), limited reapplication potential of recovered material, ease of materials separation, and labeling.

The Materials panel selected energy required for recovery, recycling infrastructure, alloy content/contamination, and limited reapplication potential of recovered material as their top concerns.

For ferrous metals, the Technology panel believes that the key issues are scrap value, alloy content, economics of reclamation and labeling (tie), and dismantling. While the Materials panel's responses indicate that the key issues are energy to process raw material, energy required for recovery, economics of reclamation, and recycling infrastructure and dismantling.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATION

Future automotive materials selection will be a more complex undertaking. Designers and engineers will continue judging materials for a given application based on weight, strength, surface finish, cost, processing times, and other traditional criteria. However, given the future regulatory climate and consumer emphasis on environmentalism, manufacturers will be specifying materials with increasing attention to the material's recyclability. This question focuses on the general recycling barriers across a few, broad categories of materials. Specific materials compounds, process requirements, and end-use application will determine the true economic feasibility of recycling a specific material. The responses to this question are a useful barometer of perceived and real barriers that certain classes of materials face.

Across all materials classes, the general economics of reclamation, energy required for recovery, labeling, and alloy content or contamination are the leading recycling factors that materials providers and processors must address. These factors may favor a material's use (such as the economics of recycling for ferrous metals) or they may present a perceived barrier (such as contamination for thermosets). Materials suppliers must highlight the positive and minimize the negative attributes of materials. Materials evaluation should take place from the perspective of the end product; it should not be isolated from a systems view. For example, five individual plastics may have excellent recycling attributes, but if the final product integrates the plastics in such a manner that dismantling or separation is impossible, then the individual characteristics are lost due to a lack of foresight in product design and engineering.

It is foreseeable that some materials may be removed from the sale because of lack of market demand given recyclability difficulties. Of course where there is risk there is also opportunity. It is imperative that manufacturers consider and involve the materials supplier's input in the early stages of product design and engineering.

MAT-14. Regarding the issue of federal or state level regulatory activity to enforce the recyclability of automotive materials, please rank on a scale of 1 to 5 (where 1=extremely important, 5=not important) your forecast for the probability of the following regulatory areas.

Recycling Regulatory Areas	Ranking
Disposal of automotive fluids (e.g., battery acid, coolants, etc.)	2.0
Disposal of used tires	2.0
Recyclability of plastics/polymers	2.1
Mandate uniform identification/coding standards to facilitate separation	2.2
Regulation/licensing of dismantlers/salvage yards	2.5
Financial penalties/incentives based on percent Gross Vehicle Weight (GVW) considered non-recyclable	3.4
Require OEMs to take back and recycle/dispose of vehicle at end of product life cycle (per German proposals)	3.7

SELECTED EDITED COMMENTS

- There is an opportunity for a huge bureaucracy. Our "know-best" theoreticians in Washington cannot avoid this.
- At state level, the automotive shredders could be regulated and currently produce 20% plastic waste. Quebec has already passed legislation. Federal government cannot single out plastic but state governments can! Some shredders are refusing Chevrolet APVs and Corvettes because recovery value is too low.
- Eventually, I believe that regulations will mandate coded materials, require recyclability, and eventually cradle-to-grave responsibility or recycle deposit.
- A tax on new cars to fund recycling is probable.
- OEMs must recycle their own scrap cars.
- U.S. government will mandate the percentage of recycled vehicles (similar to CAFE) noting specific levels for given years.

MANUFACTURER/SUPPLIER COMPARISON

Both panels agree that government regulation will occur, enforcing the recyclability of automotive materials. Manufacturers believe that disposal of fluids, mandated uniform identification/coding standards, and recyclability of plastics and polymers will be targeted areas. Suppliers believe that each of these targets, plus disposal of used tires, are possible regulatory initiatives.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

Our Materials panelists foresee regulatory activity in disposal of automotive fluids and used tires, recyclability of plastics, and uniform materials identification or coding standards. Some states are already requiring a tax or deposit to be paid on new tire purchases. These deposits are returned to the customer when he or she trades in the old set of tires to an authorized retail outlet. This strategy has been very successful with lead acid batteries to the point that over 90% of all used batteries are recycled. Just as bottlers and retail outlets have learned to live with bottle deposits it appears the time has come for tire producers to do so as well.

The other likely regulatory areas are far more encompassing. Recyclability of plastics and labeling may involve a wide range of alternatives. In this regard it is imperative that the auto manufacturers, component producers, and materials processors take a proactive stance in leading the regulatory agenda. If it is inevitable that regulation will occur, then industry has an opportunity to build credibility, provide accurate information, and create public goodwill by participating in the regulatory process in a proactive, not resistive and reactive manner.

There is a significant level of recycling regulatory activity occurring at the federal and state level. Much of this activity is purely politically driven: politicians, environmental action groups, and others taking advantage of the pro-environmental consumer sentiment to push legislative and agency rule-making procedures. A significant amount of the activity is well meaning and, in fact, has the business community's support. This regulatory activity tends to be technically sound and market realistic.

MAT-15. **What are the most significant issues or problems that will impede the dismantling and reclamation of NAPPV components and materials?**

Significant Impediments to Dismantling/Reclamation	Percent Responding
Economics/Cost	34%
Within this category, 20% of the respondents cited the cost of labor required for dismantling	
Identification/Separation	21%
Within this category, 47% of the respondents cited contamination as a significant problem in the area of separation	
Logistics/Infrastructure	14%
Design for disassembly	10
Legislation (state and local)	8
Market for recovered materials	8
Disposal	5

REPRESENTATIVE RESPONSES

- Contamination by fasteners and molded-in inserts will retard use of adhesives for permanent assembly. This takes all the benefits out of recycling as currently structured.
- In Europe, most cars are dismantled and then shredded. In U.S. only 1 million vehicles/year are dismantled (versus 20 million/year in Europe). More dismantling equals more efficiency and less waste generation. In U.S., 95% of cars go to shredders and 20% (by weight) ends up as residue and, therefore, landfills. The Japanese are likely to follow Germany and the car companies will self-impose own regulations to design for disassembly and recovery. Their regulations will likely be worldwide standards. California is currently discussing an advanced disposal system for all waste (based on weight) which would directly affect cars and the purchase cost.
- There is no known technique for separating materials from reinforcements in composites. It is difficult to separate different plastics from one another.
- Commingling of various materials (metals with metals; metal with plastic; and automotive fluids with plastics) makes separation difficult. Automotive shredder/dismantlers are not equipped to separate more than eight distinct materials. By the year 2000, 50 individual materials will need separation at the dismantler level. Methods to further separate auto fluff into plastics and foam will be necessary.
- OEMs and suppliers need to consider recyclability/reclamation in the vehicle design process.

MANUFACTURER/SUPPLIER COMPARISON

These comparisons are not made for open-ended questions.

TREND FROM PREVIOUS DELPHI SURVEYS

Although the exact question was not asked, Delphi V (1989) panelists responded to the following question: It is clear that solid waste and material recycling/environmental issues will become far more important in the upcoming decade. It is also becoming apparent that light-duty vehicle design will undoubtedly be impacted by these issues. Please indicate ways in which you think the automotive industry, both OEMs and suppliers, will or should respond in the design, production, and ultimate retirement of future vehicles.

The following table presents the Delphi V results, which address many of the identified dismantling and reclamation issues and problems.

Delphi V (1989) Industry Strategies to Address Recycling Issues	
Recycling Strategies	Percent of Panelists' Responses
Need for OEMs and suppliers to consider recyclability/reclamation in vehicle-design process	34%
Need for OEMs and suppliers to develop reclamation programs (including identification systems to improve separation)	31
Need to develop recyclable materials	19
Development of in-plant recycling programs/ reduction of waste associated with manufacture	7
Increase vehicle durability	7
Enforcement of recyclability	2

STRATEGIC CONSIDERATIONS

Economics, based on labor and other costs of collection and disassembly, is the significant barrier impeding dismantling and reclamation of NAPPV components and materials. Technical issues, such as material identification and logistics, become manageable or acceptable when an economic incentive is present. It is evident that the issue of dismantling will not be solved strictly within the traditional automotive industry. The auto industry should work with other impacted industries (such as consumer appliances), state and federal regulatory agencies, shredders and scrap yards, aftermarket participants, consumers, and even insurance companies (for issues of safety and theft prevention) to address this problem.

The secondary markets may evolve over a period of time based strictly on economics of recovered materials, or they may never be economic without supportive public policy. If state or federal regulations require disassembly and recycling to significantly reduce landfill needs, then these costs must be recovered in the price of products, through more efficient operations elsewhere, or through secondary market sales. It would be prudent for manufacturers and suppliers to design for disassembly and recycling in the conceptual and early engineering phases. This should minimize total system costs because product designs will facilitate needed disassembly activity.

Current products will be more difficult to handle; identification and separation problems are identified by 21% of the panelists as a barrier. These issues are complex and manufacturers and suppliers need to work closely with regulatory groups to ensure realistic and effective standards, research organizations to assure adequate knowledge bases, and the consuming public to ensure widespread understanding of the costs and benefits involved.

III. BODY AND CHASSIS MATERIAL USAGE

MAT-16. What percentage of NAPPVs will use an integral frame or other design in MYs 1995 and 2000?

NAPPV Frame Construction	Est. 1990 MY*	Median Response		Interquartile Range	
		1995	2000	1995	2000
Integral Body/Frame or Unibody	92.0%	91%	85%	80/92%	75/92%
Separate Body/Frame	7.3	7	5	5/10	2/10
Space Frame	<0.7	2	10	1/5	5/15

*Compiled from: Automotive News Market Data Book, 1990

SELECTED EDITED COMMENTS

- Frame construction will be market and law driven. The full size vehicles using separate body/frame have just been redone. This could carry them over to 2000.
- Monocoque (unibody) is inherently the lightest possible structure. Constant pressure to reduce mass will limit growth of competing designs.
- Space frame growth is probably an exclusive GM phenomenon. I do not believe it is a sensible way to build a car.
- Space frame/composite combinations will rise significantly.
- The numbers do not seem to reflect light-duty trucks. Separate body/frame percentage should be much higher. In any event, I see little change.

MANUFACTURER/SUPPLIER COMPARISON

The two panels essentially agree upon the share of separate body on frame for 1995 and 2000. However, the manufacturers forecast a greater share of space frame construction: 5% versus the suppliers' 2% in 1995 and 11% versus the suppliers' 5% in 2000. These differences are significant indicating a variation of manufacturer and suppliers' expectations and possible conflicting strategies.

COMPARISON OF FORECASTS: TECH-27

The Technology and Materials panelists are in close agreement regarding forecasts for unibody, separate body/frame, and space frame for the year 1995. For the year 2000, the Materials panelists forecast two-and-a-half times more space frames than do the Technology panelists (Materials = 10%, Technology = 4%). There is a corresponding decrease in the percentage of integral body/frame construction forecast by the Materials panelists for the year 2000 (85%) compared with the Technology panel projection for the same year (92%).

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

The unibody frame design continues to be viewed as the dominant vehicle structure through the year 2000. In fact, we found significant consistency in the forecast between Delphi VI and Delphi V Technology volumes. The forecasts are almost exactly the same.

The space frame appears to be growing in importance at the expense of the separate body frame design. As we observed in our analysis in Delphi V, there are possible changes in basic construction techniques on the mid- and long-term horizon that could rather dramatically alter the forecast. While this would not be likely during the next few years, near the end of the decade the likelihood of fundamental change in this area increases. It should also be noted that there are wide differences of opinion within the industry with regard to relatively new systems such as the space frame. Some manufacturers are rapidly developing second- and third-generation, space-frame capabilities whereas others have only modest experience.

As interest in new body-exterior and structural materials accelerates, and demands for improved fuel economy through weight, but not necessarily size, reduction occur, some very creative and innovative concepts may emerge. At the same time, the traditional techniques are being refined rather significantly. This has certainly been observed in the efforts of the Auto/Steel Partnership.

What is conventional today was far from conventional five and ten years ago because of the dramatic improvements that have been made in most elements of the body-design and fabrication process. Despite the relative stability of this forecast for integral body/frame designs, we would reiterate that this basic technology must be watched closely in the years ahead. Breakthroughs in materials, design, and construction techniques could have a profound impact on the basic structure of the vehicle.

MAT-17. **What is your forecast for the material mix of steel, aluminum, and plastic-reinforced composites used in frame/structural members in integral body/frame and in space-frame designs for NAPPVs in the MYs 1995 and 2000?**

Integral and Space Frame Construction	Median Response		Interquartile Range	
	1995	2000	1995	2000
Steel	90%	82%	85/90%	75/85%
Aluminum	5	7	5/9	5/10
Composites	5	11	2/7	5/15
Total	100%	100%		

SELECTED EDITED COMMENTS

- Aluminum is impaired by its cost. Composites are impaired by the liability of failure mechanism (i.e., fractures).
- Composites are still in their infancy. Joining is an issue. Adhesives have durability issues.
- Gradual adoption of aluminum and composites will occur unless an energy crisis hits.
- Modest increases in use of aluminum and composites usage will occur based on CAFE. Rate of growth will be slow.
- This is really two questions. The ratio might be different for unibody or space frame. In either case, recycling concerns and the difficulty of designing structural components from fiber reinforced composites really limit their potential in structural applications.

MANUFACTURER/SUPPLIER COMPARISON

There are no differences between the responses of the two panels.

COMPARISON OF FORECASTS: TECH-22

There are no significant differences between the two panels' forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

Steel will remain as the overwhelmingly dominant structural material in both the integral body/frame and space frame designs through the year 2000. However, the use of aluminum and polymer-based composites is expected to expand, but rather gradually. Generally, the views in the present Delphi are consistent with those of Delphi V Technology panel, with slightly decreased expectations for composite materials in space frames. In any event, the magnitude of the forecast for aluminum and composites, while small, is very aggressive when compared with today's production levels, which are essentially zero. If even several percentage points of application are achieved, this would indeed be viewed as revolutionary, requiring very careful watching. This is a highly volatile area where major advances with alternate materials are possible and, indeed, likely. Also, considerable improvements in the application of more traditional, steel-based materials can be expected. This is an important area for many in the industry and must be monitored closely. In our opinion, the chances for surprises are rather high.

MAT-18. In what year do you foresee the first production vehicle with a polymer-based composite intensive body/frame structure (excluding skins) will be introduced?

Year of Composite Frame Introduction	Median Response	Interquartile Range
	2000	1997/2005

SELECTED EDITED COMMENTS

- A giant technological or manufacturing leap will be required.
- Low volume may be used for learning curve purposes.
- Major costs, engineering, and manufacturing hurdles remain to be overcome before a real volume production vehicle is introduced.
- There will be no introduction in foreseeable future.
- These will be used in electric vehicles.

MANUFACTURER/SUPPLIER COMPARISON

Both panels expect introduction of these structures in 2000. The supplier panel's interquartile range is wider with 25% of the panel expecting introduction as soon as 1997 and 25% expecting introduction as late as 2005.

TREND FROM PREVIOUS DELPHI SURVEYS

The foreseen introduction date continues to be extended outward into the future. The 1987 forecast median estimate was 1995; this was extended to 1998 in Delphi V (1989), and finally to 2000 in Delphi VI. Although composite-intensive frame structures have been proven through prototypes, processing times, production cost, and other engineering issues limit production volume expectations.

STRATEGIC CONSIDERATIONS

Increasing the amount of composites in vehicle structures remains an elusive goal. Generally, costs are viewed as excessive for high volume applications with the present level of production technology. One panelists' comment is particularly interesting with regard to electric vehicles. Weight reduction is extremely important in electric vehicles and consequently weight-saving technology will be pushed. This may be the kind of stimulus needed to bring composites to commercialization and lead to a broader range of applications over the longer term. Also, some intriguing technology is being developed within the United States Advanced Composites Consortium among the three domestic manufacturers.

We generally believe that the composite technology is on the steep slope of the learning curve and must be watched carefully for possible breakthroughs on any of a number of fronts. The promise of significant parts consolidation and consequent production of vehicle structures with relatively few parts is theoretically very attractive and remains a driving force. Another factor, obviously, is related to future fuel-economy standards, which may in turn drive composite technology much as it is today with electric vehicles.

One intriguing general comment is that industry is increasingly beginning to view materials not just as steel, plastic, or aluminum, but are beginning to consider more material systems where one can envision structures that are based on a true systems approach with optimum combinations of a number of materials. We are not sure some of these combinations would generally be classified as polymer based composites, but in a broader sense, they certainly could be viewed as composite materials.

MAT-19. **What percentage of the following components do you expect will be produced from thermoplastics or from thermosets by the years 1995 and 2000?**

Sheet Applications	Median Response				Interquartile Range			
	Vertical*		Horizontal**		Vertical*		Horizontal**	
	1995	2000	1995	2000	1995	2000	1995	2000
Thermoplastics	10%	20%	0%	5%	10/10%	20/25%	0/2%	5/10%
Thermosets	10	15	10	20	5/10	10/20	5/15	10/30
Steel	80	60	85	70	80/85	50/70	80/95	55/80
Aluminum	1***	5	5	5	0/5***	3/5	3/5	5/10

Structural Applications	Median Response				Interquartile Range			
	Vertical*		Horizontal**		Vertical*		Horizontal**	
	1995	2000	1995	2000	1995	2000	1995	2000
Thermoplastics	0%	5%	0%	3%	0/2%	5/5%	0/0%	0/5%
Thermosets	5	15	5	15	3/5	10/15	5/10	10/15
Steel	93	75	95	77	85/97	75/85	85/95	70/81
Aluminum	2	5	1***	5	0/10***	1/15	0/10	1/20

*Vertical refers to door, outer; fender, outer.

**Horizontal refers to hood, outer; deck lid, outer.

*** 1% or less is not factored into an adjusted total.

SELECTED EDITED COMMENTS

- Aluminum will see some applications in luxury model sheet applications; aluminum will be used in structural components (e.g., NSX-type vehicles).
- By 2000, many of the cost/volume issues for composites will be resolved.
- Due to recycling, thermoplastics will be favored where performance allows.
- Recycling concerns will limit growth of fiber-reinforced composites. In structural applications, non-uniformity of properties limits fiber-reinforced composites from an engineering standpoint. Per pound cost of thermoplastics will limit applications.
- Structural applications are meaningless.
- The process limitations will drive us to an "alloy" of thermoplastic and thermoset for minimum secondary operations (thermoplastic) and lower investment and stiffness (thermoset).

MANUFACTURER/SUPPLIER COMPARISON

There is general agreement between manufacturers and suppliers on vertical panel applications for 1995 and 2000. However, there are significant differences in the other forecasts. The following tables present these differences. Manufacturers predict much higher penetration of aluminum for both sheet and structural applications and plastic usage for sheet applications. These differences may arise from varying expectations of fuel-economy standards, methods to achieve increased fuel economy standards, cost, and processing advancements.

Horizontal Sheet Applications	Percentage of Total			
	1995		2000	
	OEM	Supplier	OEM	Supplier
Thermoplastics	0%	0%	5%	6%
Thermosets	15	10	25	18
Steel	80	87	60	70
Aluminum	5	3	10	6
Total	100%	100%	100%	100%

Vertical Structural Applications	Percentage of Total			
	1995		2000	
	OEM	Supplier	OEM	Supplier
Thermoplastics	1%	0%	5%	5%
Thermosets	5	5	14	10
Steel	84	93	67	82
Aluminum	10	2	14	3
Total	100%	100%	100%	100%

Structural Applications	Percentage of Total			
	1995		2000	
	OEM	Supplier	OEM	Supplier
Thermoplastics	0%	0%	5%	5%
Thermosets	9	5	14	14
Steel	82	94	67	78
Aluminum	9	1	14	3
Total	100%	100%	100%	100%

TREND FROM PREVIOUS DELPHI SURVEYS

In past Delphi studies this question was asked to capture the mix of only plastic materials, therefore it is impossible to make comparisons.

STRATEGIC CONSIDERATIONS

This is a relatively far-ranging qualitative question, which we have asked repeatedly (with regard to plastics) in our Delphi forecasts, to gain some sense of general use trends of a variety of materials used in both sheet and structural applications in both horizontal and vertical positions within the vehicle. Of course, the horizontal/vertical issue is perhaps more appropriate for sheet application of polymers rather than the general structural components or metals. In general, panelists forecast increasing use of both thermoplastic and thermoset polymers for sheet and structural applications. The quartile ranges for some of the applications are very tight, whereas in other cases, they are extremely broad, indicating a high level of uncertainty. It is important to note that the broad range may indeed represent uncertainty, but it also may reflect differing strategies of various industry participants. One manufacturer may be evolving a strategy that is more focused on one technology, whereas another manufacturer may have chosen to focus on a different technology. This could result in a broad interquartile range.

The panelists' comments in this question are intriguing in that they reflect some very different views on these various materials applications. Steel is expected to maintain its dominant position with significant inroads being made by aluminum (compared with past forecasts). Thermoset polymers generally continue to be favored for horizontal applications with thermoplastics in the vertical position. The growth in both aluminum and polymer expectations is rather significant and is certainly indicative of a important competitive battle between a variety of materials for automotive structures and sheet in the latter part of this decade.

Another issue beginning to creep into the materials picture is recycling, and as noted by several comments, a green movement could increasingly impact materials selection. All in all, this is an extraordinarily complex issue, and we expect the future to be highly volatile with regard to materials selection. Needless to say, no producer of any given material should feel comfortable about its future role in motor vehicles.

MAT-20. Please estimate the number of years before panel penetration will occur in a severely corrosive environment (such as Detroit or Pittsburgh) for NAPPVs produced in MYs 1995 and 2000.

	Median Response		Interquartile Range	
Years to panel penetration	1995	2000	1995	2000
	9	10	7/10	8/10

SELECTED EDITED COMMENTS

- The number of years can vary significantly due to design or type of panel, even if the same base material is used.
- The issue is less penetration and more loss of physical properties due to ultraviolet radiation, acid rain, and abrasion of plastics.

MANUFACTURER/SUPPLIER COMPARISON

There are no significant differences between the responses of the two panels.

TREND FROM PREVIOUS DELPHI SURVEYS

The number of years before panel penetration in severely corrosive environments seems to have settled in between eight and ten years. Delphi IV estimated the 1995 period to be ten years. This dropped in Delphi V (1989) to eight years for 1995 and ten years for 2000. The current study (nine years and ten years in 1995 and 2000, respectively) reinforces earlier Delphi trends to the ten-year level.

STRATEGIC CONSIDERATIONS

We have asked this question for a number of years to ascertain trends in panel penetration in a severely corrosive environment. In general, we find that the forecasts have remained relatively constant over a considerable period of time. The two comments presented in this question are important. One clearly raises the issue of type of panel or how the panel is designed, which introduces a factor in addition to the particular material selected. The other is a broader issue with respect to general degradation of physical properties, which may be considerably different than panel penetration. Still, the forecast of about ten years before panel penetration suggests that many of the traditional problems with corrosion in body panels have been largely eliminated and will probably not be a source of future competitive advantage for industry participants. Of course, the cost of corrosion protection is very important and this could certainly have a competitive impact on individual company cost structures and profit margins.

IV. MATERIAL APPLICATIONS: TOTAL VEHICLE

MAT-21. **Consider the following list of automotive components. Please indicate the percentage of each likely to be made from the listed materials in model years 1995 and 2000. (It is not necessary to enter a response for every component—just those you are familiar with.) Where you answer, please ensure that your estimates add across to 100%. Please use zeros where applicable.**

	1995 MODEL YEAR Median Response				
Composites	Steel	HSLA Steel	Aluminum	Reinforced Plastic/Composites	Nonreinforced Plastic
Hood, Outer	83%	4%	3%	10%	0%
Hood, Inner	85	0	5	10	0
Roof	95	0	0	5	0
Floor Pan	100	0	0	0	0
Bumper, Fascia	10	0	0	25	65
Bumper, Support	25	55	0	20	0
Fuel Tank	75	0	0	0	25
Seat Frame	50	40	5	5	0
Wheels	30	30	40	0	0
Radiator Support	80	10	0	10	0
Suspension Springs	85	5	0	10	0
Suspension Control Arms	55	40	5	0	0

	1995 MODEL YEAR Interquartile Range				
Composites	Steel	HSLA Steel	Aluminum	Reinforced Plastic/Composites	Nonreinforced Plastic
Hood, Outer	65/90%	0/20%	1/5%	5/10%	0/0%
Hood, Inner	70/90	0/5	0/5	5/10	0/0
Roof	70/95	0/2	0/0	2/5	0/0
Floor Pan	70/100	0/0	0/0	0/5	0/0
Bumper, Fascia	0/15	0/0	0/0	10/50	40/70
Bumper, Support	15/25	40/65	0/5	20/30	0/0
Fuel Tank	70/75	0/0	0/0	0/0	15/30
Seat Frame	20/70	20/70	0/5	0/10	0/0
Wheels	20/50	0/35	35/45	0/5	0/0
Radiator Support	50/80	0/15	0/0	0/20	0/0
Suspension Springs	0/90	0/15	0/2	0/20	0/0
Suspension Control Arms	0/55	0/40	0/5	0/5	0/0

Composites	2000 MODEL YEAR Median Response				
	Steel	HSLA Steel	Aluminum	Reinforced Plastic/Composites	Nonreinforced Plastic
Hood, Outer	60%	10%	10%	20%	0%
Hood, Inner	55	5	15	25	0
Roof	80	5	5	10	0
Floor Pan	82	10	3	5	0
Bumper, Fascia	0	0	0	25	75
Bumper, Support	10	40	15	35	0
Fuel Tank	55	0	0	5	40
Seat Frame	25	45	10	20	0
Wheels	20	30	40	10	0
Radiator Support	50	10	5	35	0
Suspension Springs	70	25	0	5	0
Suspension Control Arms	35	50	10	5	0

Composites	2000 MODEL YEAR Interquartile Range				
	Steel	HSLA Steel	Aluminum	Reinforced Plastic/Composites	Nonreinforced Plastic
Hood, Outer	40/75%	0/15%	5/15%	15/25%	0/7%
Hood, Inner	50/65	0/10	5/20	20/30	0/0
Roof	60/90	0/10	0/5	0/15	0/0
Floor Pan	60/93	0/20	0/5	0/10	0/0
Bumper, Fascia	0/10	0/0	0/0	10/40	50/80
Bumper, Support	0/10	15/50	0/15	30/50	0/0
Fuel Tank	30/80	0/0	0/0	0/20	20/50
Seat Frame	0/25	25/60	0/20	5/80	0/0
Wheels	10/25	10/30	30/50	0/10	0/0
Radiator Support	5/50	0/20	0/5	0/40	0/0
Suspension Springs	0/70	0/30	0/0	0/15	0/0
Suspension Control Arms	0/70	0/60	0/10	0/5	0/0

SELECTED EDITED COMMENTS

- Components that may utilize parts made from different materials were treated as having only one base material. For example, an HSLA wheel may in fact have a plain steel rim and an HSLA spider. Suspension spring material may not be made of either steel or HSLA. The assumption is that a heat treatable steel could be categorized as HSLA.
- Hood design will incorporate HSLA steels for weight reduction.
- Cast iron must still be considered as a viable material (i.e., ductile), and also magnesium's potential (e.g., seat frames) must be evaluated.
- Recycling concerns will reduce consumption of fiber-reinforced composites.

TREND FROM PREVIOUS DELPHI SURVEYS

The following tables present Delphi V versus Delphi VI results.

Composites	Forecast for 1995 Model Year: Delphi V versus Delphi VI									
	Steel		HSLA Steel		Aluminum		Reinforced Plastic/ Composite		Nonreinforced Plastic	
	Delphi V	Delphi VI	Delphi V	Delphi VI	Delphi V	Delphi VI	Delphi V	Delphi VI	Delphi V	Delphi VI
Hood, Outer	80%	83%	0%	4%	0%	3%	20%	10%	0%	0%
Hood, Inner	75	85	0	0	0	5	25	10	0	0
Roof	95	95	0	0	0	0	5	5	0	0
Floor Pan	93	100	2	0		0	5	0	0	0
Bumper, Fascia	2	10	0	0	0	0	17	25	80	65
Bumper, Support	35	25	30	55	1	0	35	20	0	0
Fuel Tank	65	75	0	0	0	0	0	0	35	25
Seat Frame	65	50	15	40	0	5	20	5	0	0
Wheels	55	30	10	30	30	40	5	0	0	0
Radiator Support	60	80	5	10	0	0	35	10	0	0
Suspension Springs	85	85	0	5	0	0	15	10	0	0
Suspension Control Arms	75	55	20	40	0	5	5	0	0	0

Composites	Forecast for 2000 Model Year: Delphi V versus Delphi VI									
	Steel		HSLA Steel		Aluminum		Reinforced Plastic/ Composite		Nonreinforced Plastic	
	Delphi V	Delphi VI	Delphi V	Delphi VI	Delphi V	Delphi VI	Delphi V	Delphi VI	Delphi V	Delphi VI
Hood, Outer	65%	60%	5%	10%	0%	10%	30%	20%	0%	0%
Hood, Inner	65	55	0	5	0	15	35	25	0	0
Roof	80	80	0	5	0	5	20	10	0	0
Floor Pan	80	82	0	10	0	3	20	5	0	0
Bumper, Fascia	1	0	0	0	1	0	15	25	83	75
Bumper, Support	20	10	20	40	0	15	60	35	0	0
Fuel Tank	40	55	0	0	0	0	5	5	55	40
Seat Frame	42	25	14	45	2	10	42	20	0	0
Wheels	42	20	10	30	36	40	12	10	0	0
Radiator Support	40	50	5	10	0	5	55	35	0	0
Suspension Springs	80	70	0	25	0	0	20	5	0	0
Suspension Control Arms	60	35	30	50	0	10	10	5	0	0

STRATEGIC CONSIDERATIONS

We have asked this question in most of our previous Delphi surveys to ascertain, on a representative component basis, basic materials trends. In general, the trends are in line with past forecasts, although there has been some moderation in expectations for polymer-based composites and a modest increase in expectations for aluminum. This was generally observed in the Technology forecast as well. The quartile range for many of the components is broad, indicating either one or two factors: an uncertainty with regard to a given material technology, and/or an indication of differing strategies of various manufacturers. For example, one manufacturer may have a greater interest in aluminum for an exterior sheet application, whereas another may be relying more on plastic materials.

Although materials trends appear to be reasonably stable, they still represent a significant change from the material composition of these representative components today, and suggest rather strongly that we are on the threshold of a revolution in automotive materials. The traditional materials are presenting a formidable moving target to the competition. In addition, new variables are beginning to enter the equation. For example, the significant increase in concerns for recycling issues may be a factor in the modestly diminished expectations for plastic. An interesting observation is that expectations for new materials often begin to wane as we get closer to the end of the forecast period where such factors as cost, manufacturing problems, etc., become very real.

Fuel economy improvement through weight reduction (at a given strength level), and part-number count reductions are factors leading to forecasts of increased aluminum and plastics use for most components. These forecasts are suggestive of serious challenges for traditional materials such as steel and cast iron and emerging opportunities for lighter-weight materials. Forecasts for increased material variety also complicate manufacturers' and materials suppliers' and processors' efforts in labeling and disassembling for recycling.

Another factor of increasing importance in materials decisions is the capital and human resources constraints of the industry that tend to mitigate the speed with which new technology is adopted. On the other hand, the possibility of more restrictive fuel economy standards may hasten the application of these materials. From multiple perspectives, it is clear that it is extremely difficult to forecast with precision future materials use in today's complex environment. We might find, for example, that a given product—such as the new Saturn with the thermoplastic side panels—may ultimately settle the material choice issue, should customers begin to make a purchase decision because of plastics. If that situation were to develop, the materials competition might turn rather sharply because of customer preference for a given material. In most cases, the component material is transparent to the customer, but that may change.

MAT-22. **Please forecast the material content, in pounds, and the total curb weight (dry, unloaded) for the average North American-produced passenger car for model years (MY) 1995 and 2000, given the indicated CAFE scenarios.**

Materials	Median Response (in pounds)			Interquartile Range (in pounds)		
	1995		2000	1995		2000
	27.5 m.p.g.	30 m.p.g.	35 m.p.g.	27.5 m.p.g.	30 m.p.g.	35 m.p.g.
STEEL						
Low Carbon Steel	1,325	1,205	1,050	1,300/1,350	1,175/1,275	925/1,150
HSLA Steel	240	250	265	240/245	242/260	240/280
Stainless Steel	34	34	34	34/35	34/35	30/35
Other Steels	40	40	40	40/40	39/40	38/40
TOTAL	1,639	1,529	1,389	1,617/1,665	1,455/1,600	1,253/1,477
CAST IRON	420	350	300	400/425	350/375	290/320
ALUMINUM						
Castings	130	155	160	120/140	125/160	140/190
Wrought Aluminum	30	35	50	30/30	30/40	40/50
TOTAL	160	190	210	159/170	175/205	185/270
PLASTICS						
Unreinforced no fiber content)	140	140	150	130/150	130/150	125/180
Reinforced (<40% fiber content)	85	90	120	80/100	85/110	100/130
Structural Reinforced composites (>40% fiber)	30	40	60	20/30	35/45	50/90
TOTAL	255	270	330	240/270	255/300	300/380
COPPER (including electrical)	45	45	40	45/45	40/45	35/40
ZINC (including coatings)	18	15	15	16/18	15/18	14/18
MAGNESIUM	5	8	10	5/5	7/10	10/20
GLASS	85	80	75	85/85	80/83	70/78
CERAMICS	2	3	4	2/2	2/3	3/5
POWDERED METALS	25	28	30	25/26	26/30	28/35
RUBBER						
Tires (include spare)	95	90	90	90/95	75/100	75/95
All Other Rubber	30	30	25	30/35	30/30	20/30
TOTAL	125	120	115	120/130	120/130	95/125
TOTAL ALL OTHER	260	250	225	250/260	245/250	200/230
TOTAL VEHICLE	3,039	2,888	2,743	3,016/3,081	2,802/3,000	2,614/2,795

SELECTED EDITED COMMENTS

- At this late date, market forces or sales forces can only affect weight change by 1995. CAFE to 30 m.p.g. by 1995 would restrict availability of some models. The 2000 CAFE target of 35 m.p.g. would result in weight reduction and more radical styling. Several NAM products are increasing in weight currently.
- Aluminum in wrought or extruded form may begin to be adopted for some structural applications (e.g., cross members, frame extensions, and eventually total space frames).
- If steel is to keep its market share, it must do so through weight savings; which means HSLA.

- Safety concerns with lightweight vehicles will limit mass reduction. CAFE requirements will be met by drivetrain improvements.
- 30 m.p.g. CAFE by 1995 is unrealistic. If it becomes a reality, it would restrict models. 35 m.p.g. by 2000 is nearly unrealistic. The law, if necessary, needs to be written now.
- In going from 27.5 to 30 m.p.g. CAFE, downsizing will occur partly by actual vehicle size reduction but also by restricting sales of big cars and by use of more efficient engines and use of more weight efficient materials (aluminum, plastics, and high strength steel), 35 m.p.g. will certainly result in quotas on big cars and massive size and material changes plus smaller engines.
- There needs to be more weight reduction but I do not realistically know how to get there faster. Structural composites are currently not cost or volume effective.
- Recyclability concerns will limit the growth of fiber-reinforced structural composites. Magnesium castings will replace both aluminum and cast iron in 2000.
- Structural composite applications for intake manifolds will become reality for U.S.-made automobiles in 1992.

MANUFACTURER/SUPPLIER COMPARISON

The two panels are essentially in agreement with each other (within 10%) on their 1995, 27.5 m.p.g. forecasts. If the CAFE standard is raised to 30 m.p.g., our manufacturer panel forecasts slightly lower total weight and increased plastics usage will be required to meet a higher standard. In the 1995, 30 m.p.g. forecast, manufacturers estimate 300 pounds of plastics will be applied (compared with the suppliers' forecast of 270 pounds) with an overall weight of 2,850 pounds versus the suppliers' 2,929 pound forecast. Manufacturers decrease total weight and increase plastics applications through the reduction of steel (the 2.5 m.p.g. increase results in manufacturers reducing total steel usage 180 pounds per vehicle). The dramatic drop-off in steel between these two scenarios indicates a potential risk for steel suppliers (and suppliers who only fabricate steel parts) as it is their customers who perceive a greater amount of steel will be needed to be removed to achieve the stricter standards.

The 2000, 35 m.p.g. scenario offers increased material application uncertainty. Interestingly, the two panels forecast the same required total weight: 2,700 pounds. The panels are in agreement with each other (within 10% variation) on all material applications except steel, plastic, magnesium, powdered metals, and other rubber. The following table presents these differences.

Material	Forecast for 2000 (In pounds)	
	OEM	Supplier
Steel	1,350	1,455
Plastic	379	350
Magnesium	15	10
Powdered Metal	35	29
Other Rubber	20	30

Manufacturers expect a 35 m.p.g. standard will require a significantly higher usage of low-weight materials. While this is an opportunity for some suppliers it is a threat to others in raw material processing and finished part fabrication.

COMPARISON OF FORECASTS: TECH-20

The two panels are within 10% of each other on all major material categories except two for the 2000, 35 m.p.g. scenario: plastics and magnesium. The Materials panel predicts a much larger dependence upon plastics forecasting 330 pounds versus the Technology panel's 290 pound forecast. Because of its small base, magnesium usage is forecast to be 25% higher by the Materials panelists (10 pounds); the Technology panel expects eight pounds. These differences indicate the Materials panel's expectation that a 35 m.p.g. average fleet will require a significantly greater usage of high-strength, low-weight, high-value materials.

TREND FROM PREVIOUS DELPHI SURVEYS

Compared with Delphi V, the Materials panelists' forecasts are consistent with the expected changes between the 1995 27.5 m.p.g. and 30 m.p.g. scenarios (the 2000 forecast is not comparable). Current panelists forecast a 5% reduction in overall weight will be required to achieve the higher standard. This reduction was 2.5% in Delphi V. The two materials receiving the greatest reduction in weight to achieve the lower Delphi VI average weight are steel (which falls 7% in Delphi VI versus 3% in Delphi V) and cast iron (which falls 17% in Delphi VI versus 6% in Delphi V).

Delphi VI Materials panelists forecast lighter overall vehicle weights for both 1995 CAFE scenarios and a more restrictive 2000 CAFE scenario. The following table displays the most significant differences between the past two surveys. Readers must be aware that Delphi VI panelists considered a 35 m.p.g. CAFE standard in 2000 while Delphi V panelists considered a 32 m.p.g. standard. To achieve increased CAFE standards, current panelists may be emphasizing weight reduction over downsizing, powertrain improvements, and other fuel-economy improvement methods.

Material	1995 (In pounds)		1995 (In pounds)		2000 (In pounds)	
	1989 Delphi V 27.5 m.p.g.	1991 Delphi VI 27.5 m.p.g.	1989 Delphi V 30 m.p.g.	1991 Delphi VI 30 m.p.g.	1989 Delphi V 32 m.p.g.	1991 Delphi VI 35 m.p.g.
Total Steel	1,730	1,639	1,670	1,529	1,532	1,389
Cast Iron	420	420	395	350	345	300
Total Aluminum	150	160	155	190	180	210
Total Plastic	270	255	285	270	320	330
Magnesium	1	5	2	8	2	10
Powdered Metal	27	25	26	28	27	30
Total Vehicle	3,148	3,039	3,076	2,888	2,930	2,743

STRATEGIC CONSIDERATIONS

This question's responses presents interesting materials-demand scenarios given various CAFE standard assumptions. The overall results present a picture of expected manufacturers' demands and suppliers' responses to achieve these CAFE standards across various materials. These weight expectations are just one variable needing to be addressed in the pursuit of increased fuel mileage (TECH-4 presents the Technology panelists' opinion on all sources of fuel economy improvements).

To achieve a 35 m.p.g. CAFE standard, Materials panelists believe an additional 296 pounds need to be removed from an average 1995 vehicle achieving 27.5 m.p.g. Shifts of material usage are clearly driven by weight-strength-cost valuations. There are threats and opportunities for individual processors within this challenging environment. While the overall vehicle weight reduction (1995 27.5 m.p.g. versus 2000 35 m.p.g.) is expected to be at least 10%, certain material groups take a larger proportion of the reduction. Total steel is reduced 15%, cast iron demand is scaled back 28%, zinc drops 17%, and other materials are squeezed 13%.

The change in the weight-strength-cost valuation emphasizes the use of aluminum, plastics, magnesium, and powdered metals, which all increase more than 20% over their 1995 27.5 m.p.g. base. Even within steel, which would expect double digit percentage reductions in a 35 m.p.g. CAFE environment, while low carbon steel usage is reduced by 23%, HSLA steel increases in use by 10%. It is apparent that an intensive CAFE environment will force the usage of higher value materials.

Although the value of CAFE regulation is intensely debated, it is a U.S. governmental policy that the industry must work within. Its influence steers product strategies, engineering direction, and sourcing decisions. Therefore it is extremely important that policy makers be guided with a strong influence from the industry and that the industry closely track and analyze potential outcomes of proposed legislation.

MAT-23. What percentage of NAPPV components and systems will utilize magnesium alloys by the year 2000?

Magnesium Applications	Percent Application by the year 2000	
	Median Response	Interquartile Range
Engine blocks	2%	0/5%
Engine heads	0	0/5
Other engine components	5	5/10
Transmission housings	7	5/15
Wheels	5	5/10

Other single responses include: brakes, frames (some structural), and miscellaneous interior parts (seat frame).

SELECTED EDITED COMMENTS

- I believe magnesium will begin to make inroads because of its weight savings potential but any estimates of percent application would be wild guesses.
- The issue is still cost per pound saved and concern of handling of machining scrap.
- Unknown durability of composite and magnesium wheels makes estimates of their usage highly speculative.

MANUFACTURER/SUPPLIER COMPARISON

The panels are in agreement except for the transmission housing forecast. The manufacturers forecast a 10% penetration rate for magnesium alloys while the suppliers forecast only 5%. This may be the result of manufacturers' increasing expectations of future fuel-economy standards forcing the application or specific advanced-engineering and production efforts not known to suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi V (1989) addressed magnesium usage in two questions. The first asked "In what components will magnesium alloys begin to replace existing materials by the year 1995?" Thirty-seven percent of the respondents answered engine components, followed by covers and housing (24%), manifolds (13%), wheels (13%), and none (13%). These responses do not equate to production percentages in Delphi VI, however, they do reinforce the current data.

The second question directly asked material utilization rates, but only of engine components. Delphi V respondents forecast 5% of rocker arm covers by 2000 will be magnesium. Intake manifolds, oil pans, water pump housings, and air cleaner housings each received little interest, resulting in a median response of 0%.

STRATEGIC CONSIDERATIONS

Generally, there seems to be an increasing interest in magnesium as an automotive material. This is evident in the overall mass forecast (MAT-22) with a significant percentage increase envisioned for magnesium. There is reasonable enthusiasm for magnesium in a number of component areas, although somewhat less in engine heads and blocks than in other vehicle components listed. It is clear that magnesium is becoming less an experimental material and is being increasingly viewed as a realistic alternative—particularly to aluminum. This shift from experimental to more standard practice consideration could have a profound impact on magnesium use.

Additionally, pressures to increase fuel economy (weight reduction), and component consolidation are expected to be key drivers in the consideration of magnesium. As regulatory and market pressures change make-buy and cost-benefit decisions, all materials suppliers must be aware of emerging threats and opportunities. Normally, materials such as magnesium might not be considered a competitor because of relatively high costs per pound. However, decision equations may change; as the value of a pound of weight saved increases, engineers gain experience with magnesium, and magnesium-processing technology improves.

Another issue of continuing importance with regard to magnesium is the supply factor. Recognizing that automotive applications can represent an enormous mass of any material, even a modest increase in automotive use could tax supply and perhaps result in significant instability in the pricing. Traditionally, automotive purchasing executives have expressed reluctance to buy quantities of a given material leading to shortages that might increase price. This forecast suggests that we may be on the threshold of a rather exciting material revolution with regard to automotive applications for magnesium—further evidence of the increased competition in automotive materials.

MAT-24. What percentage of the following spark-ignited engine components do you expect to be made from Metal Matrix Composites (MMC) by 1995, 2000, and 2005?

MMC Applications	Median Response			Interquartile Range		
	1995	2000	2005	1995	2000	2005
Pistons	5%	10%	15%	1/10%	5/10%	7/20%
Connecting rods	1	3	6	0/2	1/5	5/10

NO COMMENTS

MANUFACTURER/SUPPLIER COMPARISON

Manufacturers are much more optimistic towards metal matrix composites usage. Likely root causes of these differences are noise, vibration, and harshness; cost and process innovation; fuel economy requirements; reliability; and durability factors. The following table presents the differences between the two panels' forecasts.

MMC Applications	Percentage of Total Engine Components					
	1995		2000		2005	
	OEM	Supplier	OEM	Supplier	OEM	Supplier
Pistons	5%	1%	15%	15%	20%	20%
Connecting rods	5	1	5	5	10	10

TREND FROM PREVIOUS DELPHI SURVEYS

Compared with Delphi V (1989), there is a trend towards greater interest in MMCs for pistons and away from connecting rods. The interquartile ranges are narrower in Delphi VI, indicating that the forecast is closer to an industry consensus. The following table presents a comparison of the last two Delphi studies.

MMC Applications	Forecast for 1995		Forecast for 2000	
	1989 Delphi V	1991 Delphi VI	1989 Delphi V	1991 Delphi VI
Pistons	3%	5%	7%	10%
Connecting rods	2	1	5	3

STRATEGIC CONSIDERATIONS

Metal Matrix Composites are forecast to grow dramatically over the next ten years. Although the mass forecast remains low when considering total units or weight shipped, the high percentage growth indicates significant interest in MMC technology. In engine components, reciprocating mass reduction to assist fuel economy (friction reduction) and noise, vibration, and harshness (NVH) characteristics are primary reasons for this interest. This technology offers weight-savings potential in critical moving components such as engine pistons and connecting rods. The forecast is consistent with prior Delphi surveys, but with somewhat greater expectations for pistons, and less expectations for connecting rods. The quartile range remains broad, again, either indicating uncertainty or different strategies on the part of manufacturers. We expect that this technology will be undergoing considerable development in the years ahead to increase performance and reduce costs. Furthermore, the role of these materials may be enhanced by more of a systems approach in total engine design when appropriate trade-offs can be exercised. MMC engine components may lead to savings in other areas of the engine such as reduced bearing requirements or less sophisticated NVH control because of lower reciprocating inertia within the engine.

Suppliers of components that are candidates for MMC should watch trends closely. Again, we would add as we have in so many other questions, that the present technology is presenting a moving target to candidate materials, and this would certainly apply to internal engine components.

MAT-25. What percentage of the following brake components do you expect to be made from Metal Matrix Composites (MMC) by 1995, 2000, and 2005?

MMC Application	Median Response			Interquartile Range		
	1995	2000	2005	1995	2000	2005
Brake components	0%	5%	10%	0/1%	2/5%	5/20%

NO COMMENTS

MANUFACTURER/SUPPLIER COMPARISON

There are no significant differences between the two panels' responses.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

In general, there appears to be growing interest in Metal Matrix Composites, particularly aluminum-based MMC, for brake components, although the forecast in the near term is very small—as evidenced by a zero percent median for 1995. With the desire to reduce total mass (and particularly unsprung mass) in the vehicle to enhance ride and handling, this indeed may be a realistic material alternative. It would appear that the economic and manufacturing considerations are the more important factors limiting use. As evidenced by various technical symposia, and exhibits by potential suppliers at these meetings, MMC activity is increasing significantly. Clearly, brake-component producers need to monitor developments closely and attempt to lead the way with new material applications.

MAT-26. **What percentage of NAPPVs will use materials other than conventional glass for either windshields or side windows in the year 2000?**

Alternative Material for Glass	Median Response		Interquartile Range	
	Windshield	Side Window	Windshield	Side Window
Polycarbonate	2%	10%	0/5%	5/10%
Polycarbonate-glass laminates	10	25	5/15	15/30
Special coatings and/or interlayers to Reduce solar load	20	10	10/40	5/15
Provide defrosting capability	2	5	1/10	5/5
Provide abrasion resistance for plastics (e.g., diamond film glazes)	60	30	40/65	25/30

SELECTED EDITED COMMENTS

- This is an apparent opportunity to make weight reduction inroads. Customer acceptance is an issue.
- Coated plastic or plastic/glass laminates offer significant opportunity for lightweight vehicles in the late 1990s. The technology needs to be applied (not invented) in a cost effective manner to be viable and further penetrate the available market. This is a top priority by Japanese car manufacturers.
- The driving force is weight reduction and crash performance. The difficulty is uniformity of process to a worldwide sales market.
- Recycling of glass will become an important issue requiring new technology from today's laminate technology.
- Rigid plastics in windshields have head impact values that exceed what the head can take.

MANUFACTURER/SUPPLIER COMPARISON

Significant differences arise in the side window forecast for alternative materials for glass and the windshield forecast of special coatings. The suppliers believe a higher penetration of polycarbonate penetration will occur for side windows (10% versus 5% for manufacturers), while the manufacturers foresee higher usage of polycarbonate-glass laminates (30% versus 25% for suppliers).

Regarding special coatings for windshields, suppliers are more concerned with reducing solar load (25% versus 20% for manufacturers) and providing abrasion resistance (65% versus 50%). The manufacturers view defrosting capabilities as more important than suppliers do, (5% versus 2%).

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi V panelists forecast 0% nonconventional glass usage in 1995 and 2000. The interquartile range for 1995 was narrow (0/1%) while the 2000 range was larger (0/10%). Even excluding side window and coatings expectations in Delphi VI, there appears to be a strong trend towards the substitution of polycarbonates for window glass.

STRATEGIC CONSIDERATIONS

Automotive window glass, although involving laminates and complex shapes, has remained a relatively stable technology. However, future use of polymers, special coatings, and laminates to reduce sun load, improve defrosting capabilities, and provide abrasion resistance will increase automotive window complexity. While Delphi V (1989) panelists did not view polycarbonates as suitable for side or front windshield applications, Delphi VI panelists suggest interest is growing.

As designers specify larger window areas and more complex shapes for styling reasons, the weight of traditional glass materials may be excessive, promoting interest in lighter-weight alternatives. And, considering the expected dramatic increase in the value of a pound of weight saved in future vehicles, the potential of weight savings in the glass area would seem to give strong support to the rather rapid development of a non-glass "greenhouse." In addition, sun load, safety, and structural strength are all major considerations that glass suppliers and processors are facing. It seems clear that any new material will have to be at least as good as traditional glass technology in such areas as scratch resistance, clarity, and durability to be considered by the industry. Again, it must be kept in mind that glass will present a fast moving target to all competitors.

V. MATERIALS APPLICATIONS: POWERTRAIN

MAT-27. **For the following engine components, please indicate what percentage is likely to be made from the listed materials by the year 2000.**

Materials	Median Response	Interquartile Range
Crankshaft		
Cast iron	70%	60/70%
Steel	30	30/35
Camshaft		
Cast iron	50%	25/65%
Steel	40	25/40
Composites: (e.g., steel/powdered metal combination)	10	5/10
Piston		
Cast aluminum	70%	70/80%
Reinforced aluminum	20	15/20
Ceramic	0	0/5
Magnesium	5	5/10
Hybrid (e.g., plastic skirt/ceramic crown)	5	5/5
Connecting Rod		
Cast iron	25%	20/30%
Steel	20	5/30
Aluminum	5	0/5
Powdered metals	45	45/60
Magnesium	1	0/5
Composites (e.g., aluminum MMC, carbon titanium)	4	3/10
Intake Manifold		
Cast iron	10%	5/20%
Aluminum	60	40/70
Plastic/polymer composite	20	20/30
Magnesium	10	5/10

Materials	Median Response	Interquartile Range
Exhaust Manifold		
Cast iron	55%	50/80%
Steel	10	10/15
Stainless steel	35	15/40
Rocker Arm Cover		
Plastic	60%	30/60%
Aluminum	20	15/30
Steel	10	10/20
Magnesium	10	5/20
Oil Pan		
Steel	50%	40/80%
Aluminum	20	10/30
Plastic	10	10/20
Hybrid	10	10/20
Other (e.g., steel-plastic-laminates, magnesium, composites)	10	*
Water Pump Housing		
Cast iron	20%	10/25%
Steel	10	10/15
Aluminum	40	30/40
Plastic	30	20/35
Valves		
Steel	90%	85/90%
Ceramic	5	1/5
Titanium	4	2/10
Other (e.g., ceramic coated steel, MMC, hollow valves)	1	

*Indicates a single response without an interquartile range.

NO COMMENTS

MANUFACTURER/SUPPLIER COMPARISON

The following table presents the differences between the two panel's forecasts. Because of the level of detail asked, there are many variations within particular components and materials applications. Where significantly large differences exist, suppliers and manufacturers must investigate the root causes with purchasing, engineering, and marketing contacts.

Materials	OEMs	Suppliers
Crankshaft		
Cast iron	70%	65%
Steel	30	35
Camshaft		
Cast iron	66%	50%
Steel	24	40
Composites: (steel/powdered metal combination)	10	10
Piston		
Cast aluminum	72%	70%
Reinforced aluminum	14	20
Ceramic	*	0
Magnesium	9	5
Hybrid (e.g., plastic skirt/ceramic crown)	5	5
Connecting Rod		
Cast iron	10%	24%
Steel	30	19
Aluminum	*	5
Powdered metals	50	48
Magnesium	*	1
Composites (e.g., aluminum MMC, carbon titanium)	10	3
Intake Manifold		
Cast iron	10%	11%
Aluminum	70	50
Plastic/polymer composite	15	28
Magnesium	5	11

Materials	OEMs	Suppliers
Exhaust Manifold		
Cast iron	80%	53%
Steel	*	10
Stainless steel	20	37
Rocker Arm Cover		
Plastic	30%	57%
Aluminum	40	14
Steel	10	10
Magnesium	20	5
Hybrid	*	14
Oil Pan		
Steel	69%	56%
Aluminum	17	11
Plastic	9	11
Hybrid	5	22
Water Pump Housing		
Cast iron	17%	11%
Steel	8	11
Aluminum	50	34
Plastic	17	34
Hybrid	8	10
Air Cleaner Housing		
Steel	10%	20%
Aluminum	10	10
Plastic	80	70
Valves		
Steel	90%	88%
Ceramic	5	5
Titanium	5	3
Other (e.g., ceramic coated steel, MMC, hollow valves)	*	4

* Indicates no response.

TREND FROM PREVIOUS DELPHI SURVEY

There is a trend towards magnesium, powdered metals, and stainless steel across a number of components. Delphi VI gives the first mention of magnesium pistons for year 2000 applications. Powdered metals are the clear winner for connecting-rod applications. Their successful application will be at the direct expense of steel connecting rods. Magnesium may also be a big gainer in intake manifolds with 10% share expected by 2000 (the 1989 study forecast 0%). There is a trend towards stainless steel (35% for Delphi VI versus 20% in Delphi V) exhaust manifolds at the expense of cast iron. Delphi VI panelists doubled the 2000 share of magnesium rocker arm covers (10% versus 5%) from the 1989 survey. For water pump housings, 10% expectations for steel now hold compared with 0% in 1989. This is a direct substitution for cast iron.

STRATEGIC CONSIDERATION

The competition among a variety of materials for the various engine components selected for this question remains high. In most cases, the interquartile range is relatively broad and is an indication of the uncertainty or, as we have noted before, a measure of differing strategies on the part of various manufacturers and suppliers. Clearly, the competition is amplified by the expectations that a major fraction of North American-produced engines will be redesigned during the coming decade (see TECH-52).

For these engines, engineers will completely review all components for possible change and improvement. Furthermore, growing demands for improved powertrain performance, including smoothness, reliability, fuel economy, and power, insures a business-as-*unusual* environment for engine components.

There is reasonable stability in these forecasts compared with Delphi V of several years ago, and the shifts from Delphi V are consistent with events of the last two years. Generally, lighter-weight materials appear to be gaining favor. For example, magnesium expectations have been increased for pistons, inlet manifolds, valve covers, oil pans, composites and powder metallurgy for connecting rods. It must be remembered that many of these materials technologies are in a relatively early stage of development and continued significant progress might be expected in the years just ahead. We should also recognize that traditional materials are hardly remaining stationary targets for the new materials. Dramatic improvements have been made in many cases.

Finally, we suspect that as engine and component designers increasingly use a systems approach, trends are likely to emerge that will lead to a coalescence on a smaller set of materials technologies for the various components. In the meantime, competition among the various candidate materials will be lively, indeed, and important to track closely for anyone in the engine component business.

MAT-28. **What percentage of spark-ignited engines in NAPPVs will use the following ceramic engine components in the years 1995 and 2000?**

Spark-Ignited Engines: Ceramic Components	Median Response		Interquartile Range	
	1995	2000	1995	2000
Valvetrain components (includes valves, inserts, guides, seats, tappets, cams, etc.)	3%	10%	1/3%	2/10%
Exhaust manifold/port liner	3	8	0/5	2/10
Turbocharger turbine/rotor	5	15	1/5	5/18

SELECTED EDITED COMMENTS

- Ceramic products will be pushed by Japanese OEMs and suppliers.
- There will be slow growth with ceramics.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturers forecast greater ceramic usage in valvetrain and exhaust manifolds than do suppliers, while suppliers foresee greater ceramics use for turbochargers' turbines. The following table presents these differences. The likely root causes of these differences are differing views of cost, process innovation, fuel economy requirements, reliability, and durability factors.

Spark-Ignited Engines: Ceramic Components	Percentage of Total			
	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Valvetrain components	5%	3%	15%	7%
Exhaust manifold/port liners	5	1	8	7
Turbocharger turbine/rotor	1	5	2	15

COMPARISON OF FORECASTS: TECH-65

Materials and Technology are in close agreement on the forecasts for 1995 and 2000 valvetrain ceramic usage. The Materials panelists are more optimistic regarding ceramic exhaust manifold applications and more pessimistic regarding turbocharger usage. The following table presents these differences. It appears that Technology panelists believe processing, durability, and reliability problems can be overcome for turbocharging applications, however, their wide interquartile range suggests great uncertainty.

Spark-Ignited Engines: Ceramic Components	Percentage of Total			
	Technology Panel		Materials Panel	
	1995	2000	1995	2000
Valvetrain components (includes valves, inserts, guide seats, tappets, cams, etc.)	2%	10%	3%	10%
Exhaust manifold/port liner	1	5	3	8
Turbocharger turbine/rotor	10	20	5	15

TREND FROM PREVIOUS DELPHI SURVEYS

Compared with previous studies, there is increased interest and expectations for ceramic engine components. The trend towards greater use is especially prevalent in the 2000 forecast. The following table presents a comparison between Delphi V and Delphi VI results.

Spark-Ignited Engines: Ceramic Components	Forecast for 1995		Forecast for 2000	
	1989 Delphi V	1991 Delphi VI	1989 Delphi V	1991 Delphi VI
Valvetrain components	5%	3%	7%	10%
Exhaust manifold/ port liner	3	3	7	8
Turbocharger turbine/ rotor	2	5	6	15

STRATEGIC CONSIDERATIONS

Ceramics continue to be an elusive material as applied to engines. About ten years ago, amid much fanfare, the powertrain expectations for the ceramic applications were relatively high. The present forecast for ceramic components is rather modest for the next eight to ten years, but still suggests that ceramics will be a material with reasonably significant applications in the powertrain. Of course, it must be recognized that if manufacturing and cost problems are resolved, interest in ceramics could escalate rather dramatically. For example, it already seems clear that where turbochargers are used, ceramic "hotwheels" are very attractive and will probably become the dominant technology over the long term. The virtues of the ceramics, including high temperature performance, thermal insulation, and wear resistance, can be of significant value in some components. However, it should be noted that in-cylinder applications with spark-ignition engines can cause increases in gas temperatures and cause problems with engine octane requirement. Furthermore, higher temperatures could exacerbate problems of NO_x emissions. In contrast, the diesel engine can use higher cylinder temperatures to its advantage with respect to emissions and fuel cetane requirement.

It is clear that manufacturing considerations are still a key barrier to the application of ceramics, as are durability problems associated with microfractures in the structure which could lead to catastrophic failure in such areas as valves or pistons. We continue to see no real enthusiasm for a so-called ceramic-intensive engine. Rather, ceramics will be used, at best, on a part-by-part basis in future engines.

Finally, it must be noted that any problems with a material's reliability or durability that would compromise engine quality in any way must be dealt with appropriately. Satisfying today's quality-conscious customer requires it.

MAT-29. **What percentage of light-duty vehicle engines produced in the U.S. in MYs 1995 and 2000 will utilize aluminum cylinder heads and/or blocks?**

Light-Duty Engines	Est. 1990 MY*	Median Response		Interquartile Range	
		1995	2000	1995	2000
Aluminum heads	33%	50%	70%	40/50%	60/75%
Aluminum blocks	3.5	10	20	5/25	15/25

*Compiled from: Automotive News Market Data Book, 1990

SELECTED EDITED COMMENTS

- There will be a steady growth in aluminum heads and blocks.
- Weight savings opportunities will cause more aluminum blocks to be specified.

MANUFACTURER/SUPPLIER COMPARISON

For aluminum heads, manufacturers' and suppliers' 1995 forecasts are identical: 50%. For 2000 there is a slight difference with the manufacturers forecasting greater penetration: 75% versus 70% for the suppliers. While both panels forecast 10% aluminum block penetration for 1995, the suppliers are more optimistic for 2000, predicting 20% of the U.S. engine-block production to be aluminum versus 15% for manufacturers.

COMPARISON OF FORECASTS: TECH-62

The two panels agree on 1995 and 2000 forecasts of aluminum block applications. The Materials panelists are 10% higher (50% versus 40%, and 70% versus 60%) than the Technology panelists for both 1995 and 2000 forecasts.

TREND FROM PREVIOUS DELPHI SURVEYS

The trend towards aluminum application in engine blocks and heads is firmly established. The current forecast is essentially the same as Delphi V (1989) with 1995 head application lower (50% versus 55%, however, the Delphi VI median response is at the top of the interquartile range) and 2000 block application higher (20% versus 15%).

STRATEGIC CONSIDERATIONS

The trend to aluminum in engine cylinder heads, and to a lesser extent, cylinders blocks, is continuing and is generally consistent with the forecast of recent Delphi surveys. The forecast for aluminum cylinder heads for 1995 and 2000 is slightly less than Delphi V, whereas the forecast for aluminum blocks is greater. The quartile range for the year 2000 is reasonably broad, indicating a modest level of uncertainty. As the industry moves forward with its aggressive plans to redesign a major fraction of engines produced in North America during this decade, aluminum figures prominently as an engine material. If, as many suspect, there is a significant increase in CAFE standards, it seems likely that the trend to aluminum could accelerate as a means to achieve mass reduction in future vehicles. We believe the use of aluminum in engines is an efficient way to reduce mass at a relatively low cost compared with other areas of the vehicle.

It should also be remembered that cast iron is hardly a stationary target for lightweight metals. Considerable improvements continue to be made leading to surprising levels of mass reduction. Some new technologies give promise of reducing the mass difference to reasonably low values. However, these technologies must be demonstrated in high-volume production to be considered a real threat. These data are generally consistent with other areas of this report, suggesting that powertrain trends will be dynamic and, in may respects, unpredictable in the years ahead. Clearly, both fuel economy and emissions standards will have a significant impact on future engine materials.

The value of a pound of weight saved is expected to increase rather markedly (as evidenced in TECH-21), and should reinforce expectations for aluminum. On the other hand, cast iron presents important advantages in terms of engine noise, tolerance to overheating, low cost, and other considerations that have led to the prominent role that cast iron still plays in today's engines.

MAT-30. Of the aluminum blocks forecast in MAT-29, please forecast the percentage that will be unsleeved and the percentage that will be sleeved.

Aluminum Block Engines	Median Response			Interquartile Range		
	1995	2000	2005	1995	2000	2005
Unsleeved	5%	15%	25%	5/10%	10/25%	20/50%
Sleeved	95	85	75	90/95	75/90	50/80
Total	100%	100%	100%			

SELECTED EDITED COMMENTS

- A major issue is repairability and distortion.

MANUFACTURER/SUPPLIER COMPARISON

The panels are in agreement for 1995 and 2000. However, the manufacturers are more optimistic towards unsleeved engines in 2005: 40% penetration versus 25% for suppliers.

TREND FROM PREVIOUS DELPHI SURVEYS

The current study reaffirms the trend towards unsleeved designs, although at a slower rate. Delphi VI panelists estimate 5% and 15% of aluminum engines will be of unsleeved designs in 1995 and 2000, respectively. This compares to the Delphi V estimate of 10% in 1995 and 20% in 2000.

STRATEGIC CONSIDERATIONS

To sleeve or not to sleeve in aluminum engine blocks has been the subject of significant engineering effort over the past 20 or 30 years. The Chevrolet Vega engine of many years ago used a high silicone alloy aluminum block without sleeves. This engine did not prove to be highly durable, but apparently the problem was more related to intolerance to over-heating due to loss of cooling rather than inherent problems with the aluminum cylinder bores. The legacy of that engine continues to impede reconsideration of so-called bare-bore engines. However, the technology is used in some excellent vehicles around the world and has been developed to the point that it must be considered a validated technology. So, the reluctance remains, perhaps in part, due to the Vega experience and more forgiving nature of cast iron and other materials used in sleeved engines.

It is interesting that the panelists believe that there will be a steady increase in unsleeved designs in the years ahead to the point where about 25% of all engines are expected to be unsleeved by the year 2005. The interquartile range is significant, indicating a high level of uncertainty or different strategies on the part of the various manufacturers. The one selected comment is important in terms of both repairability and bore distortion, which may be particularly important today compared with past years. Bore distortion causes greater friction and lower fuel economy. Improved design techniques should help resolve this problem. The overall simplicity of the unsleeved design ultimately may yield somewhat less expensive engines if the other problems can be resolved. The fact of life today is that with increasing emphasis on quality and substantially longer warranty periods, manufacturers will continue to be cautious in accepting uncertain technologies, or at least technologies with which they have limited experience.

MAT-31. Which powertrain components (including housings and gears) for NAPPVs will be made from various forms of powdered metals (PM) in 1995 and 2000?

Powertrain Components Powdered Metal	Median Response		Interquartile Range	
	1995	2000	1995	2000
Connecting rods	30%	60%	10/45%	30/70%
Valvetrain components:				
Valve seats	40%	70%	40/65%	60/80%
Valve guides	30	40	20/50	30/80
Valve seat inserts	30	50	25/40	40/60
Tappets/lifters	10	20	5/15	10/30
Rocker arms	5	10	2/10	5/25
Camshaft lobes	5	20	5/5	10/30
Transmission gears	5%	10%	0/10%	0/15%

SELECTED EDITED COMMENTS

- I expect to see a large and rapid increase in powdered-metal valve guides for aluminum cylinder heads.

MANUFACTURER/SUPPLIER COMPARISON

Suppliers forecast significantly higher penetration rates for powdered metals across all surveyed components. These differences indicate a significant variation between potential supply and demand. Powdered metal usage should be investigated further with manufacturers' and suppliers' engineering, purchasing, and marketing contacts to obtain program-specific information. With this much variation it appears that new program decision points have not been reached. The following table presents the two panels' forecasts.

Powertrain Components Powdered Metals	1995		2000	
	OEM	Supplier	OEM	Supplier
Connecting rods	5%	30%	15%	60%
Valvetrain components:				
Valve seats	2	50	5	75
Valve guides	5	40	10	60
Valve seat inserts	2	30	5	50
Tappets/lifters	2	10	3	30
Rocker arms	2	10	5	25
Camshaft lobes	2	8	10	30
Transmission gears	5%	10%	10%	15%

TREND FROM PREVIOUS DELPHI SURVEY

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATION

There is reasonable consensus that the application of powdered metals will increase significantly in a number of powertrain components. In some cases, the expected growth rate is extraordinarily large such as in connecting rods and valve seats. In others, it is more modest. Clearly, the potential of near net shape components as well as carefully controlled properties has led to the increased enthusiasm of the panelists. However, it should be noted that supplier materials specialists are much more enthusiastic than those of the manufacturers. This is certainly cause for concern and suggests that trends should be watched closely. Also, the quartile range is sufficiently broad to indicate uncertainty or, as we have noted before, significantly different strategies on the part of various companies. Clearly, suppliers of the various components must watch trends closely because of the growing, but yet uncertain, interest in powdered metals throughout the powertrain. The overall trends in this question suggest that the technology is changing rapidly.

MAT-33. **There are major concerns regarding the use of alcohol-based fuels in NAPPVs and automotive material selection decisions, particularly with respect to fuel tanks. What percentage of alcohol-fueled NAPPVs will use the following fuel tank materials by MY 2000?**

Alcohol-Fueled NAPPVs: Fuel Tank Materials	Median Response	Interquartile Range
Stainless steel	20%	10/30%
Coated low-carbon steels	30	20/50
Polymer-based materials	50	20/60

SELECTED EDITED COMMENTS

- Stainless steel, while being technically satisfactory, is too expensive. The stainless share will probably start high and then decline.
- Polymer-based materials offer the best opportunity for cost-effective corrosion resistance.
- Organic-coated, electro-plated, low-carbon steels will displace the higher cost stainless steel materials.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturers forecast much lower penetration rates for these fuel tank materials than do suppliers. Perhaps manufacturers do not perceive the need to switch to alternative materials for alcohol-fueled vehicle fuel tanks, or they foresee another material not presented in this question (although comments did not refer to any). The following table presents the two panels' forecasts.

Alcohol-Fueled NAPPVs: Fuel Tank Materials	OEM	Supplier
Stainless steel	29%	20%
Coated low-carbon steels	42	30
Polymer-based materials	29	50

COMPARISON OF FORECAST: TECH-67

The Technology and Materials panels' forecasts are not directly comparable because the Technology panelists were not instructed to sum their responses to 100%. It does appear that the panels do differ in that the Technology panelists place a high priority on stainless steel while the Materials panelists view polymer-based materials as the leading candidate. Materials panelists appear to have full faith in the ability of polymer-based material tanks to handle the challenges of alcohol-fueled NAPPVs. The interquartile ranges are very large for both panels suggesting vehicle manufacturers, processors, and materials providers must work closer together to better understand this future market. The following table presents the existing differences.

Alcohol-Fueled NAPPVs: Fuel Tank Materials	Materials Panelists	Technology Panelists
Stainless steel	20%	30%
Coated low carbon steels	30	20
Polymer-based materials	50	10

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

With increasing expectations for the use of alcohol in fuels, either as a pure fuel or in combination with gasoline, a key materials issue is fuel-tank material. Many materials are attacked by alcohols, and this problem must be resolved before alcohol becomes a reasonable alternative fuel. The panelists generally viewed polymers as the preferred material, compared with both low-carbon steels and stainless steels.

Alcohol is not likely to become a dominant fuel over the next ten-year period, but it will likely experience significant use in some areas. For example, several manufacturers have recently announced production of a modest number of vehicles capable of using a broad range of alcohol and gasoline blends. We believe that materials developments in both plastics and lower-priced metals may yield positive results. With regulatory requirements and the durability expectations of today's customer, the use of alcohol or other fuels is not a trivial issue. Finally, we must question how much faith we can place in short-term, accelerated materials testing when vehicles are expected to perform over a number of years.

VI. MATERIALS APPLICATIONS: BRAKES AND WHEELS

MAT-34. **What percentage of brakes and clutch friction surfaces in NAPPVs will be made from the following materials in MYs 1995 and 2000?**

NAPPV: Brake/Clutch Materials	Median Response		Interquartile Range	
	1995	2000	1995	2000
Brakes				
Ceramic-based	5%	5%	3/40%	5/5%
Kevlar-based	5	10	5/35	5/30
Fiberglas	10	18	0/18	0/20
Carbon-based	7	5	0/15	2/7
Clutch				
Ceramic-based	5%	2%	5/32%	0/5%
Kevlar-based	5	5	5/43	5/40
Carbon-based	0	8	0/10	0/10
Metal fibers	5	5	0/20	0/20

NO COMMENTS

MANUFACTURER/SUPPLIER COMPARISON

The following table presents the forecasts in which the panels disagree. These differences may arise from varying expectations of performance requirements, cost, and processing advancements.

NAPPV: Brake/Clutch Materials	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Brakes				
Kevlar-based	5%	5%	10%	5%
Fiberglas	0	18	0	18
Carbon-based	0	7	0	7
Clutch				
Ceramic-based	5%	0%	2%	0%
Carbon-based	0	10	0	10
Metal fibers	0	5	0	5

TREND FROM PREVIOUS DELPHI SURVEYS

There has been a dramatic shift away from advanced brake and clutch friction materials. Delphi VI interquartile ranges are large, indicating uncertainty in this system. The following table presents the change in thought between Delphi V and Delphi VI.

NAPPV: Brake/Clutch Materials	Forecast for 1995		Forecast for 2000	
	1989 Delphi V	1991 Delphi VI	1989 Delphi V	1991 Delphi VI
Brakes				
Ceramic-based	40%	5%	45%	5%
Kevlar-based	35	5	30	10
Fiberglas	18	10	18	18
Carbon-based	7	7	7	5
Clutches				
Ceramic-based	32%	5%	30%	2%
Kevlar-based	43	5	40	5
Carbon-based	10	0	10	8
Metal fibers	5	5	7	5

STRATEGIC CONSIDERATIONS

As noted in the comments regarding trends from previous Delphi surveys, our Materials panelists have rather dramatically down scaled their expectations for the application of a range of different friction materials in both brakes and clutches. We are not sure why this has occurred. It is possible that the realities of cost, manufacturing, etc. of many of these new materials have made them less attractive than they appeared to be initially. Additionally, perhaps, some of the environmental issues are becoming resolved, to a degree, with respect to traditional materials.

There is no question that when one considers any material substitution from a true systems standpoint, the problem is far more challenging than when only one or two variables are considered (such as environmental impact or recycling). The interquartile range overall is extremely broad, which, as we have noted in several other questions, is an indication of widely divergent views within the industry and/or significantly different strategies on the part of the various industry participants. In any event, the very rapid changes is in these forecasts are cause for concern, and developments must be watched closely by suppliers of these materials.

MAT-35. It is estimated that approximately 31%* of MY 1990 North American-produced passenger cars had styled wheels. What percentage of styled wheels will be made from each of the following materials in MYs 1995 and 2000?

Styled Wheel Materials	Median Response		Interquartile Range	
	1995	2000	1995	2000
Steel	41%	25%	35/45%	20/30%
Aluminum	52	60	48/55	55/65
Composites	2	5	1/5	5/10
Magnesium	5	10	2/5	5/10

* Source: Automotive News Market Data Book, 1990.

SELECTED EDITED COMMENTS

- Clarification of "polycast" as a steel, composite, or "other" would be helpful to improve Delphi accuracy.
- Composites issues are failure mode and cost (too few manufacturers in the business).
- Composites' "hidden damage" potential will raise safety issues and inhibit growth.

MANUFACTURER/SUPPLIER COMPARISON

The panels are in agreement except for magnesium applications. The suppliers expect magnesium to capture 5% of the 1995 market and 10% of the 2000 market. This compares with 1% and 5% forecasts by the manufacturers for 1995 and 2000, respectively. Differences in cost, process advancements, customer preferences, and fuel-economy standards may drive these variations. The variations may result in difficulties if the suppliers develop capacity for 10% of the 2000 market, while their customers only demand volume equal to 5% of the market.

TREND FROM PREVIOUS DELPHI SURVEYS

Steel is now estimated to hold onto a larger share of the styled-wheel business and aluminum will also face greater competition from composites and magnesium. This new competition from magnesium and composites expected by current Delphi VI panelists is illustrated in the following table.

Styled Wheel Material	Forecast for 1995		Forecast for 2000	
	1989 Delphi V	1991 Delphi VI	1989 Delphi V	1991 Delphi VI
Steel	30%	41%	20%	25%
Aluminum	65	52	65	60
Composites	5	2	15	5
Magnesium	0	5	0	10

STRATEGIC CONSIDERATIONS

Material choice for future automotive wheels continues to be an interesting issue. Aluminum expectations are growing, whereas those of steel are decreasing. The interquartile range of the data is reasonably tight for steel and aluminum suggesting that there is growing consensus within the industry on these materials.

Compared with Delphi V several changes are noted. The expected trend to aluminum is modestly less than forecast two years ago, and the expectations for composite materials has been considerably downgraded even as magnesium has surged as a long-term candidate. There is no question that wheel materials will remain a competitive market for the coming decade. One important factor, undoubtedly, will be the cost, particularly as it relates to commodity pricing. If the rather aggressive expectations for both aluminum and magnesium bring the supply/demand curves close together, price volatility could increase. Industry has historically found this to be rather distasteful. The sheer volume of the automotive market increases the likelihood that this will occur.

VII. MANUFACTURING AND PAINT TECHNOLOGIES

MAT-36. **What percentage of North American light-duty vehicle-body joining operations will utilize the following techniques by the years 1995 and 2000?**

Body Joining Operations	Median Response		Interquartile Range	
	1995	2000	1995	2000
Resistance/spot welding	65%	50%	65/70%	50/60%
Mechanical fasteners	20	25	20/25	20/30
Adhesives	10	15	5/10	10/20
Laser welding	5	10	3/5	10/20

Other single responses include: conventional spot welding with snap fits.

SELECTED EDITED COMMENTS

- Adhesives use will grow rapidly. Laser welding costs will drop, permitting more use.
- Adhesives have high potential but low confidence due to content durability and environmental failures. Laser welding has specific applications. Mechanical fasteners are expensive and labor intensive but good for dissimilar materials.

MANUFACTURER/SUPPLIER COMPARISON

There are no significant differences between the two panels' responses.

TREND FROM PREVIOUS DELPHI SURVEYS

In previous studies, this question was not asked in a comparable manner.

STRATEGIC CONSIDERATIONS

In general, there appears to be a trend away from resistance or conventional spot welding towards mechanical fasteners, adhesives, and laser welding. However, this is by no means a revolutionary change. Instead, a rather gradual transformation is expected during the 1990s. The interquartile ranges in this question are rather tight, indicating that even though there is reasonable consensus on the trends, this area will still be extremely competitive in the years ahead. Obviously, any supplier of a given technology must monitor trends closely because the chances for surprise appear to be rather high. New technologies are likely to emerge. For example, a new adhesive technology could quickly alter the forecast. Also, it should be noted that once a given vehicle or component is tooled, it may not be cost effective to switch to a new fastening technology. Rather, the switch would more likely occur later as the component or vehicle is retooled. This is probably an important factor in the rather gradual change envisioned in these fastening technologies. In a general sense, it would appear that the industry is searching aggressively for ways to improve cost and quality of products, and this clearly applies to the fastening and bonding area of the vehicle.

MAT-37. What percentage of NAPPVs will utilize the following bonding/joining technologies by the year 2000?

Bonding Applications	Median Response		Interquartile Range	
	1995	2000	1995	2000
Urethanes	38%	38%	25/40%	35/45%
Epoxies	38	38	15/40	20/40
Acrylics	19	10	5/20	10/19
Foam tape	5	5	5/5	2/5

NO COMMENTS

MANUFACTURER/SUPPLIER COMPARISON

There are significant differences between the two panels' responses. This indicates wide variability of known, approved programs and future strategy directions. The following table presents the differing results.

Bonding Applications	1995		2000	
	OEM	Supplier	OEM	Supplier
Urethanes	25%	38%	25%	38%
Epoxies	15	38	20	38
Acrylics	5	19	10	15
Foam tape	35	5	35	5

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

While the interquartile ranges are large, both urethanes and epoxies received strong support from materials panelists as joining/bonding materials. However, the interquartile range for other adhesive bonding technologies is reasonably tight. This relatively high degree of consensus suggests that the materials specialists are generally together on this issue.

There are some important differences between the manufacturers and suppliers, which should be noted in the manufacturer/supplier comparison table. As with many other areas of the vehicle, intense competition is present, which should prove to make life interesting for those dealing with bonding chemistry. Obviously, any of these technologies must meet the increased demands for low system cost, as well as quality and durability, to be considered viable. Technical developments must be watched closely to ascertain if one of these technologies begins to move to the forefront.

MAT-38. There is some reluctance to utilize adhesive bonding. Please rate the importance of each concern/factor in slowing the adoption of adhesive bonding technology.

Adhesive Bonding Barriers	Concern		
	Little or No	Moderate	Extreme
Quality, durability, reliability (QDR)	0%	32%	68%
Cost	10	80	10
Manufacturing methodology	5	38	57
Design understanding	8	46	46

Other extreme importance responses include: recyclability.

SELECTED EDITED COMMENTS

- Assessing the quality of a bond is very difficult. This is especially critical for structural joints.
- Impact toughness for all environments will be a key quality criterion.
- Repairability will be of extreme concern.

MANUFACTURER/SUPPLIER COMPARISON

Quality, durability, and reliability are the most extreme concerns of both manufacturers and suppliers. Cost is the second most important concern of both panels.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

In general, the results of this question are self-explanatory. The concerns with quality, durability, reliability, manufacturing methodology, and design understanding are plainly evident. These areas of concern must be viewed as crucial to the success of adhesive bonding. In today's environment, it is absolutely necessary to totally validate a technology before it can be considered for general application. Based on the enthusiastic response of many toward bonding technology, we suspect that the developments will be rapid in the years ahead if concerns are set aside. An important area that is emerging with respect to these new bonding technologies is life-cycle management, or recycling concerns, which will need to be addressed along with the more traditional factors.

MAT-39. What percentage of NAPPVs will utilize either of the following paint technologies by the year 2000?

Paint Technologies	Median Response	Interquartile Range
Exterior Paint/Top Coat		
Water-base paints	68%	55/80%
High solids paints	22	15/30
Powdered coatings	10	4/19
Finish Technologies		
Mold-in color	13%	7/20%
Film applied coating	5	1/10
Prepainted steel coils	5	0/10

NO COMMENTS

MANUFACTURER/SUPPLIER COMPARISON

Manufacturers forecast a much higher application of mold-in colors (20% versus 10% by suppliers) for 2000. Suppliers forecast greater usage of high solid paints (25% versus 20%) and powdered coatings (15% versus 10%) than manufacturers.

TREND FROM PREVIOUS DELPHI SURVEYS

In previous studies, this question was not asked in a comparable manner.

STRATEGIC CONSIDERATIONS

Basically, two different areas are explored in this question. First is the general area of paint technologies and the second is some of the possible new innovations in finished technology that could be applied to automotive panels. In terms of the paint systems, there is overwhelming support for water-based systems by the year 2000. One of the major drivers for change in paint technologies is aggressive environmental standards that require significant changes in traditional painting processes. It also should be observed that the paint shops are enormously expensive parts of the assembly plants, and that with growing capital shortages it would seem highly desirable to achieve satisfactory finishes from an environmental standpoint, while still being able to offer the customer the kind of colors and finish quality that they desire at a minimal capital cost. We would assume that the panelists are taking these factors into consideration in their very strong support for water-based technologies. However, there are significant levels of support for both high-solid and powdered-coating systems. With regard to the new finish technology (mold-in for plastic color, film applied coatings, and pre-painted steel coils), there is enough support to suggest that we will see some interesting competition develop with the more traditional paint technologies in the future. We suspect the rate of developments in these areas will be high. This will assure that the entire area of coatings and finishings will be volatile and could be subject to change for some years to come.

MAT-40. **Taking into consideration expected changes in body materials, paints and other coating technologies, and growing environmental and energy concerns, what is the lowest maximum curing oven temperature likely by the year 2000?**

	Median Response	Interquartile Range
Lowest maximum curing oven temperature	225° F	200/275° F

SELECTED EDITED COMMENTS

- The issue is protection of steel components while lowering temperature for plastic and adhesive applications.
- Volatile organic compounds (VOC) restriction will become severe.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturers forecast a lower maximum curing oven temperature: 200°F versus the supplier response of 275°F. This may impact materials specifications and process requirements.

TREND FROM PREVIOUS DELPHI SURVEYS

This question was not asked in a previous Delphi Materials forecast.

STRATEGIC CONSIDERATIONS

There appear to be considerable benefits with the reduction of paint-oven cure temperatures, including such widely ranging factors as reduced energy costs (to maintain oven temperature) and reduced impact on some materials (particularly polymers). A systems-based approach to materials and finishing seems to be yielding results in terms of improved temperature cure performance. The newer paint technologies could offer significant benefits to the automotive manufacturer, but, of course, changes may represent competitive problems for suppliers of current coating materials.

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