THE UNIVERSITY OF MICHIGAN

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

- MARKETING
- TECHNOLOGY
- MATERIALS

VOLUME 3: MATERIALS

DELPHI V FORECAST AND ANALYSIS OF THE U.S. AUTOMOTIVE INDUSTRY THROUGH THE YEAR 2000

MATERIALS

December 1989

Published by

Office for the Study of Automotive Transportation
University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, Michigan 48109–2150

This research is self-supporting. Future studies are dependent on revenue from the sale of this publication.

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Cover by Kathleen Crockett Richards,
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Printed in the United States of America.

First edition published 1989. UMTRI 89–13–2

89 10 9 8 7 6 5 4 3 2 1

ACKNOWLEDGMENTS

We wish to acknowledge the people who contributed their skills, intelligence, and time toward the completion of this study. Our panelists unselfishly provided untold, thoughtful, reflective, and—we are sure—frustrating hours completing our detailed questionnaires. Our panelists truly make this a forecast of, by, and for the industry. Delphi V subscribers provided essential start-up funding allowing the undertaking of this substantial and comprehensive project.

Further, we wish to acknowledge those who worked hard hours accomplishing Delphi V production. Rose Kronsperger and Jennifer Jones contributed substantially to our word processing and data entry demands. In addition, we are indebted to Betsy Folks for panelist and questionnaire data support and Leda Ricci for an outstanding effort of final text processing. We are also grateful to Dan Mandoli for additional data entry assistance. It was only through the dedicated and concerted effort of these individuals that this project became a reality.

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FOREWORD

INTRODUCTION

Delphi V 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 are selected because they occupy positions of responsibility within the automotive industry and have strategic insight on important industry trends. In many cases they are in a position to influence these trends. This report, published in three volumes, is the fifth in this series of in-depth studies of long-range automotive trends that began with Delphi I in 1979 and continued with Delphi II in 1981, Delphi III in 1984, and Delphi IV in 1987.

The Office for the Study of Automotive Transportation performs the data collection and analysis, presentation, and interpretation of the results. Since the forecasts we present are those of the panelists, Delphi V is, essentially a consensus industry forecast of itself. These forecasts are not "crystal ball" predictions, but rather well-informed estimates, predictions, and opinions. Such forecasts provide an important basis for business decisions and provide valuable strategic planning information for those involved in all areas of the North American automotive industry, including manufacturers; service, component, and material suppliers; government; labor; public utilities; and financial institutions. We believe these to be the most authoritative and dependable North American automotive trends available.

A key point to keep in mind with regard to the Delphi forecast is that it presents a vision of the future which is, in a sense, an important basis for industry decision-making. It is obviously not a precise statement of the future but rather what the industry *thinks* the future might be.

THE DELPHI METHOD: GENERAL BACKGROUND

This study is based on the Delphi forecasting process. With this method various groups of 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, iterative method of forecasting based on independent inputs regarding future events from these experts.

The Delphi method is dependent upon the judgment of knowledgeable experts. This is a particular strength of this method because, in addition to quantitative factors, predictions that require policy decisions 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 make their forecasts come true. Even if subsequent events result in a change of direction of a particular forecast, this does not negate the utility of the Delphi. This report's primary objectives are 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 (accompanied by feedback of earlier-round responses of peers) to take advantage of group input while avoiding biasing effects often typical of 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 (cf. 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. This 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 of The University of Michigan faculty and 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 dealing with the topic being surveyed and are acknowledged to be 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 panel members are not made known to each other. Upon publication of the final Delphi report, all questionnaires and lists of panelists are destroyed.

The characteristics of the 330-member panels are as follows: 17% of the Technology Panel were composed of CEOs, presidents, or vice-presidents; 26% were directors; 36% managers or supervisors; 12% were engineers (chief, assistant chief, and staff); and 10% of the panel were made up of academic specialists and consulting technical engineering specialists. The Marketing Panel was composed of 22% CEOs, presidents or vice-presidents; 14% directors; 34% managers; 18% engineering specialists; and 16% academic and consulting marketing specialists. Among Materials panelists, 12% were CEOs, presidents and vice-presidents; 21% were directors; 36% managers and supervisors; 8% engineering specialists; and 23% academic and consulting materials specialists. Approximately 57% of the Delphi V panelists were employed by vehicle manufacturers, 32% by components and parts suppliers, and 11% were specialists, consultants, and academics.

PRESENTATION OF DELPHI FORECASTS AND ANALYSIS

When a question calls for a response in the form of a number, the group response is reported in terms of 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. The median value is the middle response, and 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 35% and 45%, with 40% representing a measure of central tendency. That narrow interquartile range would indicate a fairly close consensus among the respondents.

In contrast, the percentage forecasts for a different question might show a similar median forecast of 40%, but with an interquartile range of 20–70% indicating little 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 exposes such differences through the presentation of the interquartile range (IQR).

Note that the median results are typically expressed as round numbers (5, 10, 50), rather than more specific-appearing numbers (e.g., 12.7, 45.3) which might develop if averages were used.

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 arrive at their forecasts.

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 shown in the report following the forecast tables. Redundant or derogatory comments are excluded. These replies may be important indicators that are not apparent in the numerical data. An individual panelist may be aware of something unique that planners should carefully consider. However, readers should be careful not to over-emphasize a particular comment. It is possible for a well-stated contrary opinion to mislead the reader into ignoring an important majority opinion that is represented by numerical data.

Manufacturer/Supplier Comparison. Delphi V panelists include respondents from 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 *Manufacturers* (or for brevity in tables, *OEMs*—Original Equipment Manufacturers) and *Suppliers*.

For obvious competitive reasons, the automotive vehicle 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 or perspective of the forecast, our analyses include a comparison of the forecasts from manufacturer and supplier panelists in an attempt to illustrate where significant agreements or differences exist between the opinions of the two groups.

Comparison of Panels. The three groups of Delphi panelists (Technology, Marketing, and Materials) are asked questions that specifically focus on their respective areas of expertise. However, a few questions are considered common to two or more panels. 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 the same question. 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 interests 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 that collects and presents the opinions and attitudes of a group of experts at that particular point in time. Some questions, in various forms, were asked in previous Delphis. This has resulted in the accumulation of trend data in the Delphi forecasts since 1979. 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 is a reflection of the consensus of expert opinion at that time. These opinions and forecasts are predicated on the best information available at that time. Market, economic, and political factors change. An analysis of trend data can reveal either stability or volatility in a particular market factor, material, or technology. 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 relative Delphi V forecasts, other research and studies, and OSAT's extensive interaction with the automotive industry, inferences and interpretations are made as to the core issues in questions and their impact on the industry. By no means are they expected to be exhaustive statements of critical issues but rather points the reader should consider.

MATERIALS CONTENTS

EXECUTIVE SUMMARY

The Delphi V Forecast and Analysis of the U.S. Automotive Industry Through the Year 2000 is the fifth in a series of biennial, multi-volume forecasts issued by the Office for the Study of Automotive Transportation (OSAT) of the University of Michigan Transportation Research Institute. These Delphi forecasts, initiated in 1979, present a consensus vision of the future through the eyes of industry technical executives, material specialists, and marketing leaders.

The *Delphi V: 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 vehicle design. Analyses of the competition between polymers, steel, and other materials for a variety of body, chassis, and powertrain component applications as well as recycling/environmental, energy, and sourcing issues are also presented. Although many material innovations are not visible to the consumer, their effect on future vehicle design and the automotive supplier industry may be profound. The wide range of issues explored in *Delphi V: Materials* provides an indication of major automotive materials developments and trends through the year 2000.

Delphi V: Materials is divided into six major sections: (1) *Fuels* covers areas ranging from retail gasoline fuel prices, alternate fuels, and technical strategies for resolving problems with fuel vapor emissions; (2) *General Vehicle Features and Material Planning* addresses issues concerning recycling and reclamation, the competition between plastics and steel, corrosion warranties, and the impact of new materials on vehicle design; (3) *Total Vehicle: Material Applications* includes a forecast of individual materials and total weight of cars given different fuel economy (CAFE) scenarios, as well as a materials forecast for selected key components; (4) *Powertrain: Material Applications* presents forecasts for materials usage in key engine components; (5) *Body / Chassis: Manufacturing and Assembly Trends* covers expectations for material trends in brakes, wheels, and windshields as well as automotive adhesives/sealants, joining/bonding, and paint technologies; and (6) *Sourcing Considerations* considers purchasing criteria and the sourcing of tools and steel.

The Delphi V Materials panelists' opinions and forecasts for usage and application of automotive materials and related processes and systems are cautious and yet optimistic with forecasts for change generally more modest than envisioned in previous Delphi studies. The industry appears to have focused sharply on total customer satisfaction with an emphasis on value delivered. New material applications and process technologies will become increasingly important factors in the cost and quality of future products and certainly with respect to the growing international competition.

I. FUELS

The Materials panelists forecast a generally stable energy future with only modest fuel price increases through the year 2000. However, some panelists anticipate an energy shock/ fuel crisis within the next decade. Although panelists believe that 75% of the gasoline will be unleaded regular, a significant fraction of the gasoline (20%) will be of a premium grade with limited use (5%) of a midgrade fuel. While the Materials panelists present somewhat lower forecasts for flexible-fueled vehicles (FFV) than do the Technology panelists, the forecasts of 5% application by the year 2000 and 10% by 2005 are significant and in reasonable accord with proposed government policy.

By 2005, 12% of North American-produced passenger vehicles are forecast to be fueled by either neat methanol or 15% HC/85% methanol (M-85). Panelists also addressed the increasingly significant issues of refueling vapor and high-temperature evaporative emissions. Fuel station pump containment and on-board vehicle recovery for refueling vapor both received considerable support. In addition, a significant fraction (38%) believe modified fuel composition is a viable partial solution to high temperature evaporative emissions.

II. GENERAL VEHICLE FEATURES AND MATERIAL PLANNING

Increased public concern for solid-waste management and recycling is reflected in the opinions of the Materials panelists. Development of recyclable/reclaimable materials, inclusion of recycling concerns in the basic vehicle design process, and institution of reclamation programs were also prominently mentioned.

The tough competition between steel and various polymers is expected to continue. Steel is becoming a moving target for plastics in many vehicle applications. While improvements in steel quality, corrosion protection and manufacturing processes have been significant, panelists forecast continuing modest growth in lightweight materials including both plastics and aluminum. As with the Technology and Marketing panelists, the Materials panelists view quality, new technology, styling, and low cost as absolutely essential for the future success of a product line. Materials and their processing are key factors in this equation.

III. TOTAL VEHICLE: MATERIAL APPLICATIONS

While the Materials panelists expect a continuing reduction in the weight of North American-produced passenger cars, their estimates are somewhat higher than the Technology panelists with a forecast of approximately 3100 pounds by 1995 and 3000 pounds by the year 2000 given a 27.5 mpg CAFE scenario. Surprisingly, even with more challenging CAFE requirements (30 mpg in 1995 and 32 mpg in 2000) panelists forecast relatively little additional weight reduction. Modest growth in the use of plastics and aluminum is expected, but a major reduction in the utilization of steel is not evident.

IV. POWERTRAIN: MATERIAL APPLICATIONS

Delphi V Technology panelists forecast major powertrain developments within the next decade. A majority of engines will be fundamentally redesigned, manufacturing precision will be increased and will incorporate a variety of new, advanced technical features. New materials are forecast to be an integral part of the innovations in these new engines, although there appears to be some retrenchment from previous Delphi studies regarding the rate of application of the more advanced materials.

By the year 2000, Delphi V Materials panelists expect only 5% of light-duty vehicle engines will be low-metallic content engines (50% or more non-metallic component parts). Fiber-reinforced plastics (FRP), magnesium, powdered metals (PM), ceramics, and metal matrix composites (MMC) are all considered to be future engine materials with a variety of specialized applications. By the year 2000, 70% of the cylinder heads are forecast to be made from aluminum, but the forecast for aluminum blocks is only 15%. Aluminum is expected to expand its role in radiators.

V. BODY/CHASSIS: MANUFACTURING AND ASSEMBLY TRENDS

Environmental issues and concern for possible automotive regulatory activity could have a profound effect on materials and processes including recyclability of polymer-based components, health concerns associated with asbestos in brakes and clutch friction surfaces, and emissions from paint shops. Styled wheels are forecast for 50% of passenger cars in 2000 with aluminum as the preferred material. Mold-in color for plastics presents challenging problems, particularly with color match and weatherability. New paint technologies including water-based systems (35% use by 2000) and clear-coat methods (80% penetration by 2000) could have a profound impact on industry paint shops. Significant developments in adhesives, sealants, and joining technologies are projected which could lead to 50% adhesive bonding of doors and hoods by 2000 and 20% use in other body panels in the same time frame.

VI. SOURCING AND PURCHASING CONSIDERATIONS

Outsourcing will continue to be an economically and politically sensitive issue. The quest for world class quality and cost—coupled with the establishment of U.S.-based, foreign-owned manufacturers and suppliers as no longer just "transplants," but "New American Manufacturers"—will continue to present an increasing challenge for the traditional domestic industry in the decade ahead. Transplant manufacturers are expected to increase domestic sourcing of steel (50% by 2000). Tooling for North American vehicles is expected to be increasingly sourced from transplant tooling suppliers (30% in 2000), but the majority is still forecast to be supplied by traditional domestic suppliers (55%).

I. FUELS

MAT-1. What is your estimate of retail gasoline prices per gallon in the U.S. for the following years? *(In constant 1988 dollars; that is, without adjusting for inflation.)*

Gasoline	Retail Price per Gallon					
	Median Response			Interquartile Range		
	1990	1995	2000	1990	1995	2000
Unleaded Regular	$1.03	$1.20	$1.30	$1.02/1.07	$1.15/1.25	$1.25/1.50
Unleaded Premium	1.17	1.35	1.50	1.15/1.25	1.25/1.46	1.40/1.75

SELECTED EDITED COMMENTS

- Gasoline consumption will be increasing in the United States and in the world. The OPEC cartel will eventually solve their bickering. The United States will become more dependent on imported oil.
- Taxes will be responsible for increases. Supply may influence unleaded premium.
- Prices will be completely dependent on the behavior of OPEC.
- Supply is finite. Disruptions can occur in additives for premium grade fuels.
- Widening gap between regular and premium. Possible federal gas tax could add 5–30 cents across the board.
- With larger size vehicles and new engines, unleaded premium may be more in demand.
- Capital costs associated with new refinery equipment to make gasoline more environmentally acceptable (e.g., lower volatility, less aromatics) will be reflected in pump prices.
- There will be a steady increase in price due to increasing usage, decreasing supply, and increasing taxes.
- CAFE standards will become more stringent rising to 35–40 mpg by 2000.
- Federal taxes likely to control prices by 2000.
- Demands for fuel efficiency in autos will reduce the demand for fuels keeping prices stable and competitive.
- Higher taxes plus a fuel shortage will cause a greater increase in gas prices by 2000 and beyond. These prices will be much higher than now predicted.
- Differential between regular and premium will continue to grow until 1995 and then stabilize due to larger/higher performance engine growth.
- OPEC will have the upper hand.
- Predicting gas prices is like predicting the weather by asking a ground hog.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists' forecasts are in close agreement for fuel prices through the year 2000. The two groups presented identical forecasts for unleaded premium by the year 2000 and unleaded regular for 1995. The differences in the remaining forecasts are within a 2 to 5 cents per-gallon range.

COMPARISON OF FORECASTS: TECH-1 and MKT-6

The following table shows all three Delphi panel forecasts for fuel prices in the years indicated. There is a significant degree of consensus regarding future fuel prices between the Technology, Marketing, and Materials panelists. The interquartile ranges for each group supports this high degree of consensus. These results depart somewhat from earlier Delphis in which Materials panelists traditionally forecast higher fuel prices than their Technology and Marketing counterparts.

Gasoline	Technology Panel			Marketing Panel			Materials Panel		
	1990	1995	2000	1990	1995	2000	1990	1995	2000
Unleaded Regular	$1.05	$1.20	$1.40	$1.03	$1.15	$1.25	$1.05	$1.20	$1.30
Unleaded Premium	1.20	1.35	1.60	1.15	1.28	1.40	1.15	1.30	1.50

TREND FROM PREVIOUS DELPHI SURVEYS

Gasoline price forecasts have been solicited from all previous Delphi panelists going back to 1979. The following tables provide a comparative, historical analysis of these fuel price forecasts. The first table illustrates the Materials panel forecast trend; the second table provides a *cumulative*, comparative illustration of the fuel price forecasts among all three panels, with adjustments to 1988 dollars.

Materials Panel Forecast Trend						
	Forecast for 1990		Forecast for 1995		Forecast for 2000	
Unleaded Gasoline	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V	1987 Delphi IV	1989 Delphi V
Price*	$1.70	$1.25	$1.70	$1.20†	$2.00	$1.30
1988 CPI**	2.02	1.35	1.84	1.20	2.17	1.30

*Dollars at time of survey.

**Adjusted to 1988 consensus price index (CPI).

†Delphi IV specified only unleaded gasoline. Prices per gallon shown for Delphi V forecasts are an average between unleaded regular and unleaded premium.

Cumulative Fuel Price Forecasts From Previous Delphi Surveys								
Unleaded Gasoline	Forecast for 1990				Forecast for 1995		Forecast for 2000	
	1979 Delphi I	1981 Delphi II	1984 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V	1987 Delphi IV	1989 Delphi V
Price*	$2.50	$3.00	$1.60	$1.20	$1.40	$1.28†	$1.75	$1.50†
1988 CPI**	4.07	3.90	1.90	1.30	1.51	1.28	1.89	1.50

*Dollars at time of survey.

**Adjusted to 1988 consumer price index (CPI).

†Delphi IV specified only unleaded gasoline. Prices per gallon shown for Delphi V forecasts are an average of the difference between unleaded regular and unleaded premium.

STRATEGIC CONSIDERATIONS

Future gasoline prices continue a trend toward moderation first evidenced in Delphi III. The present forecasts for 1995 are significantly lower than those of Delphi IV. This change in the gasoline forecasts may not be an indication of poor insight of our previous Delphi panelists (many of whom are panelists in Delphi V); but rather a warning that even experts cannot be certain of a future which, in this specific case, is determined by international politics as well as market forces. Possible state and/or federal gasoline tax increases may significantly change the Delphi V forecast.

Greater optimism concerning future energy price stability is understandable given a number of significant developments. These developments include:

- Lower real energy prices. Even with major Middle-East unrest occurring within the last several years, oil supply has remained relatively stable indicating that, at least for the foreseeable future, global petroleum supply may match demand. No matter how unpredictable energy-producing countries might be, their petroleum may still manage to find its way to world markets. Also, OPEC is actually controlling a smaller fraction of the petroleum supply than it had previously.
- Increased cash-flow requirements of energy-producing nations necessitate pumping increasingly larger quantities of petroleum.
- Progress in alternative fuel technology, particularly methanol and ethanol, seems to be causing concern within major energy-producing nations. Significant disruption of petroleum supplies could accelerate the move toward alternative fuels and thereby diminish the value of their petroleum resources.
- Continued improvement in overall fleet fuel economy.
- Increased reliance on market-oriented economies in communist countries may promote worldwide political and, therefore, economic stability.

Even with these factors in mind, we must consider that energy will remain, to a certain extent, a volatile commodity in the world marketplace subject to many potential dislocations.

MAT-2. For light-duty vehicles to be sold in the United States in 1995 and 2000, what is the expected segmentation between gasoline grades required by these vehicles?

Gasoline Grades	Expected Segmentation Between Fuel Grades			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Regular Unleaded	75%	75%	75/80%	70/80%
Midgrade Unleaded	5	5	1/5	4/10
Premium Unleaded	20	20	15/20	15/20

SELECTED EDITED COMMENTS

- No need for midgrade.
- Large Detroit engines, even new ones, will fall by wayside as new import engines dominate marketplace.
- People are likely to prefer smaller cars or more efficient, lower octane fuels when prices go up. Transportation cost will increase and income is likely to go down in the U.S.
- Will stay roughly the same based on the number of ultra-high performance engines where economy is not a factor.
- Smaller fuel efficient vehicles will be designed for regular unleaded.
- Expect more use of methanol as octane improver by the year 2000.
- There will be a shift to regular unleaded as gas prices increase significantly.
- Differential will grow up to 1995 and then stabilize due to larger/higher performance engine growth.
- Midgrade may be necessary for older vehicles.
- The oil companies will try as hard as possible to convince consumers to upgrade to higher priced fuels.
- Methanol will not be the fuel used in the U.S. effort for "clean burn." Engines will overcome that need.
- Environmental concerns will again affect engine and vehicle size.

MANUFACTURER/SUPPLIER COMPARISON

Manufacturer and supplier panelists provide essentially identical forecasts for the segmentation of regular and premium unleaded gasoline grades. These forecasts correspond with the consensus medians presented in the data table. There is, however, a considerable difference in opinion regarding the percentage of a "midgrade" unleaded gasoline. While the supplier panelists forecast 5% for 1995 and 10% by the year 2000, the OEM panelists forecast 0% for each of the years. In this case interquartile range (IQR) differences are also significant. The OEMs' IQRs for each year are 0/5%; essentially indicating that at least 75% of the manufacturer panelists forecast no midgrade segmentation in unleaded gasoline. The supplier's interquartile range for 1995 is 5/10% and 5/12% for the year 2000.

STRATEGIC CONSIDERATIONS

Relatively little enthusiasm is indicated for a midgrade fuel. This is consistent with the move to methanol as M-85 (85% methanol, 15% hydrocarbons). M-85 will require a separate retail distribution system and if a midgrade is also required, fuel retailers would then need at least four (five with diesel) separate tank/pump systems.

The stability in the forecast between regular and premium suggests higher performance engines will be in demand throughout the decade. Also, tougher CAFE standards may increase the incentive to use higher compression ratios increasing premium fuel demand. However, improved combustion chamber design, better controls, and improved general combustion management may reduce octane requirement and, therefore, reduce premium grade demand. Also, an additive or design breakthrough that results in octane requirement increase (ORI) control could significantly influence the regular/premium ratio.

MAT–3. What percent of North-American-produced vehicles will be capable of using the following alternate fuels by the years indicated?

Alternate Fuels	Median Response			Interquartile Range		
	1995	2000	2005	1995	2000	2005
Neat methanol to 15% HC/85% methanol (M85)	3%	5%	10%	1/5%	4/10%	5/15%
Full-range of methanol-gasoline blends (flexible-fuel vehicles)	1	5	10	0/5	3/10	5/15
Low-octane gasoline (<75 Octane)	0	2	2	0/1	0/3	0/5

SELECTED EDITED COMMENTS

- Auto industry will react to fuel availability and/or government regulation for alternative fuels. If there is a sufficient "driving force" the vehicles will be available.
- By dint of legislation and mpg givebacks on CAFE standards.
- Depends on the focus of technology: improved economy, emissions, or heating value.
- Engine developments take a long time.
- Percentage of alternate fuel vehicles will remain low.
- Cost effectiveness of methanol/alcohol does not appear to be better than gasoline unless required, subsidized, or gasoline is highly taxed. Until then, no incentive.
- Low temperature starting (less than 32°F) will inhibit development of neat methanol vehicles. Flexible-fuel (0 to 85% methanol) more likely.
- Most of the usage will be commercial vehicles: fleet, taxis, etc.
- Oil shortage will develop and prices will go up. People will prefer smaller cars for intra-city driving. Such cars should be economical and use low octane gasoline with suitable engines. There will be increasing environmental concerns on the use of hydrocarbon fuels. Use of electric cars or cars using alternate fuels that do not create environmental problems will be required in large population centers.
- Methanol "hazardous material" and handling effects must be resolved.
- Flexible-fuel programs are very active at present. Flexible-fuel systems may be required by law in 2000.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists were in general agreement on the percentage of methanol fuels. The only differences are in the forecast for flexible-fuel vehicles (FFV) in the year 2000 (OEMs=10%, suppliers=5%) and low octane fuels in the year 2005 (OEMs=4%, suppliers=2%).

COMPARISON OF FORECASTS: TECH-2

As illustrated in the following table, with the exception of low octane fuels, the Materials panelists' forecasts are generally lower than the Technology panelists. It should be noted that the interquartile ranges for both panels are quite broad, indicating considerable uncertainty. This should be taken into consideration when developing conclusions from the differences expressed by each panel.

Alternate Fuels	Forecast for 1995		Forecast for 2000		Forecast for 2005	
	Mat. Panel	Tech. Panel	Mat. Panel	Tech. Panel	Mat. Panelists	Tech. Panelists
Neat methanol to 15% HC/85% methanol	3%	2%	5%	8%	10%	12%
Flexible-fuel vehicles	1	2	5	10	10	15
Low-octane gasoline	0	0	2	1	2	1

TREND FROM PREVIOUS DELPHI SURVEYS

Alternate fuels issues were addressed in Delphi IV by both the Technology and Materials panels. An in-depth analysis of trend data related to the Delphi IV Technology forecasts regarding the utilization of methanol as an alternate fuel is presented in the current Delphi V: Technology volume, TECH-2. While the Delphi IV Materials panelists are in basic agreement with the Delphi IV Technology panelists on the substantive issues impacting the use of alternate fuels, there remain sufficient differences of perspectives regarding some areas in question to warrant a separate Materials trend analysis. The reader is encouraged to compare MAT-3 trend data with TECH-2.

In response to the following question: "What is the likelihood of production in significant quantities of each of the following for automotive fuels if there is a major and continuing interruption in international petroleum supplies?" the responses of the Delphi IV Materials panelists were somewhat different from those of the Delphi IV Technology panelists. As is evidenced in the following table, the Delphi IV Materials panelists considered the likelihood of methanol fuel production from coal slightly higher than from natural gas. Also, whereas the Delphi IV Technology panelists placed ethanol in the lower one-third of their rankings, the Delphi IV Materials panelists ranked ethanol in the upper one-third.

What is the likelihood of production in significant quantities of each of the following for automotive fuels if there is a major and continuing interruption in international petroleum supplies?

	High	Moderate	Low	Unlikely
Methanol from coal	33%	33%	28%	6%
Methanol from natural gas	28	50	22	0
Ethanol	28	39	33	0
Natural gas	27	22	44	7
Petroleum-like fuels derived from coal liquids	11	28	44	17
Liquid petroleum gas (LPG)	11	172	50	2
Hydrogen	0	0	44	56

With respect to the principle advantages or disadvantages of methanol blends from both a vehicle and fuel perspective, interesting differences emerge from a comparison of Delphi IV Materials and Technology trend data. While both panelist groups considered the availability of methanol at a lower cost the primary advantage from a fuel perspective, the Delphi IV Materials panelists exhibited considerably more enthusiasm for the octane enhancement qualities of methanol than did their Technology counterparts. Similarly, while problems revolving around both on-board and refueling volatility and vapor containment were considered by both groups to be the primary disadvantage for methanol from a fuel perspective, the Materials panelists, understandably, considered the incompatibility/ corrosive nature of methanol on fuel system components as a major impediment. Additionally, while the Delphi IV Technology panelists overwhelmingly (95%) considered octane enhancement as the primary advantage of methanol from a vehicle perspective, as evidenced in the following table, the Materials panelists were more eclectic in their summation of advantages and disadvantages.

Relevant data pertaining to Delphi IV Materials panelists' opinions on the advantages and disadvantages of methanol blends from both a vehicle and a fuel perspective are as follows.

What are the principal advantages and disadvantages of METHANOL gasoline blends from both a vehicle and a fuel perspective?

Methanol: Fuel Perspective

Advantages	% Total Responses	Disadvantages	% Total Responses
Availability at a reasonable/ lower cost	58%	Volatility control economics (handling systems/fuel storage problems)	37%
Octane enhancement	31	Corrosive nature of methanol	21
Others: Efficient, clean burning, ease of blending	11	Water tolerance (hydrophilic nature) of methanol	16
		Others: None. Cold weather start-up problems	15

Methanol: Vehicle Perspective

Advantages	% Total Responses	Disadvantages	% Total Responses
Availability at a lower cost	53%	Corrosive nature of methanol	44%
Octane enhancement and power improvement	17	Cold weather starting problems	31
Reduced exhaust gas emissions	17	Engine performance	10
Others: Higher compression ratio, ability to reduce water in gas tank	13	Lower mileage	10
		Other: Water absorption, low BTU content, evaporative emissions problems	5

Representative Responses

Methanol: Fuel Perspective

Advantages:

- Methanol can be manufactured from a variety of sources, has excellent octane value.
- Low-cost renewable source.
- Reduces dependence on petroleum.

Disadvantages:

- Volatility control, cold start-up, compatibility with fuel system materials, compatibility with engine materials and lubricants.
- Poor mileage, water susceptibility, handling systems, corrosive with moisture.
- Lower BTU value/gallon.
- Fuel storage problems.

Methanol: Vehicle Perspective

Advantages:

- Increased power output, potential for lower emissions from exhaust.
- Higher compression ratio, performance of methanol in high concentration, i.e., 90%.
- Resultant blends would boost octane values.
- Availability under adverse conditions.
- Reduced exhaust gas emissions.
- Reduces water in gas tank.

Disadvantages:

- Corrosive, absorbs water/moisture, low BTU content, evaporative emissions problems if volatility not controlled.
- Lower mileage, construction to accommodate methanol, i.e., materials in fuel system, driveability in temperature extremes.
- Attacks materials in fuel system, requires monitoring of distributors and dealers.
- Poorer warming-up driveability due to high latent heat of vaporization.

Another Delphi IV question related to the utilization of methanol from a fuel perspective had to do with its usage for octane enhancement. Although the forecasts are somewhat dated, they nevertheless provide a degree of insight into the focus of the industry with respect to methanol as either an additive, supplement, or replacement fuel. The Delphi IV Materials question and results are as follows.

What percentage of fuels will use the following for octane enhancement by 1990?

	Percent Usage	
Octane Enhancement	Median Response	Interquartile Range
No additives (additional refining)	80%	65/90%
Ethanol	10	0/15
Methanol	5	2/10
Other*	5	5/8

*Methyl tertiary butyl ethanol (MTBE) and MMT were also suggested as octane enhancement additives.

STRATEGIC CONSIDERATIONS

With growing concerns regarding the North American energy future, there is increasing interest in non-petroleum-based fuels or fuels with somewhat different properties than presently commercially available. There appears to be general consensus that in the long term we will move toward a methanol fuel strategy. It is evident from the panelists' responses that toward the latter part of the next decade an increasing fraction of vehicles will be equipped to handle straight methanol or, perhaps more appropriately, a full range of methanol/gasoline blends, a so-called "flexible-fuel vehicle" (FFV). With the present pace of alternative fuel development, it is conceivable that these forecasts could expand dramatically depending on energy scenarios, political action, and technology development. In any event, this is an area that should be watched carefully because of the broad impact it would have on the entire engine fuel management system (controls and materials), national fuel distribution systems, and consumer markets. A strategic issue with regard to these technologies is that their very availability should restrain overly aggressive petroleum pricing and supply manipulation.

Two additional concerns regarding the development of a national methanol-based fuel strategy are:

1. The ability to produce and distribute sufficient quantities of methanol fuel.
2. The net consumer cost in terms of purchase price, operating costs, and convenience.

Government agencies and vehicle manufacturers must work cooperatively in setting a public agenda for alternate fuels. It is interesting that government proposals for alcohol-fueled vehicles in the middle 1990s are similar to the Delphi forecast.

MAT–4. It is evident that fuel vapor emissions are becoming a significant issue in two areas: (1) refueling vapor emissions and (2) high ambient temperature evaporative emissions. Please indicate technical strategies likely to be employed to minimize these emissions by the year 2000.

REFUELING VAPOR EMISSIONS

Technical Strategies	Percent of Panelists' Responses
At-Station Pump Containment	60%
On-Board Vapor Recovery	40

REPRESENTATIVE RESPONSES

- Use of additional on-board canisters (charcoal or carbon). Fuel tank routing displaces vapor through this canister; purge after engine starts.
- Auto fuel lines will be modified to trap and divert vapors to on-board canisters.
- Need devices on pumps to capture vapor emissions.
- Believe upgraded pump/hose will prevail.
- On-Board Vapor Recovery (OBVR) devices and bladder style tanks are most appropriate control method.
- Stage II recovery will be deployed broadly.
- Use a quick disconnect type of nozzle to tank filler opening that eliminates emissions that are uncontrolled, use vapor trap back to large gas storage.
- Containment at the pump makes more sense but political pressures appear to be forcing vehicle installations. I doubt this will be accomplished by 2000.

HIGH-TEMPERATURE EVAPORATIVE EMISSIONS

Technical Strategies	Percent of Panelists' Responses
On-Board Vapor Recovery	50%
Modified Fuel Composition	38
Other*	12

**Other* technical strategies suggested for reducing high-temperature evaporative emissions are as follows: system validation modules, detection devices, improved sealing systems, and high temperature catalytic converters.

REPRESENTATIVE RESPONSES

- Enlarged primary canister to increase efficiency. Carbon canisters, possibly with high-temperature purge for efficiency.
- More vehicles will have high temperature catalytic convertors. New inexpensive catalysts (free of noble metals) will be perfected. They will be such that poisoning is avoided at high temperatures. High-technology ceramics will be increasingly used for support of catalysts; or maybe certain "high-tech ceramics" may be developed to serve as catalytic convertors.
- Increased use of mesh screens that will react and trap gas vapors at elevated temperatures.
- On-vehicle vapor recovery system to handle fuel vapor could be phased in prior to 2000.

STRATEGIC CONSIDERATIONS

It is becoming evident that evaporative hydrocarbon emissions both in terms of refueling vapor loss and vehicle evaporative emissions are becoming more significant issues as our national concern for the environment increases. The refueling vapor emission problem is controversial in that either a filling station vapor recovery systems, or an on-board vapor recovery system will function quite effectively. The respondents to the Delphi appear to favor centralized fuel station containment. This approach may make the greatest and quickest improvement in areas with an air quality problem. A strategy focused essentially on new vehicles would take a considerably longer period to have a broad environmental impact. Fuel station recovery technology appears to be reasonably well developed, while some uncertainties relating to on-board vapor recovery, including safety considerations remain.

The high temperature evaporative emission problem is particularly significant in high temperature geographic regions. Basically, present federal evaporative emission standards require certification at a relatively low temperature. At elevated temperatures evaporative losses increase dramatically. Automotive manufacturers appear to favor modified fuel composition and fuel station recovery to reduce volatile gasoline components. Energy companies favor on-board vapor recovery. We suspect that eventually improvements will be made both in terms of revised fuel composition with reformulated gasoline to lower evaporative losses and on-board vapor recovery.

From a fundamental perspective, both of these hydrocarbon emission sources are important and further control seems warranted. The real question is what strategy or strategies will yield the most cost effective results.

II. GENERAL VEHICLE FEATURES AND MATERIAL PLANNING

MAT-5. 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.

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	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

*A significant number of Materials panelists presented responses that can be considered within a specific "environmental" category. Thirteen percent (13%) of the panelists expressed an opinion regarding the necessity of reducing exhaust emissions, increasing CAFE standards, and the use of alternate fuels. An additional 13% expressed a need to reduce or eliminate the use of chlorofluorocarbons (CFC). Four percent (4%) of the panelists commented on the need to reduce toxic materials within the passenger area of the vehicle.

**Forty percent (40%) of the panelists within this group indicated the need to develop a materials identification method to facilitate selective recovery. An additional 20% of the panelists within this group encouraged the development of a recycling industry.

REPRESENTATIVE RESPONSES

- Requires more international cooperation to find appropriate solutions.
- An infrastructure will develop in the recycling industry to take off and sort the major and easily dismantled plastic parts for recycling by an increasing number of facilities that will take the material and reformulate it for uses in less critical parts. Designs will accommodate this.
- Means to recycle thermosets and separation of plastics is required.
- Design-select recyclable materials, design for ease of upgrading. Reduce production exhaust emissions. Retirement: 20-year life.
- Select polymeric materials than can be recycled in a cost-effective way.

- Support start up of energy conversion companies to handle/use non-metallic scrap. Promote recycling of coolant. Use alternative safer refrigerants.
- At some point in the mid-1990s, recyclability will become the most important consideration in the choice of materials used in vehicles. Engine disassembly of vehicles; materials clearly identified. Reuse parts when and where practical.
- I believe the use of plastics should be limited to those materials that can be recycled. Economics will dictate how much a stripping of material before shredding the vehicle is done.
- U.S. government will mandate percent recycled vehicles similar to CAFE noting specific levels for given years.
- Materials must be indelibly flagged to identify polymer-type for selective recovery before grinding up remaining body.
- Minimize waste generation during manufacturing and assembly.
- Thermoplastic and thermoset plastics producers should take engineering research initiatives to utilize the in-process waste material. For example, producer companies should develop use of glass-fiber materials waste, if automated fiber-reinforced plastics (FRP) technology involving engineered placement of fibers and reactive injection molding technologies for automotive parts is to increase in the future. The automotive manufacturers need to take engineering research initiatives, probably in cooperation with major universities, to develop recycling and applications technologies of thermoplastic and thermoset parts in cars.
- Use non-virgin (e.g., recycled packaging) plastics in vehicle design for non-critical parts. Require cradle-to-grave tracking of hazardous materials such as CFCs, heavy metals, lubricants, etc.
- Vehicles will have to be designed so that key materials can be more easily separated at junking time. A major effort will be needed by the plastics industry to generate recyclable as reusable (in other applications) products.
- OEMs and suppliers need to work jointly in developing programs where composites in total are made recyclable.
- (1) *Design*: vehicles need to be more readily dismantable for recyclability; (2) *Production*: use of material must be planned so that as material is recycled and its properties deteriorate it will be applied to less demanding products; (3) *Retirement*: incineration to convert the materials energy to electricity or steam if it cannot be used in applications such as building products which would have indefinite life/use.
- Automotive industry should research material recycling especially in the field of plastics.
- There will be a move to identify all materials used in the part. By 2050 the materials used in cars will be recycled almost 100%.

COMPARISON OF FORECASTS: TECH-11

The Materials panelists present a somewhat different perspective than the Technology panelists regarding recycling and environmental issues. Based on the percent of total panelists' responses, the Technology panelists clearly consider the need to develop new or improved recyclable automotive materials as the primary issue, while the opinions of the Materials panelists' reflect a need to incorporate these recyclable materials in the initial vehicle design process and the development of reclamation programs and methodology as being the primary issues. The Materials panelists also place considerably less import on the probability of governmental/legislative influence.

It should be kept in mind that panel differences regarding recycling/environmental issues are statistical and need not necessarily reflect fundamental differences in opinion between the two panels. On the other hand, the data may well reflect a substantive difference of opinion between the presumed providers (Materials panelists) and the users (Technology panelists) regarding strategic approaches to these issues.

STRATEGIC CONSIDERATIONS

There is no question that the total interface between light-duty vehicles and the environment is becoming an increasingly important issue. For some time the industry has faced problems associated with emissions and safety, but now additional factors are emerging. Recycling is one of these issues. It brings an important new challenge to automotive designers and suppliers. We envision that in the next few years most of the manufacturers will begin to develop essentially life-cycle management concepts related to their product, i.e., they will manage the product not just out-the-door and through the warranty period within their own dealer organization, but all the way through its full life-cycle.

The responses throughout this question should be read very carefully, because a wide range of views are expressed that need to be considered. Whereas some feel the entire issue is well under control, there are others voicing significant concerns, particularly with regard to plastics and freon. We believe this is a major issue and will become a significant factor in automotive design in the future. In fact, we believe important business opportunities will emerge for both the manufacturers and suppliers with regard to the overall recycling issue. Failure to consider some of the important system-based aspects of this issue could be an important competitive issue in the next decade. We believe both manufacturers and suppliers should become proactive in their approach to this matter.

MAT-6. Using the following scale, please rank the importance of the following factors in the competition between plastics and steel for body exterior applications for the years indicated.

Plastic vs. Steel for Body Exterior Applications: Relative Importance of Factors in Competition			
1995		2000	
Factors	Ranking	Factors	Ranking
Surface quality	4.4	Surface quality	4.2
Investment/tooling costs	4.0	Styling/design flexibility	4.1
Styling/design flexibility	3.9	Investment/tooling costs	4.1
Material cost	3.8	Material cost	3.8
Variable manufacturing costs	3.7	Lead time for tooling	3.8
Volume	3.7	Variable manufacturing costs	3.7
Lead time for tooling	3.6	Volume	3.7
Existing capacity	3.3	Manufacturing flexibility	3.6
Corporate attitude	3.2	Weight reduction	3.4
Weight reduction	3.2	Recyclability	3.3
Manufacturing flexibility	3.2	Repairability	3.2
Repairability	3.2	Corrosion	3.2
Corrosion	3.0	Existing capacity	2.9
Recyclability	2.4	Corporate attitude	2.8
Mold-in color	2.2	Mold-in color	2.6

Scale of Importance: Little or No Importance, 1–2; Moderate Importance, 3–4; Very Important, 5.

Other factors: customer wants, dimensional precision, overall cost, paint oven temperature, quality, and system cost.

SELECTED EDITED COMMENTS

- Consideration of materials cost should be on the basis of part weight.
- OEMs need to develop better uniform procedures for determining "manufacturing costs" so true comparisons between plastic/steel body panels can be obtained.

TREND FROM PREVIOUS DELPHI SURVEYS

In Delphi IV, the Materials panelists were asked a similar question regarding the importance of various factors in the competition between steels and plastics. Although the Delphi IV panelists were asked to rank-order the factor on the basis of 100%, the rankings are relatively comparable. While there has been some comparative movement in the rankings, the leading factors of surface quality and cost maintain their positions. The factors most noticeable in their reduction in relative importance from Delphi IV to Delphi V are weight reduction and corrosion.

Delphi IV Factors of Importance:
Plastic vs. Steel for Body Exterior Application
(Percentage of 100% Scale)

Factors	Median Response	
	1990	1995
Material cost	30%	20%
Surface quality, i.e., the ability to produce a Class A finish	20	20
Weight reduction	10	10
Corporate attitude and policy	10	5
Corrosion	8	8
Investment costs of tooling	5	10
Styling/design flexibility	5	8
Capacity	5	5
Lead time for tooling	3	3
Repairability	2	5
Recyclability	1	5
Mold-in color	1	1
TOTAL	100%	100%

STRATEGIC CONSIDERATIONS

A number of factors continue to be important in the intense competition between plastics and steel for body exterior applications. Leading factors such as cost and surface quality are ranked similarly to Delphi IV. Obviously, a key issue that could shift these responses is more stringent fuel economy requirements. With higher CAFE requirements weight reduction, which in the present forecast is viewed by most panelists as of only moderate importance, would undoubtedly be rated higher. As manufacturers consider various materials on a true systems basis, a decision-making model with appropriate weighting factors assigned to all items is needed. Each manufacturer will probably prioritize factors differently, resulting in different material decisions. It is important for any organization that many be impacted by body exterior decisions to carefully track steel and plastic technology. Furthermore, it is imperative to understand the various material selection processes used by the vehicle manufacturers.

Finally, if customers were to indicate a strong preference for plastic exteriors because of ding resistance or some other factor, may of these issues could become academic in the material-selection process.

MAT-7. Of the following components that could be made from plastics, what percent do you believe will be produced from thermoplastics and what percent from thermosets by the years 1995 and 2000?

Plastics	Median Response				Interquartile Range			
	Vertical*		Horizontal**		Vertical*		Horizontal**	
	1995	2000	1995	2000	1995	2000	1995	2000
SHEET APPLICATIONS								
Thermoplastics	40%	55%	10%	20%	30/60%	50/65%	5/15%	20/25%
Thermosets	50%	40%	90%	80%	40/70	30/50	80/90	75/80
Other	10	5	0	0	0/55	0/10	0/80	0/10
TOTAL	100%	100%	100%	100%				
STRUCTURAL APPLICATIONS								
Thermoplastics	15%	15%	5%	10%	5/20%	10/20%	0/10%	10/15%
Thermosets	85	85	95	90	80/95	80/90	90/100	85/90
Other	0	0	0	0	0/40	0/0	0/5	0/15
TOTAL	100%	100%	100%	100%				

*Vertical refers to door, outer; fender, outer.
**Horizontal refers to hood, outer; deck lid, outer.

SELECTED EDITED COMMENTS

- Larger fiber plastic composites will be predominantly used. The selection between thermoplastics and thermosets is very uncertain. Long-term creep (time dependent properties) is the area of most uncertainty for thermoplastics components.
- Where plastic applications are feasible, the trend will be toward thermoplastics for repairability and recyclability.
- The definitions you gave of vertical and horizontal panels exclude any interior applications. Interior trim is generally injection molded in sections that do not lend themselves to sheet-forming. Most exterior parts listed are also compression or injection molded. Almost all interior trim will be plastic or plastic covered by textile or carpets. Some fabrics will be backed by fiberboard type substrates.
- Major problems facing increasing use of thermosets in 1995 and 2000 are likely to be environmental issues, cycle time, precision and consistency of production parts, and cost. Major breakthroughs in reactive liquid processing (sometimes called resin transfer molding) will become adapted for high speed production of production parts. More emphasis by plastic parts producers will be put on recycling of thermoplastics and thermoset parts. Thermosets will find their greatest use in larger engineered plastic parts, while thermoplastics will be used predominantly in small parts and interior parts.
- Slow growth of thermoplastics due to performance problems and cost. Cautious growth due to recyclability. All interior sheet applications will be plastic.

TREND FROM PREVIOUS DELPHI SURVEYS

The development of this question was predicated on the results of two similar Delphi IV questions.

In Delphi IV the following question was asked: "What components do you believe will be produced completely or in part from thermoplastics in the years 1990 and 1995?" The components categories were divided into *sheet applications* and *structural applications*. In general, the sheet and structural applications of thermoplastics forecast for 1995 were an extension and amplification of those forecast for 1990, with some new applications for 1995. The data for Delphi IV 1995 thermoplastics sheet and structural applications are as follows.

Delphi IV Thermoplastics Applications: Forecast for 1995	
Applications	Percent of Respondents
SHEET APPLICATIONS	
Exterior body panels	94%
Others: Deck lids, bumpers	25
Representative Responses	
• All body panels including roof; deck lid and hoods on some percentage of automobiles.	
• Fenders, doors, bumpers, hoods, lids.	
• Hoods, decks, roofs. Everything but glass.	
• Trunk floor panel.	
• Vacuum-formed body panel skins (doors).	
• Glazing (much more), bumper backup beam, fender liners, trunk lines, interior trays, door inners; headliner adhesive, plus outer panels are possible on specialty vehicles.	
STRUCTURAL APPLICATIONS	
Bumper assemblies	40%
Doors	40
Floor pans	20
Others:	
Springs	
Firewalls, underbody panels, intake manifold engine frame, seat frames, wheels	

It is evident that Delphi IV panelists felt that the primary application of thermoplastics through 1995 would be heavily concentrated in the areas of exterior body panels and bumper fascia. It should be noted that there is a fair degree of overlap between what the panelists consider to be sheet application and structural application.

Delphi IV panelists were also asked: "Of the automotive plastics [thermoplastics and thermosets] envisioned (weight basis) for 1990 and 1995, estimate the percentage falling into the following classes." This question was asked in an attempt to give some sense of direction between the competition among these two plastic material groups. For 1995, thermoplastics were forecast to maintain 65% of the automotive plastics market, and thermosets 35%. However, the interquartile ranges for these two categories were quite substantial, indicating a considerable degree of uncertainty on this matter. The present Delphi V question was, therefore, formulated in an attempt to elucidate this general area of polymeric materials.

STRATEGIC CONSIDERATIONS

Unfortunately, this question produced some degree of confusion as noted in the comments. Our intent was to develop a qualitative sense of direction with regard to the future ratio between thermoset and thermoplastic use. Considerable growth has occurred in both general classes of polymeric materials and both can be considered to be relatively early in their learning curve. Clearly, life-cycle issues will be increasingly important in the long term; long term durability and performance and recyclability issues will certainly be key. Considerations such as cost, manufacturability, surface finish, and thermal stability will also continue to be important factors.

MAT-8. In what year do you foresee the first production vehicle with a polymer-based composite intensive body structure (excluding skins) will be produced?

Forecast Year for First Production Vehicle with Polymer-Based Composite Body Structure	
Median Response	Interquartile Range
1998	1995/2000

SELECTED EDITED COMMENTS

- Forecast for model year 2000 is based on the following assumptions: Glass fiber reinforced plastics technology will advance to a stage that parts can be molded of consistent quality, dimensional precision, consistently good aesthetics, and above all having designs that are integrated into subassemblies of lower total cost. Total weight of cars is likely to become an issue again by model year 2000.
- Nothing known that will go beyond one-of-a-kind development vehicles, no production vehicles. Not cost effective.
- Too many issues to have this happen quickly and steel is a moving target.
- The use of plastics in structural auto body parts will depend mainly on the following three advances, any of which may make the present fiber reinforced thermosets almost obsolete: (a) development of processing technology for "long-fiber" thermoplastic composites or thermosets plastics composites, (b) synthetic methods that use low-melting-point starting materials that polymerize to high molecular weight polymers without evolution of gases (the resultant matrix structure may be semi-crystalline or a thermoset plastic), and (c) in-situ crystallization of high melting polymers to form a dispersed fibrous phase in a matrix of an engineering thermoplastic.
- Engineering plastics will develop that are strong and of lower cost. The main problem holding back greater use of engineering plastics is high "clamping forces" and therefore very large tonnage presses. These problems will be overcome by model year 2000.
- Technology based on engineering placement of "strong" glass fibers combined with reactive liquid transfer molding (RLTM) process will develop into a viable manufacturing technology. This should result in, by model year 2000, increasing use of such reinforced materials in structural parts.

MANUFACTURER/SUPPLIER COMPARISON

The OEM panelists anticipate an earlier date for the production of the first plastic/composite intensive passenger vehicle structure than do supplier panelists, although the suppliers demonstrate a greater degree of consensus. The median manufacturers' forecast is 1998 with an interquartile range of 1995/2000; the supplier median year of introduction is the year 2000 with an interquartile range of 1996/2000.

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi V panelists are somewhat less optimistic than were Delphi IV panelists regarding the introduction of a polymer-based composite intensive vehicle. The median forecast in the 1987 Delphi was 1995 with an interquartile range of 1992/1995.

STRATEGIC CONSIDERATIONS

Since polymer-based and other composite materials are at an early stage of their learning curve, one would anticipate rapid and significant future developments in both body exterior and structural components. However, current panel enthusiasm is less than past Delphi studies. This suggests that progress has not lived up to expectations and significant processing improvements are occurring in traditional materials such as steel. The competitive target composites face is not stationary. An additional fundamental consideration is the cost difference between the basic polymers and steel. It seems that steel may maintain a considerable cost advantage unless, of course, systems-based improvements can be achieved in parts consolidation, weight reduction, or customer perception of value. These may become decisive factors, but, at the present time, there is not a sufficient knowledge base for composites to suggest they will replace traditional automotive structural materials. Still, with intense research and development efforts throughout the world, significant progress can be anticipated in composite structures. The technology must be watched closely. Recent joint efforts, such as the U.S. manufacturers joining together in a composites consortium, could speed progress. Furthermore, it is important to recognize that composites may not just be polymer-based, but may include combinations of a number of different basic materials.

MAT-9. Estimate the number of years before panel penetration will occur due to corrosion in a severely corrosive environment (such as Detroit or Pittsburgh) for North American-manufactured passenger cars produced in the following years.

Panel Penetration Due to Corrosion in North-American-Produced Passenger Cars			
Median Response		Interquartile Range	
1995	2000	1995	2000
8 yrs.	10 yrs.	7/10 yrs.	8/10 yrs.

SELECTED EDITED COMMENTS

- OEMs wish to increase their warranties to 10 years or the life of the vehicle.
- Corrosion protection will be achieved through use of two-side coated (galvanized) steels and superior paint and sealing systems.

TREND FROM PREVIOUS DELPHI SURVEYS

Previous Delphi II and Delphi III surveys forecast that for the 1990 model year, it would be eight years before panel penetration due to corrosion would occur. The Delphi IV forecast for 1990 was seven years. Delphi III panelists forecast ten years resistance to corrosion by the 1992 model year. This was followed by a Delphi IV forecast of ten years by 1995. The interquartile range for the Delphi IV 1995 forecast was very tight at 9/10 years indicating that three-quarters of the panelists felt that it would be 10 years before corrosive panel penetration occurred.

MANUFACTURER/SUPPLIER COMPARISON

As indicated in the following table, the OEM panelists have higher expectations for the number of years before corrosive panel penetration occurs than do the supplier panelists.

Years Before Panel Penetration							
Forecast for 1995				Forecast for 2000			
Median Response		Interquartile Range		Median Response		Interquartile Range	
OEM	Supplier	OEM	Supplier	OEM	Supplier	OEM	Supplier
10	8	7/10	7/9	10	9	10/12	8/10

STRATEGIC CONSIDERATIONS

As noted in prior Delphi forecasts, Materials panelists expect continued improvement in corrosion resistance. By the year 2000, measured on the basis of ten year panel penetration resistance, corrosion will cease to be a major automotive consideration. Improvements in design, sealing systems, coatings, processing of traditional materials (with greatly expanded use of zinc-coated steels), and advancements in automotive polymer technology certainly support the panelists' corrosion resistance performance expectations. This trend will place significant pressure on the aftermarket providers of corrosion protection.

MAT-10. What will be the duration in years for corrosion warranties in model years 1995 and 2000?

Corrosion Warranty			
Median Response		Interquartile Range	
1995	2000	1995	2000
7 yrs.	10 yrs.	5/7 yrs.	6/10 yrs.

SELECTED EDITED COMMENTS

- This will become less of an issue as quality and reliability improves.
- Ten years represents feasible vehicle life.

TREND FROM PREVIOUS DELPHI SURVEYS

The 1987 Delphi IV survey forecast that corrosion warranties for the 1990 model year would be five years. This rose to an expected ten-year corrosion warranty for the 1995 model year. The interquartile range for the Delphi IV 1995 forecast was 6/10 years, indicating that 75% of the Delphi IV panelists forecast at least ten years.

MANUFACTURER/SUPPLIER COMPARISON

Supplier panelists forecast somewhat diminished expectations for the duration of corrosion warranties than manufacturer panelists. While the manufacturers are in agreement with the years duration presented in the data table, the suppliers forecast a duration of six years for 1995 and only 7 years by the year 2000. The interquartile ranges for the supplier forecasts are correspondingly lower with 5/7 years and 6/10 years, respectively. It is interesting that Delphi IV supplier panelist corrosion warranty forecasts also were of shorter duration than OEM panelists. In that Delphi the OEMs' forecast for 1995 was ten years, whereas the suppliers forecasted an eight-year warranty.

COMPARISON OF FORECASTS: MKT-19 and TECH-10

Marketing and Technology panelist responses regarding the area of corrosion are presented below.

Corrosion: Length of Warranty	Marketing Panel	Technology Panel
Lifetime	9%	7.5%
Over 7 Years/Over 70,000 Miles	46	43.0
5–7 Years/50,000–70,000 Miles	37	36.0
No Change/Current Warranties	8	7.5
Other: Unspecified Warranty Improvements	0	6.0

STRATEGIC CONSIDERATIONS

The expectation of the Delphi panelists for corrosion warranties are in line with expectations for significant corrosion resistance improvements. With continuing emphasis on customer satisfaction and intense competition in the marketplace, the corrosion warranty forecast appears to match market demands. In fact, as noted in the Delphi V Technology and Marketing volumes, warranty protection of all vehicle and ownership areas is expected to be enhanced. This is further evidence that future products and customer services will have to meet customer value expectations.

MAT-11. Other than plastics/composites, what new materials do you think will have the greatest impact on North American produced vehicle design by the year 2000?

New Materials Impacting Vehicle Design by the Year 2000	
Materials	Percent of Respondents
Metal Matrix Composites	37%
Glass	23
Ceramics	20
New Steels	20

Aluminum, electro-rheological fluids and new electronic materials were each mentioned by individual panelists.

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi IV addressed the issue of emerging automotive materials technologies with the question: "Indicate two possible breakthroughs in automotive materials technology within the next ten years." The three leading material breakthrough areas suggested by the panelists were (1) new polymeric materials and structural composites for automotive body parts, (2) new ceramic materials for powertrain components, and (3) advances in sheet metal and steel-forming technologies. Additional breakthrough areas receiving a significant response from the panelists were new adhesive bonding technologies and the introduction of mold-in color plastics. These results, together with the very informative comments, provided a basis for the formulation of a number of the current Delphi V materials-related questions.

In order to provide some insight into the historical development of many of the responses, related materials trend data from previous Delphis are presented.

Metal Matrix Composites. Metal matrix composites (MMC) are a relatively recent material to appear on the automotive industry scene. In 1984, Delphi III panelists were asked: "In the next ten years, what are the two most likely breakthroughs in automotive materials technologies?" Of the materials technologies suggested by these panelists, the utilization of metal matrix composites did not receive a single response.

In the 1987 Delphi IV, the following question was asked regarding MMC: "What applications for MMC do you foresee in spark-ignited engines?" The responses indicated that the initial applications of MMC in internal combustion engines would be pistons and connecting rods. Both of these applications were suggested by 73% of the panelists. It was evident that metal matrix composites were viewed by Delphi IV panelists as a promising new technology.

Ceramics. In Delphi III the following question was asked: "When will ceramic engine components be used commercially, not just experimentally, and what three parts will be produced first?" The two components receiving the largest percentage of total responses were pistons (25%), cylinder head components (21%), and combustion chamber coatings (12%). The median year suggested at that time for commercial introduction was 1990. Additional engine components receiving a significant response were various valve train components and turbocharger rotor and bearings.

The 1987 Delphi IV Materials panelists were asked the following question: "What application of ceramic materials do you foresee in spark-ignited and diesel engines?" Exhaust system insulation, including exhaust port liners, and catalytic converters received the largest percent of responses (69%). This was followed by piston crowns (61%) and valve train components (42%). Turbocharger turbine/rotor and piston pins also received a significant response.

COMPARISON OF FORECASTS

The following Delphi V Technology and Materials questions provide information relevant to this forecast: TECH–33, TECH–41a, TECH–41b, TECH–42, MAT–8, MAT–16, MAT–19a, MAT–19b, and MAT–22, MAT–23, and MAT–25.

STRATEGIC CONSIDERATIONS

An interesting collection of materials is suggested to impact future vehicles by the year 2000. Metal matrix composites, particularly aluminum-based, have the strongest interest followed by glass, new steel, and ceramic materials. Panelists see considerable opportunities for some of the older, traditional materials, but in a revitalized form, or as one panelist suggested "not new glass, but much more of it." In this Delphi forecast, other questions specifically address metal matrix composites and ceramics in terms of probable application. With the growing pressure to deliver improved function, higher quality, and overall better value, the materials revolution is likely to accelerate. One critical issue will be the tradeoff between improved performance and the cost of the materials and their processing. In the case of both metal matrix composites and ceramics, they are still in an early stage of their learning curve and the long-range potential is difficult to assess. On the other hand, with glass and steel we may indeed be shifting to a totally new learning curve. Both situations present severe forecasting problems.

III. TOTAL VEHICLE: MATERIAL APPLICATIONS

MAT–12. Taking into consideration the following possible CAFE scenarios, forecast the material content, *in pounds*, and the total curb weight (dry, unloaded) for the average North American-produced passenger car for model years 1995 and 2000.

Materials (in pounds)	Median Response				Interquartile Range			
	CAFE: 27.5 mpg 1995	CAFE: 27.5 mpg 2000	CAFE: 30 mpg 1995	CAFE: 32 mpg 2000	CAFE: 27.5 mpg 1995	CAFE: 27.5 mpg 2000	CAFE: 30 mpg 1995	CAFE: 32 mpg 2000
STEEL								
Low Carbon Steel	1400	1250	1350	1200	1300/1400	1100/1350	1280/1386	1100/1300
HSLA Steel	240	250	235	250	228/250	228/275	220/240	200/250
Stainless Steel	35	35	35	32	32/35	32/43	30/35	30/37
Other Steels	55	55	50	50	50/60	45/60	45/55	45/55
TOTAL	1730	1590	1670	1532	1600/1745	1385/1695	1600/1675	1400/1590
CAST IRON	420	380	395	345	370/445	300/420	360/400	300/375
ALUMINUM								
Castings	115	130	120	140	100/140	118/160	111/140	130/150
Wrought Aluminum	35	40	35	40	30/40	30/40	30/35	30/40
TOTAL	150	170	155	180	150/175	160/200	147/170	156/180
PLASTICS								
Unreinforced (no fiber content)	140	140	140	140	120/150	130/170	110/150	125/170
Reinforced (<40% fiber content)	100	140	110	120	100/130	115/160	85/135	100/160
Structural Reinforced Composites (>40% fiber)	30	50	35	60	15/40	40/100	20/50	45/100
TOTAL	270	330	285	320	250/290	295/380	255/300	280/375
COPPER	25	22	23	20	20/25	18/25	20/25	18/22
ZINC (incl. coatings)	18	18	18	18	16/20	15/20	16/19	15/20
MAGNESIUM	1	2	2	2	1/3	1/5	1/2	1/4
GLASS	90	90	90	87	86/95	84/100	85/90	82/90
CERAMICS	2	5	2	4	1/3	2/5	1/2	3/5
POWDERED METALS	27	28	26	27	25/30	25/30	25/27	25/30
RUBBER								
Tires (include spare)	100	95	100	95	90/120	85/100	95/100	85/95
All Other Rubber	30	30	30	25	18/45	20/50	20/30	15/30
TOTAL	130	125	130	120	130/136	125/136	130/135	110/130
TOTAL ALL OTHER (includes lead, cloth, insulation, carpets, foam, fluids)	285	280	280	275	280/285	270/285	270/280	250/285
TOTAL VEHICLE	3148	3040	3076	2930	3000/3168	2900/3162	2907/3080	2750/2989

SELECTED EDITED COMMENTS

- With downsizing, more HSLA steels will be used. HSLA still remain the most cost effective product.
- Lack of repair and inspection technologies and infrastructure in the field will retard introduction of structural plastic composites.
- Fuel efficiency needs will force smaller, lighter vehicles.
- Expect to see a steady increase in the use of plastics with no dramatic step increases.
- Increase in reinforced plastics will be driven by cost reduction and part consolidation.
- New developments in plastics technology (both reinforced and unreinforced) portend greater use of plastics in load bearing structures, and in non-load bearing automotive body parts. Curb weights of cars will decrease if CAFE standard goes to 30 mpg in 1995 and 32 mpg in 2000.
- Electronics content increases dramatically, but multiplexing will mitigate copper weight increase.
- The total weight of electrical wiring harness will decrease. Increasing use of solid-state electronics and microprocessors, will also decrease the total copper content of car.
- Advent of multiplexed systems will reduce the harness weight. They will be partially offset by more electrical systems for direct drive of devices, replacing hydraulic operations (e.g., electrical power steering systems).
- Multiplexing will greatly reduce the amount of copper required.
- Rubber will increasingly be replaced by thermoplastic elastomers. Glass will go up, but will be downgauged to save weight. Structural composites growth is hindered by high manufacturing costs.
- I think glass will play a more prominent role, particularly in roof material.
- Expect increased use of aluminum castings for engine blocks, increased use of FRP and composites in body structures, and increased use of ceramics in engines for better performance.
- The major progress towards the higher mpg targets will be achieved by improvements in engine technology. I believe more progress is possible than the OEMs are indicating.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists generally agree on the average North American-produced passenger car materials mix. Significant differences in the forecasts between the two groups considered are as follows.

Materials Mix (in pounds)	CAFE: 30 mpg 1995		CAFE: 32 mpg 2000	
	OEM	Supplier	OEM	Supplier
Carbon Steel	*	*	1300	1200
HSLA Steel	*	*	180	250
Ceramics	1	2	1	5

*No significant difference.

COMPARISON OF FORECASTS: TECH-36

The following table shows the differences between the forecasts of the Materials and Technology panels given a 27.5 mpg CAFE scenario.

Materials (in pounds)	Forecast for 1995		Forecast for 2000	
	Materials Panel	Technology Panel	Materials Panel	Technology Panel
STEEL				
Low Carbon Steel	1400	1350	1250	1200
HSLA Steel	240	250	250	275
Other Steel	90	82	90	85
TOTAL Steel	1730	1682	1590	1560
CAST IRON	420	400	380	350
ALUMINUM	150	165	170	200
PLASTICS				
Unreinforced (no fiber content)	140	90	140	90
Reinforced (<40% fiber content)	100	80	140	120
Structural Reinforced	30	50	50	60
TOTAL Plastics	270	220	330	270
MAGNESIUM	1	2	*	*
RUBBER	130	120	135	125
TOTAL VEHICLE	3148	3032	3040	2943

*No difference.

TREND FROM PREVIOUS DELPHI SURVEYS

The following table represents three consecutive Materials Delphi forecasts. A similar table illustrating trends from previous Technology Delphi panels appears in TECH-36. A comparison of the trends from the two panels demonstrates a general consensus between the two groups for materials applications through Delphi IV. It becomes apparent, however, that the present Delphi reflects a significant difference of opinion between the Materials and Technology panelists regarding materials such as steel, plastic, and cast iron.

Materials (in pounds)	Forecast for 1990		Forecast for 1995	
	1985 Delphi III	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Steel	1400	1525	1325	1730
Aluminum	130	145	170	155
Plastics	215	220	300	260
Cast iron	270	380	300	420
Other	422	428	409	573
TOTAL	2437	2698	2504	3138

STRATEGIC CONSIDERATIONS

CAFE 27.5 MPG in 1995 and 2000. What is remarkable about the current Delphi forecast is the substantial increase (compared to previous Delphis) in total dry-curb weight for the years 1995 through 2000. The Delphi V Materials forecast for a total weight of 3148 lbs. in 1995 is a significant increase over the Delphi IV Materials' forecast of 2504 lbs. for the same year. The OPEC-precipitated oil shock of the early 1970s and federal regulatory activity combined to stimulate efforts on the part of the domestic vehicle manufacturers to downsize and increase the fuel economy of the average passenger vehicle. However, subsequent market factors have had a significant influence on vehicle size and, therefore, average vehicle weight. Adjusted for inflation, petroleum prices remain considerably below previous forecasts. The American consumer has indicated a continued desire for high performance and larger automobiles. Additionally, continuing improvements in powertrain efficiency, lower-rolling-resistance tires, improved aerodynamics, new materials, and advanced vehicle-design techniques have contributed to improved fuel economy without a significant change in average vehicle occupant and luggage capacity.

A notable change is evident in the area of steels and plastics. In Delphi IV Materials it was forecast that by 1995, steels would represent 1325 lbs and plastics 300 lbs. of the average weight of a North American-produced passenger car. At that time the interquartile range for steel was reasonably tight, whereas the interquartile range for plastics was rather broad. This indicated a good consensus for steel but a considerable degree of uncertainty regarding the application of plastics. While it is clear that there will be an increased utilization of plastics through the year 2000, Delphi V forecasts indicate that the competition between steel and plastics will continue to be intense.

Other automotive material forecasts demonstrating significant change from Delphi IV are aluminum and cast iron. Aluminum use is expected to grow but not to the extent of earlier forecasts. Furthermore, cast iron is forecast to decrease but not as much as forecast in Delphi IV.

Expectations for content of other materials, such as glass, magnesium, ceramics, and powdered metals are consistent with previous forecasts. Materials technology for automotive applications will continue to be an area of continuing evolution and development and, in some cases, revolution. All materials are benefiting from significant improvements in design and manufacturing. Also, the industry appears to be experiencing a substantive re-evaluation of traditional technologies. One important example is steel, which has undergone a modest rebirth as the joint efforts of the steel and auto industries have led to considerable improvements in cost-effective processing. At the same time other materials, such as plastics, are experiencing the effects of increasing environmental concerns, processing challenges, and cost issues. Emerging process and product technologies for both conventional and new materials are advancing at such a rapid pace that a clear vision of the future is difficult to obtain. This situation presents considerable challenges and opportunities for the vehicle manufacturer, component supplier, and materials supplier and ensures a most interesting and complex future for all automotive materials.

Recent concerns regarding fuel economy (possibly increased CAFE standards) and emissions could cause a resurgence of interest in lightweight materials, which would enable maintenance of vehicle size while permitting weight reduction.

CAFE 30 MPG in 1995, 32 MPG in 2000. Because of the renewed concerns for tougher CAFE fuel economy standards in the spring of 1989, we chose to delay the second round survey of Materials to permit orderly evaluation of a materials future with a tougher CAFE standard of 30 mpg in 1995 and 32 mpg in 2000. The results of the forecast with the new scenario are surprisingly close to the 27.5 mpg future. Modest reductions in total mass and weight of steel and cast iron are evident as are slight increases in both expectations for plastics and aluminum. This clearly suggests that only a modest skewing of the materials future may occur with tougher CAFE standards and emphasis will be placed on other vehicle factors such as powertrain and aerodynamics to improve fuel economy. Frankly we would be surprised if more weight reduction than forecast did not come about with the higher standard. Only time will tell however. If the CAFE standards are raised to the area of 40 mpg in 2000, the material choice issue could become chaotic and the industry thrown into turmoil.

MAT-13. Consider the following representative list of automotive components and indicate the percentage of each likely to be made in 1995 and 2000 from the materials listed. (It is not necessary to enter a response for every component—just those you are familiar with. Where you do answer, please make certain your replies add across to 100%. Please fill in every blank; use zeroes where applicable).

Components	1995 MODEL YEAR: Percent Usage					
	Median Response					
	Steel	HSLA Steel	Aluminum	Reinforced Plastics/Comp	Nonreinforced Plastics	Other
Hood, Outer	80%	0%	0%	20%	0%	0%
Hood, Inner	75	0	0	25	0	0
Roof	95	0	0	5	0	0
Floor Pan	93	2	0	5	0	0
Bumper, Fascia	2	0	1	17	80	0
Bumper, Support	35	30	0	35	0	0
Fuel Tank	65	0	0	0	35	0
Seat Frame	65	15	0	20	0	0
Wheels	55	10	30	5	0	0
Radiator Support	60	5	0	35	0	0
Suspension Springs	85	0	0	15	0	0
Suspension Control Arms	75	20	0	5	0	0
Components	**Interquartile Range**					
Hood, Outer	70/85%	0/0%	0/5%	5/20%	0/0%	0/0%
Hood, Inner	70/80	0/2	0/2	5/25	0/0	0/0
Roof	88/95	0/0	0/0	1/10	0/0	0/0
Floor Pan	85/95	0/5	0/0	0/10	0/0	0/0
Bumper, Fascia	0/5	0/0	0/3	0/37	67/90	0/0
Bumper, Support	10/40	0/40	0/0	20/50	0/0	0/0
Fuel Tank	50/70	0/0	0/0	0/10	10/35	0/0
Seat Frame	50/75	0/30	0/5	10/30	0/0	0/0
Wheels	30/63	0/20	20/25	0/10	0/0	0/0
Radiator Support	40/80	0/10	0/0	20/50	0/0	0/0
Suspension Springs	80/95	0/0	0/0	5/20	0/0	0/0
Suspension Control Arms	60/90	5/30	0/5	0/5	0/0	0/0

Components	2000 MODEL YEAR: Percent Usage					
	Median Response					
	Steel	HSLA Steel	Aluminum	Reinforced Plastics/Comp	Nonreinforced Plastics	Other
Hood, Outer	65%	5%	0%	30%	0%	0%
Hood, Inner	65	0	0	35	0	0
Roof	80	0	0	20	0	0
Floor Pan	80	0	0	20	0	0
Bumper, Fascia	1	0	1	15	83	0
Bumper, Support	20	20	0	60	0	0
Fuel Tank	40	0	0	5	55	0
Seat Frame	42	14	2	42	0	0
Wheels	42	10	36	12	0	0
Radiator Support	40	5	0	55	0	0
Suspension Springs	80	0	0	20	0	0
Suspension Control Arms	60	30	0	10	0	0
Components	Interquartile Range					
Hood, Outer	50/76%	0/10%	0/5%	15/35%	0/0%	0/0%
Hood, Inner	45/70	0/10	0/5	20/40	0/0	0/0
Roof	70/90	0/0	0/0	2/30	0/0	0/0
Floor Pan	70/85	0/5	0/0	10/25	0/0	0/0
Bumper, Fascia	0/5	0/0	0/2	0/30	50/90	0/0
Bumper, Support	5/30	0/35	0/0	35/70	0/0	0/0
Fuel Tank	20/50	0/0	0/0	0/20	40/70	0/0
Seat Frame	25/50	0/30	0/5	25/50	0/0	0/0
Wheels	25/50	0/20	25/45	5/20	0/0	0/0
Radiator Support	20/50	0/10	0/0	45/65	0/0	0/0
Suspension Springs	65/90	0/0	0/0	10/35	0/0	0/0
Suspension Control Arms	40/80	5/40	0/5	5/15	0/0	0/0

SELECTED EDITED COMMENTS

- Engineering thermoplastics will make increasing inroads into the use of fiber-reinforced plastics (FRP). Technology will evolve to make FRP parts more reliable and of consistent quality. Present technology of fiber reinforced plastics has several manufacturing problems. These recurrent manufacturing and materials problems will be overcome by 1995.
- Expect Finite Element Analysis (FEA) techniques to support continued high percentage steel usage.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in close agreement. The few areas where there are significant differences are illustrated in the following table.

Materials Applications	Forecast for 1995		Forecast for 2000	
	OEM	Suppliers	OEM	Suppliers
Seat Frame: Steel	60%	75%	*	*
Wheels:				
Steel	35	60	30%	45%
HSLA Steel	5	10	10	5
Reinforced Plastic	0	5	*	*
Radiator Support:				
Steel	40	50	25	40
HSLA Steel	10	5	10	5
Reinforced Plastic	50	25	65	60
Suspension Springs:				
Steel	80	90	60	80
Reinforced Plastic	15	10		
Suspension Control Arms: Steel	60	75	*	*

*No significant differences.

TREND FROM PREVIOUS DELPHI SURVEYS

The following table illustrates the differences in forecast component materials use between Delphi IV (1987) and Delphi V (1989).

Materials Use	Forecast for 1995 Model Year									
	Steel		HSLA Steel		Aluminum		Reinforced: Plastics/Comp.		Nonreinforced: Plastics	
	1987	1989	1987	1989	1987	1989	1987	1989	1987	1989
Hood, Outer	69%	80%	1%	0%	2%	0%	28%	20%	0%	0%
Hood, Inner	62	75	6	0	1	0	14	25	0	0
Roof	81	95	5	0	0	0	14	5	0	0
Floor Pan	86	93	0	2	0	0	14	5	0	0
Bumper, Fascia	0	0	1	0	6	0	12	15	81	85
Bumper Support	9	35	55	30	0	0	36	35	0	0
Fuel Tank	58	65	0	0	0	0	14	0	28	35
Seat Frame	33	65	40	15	0	0	27	20	0	0
Wheels	37	55	29	10	29	30	5	5	0	0
Radiator Support	30	60	35	5	0	0	35	35	0	0
Suspension Springs	63	85	0	0	0	0	37	15	0	0
Suspension Control Arms	47	75	47	20	6	0	0	5	0	0

STRATEGIC CONSIDERATIONS

Following our Delphi tradition of many years we asked Materials panelists to select futures for a number of representative vehicle components. The list is not exhaustive because of the large burden on panelists. However, it is sufficiently broad to provide a strong indication of trends throughout the vehicle.

Trends observed elsewhere in Delphi V prevail in this question as well. Panelists generally have exhibited a more conservative view of substitution of new materials for traditional ones. Steel consistently ranked higher than in Delphi IV for most components. Plastics expectations were modestly reduced in most cases, although several categories such as bumper fascia and suspension arms with reinforced plastic composites and bumper fascia, and fuel tanks for non-reinforced plastics increased.

While the material trends appear to be reasonably stable, the change forecast is still significant. We continue to believe the materials revolution continues but not with quite the fervor of a few years ago. Of course, new developments in plastics and other technologies could again change the forecast in years ahead. We surmise that the most important factors in the moderate forecast are:

- Significant improvements in steel, product design, and steel fabrication technology.
- Material developments that have not lived up to expectations.
- Slowness with which foreign competitors are adopting new materials.
- Increased cost pressures and belief that tougher fuel economy standards can be met without massive material substitution.

MAT–14. In what components will magnesium alloys begin to replace existing materials by the year 1995?

Magnesium Components by 1995	Percent of Respondents
Engine components	37%
Covers/housings	24
Manifold	13
Wheels	13
None	13

REPRESENTATIVE RESPONSES

- Engine and powertrain critical weight parts.
- Rocker arm cover, oil pan cover, and air cleaner housing.
- Wherever die cast aluminum is now used, for example: valve covers, oil pan, and transaxle housings.
- Very little, possibly some aluminum die castings.

TREND FROM PREVIOUS DELPHI SURVEYS

In Delphi IV, the following question was asked: "Given its substantially lower weight, if the price of magnesium were to stabilize at either approximately 25% or 75% higher than the price of aluminum, (a) how many pounds of magnesium do you foresee being used per passenger car and light-duty truck, (b) what components do you foresee will be manufactured utilizing magnesium?"

Although the Delphi IV question is not precisely comparable, it does present relevant and significant information that should allow for a more in-depth perspective of the industry's attitude and expectations regarding magnesium alloys and their role in automotive components. It should be noted that *Percent of Respondents* does not indicate "percent of application." Both the Delphi IV and Delphi V questions are open-ended, therefore panelists could respond with more than one suggestion. The percent of panelists suggesting a particular component may be interpreted as an indication of its popularity as a candidate for magnesium usage and, therefore, its probability of commercialization. The data, as presented in Delphi IV, is as follows.

Delphi IV: Pounds of Magnesium by Price Premium

	Median Response		Interquartile Range	
Magnesium Price versus Aluminum	Passenger Cars	Light-Duty Trucks	Passenger Cars	Light-Duty Trucks
25% Premium	20 lbs.	25 lbs.	25/25 lbs.	7/30 lbs.
75% Premium	3	5	1/5	1/9

Delphi IV: Components Utilizing Magnesium
25% Premium to Aluminum

Component Parts	Percent Respondents
Engine components (connecting rods, pistons)	39%
Transmission housings	39
Cast wheels	23
Engine heads	23
Engine blocks	15
Others*	65

**Others*: Transmission parts, brackets, bumpers, decorative parts, intake manifold, oil pumps, fuel pumps, die-cast headlamp, and door hardware.

Representative Responses

- Drivetrain cases. Passenger car engine blocks.
- Cast engine components and transmission housing on larger cars and sports cars, some light trucks.
- Most aluminum housing and brackets which don't exceed 250°F.
- Heads, die-cast headlamp doors, possible engine block.
- Metal matrix in composites for chassis and engine parts.
- Decorative applied parts.
- Covers and housings, connecting rods, headlamp doors, and wheels.

Delphi IV: Components Utilizing Magnesium
75% Premium to Aluminum

Component Parts	Percent Respondents
Die-cast specialty parts	43%
Brackets	43
No significant penetration	15

Representative Responses

- Die-cast speciality parts (brackets, valve covers, etc.).
- The real issue is price stability of secondary aluminum.
- Only castings on speciality cars.

STRATEGIC CONSIDERATIONS

As noted in the overall Material forecast, there is growing but still very modest interest in magnesium for light-duty vehicles. Significant factors in future magnesium use are the long-range expectations for supply and commodity pricing and competitive material alternatives. There is growing evidence that supply may expand and, therefore, magnesium may become a more attractive material for high-volume automotive applications. Pricing, on the other hand, is a significant question mark, particularly compared to aluminum. If reasonable stability is envisioned by the industry in the magnesium/aluminum price ratio, or greater stability in magnesium pricing occurs compared to aluminum, magnesium use could grow significantly. Certainly, if increased CAFE requirements require significant vehicle weight reduction, magnesium may become competitive for a number of components. The Delphi IV forecasts illustrate the influence of the magnesium/aluminum price ratio.

MAT-15. What new applications for the various forms of powdered metals (PM) listed are likely to replace current automotive component applications by the year 2000?

Powder Metal Form	Current Applications	New Applications
Forged PM	Wrought castings	Connecting rods Transmission gears
Injection molded PM	Part assemblies	Shifter forks
Other	Various materials that are extensively machined	Camshafts Valve lifter wear pads Power steering thrust plate

SELECTED EDITED COMMENTS

- Very limited opportunities for powdered metals.

STRATEGIC CONSIDERATIONS

The role of powdered metal technology in future automotive vehicles is very uncertain. While some new specialized applications are envisioned, there is little wide-spread enthusiasm for powdered metals technology. However, some of these applications, such as engine connecting rods, cam shafts, or transmission gears, may have significant volumes. As with other basic material technologies, we are still early on the PM learning curve. Powdered metals must be watched closely for new developments.

IV. POWERTRAIN: MATERIAL APPLICATIONS

MAT-16. For the following engine components, please indicate what percent are likely to be made from the materials listed by the year 2000.

Engine Component/Material	Percent Likely to be Made from Material	
	Median Response	Interquartile Range
Crankshaft		
Cast iron	70%	65/75%
Steel	30	20/30
Camshaft		
Cast iron	55	40/65
Steel	35	30/45
Composites (steel-powdered metal combination)	10	5/20
Piston		
Cast aluminum	70	70/80
Reinforced aluminum composite	20	15/25
Ceramic	0	0/0
Hybrid (plastic skirt/ceramic crown)	10	5/10
Connecting Rod		
Cast iron	25	15/30
Steel	60	45/70
Aluminum	5	0/10
Composites	10	0/20
Intake Manifold		
Cast iron	10	5/15
Aluminum	60	50/70
Plastic/polymer composite	30	20/40
Magnesium	0	0/5
Exhaust Manifold		
Cast iron	75	60/80
Steel	5	0/10
Stainless steel	20	15/30
Rocker Arm Cover		
Plastic	60	40/75
Aluminum	15	10/20
Steel	20	10/45
Magnesium	5	0/5
Oil Pan		
Steel	70	60/75
Aluminum	10	5/20
Plastic	15	10/20
Magnesium	0	0/0
Steel-plastic laminates	5	0/10

Engine Component/Material	Percent Likely to be Made from Material	
	Median Response	Interquartile Range
Water Pump Housing		
Cast iron	35%	20/40%
Steel	0	0/0
Aluminum	40	30/45
Plastic	25	15/35
Laminated steel/composite	0	0/5
Magnesium	0	0/2
Air Cleaner Housing		
Steel	20	15/30
Aluminum	5	0/10
Plastic	75	65/85
Magnesium	0	0/0
Valves		
Steel	90	90/95
Ceramic	5	5/10
Titanium	5	1/5

SELECTED EDITED COMMENTS

- Applications of plastics and composites in engines may increase significantly due to the weight savings they provide.
- Concern over greenhouse effect and therefore a very strong drive towards fuel efficiency will dictate the use of lightweight rigid materials in high revving, higher specific output engines.
- Reinforced plastics will favorably compete with aluminum. Titanium and ceramics appear to provide performance necessary for high speed engines.
- Steel crankshafts will be widely used, driven by OEM transplant technology. Powdered metal connecting rods will be a major player. Steel camshafts will replace iron.

MANUFACTURER/SUPPLIER COMPARISON

For the most part, engine component materials mix forecasts of manufacturer and supplier panelists are in close agreement. Differences of more than 4% are shown in the following table.

Engine Component	Material	Forecast for Year 2000	
		OEM	Supplier
Piston	Hybrid	0%	5%
Intake Manifold	Aluminum	70	50
Exhaust Manifold	Steel	0	5
Rocker Arm Cover	Aluminum	20	10
Oil Pan	Steel	60	75
	Plastic	10	18
Water Pump Housing	Aluminum	45	30
	Plastic	15	30
Air Cleaner Housing	Plastic	70	80

TREND FROM PREVIOUS DELPHI SURVEYS

A comparison of Delphi IV and Delphi V engine component materials forecasts provides an example of significant change in the automotive industry material specialists' opinion regarding the future role of certain material technologies. In Delphi IV the question was posed as follows: "For the following engine components, please indicate possible materials/processes for their production by 1995." Delphi IV panelists projected an enthusiasm for new technologies but Delphi V panelists appear to have moderated their views. While the Delphi IV and the Delphi V questions are not specifically comparable (i.e., percent application versus percent responses), the following table illustrates a continuity with or, at times, a rather significant change in perspective. It is important that the reader maintain a perspective on the difference between the popularity of a "possible" material (Delphi IV) and forecasts for the percent of a component expected to be produced from the same material (Delphi V).

Delphi IV: 1995 Forecast		
Engine Component	Material	Percent Total Respondents
Camshaft	Powdered Metals	25
Piston	Ceramics	29
Connecting Rod	Aluminum	39
	Steel	19
	Composites	19
	Cast Iron	15
Intake Manifold	Aluminum	48
	Plastic	48
Exhaust Manifold	Cast Iron	32
	Steel	24
	Stainless Steel	12
	Ceramics	16
	Aluminum	12
Oil Pan	Plastics	46
	Steel	29
	Aluminum	21
	Magnesium	4
Water Pump Housing	Plastics	46
	Cast Iron	4

STRATEGIC CONSIDERATIONS

Considerable uncertainty is suggested for key engine component materials, both by the variety of technologies that could be used as well as by usage shifts from Delphi IV forecasts. With a significant fraction of engines expected to be redesigned during the 1990s (TECH-49) it is likely that engine engineers will completely review all components for possible change and improvement.

Continuing emphasis on quality and performance, including the "look" of quality from a cosmetic standpoint, will impact engine exterior components. In addition, the prospect of tougher fuel economy standards and noise, vibration, and harshness improvements will certainly prompt an emphasis on internal moving component precision and mass control.

We suspect that as a true systems approach is used by engine designers, trends could emerge that will lead to coalescence on a smaller set of technologies. In the meantime, the battle between various candidates will be lively and important to track closely in the engine component business.

MAT-17. What percentage of North American-produced light-duty vehicles will be equipped with engines that consist of 50% or more non-metallic component parts in the year 2000?

Percent Engines with 50% or More Non-Metallic Component Parts in the Year 2000	
Median Response	Interquartile Range
5%	0/20%

SELECTED EDITED COMMENTS

- Assumes gas prices stay low as forecast.
- Non-metallics will continue to replace lighter components (e.g., valve guides/seats, etc.) and cam followers.

MANUFACTURER/SUPPLIER COMPARISON

There is a difference of opinion between the manufacturer and supplier panelists about the percent of engines consisting of 50% or more non-metallic component parts by the year 2000. The supplier forecast of 5% is in agreement with the consensus forecast, although the upper interquartile range is 10%. The OEM panelists forecast 2% with the interquartile range in accord with the consensus interquartile range.

COMPARISON OF FORECASTS: TECH-40, TECH-41, MAT-16, MAT-18a

Forecasts related to the utilization of potential ceramic-and polymer-based engine components are addressed in the following questions: TECH-40, TECH-41a, MAT-16, MAT-18a.

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi IV panelists were asked three questions related to the probability of non-metallic engines. The Delphi IV forecast of North American passenger vehicles that will be equipped with engines consisting of 50% or more non-metallic component parts was 5% by 1995 (interquartile range 0/15%) and 15% (interquartile range 5/50%) by the year 2000. The very wide interquartile ranges for these forecasts is significant. Another Delphi IV question queried the opinion of panelists regarding the potential for passenger car engines that would be 50% or more non-metallic within a 1995–2000 time frame. Sixty-four percent (64%) of the respondents were affirmative and 32% were negative (with 4% undecided). While these percentages represent an almost 2:1 belief on the part of the Delphi IV panelists in the potential for non-metallic engines based on 50% or more plastic or ceramic content, there are several factors that should be considered within the context of the present forecast. A significant percentage (22%) of the previous Delphi IV panelists expressed a concern that cost will continue to be a major impediment to volume production. Additionally, 32% of those panelists expressed the opinion that the potential for the production of such an engine within this century was either very low or non-existent.

STRATEGIC CONSIDERATIONS

With growing interest in non-metallic, particularly composite components, there are modest expectations for these materials in future engines. This is a difficult question to interpret quantitatively, but it does suggest there is a potentially significant role for non-metallic materials in engines. Materials panelists expect a modest fraction of future engines will have a reasonably high density of non-metallic components. With a forecast of this magnitude, companies must watch non-metallic engine component development carefully. In separate questions (MAT–16 and MAT–18a) addressing both ceramic and polymer-based components it is evident there is considerable interest for specific engine components.

On a weight basis the fraction of non-metallic components should be considerably less than on a part basis since the block, head, and exhaust manifold will probably, at least for the next decade, continue to be produced from metals.

MAT-18a. What percent of spark-ignited engines in North American-produced passenger vehicles will use the following ceramic engine components in the years 1995 and 2000?

Spark-Ignited Engines: Ceramic Engine Components	Percent Usage in N.A.-Produced Passenger Cars			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Valve train components (includes valves, inserts, guides seats, tappets, cam, etc.)	5%	7%	2/5%	5/10%
Exhaust manifold/port liner	3	7	2/5	5/10
Turbocharger turbine/rotor	2	6	1/5	2/10
Piston crown	2	5	0/5	1/10
Piston rings	2	5	0/5	1/7
Seals	2	5	0/5	0/10

SELECTED EDITED COMMENTS

- High temperature moldable and machinable ceramics, and ceramic/metal composites should be included as a generic materials class for engine components. Expect small use of ceramics.
- Ceramics use will probably be confined to use as coatings with a few minor exceptions (e.g., turbocharger rotors).
- If ceramic components are used in passenger cars they will probably be used in newly designed engines. There is a possibility that some turbine-powered vehicles will be marketed by the year 2000. If so, there will be a sharp increase in the use of ceramic components.
- Interest in ceramics for engine applications seems to have waned in the past couple of years.
- Main driving force for ceramics will be high speed engines (with emissions secondary) requiring lightweight valve train components. However, expect slow growth.

MANUFACTURER/SUPPLIER COMPARISON

Differences in the forecasts of the manufacturer and supplier panelists exceeding more than 2% are shown in the following table.

Ceramic Engine Components	Percent Usage in Spark-Ignited Engines: Forecast Differences			
	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Exhaust manifold/port liner	*	*	10%	5%
Turbocharger	*	*	10	15
Piston crown	0%	2%	2	8
Piston rings	0	2	*	*

*No differences.

COMPARISON OF FORECASTS: TECH-41a

The following table illustrates the Technology and Materials Panel forecast differences.

Ceramic Engine Components	Percent Usage in Spark-Ignited Engines: Forecast Differences			
	Technology Panel		Materials Panel	
	1995	2000	1995	2000
Valve train components	2%	10%	5%	7%
Exhaust manifold/port liner	3	10	3	7
Turbocharger turbine/rotor	5	15	2	6
Piston crown	2	8	2	5
Piston rings	0	0	2	5
Seals	2	10	2	5

TREND FROM PREVIOUS DELPHI SURVEYS

In Delphi IV, Materials panelists were asked: "What percent of ceramic materials do you foresee in spark-ignited and diesel engines?" The leading applications in spark-ignited engines (expressed as percent of respondents for each variable) were: exhaust system insulation (69%), piston crowns (61%), and valve train components (42%). As in other comparisons of Delphi IV and Delphi V related questions, while the responses are not precisely comparable, there is a relevant progression from *what* to *when and how much* that can provide an interesting analysis of the stability of certain technology application forecasts. In this particular case, the projected relative importance of ceramics usage in valve train components and exhaust systems appears to be maintained.

STRATEGIC CONSIDERATIONS

Optimism for ceramic engine components continues although somewhat tempered from just a few years ago. However, the magnitude of the individual forecasts from 1995 through the year 2000 suggest that ceramics could play a minor, but still important role in a variety of key engine components. With successful production experience it is conceivable that ceramic use could expand rapidly.

There are significant differences between spark-ignited and diesel engines in terms of the basic combustion process. The insulating qualities of ceramics in the diesel engine combustion chamber are highly advantageous in terms of diesel combustion. Just the opposite is true with the spark-ignition engine, since the higher gas temperatures due to reduced heat transfer could increase engine octane requirement.

Manufacturing considerations are still extremely important and a key factor limiting a number of applications. It is conceivable that tightening emissions and fuel economy standards will accelerate ceramic development efforts.

It appears the concept expressed a few years ago of an essentially "ceramic engine" has faded and is replaced with a more realistic assessment of ceramics on a part-by-part basis.

Strong concerns remain with reliability, durability, and producbility aspects of ceramics. In today's quality- and cost-conscious environment, mistakes are not acceptable.

MAT-18b. Do you foresee any non-engine automotive application for ceramics? Please indicate application and forecast for year of introduction.

Other Non-Engine Ceramic Automotive Applications	Year of Introduction
Exhaust gas heat insulator	1990
Thermal sensor for exhaust gases	1990
Support for catalysts for controlling "quality" of exhaust gases	1995
Ornamentation	1997
High-temperature headlamps	1998
Wear parts-locks-latches	2000

COMPARISON OF FORECASTS: TECH-41b

Technology panelists forecast the following additional non-engine ceramic automotive applications: brake, transmission, electric motor, hydraulic pump, and exhaust system components; electronic chip housings; and wheels.

STRATEGIC CONSIDERATIONS

There is some enthusiasm for non-engine applications for ceramics that range from various surface coatings to insulators in high-temperature headlights. Obviously, this is a highly qualitative question and serves only to alert the reader to possible broader ceramic material applications. In some areas, ceramics are already used extensively such as in the catalytic reactor and exhaust oxygen sensor and it appears that the respondents may be suggesting new incremental developments of these applications. The future of ceramics will be dependent on developments that lie ahead of us, particularly in the processing area.

MAT-19a. What percent of light-duty vehicle engines produced in the U.S. in 1995 and 2000 will utilize aluminum cylinder heads and/or blocks?

Aluminum Application	Percent of U.S.-Produced Light-Duty Vehicle Engines			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Aluminum Heads	55%	70%	50/60%	55/80%
Aluminum Blocks	10	15	5/10	10/20

MANUFACTURER/SUPPLIER COMPARISON

As illustrated in the following table, the OEM and supplier panelists offer somewhat differing forecasts, particularly in the area of aluminum blocks. While the quartile ranges for 1995 and 2000 forecasts of each group are reasonably tight, the differences between these groups are significant regarding their relative distribution.

Aluminum Application	Forecast for 1995				Forecast for 2000			
	Median Response		Interquartile Range		Median Response		Interquartile Range	
	OEM	Supplier	OEM	Supplier	OEM	Supplier	OEM	Supplier
Aluminum Heads	60%	50%	50/60%	45/60%	70%	60%	65/80%	50/80%
Aluminum Blocks	10	5	8/10	5/10	15	10	12/20	7/20

COMPARISON OF FORECASTS: TECH-39a

The forecast of the Technology panelists for the percent of North American-produced light-duty engines utilizing aluminum heads and/or blocks are in accord with the Materials panelists' forecast.

Aluminum Application	Delphi V Technology Forecast			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Aluminum Heads	50%	70%	50/60%	65/80%
Aluminum Blocks	6	12	5/10	10/20

TREND FROM PREVIOUS DELPHI SURVEYS

As demonstrated in the following table, the current Materials panelists have substantially reduced their expectations for both aluminum heads and aluminum blocks.

Aluminum Application	Forecast for 1990	Forecast for 1995	
	1987 Delphi IV	1987 Delphi IV	1989 Delphi V
Aluminum Heads	50%	70%	55%
Aluminum Blocks	20	40	10

STRATEGIC CONSIDERATIONS

On a percentage basis, a significant increase is forecast by the panelists for aluminum head and block use. Aluminum heads are expected to be far more prominent than aluminum blocks during the next decade. The growth in aluminum head application is consistent with the trends observed in the prior forecast, whereas there has been a decrease in expectations for aluminum cylinder blocks. The recent volatility in commodity prices, particularly aluminum, may be damping expectations. Furthermore, it is evident that the threat from aluminum has prompted significant improvements in cast iron technology with the development of high-quality, thin-wall castings.

With the high rate of engine redesign during the next ten years, alternative materials for both blocks and heads should be carefully examined. In a rather stable powertrain environment, change should be expected to occur slowly. However, with a fast rate of change, a shift to new materials may suddenly accelerate. There are some novel approaches being evaluated in both cylinder block and head technology that may prompt consideration of materials that are presently receiving little consideration. As noted earlier, renewed emphasis on fuel economy and tighter emissions standards could have significant impact in this area as well, particularly as it relates to vehicle weight and providing customer value.

MAT–19b. What percent of North American-produced light-duty vehicle engines will utilize aluminum cylinder heads and/or block configurations in the years 1995 and 2000?

Light-Duty Engines	Percent Usage			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
4-CYLINDER				
Aluminum Heads	60%	80%	55/60%	70/80%
Aluminum Blocks	10	15	10/15	10/30
V–6				
Aluminum Heads	55	75	50/70	65/80
Aluminum Blocks	10	15	5/10	10/25
V–8				
Aluminum Heads	40	65	40/65	50/80
Aluminum Blocks	5	10	2/20	5/25

SELECTED EDITED COMMENTS

- Germans and Japanese are obviously well ahead of the Big Three in aluminum engine technology.
- The problem is unique investment requirements for aluminum while maintaining iron for "heavier duty" cycles. Aluminum needs to address this if they wish to really increase volume in the tight investment period of 1990–1995.

MANUFACTURER/SUPPLIER COMPARISON

In general, the manufacturer and supplier panelists are in close agreement on the forecasts requested in this question. However, a difference of opinion is apparent regarding the percent of aluminum heads by the year 2000. For that year the OEM panelists indicate a level of 5% more than the supplier panelists for each configuration; OEM panelists: 4–cylinder=80%, V-6=75%, and V-8=65%. The only panelists' difference in the aluminum block forecasts is for V–6s in the year 2000; the OEM panelists forecast 20% and the suppliers 10%.

STRATEGIC CONSIDERATIONS

In general, the forecast for aluminum cylinder heads is consistent with the forecast of the Technology panel (TECH–49) for complete engine redesign in the 1990s. They forecast a greater level of redesign for four-cylinder engines, followed by sixes, and then V–8s. Obviously, a newly designed engine is more likely to have a fundamental materials change. The same trend, to a degree, is observed for block material.

Four-cylinder engines are a particular challenge because noise, vibration, and harshness problems are inherently more significant with this configuration, and material decisions are, therefore, more important to the overall performance and quality perception of the engine.

MAT-19c. Of the aluminum blocks forecast in MAT-20a, please forecast the percentage that will be unsleeved and the percentage that will be sleeved.

Aluminum Blocks	Percent Unsleeved/Sleeved			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Unsleeved	10%	20%	5/20%	10/30%
Sleeved	90	80	80/95	70/90

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in agreement regarding the percent of sleeved and unsleeved aluminum blocks. The interquartile ranges for each year are very close.

COMPARISON OF FORECASTS: TECH–39b

The Delphi V Technology panelists offer somewhat lower forecasts for the percentage of sleeved aluminum blocks than the Materials panelists.

Aluminum Blocks	Delphi V Technology Panel Forecast			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Unsleeved	5%	15%	5/10%	10/20%
Sleeved	95	85	90/95	75/90

TREND FROM PREVIOUS DELPHI SURVEYS

The following table shows the 1987 Delphi IV Materials forecast for unsleeved aluminum blocks compared with the current Delphi V forecast.

Delphi IV and Delphi V Materials Forecast: Percent *Unsleeved* Aluminum Blocks		
1987 Delphi IV		1989 Delphi V
1990	1995	1995
10%	30%	10%

STRATEGIC CONSIDERATIONS

Materials panelists view the use of unsleeved aluminum engines with a degree of suspicion, as evidenced by relatively low expectations for both 1995 and 2000. This is undoubtedly due in part to a history of unsatisfactory applications. However, with the continued impressive developments around the world suggesting there are no inherent problems with today's unsleeved designs, the modest expectations are quite surprising. The North American industry must have absolute proof in hand before significant shifts will occur to unsleeved designs. This is consistent with increasing emphasis on quality and substantially longer warranty periods which cause manufacturers to be cautious about accepting uncertain technologies.

MAT-19d. What percent of sleeves in North American-produced light-duty vehicle engines will use the following materials in the years indicated?

Sleeve Material	Percent Usage in N.A.-Produced Light-Duty Engines			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Cast Iron	85%	80%	55/90%	48/85%
Steel	10	10	2/25	2/25
Aluminum	5	5	2/10	5/7
Ceramics	0	5	0/5	0/8

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists present somewhat different forecasts for sleeving materials.

Sleeving Material	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Cast Iron	85%	80%	85%	75%
Steel	10	5	10	5
Aluminum	10	3	5	5
Ceramics	1	0	2	5

COMPARISON OF FORECASTS: TECH-39b

With regard to sleeving materials for aluminum blocks, the Technology panelists consider cast iron the most likely material (65% application), followed by ceramics (22%), and aluminum (13%). The Technology panel does not consider steel a likely sleeve material.

TREND FROM PREVIOUS DELPHI SURVEYS

The Delphi IV Materials panelists expected that by 1990, 80% of aluminum blocks would use cast iron sleeves. The forecast for the 1995 model year was for 70% cast iron sleeves. Other sleeving materials suggested by the Delphi IV panelists (no percent application given) were aluminum-ceramic composites, high silicon aluminum alloys, 390 aluminum, and ceramics.

STRATEGIC CONSIDERATIONS

While cast iron is overwhelmingly the favorite sleeving material, there is significant enthusiasm for other materials, most notably aluminum and steel. Even ceramics receive some mention. Of course, the ceramic-type may be viewed as either a whole ceramic liner or as a ceramic coating on another material. In any event, competition is likely to accelerate in this area.

We suspect that ultimately manufacturers would like to eliminate the need for a separate liner, but as noted in MAT–19c, there is not sufficient confidence in this approach. It is crucial to follow developments on a worldwide basis. As noted in one comment, some of the leading edge developments are found outside of North America.

MAT-20. What percentage of North American-produced light-duty vehicle radiators manufactured in model years 1995 and 2000 will use cores and/or end tanks made from the following materials?

Material	Percent Usage in N.A.-Produced Light-Duty Radiators			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
PASSENGER CAR				
Cores				
Aluminum	70%	85%	70/75%	80/85%
Copper	30	15	25/30	10/20
End Tanks				
Aluminum	20	15	10/30	5/20
Copper/Brass	20	15	10/30	10/20
Plastic	60	70	25/70	60/90
LIGHT TRUCK				
Cores				
Aluminum	65%	75%	60/70%	45/80%
Copper	35	25	30/40	20/30
End Tanks				
Aluminum	30	20	15/40	5/30
Copper/Brass	40	20	20/45	15/30
Plastic	30	60	15/60	50/75

SELECTED EDITED COMMENTS

- I believe that (1) where large numbers of aluminum radiators have been in service all over the US, the internal corrosion caused by poor coolant maintenance will be a major problem by 1995; (2) that aluminum tanks will be used very little because of the problem of erosion corrosion or surface corrosion; and (3) the copper industry will provide new joining methods by 1995 that will eliminate the problems of present lead-tin solders. With a better joining material, copper and brass radiators will be lighter, more durable, and have better corrosion resistance than aluminum radiators.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in agreement on the materials mix for cores in both passenger cars and light trucks. There is, however, considerable disagreement for end tanks on both vehicle classes.

End Tanks	Percent Materials Mix			
	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
PASSENGER CARS				
Aluminum	10%	25%	15%	10%
Copper/Brass	20	15	15	10
Plastic	70	50	70	70
LIGHT TRUCKS				
Aluminum	40%	30%	45%	20%
Copper/Brass	40	20	30	20
Plastic	15	20	20	60

TREND FROM PREVIOUS DELPHI SURVEYS

In 1987 Delphi IV Materials panelists forecast that by 1995, 75% of U.S-produced passenger cars and 60% of light trucks would be equipped with aluminum radiators.

STRATEGIC CONSIDERATIONS

A continued trend to aluminum radiators is evident. With the current emphasis on quality, the one major comment offered cannot be taken lightly, however. As manufacturing facilities are shifted away from copper-based materials, it is increasingly less likely that a reversal in material choice will occur. Of course, if copper-based designs emerge that can be produced in aluminum-oriented production facilities, the potential for copper designs could increase. This notion is a bit far-fetched at this time, however.

MAT–21. Given the increasing environmental concerns, what new technologies do you foresee will be introduced in automotive coolant/cooling systems and refrigerant/AC systems by the year 2000?

New Technologies in Coolant/Cooling Systems and Refrigerant/AC Systems by the Year 2000	Percent of Panelists
New Non-CFC/Freon Refrigerants	83%
New Refrigerant Recovering Systems	17
"Full-Fill" Cooling Systems	11
No New Technologies	11

REPRESENTATIVE RESPONSES

- Currently-used fluorocarbons are likely to be replaced.
- New refrigerants which are currently in lab evaluation will be used.
- Collect and reprocess engine coolant, collect and reprocess refrigerant, use more environmentally-friendly refrigerants.
- Non-water/glycol coolant system.
- Larger compressors with variable displacement.
- Possible oil cooling. New refrigerants that are safe and development of refrigerant recovery program.
- As little change from present as technically possible; systems will be somewhat larger and less efficient.
- Coolant-propylene glycol is not toxic.
- Ethylene glycol eventually will have to go, but not by the year 2000. Freon-12 will be replaced.
- Main environmental concern is the depletion of ozone in stratosphere. For this, year 2000 is too far away!! By 1992, use of chlorofluorocarbons as AC refrigerant must be phased out. Already several promising refrigerant materials have been developed; hydrogen containing chloro-fluorohydrocarbons or fully fluorinated materials appear promising. R&D efforts on such alternative materials should be accelerated.
- R-134A appears to be the most likely substitute for the present freon. Propylene glycol or sodium sebicate vibrators may replace present formulas.
- There may be more efficient refrigerants waiting to be developed. Totally sealed A/C systems requiring no tip-up should be developed. More sophisticated servicing equipment that eliminates leaks to the atmosphere will be developed. Glass impervious to the infrared end of the spectrum will become prevalent.
- Requires more international cooperation to find appropriate solutions.

STRATEGIC CONSIDERATIONS

The primary change envisioned with engine cooling and HVAC system is the substitution of new refrigerants for CFC. The overwhelmingly strong support for this shift is evident. Of course, this change will hardly occur without significant challenges since many HVAC system components will probably have to be redesigned. Most will have to be upscaled because of the lower efficiencies of currently proposed alternative refrigerants. An adjunct technology receiving considerable attention is one relating to systems to aid recovery of refrigerants during service and scrappage. We do not believe that these changes will result in a major dislocation to the industry, although investment in new technology may be significant and require major system redesign. Obviously, any supplier of HVAC components will be required to participate in the redesign process.

With engine cooling, the only significant news is the possible trend to "full-fill" systems, and the chance that less toxic coolants such as propylene glycol might be used.

There is no question that increasing environmental concerns will stress the industry in practically every area including vehicle fluids. We suspect that the pressure on problem substances will continue unabated throughout the 1990s.

MAT-22. What percentage of the following spark-ignited engine components do you foresee will be made from Metal Matrix Composites (MMC) by the years 1995 and 2000?

Engine Components	Percent MMC Application in Spark-Ignited Engines			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Pistons	3%	7%	1/10%	1/20%
Connecting rods	2	5	0/5	5/10

SELECTED EDITED COMMENTS

- Japanese will lead the way (again)!

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists offer dramatically different and contrasting forecasts regarding metal matrix composite spark-ignited engine components. The respective forecasts and interquartile ranges are presented below.

Engine Components	Percent MMC Application in Spark-Ignited Engines							
	OEM Forecasts				Supplier Forecasts			
	Median Response		Interquartile Range		Median Response		Interquartile Range	
	1995	2000	1995	2000	1995	2000	1995	2000
Pistons	10%	20%	3/10%	10/20%	1%	5%	0/3%	0/7%
Connecting Rods	5	10	1/10	8/10	2	5	0/5	3/5

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi IV panelists were asked the following questions: "What applications for metal matrix composites do you foresee in spark-ignited engines?" Almost three-quarters (73%) of the respondents specified pistons and connecting rods. Other suggestions included cylinder liners/inserts, rocker arms, valves, and push rods.

The Delphi IV panelists were also asked if they foresaw other non-engine automotive applications for MMC. The primary applications suggested were chassis components, internal transmission components, fly wheels, levers, and brackets.

COMPARISON OF FORECASTS: TECH-42

The Technology panelists are in reasonably close agreement regarding the metal matrix piston and connecting rod forecast.

Engine Components	Delphi V Technology Forecast for Percent MMC Application			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Pistons	1%	5%	0/2%	1/7%
Connecting rods	1	5	0/2	1/8

Other MMC applications suggested by the Technology panelists are: cam follower, piston pin, rocker arm, and gears/sprockets.

STRATEGIC CONSIDERATIONS

As with many new technologies, there is reasonable enthusiasm for MMC. Developments should be watched closely considering the major incentives for weight reduction in such areas as moving engine components. Obviously, suppliers of components that are candidates for MMC substitution must track this technology closely to minimize the chance for surprises.

V. BODY/CHASSIS: MANUFACTURING AND ASSEMBLY TRENDS

MAT-23. What percent of brakes and clutch friction surfaces in North American-produced passenger vehicles will be made from the following materials in the years indicated?

Friction Surface	Median Response		Interquartile Range	
	1995	2000	1995	2000
BRAKES				
Ceramic fiber	40%	45%	35/40%	40/50%
Kevlar-based	35	30	30/35	25/40
Fiberglas	18	18	10/20	10/20
Carbon-based	7	7	5/10	5/10
CLUTCHES				
Kevlar-based	43%	40%	35/50%	38/50%
Ceramics	32	30	25/35	25/40
Plastics	5	8	5/10	5/12
Carbon	10	10	5/10	10/10
Cellulose fibers	5	5	5/10	5/10
Metal fibers	5	7	5/10	5/10

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists agree on the percent of brakes and clutches that may be made from ceramics/ceramic fibers, Kevlar-based material, Fiberglas, and plastics. Their only disagreements are in the use of carbon-based materials and cellulose fibers. With regard to materials for brakes, the OEM panelists forecast 5% for both 1995 and 2000, whereas the supplier panelists forecast 10% for each of those years. In the area of clutch materials the manufacturer panelists forecast carbon at 10% for 1995, suppliers 5%; the OEMs forecast cellulose fibers at 10% for each of the years, suppliers 5%.

COMPARISON OF FORECASTS: TECH-41b

Delphi V Technology panelists were asked the following question: "Do you foresee any non-engine automotive application for ceramics?" Of the number of applications suggested, brake components/friction materials received three responses. The forecast year and percent of application are presented below. There are no correlative comparisons available for the other materials.

Delphi V Technology Panel Forecast: Ceramics Application in Brake Components	
Forecast Year	Median Percent Application
1992	10%
1997	40
1998	10

STRATEGIC CONSIDERATIONS

With growing environmental concern about asbestos friction materials, many substitutes are being considered. This is a critical materials issue in light of the high performance requirements in both brakes and clutches. While ceramic fiber and Kevlar-based materials are most prominently noted, other materials cannot be ignored. Furthermore, it is entirely likely that the solution may be derived from a combination of several material types. Also, it should be noted that some suggested material substitutes bear a family resemblance to one another. For those involved with friction materials the future appears uncertain at this time and the real winners are difficult to determine.

MAT-24. The Delphi V Technology Panel provided the following forecast for the percent of North American-produced passenger vehicles that will be equipped with styled wheels (i.e., no wheel covers) for the years 1995 and 2000.

Light-Duty Vehicle	Delphi V Technology Panel Forecast: Percent Equipped with Styled Wheels			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Passenger Cars	30%	50%	20/60%	30/80%
Light-Duty Trucks	10	30	10/30	15/50
Vans	20	30	10/40	20/50

Of styled wheels used on passenger cars and light-duty vehicles, what percent will be made from the following materials in the years indicated?

Material	Percent Material Use in Styled Wheels			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
Steel	30%	20%	20/40%	10/33%
Aluminum	65	65	50/79	50/75
Composites	5	15	2/10	5/20

Other: Magnesium.

SELECTED EDITED COMMENTS

- If by "composites," fiber-reinforced plastics are implied, then the low heat conductivity of these materials to conduct heat from the tires is a serious fundamental limitation of current economical plastic composites.

MANUFACTURER/SUPPLIER COMPARISON

The following table shows the difference between the OEM and supplier forecasts for percentage of materials to be used in styled wheels.

Material	Percent Material Use in Styled Wheels			
	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
Steel	30%	25%	15%	25%
Aluminum	60	65	60	60
Composites	10	5	10	15

STRATEGIC CONSIDERATIONS

Styled wheels are expected to continue their growth in popularity as is evident from the Materials panel forecast. Aluminum is viewed as the material of choice and is favored by a 2:1 ratio over steel throughout the next decade. Composite materials are forecast to triple their penetration in styled wheels.

MAT-25. What percent of North American-produced passenger vehicles will use material other than conventional glass for windshields in the following years? Also please specify material.

Percent N.A.-Produced Passenger Vehicles Using Alternative Material for Windshields			
Median Response		Interquartile Range	
1995	2000	1995	2000
0%	0%	0/1%	0/10%

SELECTED EDITED COMMENTS

- Will use special coatings and/or interlayers to block solar load and provide defrosting capability but will still be installed in standard glass windshields. Some smaller possibility that super-hard coatings based on chemically- or plasma-deposited diamond films could allow a switch to plastic glazing by 2000.
- In order to replace glass for windshields, development of a clear plastic that does not shatter and is abrasion-resistant is an R&D challenge for future polymer materials.
- Laminated glass/part carbonate.
- Polycarbonate and acrylics for small side lights but abrasion resistance (wipers and ice scrapers) will require glass in at least the outer layer of laminated windshields and probably rear lights as well.
- Glass-coated polycarbonate.
- Glass is essentially irreplaceable. We'll see *thinner* glass, but outer surface will still be glass.

MANUFACTURER/SUPPLIER COMPARISON

Taking into consideration the median and lower interquartile range, at least 75% of the manufacturer and supplier panelists agree that there will be no alternate material for conventional glass for windshields by 1995 or 2000.

COMPARISON OF FORECASTS: TECH-33

The Technology panelists also forecast no alternative material for glass windshields by 1995. However, they felt that 3% of North American-produced passenger vehicles would utilize some alternative material by the year 2000.

STRATEGIC CONSIDERATIONS

All quality and economic issues must be resolved before non-glass windshields can be considered as a viable technology. Material panelists are less optimistic than the Technology panelists. It is also evident from the comments that the technology is hardly static, as glass in combination with other materials is being seriously studied. Styling trends appear to be dictating larger "greenhouses" which in turn, increase incentives to reduce the weight of a unit area of glass. These pressures will prompt a continued search for thinner glass, hybrids, or outright substitutes. With rapid polymer developments, we would not be surprised to see a high-performance substitute emerge but with limited application in the next ten years. The windshield would probably be the last part of the "greenhouse" to be replaced. Side glass or quarter windows would probably be the first true non-glass applications if scratch-resistance and economic problems can be resolved.

MAT-26. What developments do you foresee in the area of adhesives/sealants by the year 2000? Please comment.

Adhesive/Sealant Developments by the Year 2000	Percent of Responses
Faster set adhesives/sealants	31%
Heat activated adhesives/sealants	19
Polymeric adhesives	19
One/two-component systems	19
Reduced solvent/water-based	6
Reduced curing temperatures	6

REPRESENTATIVE RESPONSES:

- "Activated" adhesives (like today's heat activated acrylic epoxies) to allow useful strength in less than 60 seconds (line station time in assembly).
- Green strength times will decrease for steel-steel bonding applications. Steel-plastic applications will also increase.
- Heat activated sealants. Engineered polymeric adhesives.
- Quick set structural adhesives/sealants that are easy to handle and dispense.
- RIM processing of reactive adhesive systems allowing quick cures and immediate handling of parts.
- Tighter fits and smaller volumes per joint. Simple two-component systems. Lower temperature curing.
- Adhesives that join metal and plastic parts and function over a broad temperature range.
- Adhesives that can be activated by microwave heating and have good strength and short-curing cycles.
- High performance polymer adhesives that function at elevated temperatures and can be conveniently employed.

TREND FROM PREVIOUS DELPHI SURVEYS

Delphi IV contained a question which presented relevant information applicable to a trend assessment for both this question and MAT–27. In that survey, forecasts were requested for possible new advances in adhesive bonding and welding techniques for body joining and panel attachment by model year 1990. The forecasts requested were segmented into techniques considered applicable to either lower-technology/high-volume and high-technology/lower-volume passenger cars. The forecasts presented gave no indication of any significant differences in utilization between the two categories.

STRATEGIC CONSIDERATIONS

With growing interest in quality improvements, cost reduction, and new manufacturing methods, adhesive and advanced sealant technology is being aggressively pushed by both manufacturers and certain suppliers. Key issues appear to be ease of use, faster set, integrity, and, in general, those factors that address overall manufacturing challenges. With development of better technologies, it is likely manufacturers will accelerate their consideration of these materials in the design of future products, such as the General Motors' APV. As with any emerging technology that could have an important impact on the industry, this area must be closely watched. Considering the enormous cost and quality pressures on the industry, as well as the desire to offer innovative designs to the customer, adhesive and sealant technology will continue to be very dynamic.

MAT-27. What new automotive joining techniques do you foresee by the year 2000? Please comment.

New Joining Techniques by the Year 2000	Percent of Responses
Adhesives	41%
Laser Welding	25
Mechanical Fasteners	17
Other Welding Techniques	17

REPRESENTATIVE RESPONSES:

- Adhesives will make major gains at the expense of mechanical fasteners. Polymers will serve as an adhesive, a sealant, and a vibration dampener. Work is needed on making preferred repair techniques available in the aftermarket, but no really "new" fundamental science is needed.
- Expect expansion of laser welding in all areas.
- Laser welding at high speeds.
- More use of Velcro, snap fits, and integrated joint and hinge moldings.
- Programming of individual spot weld cycles during body assembly. Replacement of some welding joints with adhesives and or mechanical joints. Laser welding of blanks and stampings. Development of high strength, high temperature adhesives.
- Friction welding at high rotational speeds of components to be joined of either same materials, or of dissimilar materials.
- Metal/metal adhesives that replace welding (i.e., high-strength adhesives that retain their strength over a broad temperature range).
- Flame welding of thermoplastic body parts.

TREND FROM PREVIOUS DELPHI SURVEYS

See MAT-26.

STRATEGIC CONSIDERATIONS

The strongest response to this question relates to the use of adhesives and laser welding. Both technologies appear to offer considerable promise. As noted in MAT-26, the variety of adhesives being considered is significant and developments can be anticipated to accelerate. Mechanical fasteners, such as innovative bolts and Velcro-type systems could offer manufacturers continued flexibility as they pursue cost reduction and quality improvements. We may be at the threshold of a revolution in how vehicles are assembled. It would seem imperative for any participant in the industry to follow developments in joining and fastening to assure they remain near the leading edge of developing technology. It is conceivable that within the next ten years, considering the developments suggested here, the basic production method of vehicles will be fundamentally altered.

An interesting point raised in response to this question is the multi-functional characteristics of some new fastening techniques which provide adhesive, sealant, and vibration damping features. As the industry becomes more accustomed to a systems approach to problem solving, the full advantages of some of these new technologies may be realized.

MAT-28. What percent of body joining presently performed by conventional spot-welding will use the following joining/bonding technologies in the areas specified by the years 1995 and 2000?

Technology/Areas	Utilization of New Bonding/Joining Technologies			
	Median Response		Interquartile Range	
	1995	2000	1995	2000
ADHESIVES				
Deck Lids, Door, Hoods	20%	50%	10/40%	25/70%
Other Exterior Body Panels	10	20	10/20	15/30
Underbody Structural Assemblies	10	20	5/20	15/25
NON-ELECTRICAL RESISTANCE WELDING				
Deck Lids, Door, Hoods	20	25	5/30	10/30
Other Exterior Body Panels	15	20	5/30	10/50
Underbody Structural Assemblies	20	30	5/3	5/60

SELECTED EDITED COMMENTS

- It is hard to evaluate due to the fact that a combination of sealant/adhesives with reduced mechanical linkages is probable.
- Durability of structure adhesives, a difficult property to predict, will retard the introduction of adhesives into critical safety areas.
- The use of fiber-reinforced plastics will accelerate adhesive use.
- Increasing use of structural polymer adhesives will depend upon the increasing use of plastics in automotive parts—more plastics, more polymer adhesives. Increasing automotive use of adhesives will depend upon technological developments of adhesive applications and adhesive curing.

MANUFACTURER/SUPPLIER COMPARISON

As illustrated in the following table, in all areas surveyed there is a substantial difference of opinion between the manufacturer and supplier panelists regarding the utilization of new joining/bonding technologies.

Technology/Area	Utilization of New Bonding/Joining Technologies			
	Forecast for 1995		Forecast for 2000	
	OEM	Supplier	OEM	Supplier
ADHESIVES				
Deck Lids, Doors, Hoods	20%	30%	30%	50%
Other Exterior Body Panels	10	20	15	30
Underbody Structural Assemblies	5	10	15	20
NON-ELECTRICAL RESISTANCE WELDING				
Deck	10	30	25	30
Other Exterior Body Panels	20	5	20	10
Underbody Structural Assemblies	20	5	60	25

TREND FROM PREVIOUS DELPHI SURVEYS

The issue of new joining/bonding technologies was addressed in the 1987 Delphi IV. Opinions were solicited for new body joining and panel attachment techniques by 1990 for two different car market categories. Although emerging technologies in these areas may have progressed beyond the Delphi IV 1990 time-frame, the responses serve as a valuable adjunct to the present question. The Delphi IV question and relevant responses are as follows.

It is becoming increasingly clear that the U.S. passenger car market is being segmented into two categories: lower-technology/high-volume (e.g., Cavalier, Escort, Aries) and high-technology/lower-volume (Corvette, Mark VII, LeBaron GTS). Also adhesive bonding and new welding techniques are being extensively utilized for body joining and panel attachment. Other than those, what new techniques do you foresee for body construction and panel attachment in the following model mix by the year 1990?

LOWER TECHNOLOGY/HIGH VOLUME PASSENGER CARS

New Body Joining Techniques

The three leading new techniques forecast for body joining in the year 1990 are as follows:

New mechanical fastening techniques for body construction
New adhesives
Laser welding

These three new techniques accounted for approximately three-quarters of the responses. New mechanical fastening techniques, to include clinching, snap fits, and tab methods (crimp, etc.), received over twice the responses of each of the two remaining techniques. Other suggestions accounting for the remainder of the responses are as follows: D.C. resistance spot welding; curing of adhesives by U.V.; ultrasonics; and use of coated steels as a catalyst.

Representative Responses

New mechanical connections to eliminate some of the welding requirements.
Reinforced plastic panels with bonded-in steel reinforcements which are adhesively bonded into complete body shell.

New Panel Attachment Techniques

New mechanical fasteners/connections are the predominant response of the panelists. New adhesive techniques including foam tape and hot-melt bonding were also suggested.

Representative Responses

More integration and less need for joining in general.
Hood, deck lid, and doors to have molded-in steel-hinged striker and restraint attachments.

HIGH TECHNOLOGY/LOWER VOLUME PASSENGER CARS

New Body Joining Technologies

Mechanical fastening/assembly, new adhesives, and laser welding accounted for the overwhelming majority of the responses.

Representative Responses

Resin transfer molded floor pans, protruded structural members, thermoplastic body panels jointed by techniques still being developed.
Larger single piece steel stampings with integrated support formations.
Components will be made from plastics and designed in consolidation (joined to each other during manufacture).
Thermosets.
Foam tape.

New Panel Attachment Techniques

New mechanical fastening techniques and laser welding along with plastic rivets for space frames were the predominant responses.

Representative Responses

Use of plastic RRIM, RIM, and SMC for outer skins with mechanical attachments molded in.
Vibrational welding for plastic panels.

STRATEGIC CONSIDERATIONS

It is very clear that traditional joining technologies are undergoing significant review as both adhesives and other types of welding begin to emerge as realistic alternatives. Of course, the ultimate choice will depend on other factors including commitment to existing facilities, economics, long-term durability, design procedures and others. The potential for innovation is very high and consequently the potential for change is also high. This area must be followed very closely because of the enormity of the potential impact of new joining technologies.

MAT-29. What new paint technologies do you foresee will be introduced by the year 2000?

New Paint Technologies Introduced by the Year 2000	Percent of Responses
Lower E-coat/cure temperatures	29%
Water base	19
Powdered paints	10

Others: Formable sheet coatings, high-quality pre-paint, primerless topcoat systems, two component polyurethane coatings, ultra-high gloss, and DOI (clarity).

REPRESENTATIVE RESPONSES

- Bake in-mold coating of body panels.
- Maximum oven cure temperatures below 330° (conventional and polyurethane paint chemistries).
- More extensive use of powder coatings.
- Topcoat systems without using primers. Bake temperature at 250°F.
- Water-based topcoats will be broadly commercial in new facilities.
- Paint temperatures will be significantly lower.
- Water-based topcoats. Lower temperature cure requirements for E-coat.
- Powdered paints that adhere and cure at lower temperatures for thermoset and thermoplastic body parts.
- Solventless liquid paints that adhere to thermoset and thermoplastic body components—i.e., adaptation of reactive injection molding technology with dispersible paint pigments. In-mold coatings that can be applied during molding of thermoplastic and thermoset parts.

COMPARISON OF FORECASTS: TECH-35b
Also see MAT-32, Mat-33, and Mat-34

A significantly greater percent of Technology panelists forecast paint film coatings and base-coat/clear-coat paint technologies than the Materials panelists. While this may be an artifact of a particular survey sample, it may be an indication of relative ranking. The Technology panelists' responses are presented below.

Delphi V Technology Panel: Paint Technologies by the Year 2000	Percent of Responses
Mold-In Color	15%
Paint Film Coatings	15
Decrease in Cure Temperature	15
Base Coat/Clear Coat	15
Other	40

STRATEGIC CONSIDERATIONS

Various concepts in paint technology are being considered by the industry. They range from the use of mold-in color for plastics to different systems for base-coat clear-coat. This is clearly an area ripe for innovation. For example, off-line painting with acceptable color match could be an exciting future development. With increased usage of plastics there is concern about bake-oven temperatures as well as ongoing concerns regarding environmental impact of the paint operation. These will certainly be key factors in new paint technologies that emerge. Also, the customers' demand for quality and variety will stimulate new paint process development.

MAT–30. In what year, if ever, do you foresee commercial application of mold-in color for plastic body panels?

Forecast Year for Commercial Application of Mold-In Color for Plastic Body Panels	
Median Response	Interquartile Range
1997*	1995/2000

*Thirteen percent (13%) of the responding panelists indicated that they do not foresee the commercial application of mold-in color for plastic panels.

SELECTED EDITED COMMENTS

- Will not be able to meet surface finish demands.
- New techniques will be developed that provide the benefits of mold-in color but without the problems of mold-in color.
- Eventually it will probably be achieved, but it is difficult to say in which year.
- Mold-in color is likely for thermoplastic parts.
- In-mold coating should be distinguished from "mold-in" color technology. In the former, the plastic part is molded, the mold is opened slightly, and a fluid curable coating is injected to cover the part. "In-mold" coating appears to be the technology that is likely to become commercial by 1995 for automotive body parts.
- Must control ultra-violet effects on plastics.
- The 1976 Monza Town Coupe had mold-in color valence panels.

MANUFACTURER/SUPPLIER COMPARISON

The median year forecast by the manufacturer panelists for the commercial application of mold-in color is 1995; the median year forecast of the supplier panelists is 1997.

COMPARISON OF FORECASTS: TECH-35b

When queried regarding new paint finish technologies expected to be commercially in use by the year 2000, mold-in color was suggested by only 15% of the Technology panelists. It should be noted that several of the other paint technologies received a comparable percentage of panelists' responses.

STRATEGIC CONSIDERATIONS

As noted in one comment, this question can be interpreted in several ways. Regardless of the definition or particular technology, the results suggest this area be followed closely if there is potential for impacting one's business. Certainly such issues as color match, finish quality, and other factors will be crucial. It can be stated with some degree of certainty that any new technology must provide improved value or the new technology will not be implemented.

MAT–31. What major factor(s) continue to inhibit the achievement of mold-in color for plastic body panels?

Major Factors Inhibiting Mold-In Color for Plastic Body Panels	Percent of Panelists
Color match difficulties*	61%
Weatherability/color fastness	35
Surface/color quality	30
Cost	9

*Fourteen percent (14%) of the panelists within this group specified problems with metallic colors.

See *Representative Responses* for a review of single responses.

REPRESENTATIVE RESPONSES

- Cannot get color/gloss match with adjacent painted panels initially and aging will increase appearance differences. Cannot get metallic effects to look at all like metallic paints.
- Color match to adjacent nonplastic panels.
- Surface irregularities, paint pops.
- Part to part color uniformity, difficulty matching metallic colors, and DOI versus steel.
- Cost, surface quality, and recyclability.
- Light, UV, and weather resistant. Color matching. Color stability.
- The problem of obtaining a glamorous appearance.
- Color-match, scratch-resistance, and limited number of weather-stable polymers. Color match is so difficult.
- Differential fading in service; matching of replacement panels in crash repair.
- Differences in weatherability among materials which will affect appearance.
- Mold-in color basically is best with non-reproducible optical/aesthetic effects; different for different regions of a moldable part. In-mold coating is a more promising technology.
- Obtaining uniform color throughout parts and matching other body applications.
- Process variability and service repair.

STRATEGIC CONSIDERATIONS

As noted in the *Strategic Considerations* of MAT–30, all quality and economic issues must be resolved before this can be considered as a viable technology. It is difficult to forecast when or if these challenges will be resolved.

MAT–32. What percentage of North American-produced vehicles will utilize a water-based paint system in the following years?

Percent Water-Based Paint System Application			
Median Response		Interquartile Range	
1995	2000	1995	2000
20%	35%	18/25%	25/50%

SELECTED EDITED COMMENTS

- Solvent-less systems or totally reactive systems will be developed and take over.
- There will be legislation forcing water-based paint systems.
- Water-based paints for automotive body applications that one can project will require an inordinate amount of energy for drying, etc. and will not stack up economically with other nonsolvent based paints that are likely to be developed.
- Development/acceptance of a water-based system will be driven by clean environment requirements.
- Legislation will be prime mover.
- Powder-base paints may gain support if temperature issues can be resolved.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists agree that 20% of North American-produced vehicles will utilize a water-based paint system by 1995. For the year 2000, the OEM panelists forecast 35% of the vehicles, whereas the supplier panelists forecast 30%.

COMPARISON OF FORECASTS: TECH–35a

There is a significant difference of opinion between the Materials and Technology panelists regarding water-based paint system utilization. In general the Technology panelists were considerably more optimistic in their forecasts projecting 30% utilization by 1995 and 50% by 2000. The upper interquartile range for the Technology forecasts are also significantly higher at 60% and 90%, respectively.

TREND FROM PREVIOUS DELPHI SURVEYS

An in-depth analysis of Delphi trend data related to water-based paint systems and other emerging paint technologies is presented in TECH–35a.

STRATEGIC CONSIDERATIONS

Significant growth is envisioned in water-based paint systems. This, in part, is prompted by increasingly stringent environmental regulations in industry paint shops as well as customer demand for greater color variety and improved paint quality. Considering the enormous expense of paint facilities and aftermarket paint shops, the implications can be rather substantial. Additionally, there are other basic paint systems that could achieve commercialization in the next ten years and challenge the forecasts presented in this question. This is a rapidly evolving area. Careful attention should be given to water-based and other emerging paint technologies.

MAT-33. What percent of North American-produced vehicles will make use of base-coat/clear-coat methods by the years indicated?

Percent Base-Coat/Clear-Coat Application			
Median Response		Interquartile Range	
1995	2000	1995	2000
60%	80%	50/70%	70/90%

SELECTED EDITED COMMENTS

- This will be a slow evolving technology at best if it is to be based on water-based paints. The solvent-based systems, on the other hand, are not likely to be useful for environmental reasons.
- Clear-coat provides best "in-use" environmental protection of paint from insects, acid rain, etc.

MANUFACTURER/SUPPLIER COMPARISON

While the supplier panelists are in agreement with the consensus median forecasts, the OEM panelists project that by 1995, 75% (with an upper interquartile range of 80%) of North American-produced passenger vehicles will make use of base-coat/clear-coat systems. The OEM panelists expect this percentage to rise to 90% (with an upper interquartile range of 90%) by the year 2000.

STRATEGIC CONSIDERATIONS

The trend to base-coat/clear-coat painting is irrefutable from these data. However, environmental issues will probably be a factor in the long-range choice. With the many emerging paint technologies we suspect clear coating will be almost standard by the turn of the century. Customers seem to exhibit a preference for clear coating as a protective and appearance measure. Any area of paint technology must be carefully tracked because of the emerging competition.

MAT-34. Do you anticipate electrocoat and/or paint bake oven temperatures will change by the year 2000? If so, by how much and in what year?

Temperature Change	Percent of Responses	Median Response		Interquartile Range	
		Degree of Change	Year	Degree of Change	Year
ELECTROCOAT					
Yes	88°	−50°	1995	−100/−20°	1995/1998
No	11				
PAINT BAKE OVEN					
Yes	100	−50	1995	−70/25	1995/1998
No	0				

SELECTED EDITED COMMENTS

- All oven temperatures will be below 330° by the year 2000. Change will be gradual as lines are redesigned.
- Change will be driven by increased use of composites and adhesives.
- Energy conservation will be the driving force.
- Incentive for the above evolutionary technologies will decrease as advanced powder coating (electrostatic painting) or solventless paint vehicles are developed in the future.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in complete agreement on the probability of changing electrocoat and/or bake oven temperatures. They are also in agreement with 1995 as the year this change may occur. Regarding the degree change in temperature, the interquartile range within each group reflects diversity of opinion evident in the overall median and interquartile range. While there was complete agreement that these temperatures would decrease, the supplier panelists, in general, expect a somewhat larger decrease than do the OEM panelists.

STRATEGIC CONSIDERATIONS

With significant reductions expected in both electrocoat and paint oven temperatures, an array of new technologies may emerge including greater use and variety of plastics, increased use of adhesives and sealants, and other materials that are today stressed by temperatures beyond their limits. Another interesting point made in this question relates to energy conservation as a driving force.

Decreases in temperature of the magnitude suggested could have a significant impact on the overall energy requirement in automotive paint shops. Current materials that accommodate higher oven temperatures will undoubtedly experience greater competition with future lower-temperature systems.

V. SOURCING CONSIDERATIONS

MAT–35. The OEMs are moving in the direction of considering factors in addition to price in the purchase decision for components. Using the following scale, please rank what relative value is actually assigned by the OEMs to each factor listed, and what you feel it should be (1=least valuable, 5=most valuable).

Average Ranking of Factors Considered by OEMs in Purchase Decision

Actual	Average Ranking	*Should* Be	Average Ranking
Price	4.6	Quality	4.8
Reliability of delivery	3.7	Reliability of delivery	4.2
Prior relationships	3.7	Quality-improvement programs	4.2
Quality	3.6	Manufacturability	4.1
Quality-improvement programs	3.5	R&D assistance	3.8
Manufacturability	3.1	Price	3.8
R&D assistance	2.7	Prior relationships	3.1
Supplier location	2.5	Supplier location	2.9

SELECTED EDITED COMMENTS

- Cost improvement programs, actual=2, should be=5.
- History of advanced automotive materials technology developments, actual=1, should be=4.

STRATEGIC CONSIDERATIONS

It is clear that quite a number of factors are involved in the purchase decision of components and materials. Presently, the prevailing view is that the greatest emphasis is placed on price or cost. While the present emphasis on quality, reliability, delivery, manufacturability, research and design assistance, and overall quality improvement programs is high, panelists believe emphasis should be even greater. Modest shifts are suggested with regard to both prior relationships and supplier locations. The results of this question strongly suggest that it would be advisable for manufacturers and suppliers alike to begin moving aggressively toward a more value-based, rather than a price-based, purchasing strategy. In a value-based strategy, a wide range of factors should be considered related to the overall value of the purchased item, including all life-cycle costs.

MAT–36. What percent of steel used by New American Manufacturers (NAM) (transplants) will be sourced from traditional domestic suppliers within the U.S. and Canada?

Percent NAM Steel Sourced Within U.S. and Canada			
Median Response		Interquartile Range	
1995	2000	1995	2000
40%	50%	35/50%	40/70%

SELECTED EDITED COMMENTS

- Money exchange rate will influence sourcing decisions.

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in agreement regarding the percent of steel that will be domestically sourced by transplant manufacturers. The interquartile ranges for both groups indicate a very high degree of consensus.

COMPARISON OF FORECASTS

The following questions relate to New American Manufacturers' (NAMs') sourcing issues: TECH–14b, TECH–15b, MKT–43, and MKT–46.

TREND FROM PREVIOUS DELPHI SURVEYS

The sourcing of steel used by transplants or New American Manufacturers (NAMs) was first addressed in Delphi IV. In 1987 the percent of steel forecast to be sourced from domestic suppliers was projected to be 30% by 1990. The interquartile range of 20/50% for 1990 indicates only a fair degree of consensus. This interpretation also holds for the Delphi IV 1995 forecast of 50% (with an interquartile range of 30/60%). When currency fluctuations affecting relative cost, the availability of certain steel products, and the continuing growth of steel production by third-world nations is taken into consideration, the forecast of Delphi V panelists for 40% domestically-sourced steel by 1995 by the NAMs is within the range projected by Delphi IV panelists.

STRATEGIC CONSIDERATIONS

Continued gradual growth in the sourcing of steel in the United States is forecast for the New American Manufacturers (NAM) or transplants. With growing pressure to increase domestic sourcing and the overall improved quality of North American-produced materials, it would be surprising if the forecast level of domestic sourcing is not met during the next decade. Most of the transplant manufacturers appear to have aggressive domestic sourcing programs for basic materials. As the NAMs establish closer supplier relationships with North American suppliers, domestic sourcing of most materials and components should accelerate. Of course, an increase in joint ventures between Japanese companies and the American supply base may occur, further amplifying this trend.

MAT-37. In your estimate what percent of tooling for North American-produced passenger vehicle production is currently performed by (1) domestically-based, U.S.-owned companies, (2) by foreign-owned transplant companies in the U.S., or (3) sourced off-shore *and* what will it be in the years indicated?

Tooling Performed	Percent for N.A.-Produced Passenger Vehicle Production					
	Median Response			Interquartile Range		
	Current Estimate	1995	2000	Current Estimate	1995	2000
Domestic U.S.-Owned	75%	60%	55%	60/85%	50/80%	40/75%
Transplants	10	25	30	10/20	15/30	20/35
Off-Shore (non-North American)	15	15	15	5/20	10/20	5/20

MANUFACTURER/SUPPLIER COMPARISON

The manufacturer and supplier panelists are in agreement regarding all tooling scenario forecasts. The interquartile ranges for both groups are very tight indicating a high degree of consensus.

STRATEGIC CONSIDERATIONS

A gradual shift is forecast in the sourcing of North American vehicle tooling with a trend from domestic, U.S.-owned companies to transplant manufacturers. It cannot be determined from the results of this question whether this reflects expected growth of the transplant automotive manufacturers or increased production of tooling by independent, foreign-owned companies. We believe the forecast is probably a combination of both factors. One thing is clear, with increased pressure on costs, productivity, and quality it is imperative for the manufacturers to utilize the best tooling sources without regard to ownership or location.

There is no clear indication tooling purchases outside North America may significantly increase. Obviously, traditional domestic suppliers of tooling are expected to lose business. Of course, the absolute magnitude of the tooling business may grow or decline based on other factors such as increased frequency of new vehicle introductions, new tool-making technology, improved efficiency in tooling design, or, for example, reduction in the number of dies to produce a given steel panel. We anticipate an interesting, and perhaps tumultuous, future in the tooling side of the industry.

INDEX OF QUESTIONS LISTED BY TOPIC

CORPORATE ACKNOWLEDGMENTS

The Office for the Study of Automotive Transportation would like to thank its Corporate Sponsors and Delphi V subscribers for their generous support of this project. Our Corporate Sponsors provide annual, unencumbered funding for initiation of non-funded work and public service activities. Corporate Delphi V Subscribers contributed directly to this project covering substantial start-up costs and suggesting potential questions. This project could not have been structured, initiated, or completed without their assistance.

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