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TECHNOLOGY

MATERIALS

DELPHI IV FORECAST AND ANALYSIS
OF THE U.S. AUTOMOTIVE INDUSTRY THROUGH 1995

MATERIALS

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FOREWORD

INTRODUCTION TO THE STUDY

Delphi IV is a detailed presentation and analysis of data provided by three separate panels of automotive executives, managers, and engineers who are expert in technology, materials, and marketing. This report, published in three volumes, is the fourth in a series of in-depth studies of long-range automotive trends that began with Delphi I in 1979 and continued with Delphi II in 1981 and Delphi III in 1984.

We have performed the functions of data collection, data reduction, editing, and reporting, and analyzed the results. However, we emphasize that the forecasts are not ours but those of the participants. This is a consensus industry forecast of itself—and many of the experts are in positions where they can make their forecasts come true.

We take pride in our efforts to report Delphi IV forecasts, but no credit. The honor goes to the executives, managers, and engineers who provided them. Because of their source, we consider these to be the most authoritative and dependable automotive forecasts available.

THE DELPHI METHOD

General Background

This study is based on the Delphi forecasting process, in which panels of experts consider the issues under investigation and make predictions about future developments. Developed for the U.S. Air Force by the Rand Corporation, Delphi is a systematic, iterative method for forecasting based on independent inputs from a group of experts. Its objective is to measure the degree of consensus among a panel of experts regarding future events.

The Delphi method relies on the judgment of knowledgeable experts. This is a strength (in contrast to purely numerical projections) because predictions that require policy decisions are strongly influenced by personal preferences and expectations, in addition to more quantitative factors. The Delphi results reflect these personal factors. The respondents whose opinions are recorded in this report are often in a position to at least partially make their predictions come true. Even if they are moving in a direction that subsequently turns out to be mistaken, the primary concern is to learn what that direction is.

Process

The Delphi method uses repeated rounds of questioning (accompanied by the responses of peers to earlier rounds) to take advantage of grouped inputs while avoiding biasing effects so 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 discussion. 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 interests, 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. Norman C. Dalkey, "The Delphi Opinion." Memo RM-588 PR, p. 14, Rand Corporation, 1969).

Panelists

In the Delphi method, panelists are not made known to each other. Their anonymity prevents attaching a specific opinion to any individual. Among other advantages, this enables respondents to feel comfortable in revising their previous opinion after seeing new information submitted by other panelists. All participants are encouraged to comment on their own forecast and on group results, and that information is furnished the participants in the next round. The procedures reduce the effects of personal objectives (such as the desire to win an argument) and help the panelists to remain focused on the question, positions, and comments at hand.

Presentation of Results

Numerical results are shown as medians, a measure of central tendency that mathematically summarizes an array of judgmental opinions while discounting extremely high or low estimates.

Uncovering differences of opinion is one of the major strengths of the Delphi method. Unlike some survey methods, where differences of opinion among experts are buried in averages, Delphi exposes such differences through the presentation of the interquartile range (IQR). A lack of consensus so demonstrated is little comfort to an individual or firm looking for planning guidance, but it is better to know the truth than to be misled.

Sample Size

Delphi surveys are undertaken with sample sizes that may appear small when compared to the relatively large numbers needed to provide accurate results in a probability sampling of an extensive universe. Delphi is by design not a random technique, however, and should not be assessed with the measures used to evaluate probability surveys. Delphi respondents are carefully selected, not chosen at random, and the universe of qualified automotive respondents is so relatively small that our sample approaches a census.

PANEL CHARACTERISTICS

The heart of a Delphi survey is the careful selection of expert respondents. Neither the Delphi process nor any other research method will result in meaningful predictions unless contributors are truly expert. The selection of such experts for the Delphi survey is made possible by close ties of long standing between University of Michigan faculty and staff and representatives of the automotive industry. The opinions of more than 225 experts in the automotive industry are the basis of this Delphi IV forecast.

Lists of prospective expert panelists were developed: one each for Marketing and Materials, and three for Technology (Body/Chassis, Powertrain/Drivetrain, and Combined). Each prospect was evaluated by a committee of persons with long experience and wide contacts in the automotive industry. Many of the panel members are known personally by one or more members of the committee. Panel members were selected who occupy an automotive industry position dealing with the topic being surveyed and are known to be deeply knowledgeable and broadly experienced in the subject matter.

Panels include some respondents employed with motor vehicle manufacturers and others working for their suppliers of components, parts, and materials. It is common within the industry and convenient here to refer simply to "manufacturers" and "suppliers."

Panel members and their replies are kept anonymous. However, panelists were asked to mail in a business card to enable us to send them follow-up questionnaires. These cards were used to determine the following panel characteristics: approximately 25% of the Technology panelists were presidents or vice presidents; 40% were directors and managers; 24% were engineers, and included chief, assistant chief, and staff. The others were technical specialists. About 45% were employed by vehicle manufacturers, 50% by component and parts suppliers, and 5% by materials suppliers.

The Marketing panel was made up of 30% presidents, chairmen, CEOs, and vice presidents; 30% were managers, and 16% were directors. The remainder were marketing and planning specialists. Twenty-one percent were employed by vehicle manufacturers, 60% by component and parts suppliers, and 19% by materials suppliers.

Among Materials panelists, 77% were general managers, vice presidents and directors, 7% engineers, and the others consisted of technical, marketing, and planning specialists. Employment was 22% by vehicle manufacturers, 26% component and part suppliers, and 52% materials suppliers.

HOW TO USE THIS REPORT

In the course of their planning activities, industry executives make extensive use of quantitative analyses and forecasts. But, because of major unknowns in the future environment of the industry, those executives also rely heavily on judgment. The Delphi procedures measure the results both of numerical analyses and of judgmental factors being exercised by the experts.

How useful are the Delphi forecasts? A factor to consider is that the experts whose opinions constitute the forecasts are in positions within the automotive industry where they have the responsibility, authority, and resources to make at least some of their predictions come true.

No matter how uncertain it is, the automotive future must be anticipated. With lead times up to five years for vehicles, and longer for some facilities, manufacturers had to begin taking action years ago in order to produce vehicles today. If a forecast reflects a high degree of consensus, it is a path the industry is following. Knowing this provides you with planning lead time–time that could be used either to plan to mesh with the forecast or to attempt to change the factors that are the basis for the forecast. In many cases it may be possible to change the future before it arrives.

For suppliers and others interested in the automotive industry, these Delphi forecasts establish the best planning base we know. They provide lead time to move with trends or to alter events and change undesirable trends.

Delphi forecasts are primarily strategic planning instruments—not the only ones, but part of a collection that should be used in the planning process. The value of a Delphi forecast is measured by how well it helps you and your organization to succeed in the years ahead.

Note: The best method to locate individual items of interest is to consult the *Index of Questions Listed by Topic* at the end of this document.

PRESENTATION OF STUDY RESULTS

The many forecasts assembled in Delphi IV may not always appear to be related to each other, but generally they are. Readers should realize that the automotive industry and its products represent a unified system. It is, of course, greatly complex, but an understanding of the interrelations between parts will lead to the most effective long-range planning.

This complexity explains the broad range of the U-M Delphi forecasts. For example, unit sales of cars and trucks are forecast in detail and dozens of underlying trends that drive sales and production are covered, including fuel prices, market shares, supplier relations, and vehicle quality.

Numerical Tables

When the question asked panelists 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 value is the middle response, and the interquartile range 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 interquartile range 35-45%. This means that one-quarter of the respondents answered 35% or less, another quarter chose 45% or more, and the middle half of all responses ranged between 35% and 45%. 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 median of 40% (the same as in the preceding example) but an interquartile range of 20–70%, indicating little consensus among the respondents or substantial uncertainty with regard to the future. This would be a warning that the median forecast of 40% may not have a high predictive value—which is in itself valuable information.

Interpretation of Interquartile Range

The interquartile ranges are a key to maximizing benefits from a Delphi study. A close consensus, as indicated by a tight interquartile range, is encouraging in the sense that it indicates agreement among experts. Such a consensus does not "prove" the forecast is necessarily going to come true; a sudden change in the international scene could lead all respondents to agree on a different set of answers. What a consensus does indicate, however, considering the expert knowledge and key position of the respondents, is that anyone whose interests are tied to the future of the U.S. automotive industry can make plans based on the knowledge that, until new factors prevail, industry plans and actions at all levels in vehicle manufacturer and major supplier companies will probably reflect the consensus. But it should always be remembered that even the best forecasts are trend predictions about which cyclical variations are almost a certainty.

A broad interquartile range suggests that the forecast should be viewed with less confidence and a high priority be placed on closely following the subject under consideration in order to keep alert to significant developments.

Respondents' Comments

In a Delphi survey, respondents are encouraged to write in comments—to explain their forecast and to convince other respondents to change their positions. Many of these comments are shown in this report. Duplicate comments are excluded. These replies may be important clues to future events or trend changes that are not apparent in the numerical data. An individual panelist may know something unique and special that planners should carefully consider. However, readers should be careful not to overrate the comments. 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. Of course, one point in collecting and displaying comments is that—perhaps—one or more of them should lead to contrary action. In the final analysis, it is up to the reader to decide.

Discussion

Narrative discussions are presented to highlight future trends and the interquartile ranges of the survey results.

Comparison of Vehicle Manufacturers and Supplier Panelists

For competitive reasons the manufacturers try to maintain secrecy regarding their forward plans, and it might be thought that their representatives know more than others about the automotive future. Offsetting this, the manufacturers source from 30 to 70 percent of each finished product with suppliers and work together closely with few secrets between them. However, the size (hundreds of suppliers) and complexity of the information network can prevent optimal information transfer. Therefore, our analysis includes a comparison of answers from manufacturer and supplier respondents to determine if there are significant differences of opinion.

Trends from Previous Delphi Surveys

A single Delphi survey is a snapshot of time: it collects and presents the opinions and attitudes of a group of experts at one point of time. But the market and business environment change; better information becomes available as we move closer to the forecast period. Data from previous Delphis are presented to track these changes in opinion. Significant changes (as in forecasts of fuel prices) should prompt the reader to consider the environmental drivers behind the forecast.

Strategic Considerations

Based on the replies to the question being discussed, other Delphi IV results, earlier Delphi studies, and OSAT's extensive interaction with the automotive industry over several years, inferences are drawn as to major developments and their impact on the industry.

Reference To Other Delphi IV Sections

Where appropriate, we have cross-referenced discussions or numerical tables in other Delphi IV volumes. This allows the reader to gain input from a different perspective of expertise. It is important that all dimensions—marketing, engineering, manufacturing, and distribution—be considered in developing a business strategy.

CONTENTS

EXECUTIVE SUMMARY

The Materials volume of The University of Michigan *Delphi IV Forecast of the U.S. Automotive Industry Through 1995* describes emerging technological trends in the areas of materials, fuels and lubricants, and manufacturing processes. An in-depth analysis of the competition between plastics and steel is provided as well as projected automotive applications for various materials and processes. Although a great many of these innovations are invisible to the consumer, their impact on future vehicle design and the automotive supplier industry is profound.

A forecast of total vehicle weight (Mat-5) as well as the basic breakdown of materials use in future vehicles (Mat-6) shows that vehicle downsizing is continuing but at a slower rate than envisioned several years ago.

For the consumer, the increasing utilization of coated steels and polymer-based materials means improved corrosion protection (Mat-34) and improved corrosion warranties (Mat-35). For the automotive manufacturer and supplier, future vehicles will be designed incorporating an increased usage of coated steels (Mat-36) and plastics (Mat-13) as well as several means of supplemental protection (Mat-37) to ensure maximum corrosion protection.

The likelihood of new materials technology breakthroughs (Mat-4) could provide impetus for radical innovations in the material composition of engines and engine components (Mat-7 through Mat-11B, Mat-48), and in the materials used in body exterior panels and structures (Mat-6, Mat-14, Mat-20, and Mat-21). The relative competitiveness between plastics and steel is examined in-depth (Mat-13 and Mat-15 through Mat-19) as are the demands new engine designs and technology will impose on future fuels and lubricants (Mat-24 through Mat-31, Mat-33A, and Mat-33B).

The Delphi IV Materials forecasts also address manufacturing trends and issues that impact both the industry and the workforce. These include the utilization of statistical process control (Mat-40), advanced techniques for body construction and panel attachment (Mat-41), and robotics (Mat-42 through Mat-44).

In addition to a comparison of the responses of OEM and supplier panelists included in the analyses of data, questions relating to issues of specific interest to the automotive supplier community such as investment prospects based on the automotive applications of various plastics (Mat-23), the ranking of supplier support services (Mat-38), factors considered in a purchasing decision (Mat-39), and materials usage and sourcing under various scenarios (Mat-45 through Mat-47 and Mat-49) provide significant insight into a complex and rapidly evolving new order in the relationship between manufacturers and suppliers.

MAT-1. What is your estimate of retail fuel prices per gallon in the U.S. in 1990? 1995? 2000? *(In constant dollars; that is, without adjusting for inflation.)*

	Retail Price per Gallon					
	Median Response			Interquartile Range		
	1990	1995	2000	1990	1995	2000
Unleaded Gasoline	$1.25	$1.70	$2.00	$1.15/1.30	$1.50/1.80	$2.00/2.50
Diesel Fuel	1.20	1.70	2.00	1.10/1.30	1.40/1.80	1.80/2.20

Selected Edited Comments

For the next couple years prices will rise slightly. By the end of the century as current wells become depleted and new wells become much more expensive to operate and find, prices will jump rapidly.

Middle east oil prices will most likely firm up by 1989-90. There price increases above inflation will occur after 1990.

No question about another oil shortage. . . and severe too. Median estimates are much too low.

Oil is a finite resource. Its price is bound to rise.

OPEC is disorganized and has lost its clout. U.S. oil industry is pushing for higher prices—but a stable escalation—not like we saw in the last decade.

Predictions are almost a waste of time because of the influence of unpredictable political decisions.

Projected price increase for gasoline in 2000 will increase demand for diesel fuel.

We should not forget the lessons of the past. Oil, over time, will become a more expensive commodity.

By the end of the century there will be another oil shortage. Domestic oil production to fall off.

I feel it's only a matter of time before some political event will result in a significant shortage of oil and gas. Our country is ill prepared.

Oil supply will become more centralized in the Middle East after 1995 with a resulting price increase.

Discussion

Gasoline and diesel fuel prices are expected to remain at relatively low levels compared to previous forecasts. Unleaded gasoline is forecast to be $1.25 in 1990, rising to $1.70 in 1995 and $2.00 in the year 2000. Diesel fuel prices are expected to keep a comparable pace with gasoline, rising from an expected $1.20 in 1990 to $1.70 in 1995 and $2.00 in the year 2000. It is of interest to note that the Materials panels exhibit the broadest interquartile ranges of all the Delphi panelists, particularly on the high end. Since the Materials group incorporates panelists from the fuels and lubricants industry, the interquartile range can be interpreted as either a genuine lack of consensus regarding the direction of fuel prices within this group or a more fundamental feeling that prices could be higher than the levels forecast by the other Delphi panels. Either way, the prices forecast and their respective interquartile ranges merit serious attention.

Discussion of Panelists' Comments

In general, the Materials Panel forecasts for the price of fuel through the year 2000 are higher than the forecast of the other Delphi panels and the comments reflect the overall Materials Panel opinion that fuel prices are expected to steadily rise through the remainder of the century. Although the comments represent a diversity of opinion regarding probability of political events influencing the oil market and the rate of price increase, substantial concern for a major "oil shock" is evident.

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer and supplier panelists were very close to the median forecasts and each other in their projections for the price of unleaded gasoline and diesel fuel for the years 1990 and 2000. For the year 1995, the manufacturer panelists were significantly lower than both the median and the supplier panelists with forecasts of $1.50 for unleaded gasoline and $1.55 for diesel fuel.

Comparison of Replies to TECH-1 and MKT-4

The Materials panelists display a pattern of being consistently higher than the Technology and Marketing panelists in their forecast for the years 1995 and 2000.

	Technology Panel			Marketing Panel			Materials Panel		
	1990	1995	2000	1990	1995	2000	1990	1995	2000
Unleaded	$1.20	$1.40	$1.75	$1.20	$1.35	$1.60	$1.25	$1.70	$2.00
Diesel	1.20	1.40	1.65	1.20	1.35	1.60	1.20	1.70	2.00

Trend from Previous Delphi Surveys

In Delphi III, Materials panelists forecast that unleaded gasoline would be $1.70 in 1990 and diesel fuel would be $1.60. These higher prices are consistent with higher prices forecast by the Technology and Marketing panels from previous Delphis. For Technology Panel trends from previous Delphis, see Technology Volume: TECH-1, "Trends from Previous Delphi Surveys."

Strategic Considerations

The continuing decline in 1990 fuel price forecasts to a level less than half of predictions made in earlier surveys is not an indictment of our earlier panelists (many of whom are panelists in Delphi IV), but a warning that even experts cannot be certain of a future which is, as in this case, determined by politics rather than free markets. Lower recent forecasts reflect a return to "freer markets" for fuel pricing in the U.S., but the occurrence and timing of domestic political changes that enabled that return could not have been judiciously forecast.

It may appear the panelists are predicting no recurrence of government interference in energy markets before 2000—a forecast that would seem highly unlikely with four presidential elections in the period and continued Middle East instability. Fourteen years is a long time to expect relatively stable supplies and prices for energy, and our panelists are, of course, keenly aware of the fact. But they lack a method to predict the timing or extent of a political or military impact. The Materials panelists expressed strong concerns in their comments relative to possible future problems.

The most dramatic change in American cars in recent years has been in fuel efficiency. Domestic U.S. manufacturers have improved the average fuel economy of their cars from approximately 12 mpg in 1974 to 26–27 mpg currently. But economy improvements are approaching the point of rapidly diminishing returns.

There is a limit to the dollar value of fuel economy, particularly if the effort to achieve CAFE produces a much more costly car or an impractically small vehicle. Some motorcycles get 125 mpg, but lack utility for a family of four with a dog and a boat trailer.

The objective here is to put fuel economy into perspective: it is important, but so are other vehicle characteristics. The vehicle's designers and its buyers must consider an array of consumer value factors, including package size, performance, comfort, durability, and safety. The key word in evaluating fuel economy, or any other vehicle characteristic, is "optimum": enough, but not too much. Manufacturers must strive to offer products that meet consumers' trade-off analyses. This is by no measure a trivial task.

Figure M-1 shows the relationship between car efficiency and annual fuel costs. For example, at $1.00 per gallon, a gain or annual savings of $83 is achieved by moving from a 30 mpg car to one that gets 40 mpg. But this $83 change can also be evaluated from the other direction.

If you own a subcompact, two-adults plus two-small-children car that achieves 40 mpg, would it be worth an extra $83 per year in fuel costs to drive a 30 mpg model that has room inside for five adults plus their luggage? This is the kind of question that Americans—including those responsible for designing American (and imported) cars—ask themselves. Recently, car buyers in the U.S. have been answering by buying larger cars. Particularly since the price of gasoline fell below $1.00 per gallon.

However, the design and purchase answers cannot be based solely on financial and comfort considerations or in permanent free-market energy. Consequently, economics may not be sustainable in the future. Vehicle buyers and designers must keep in mind the question of fuel availability as well as price.

		A $1.00/Gal.		B $1.50/Gal.		C $2.00/Gal.	
MPG	GAL'S	COST	GAIN	COST	GAIN	COST	GAIN
10	1000	$1000		$1500		$2000	
20	500	500	$500	750	$750	1000	$1000
30	333	333	167	500	250	666	334
40	250	250	83	375	125	500	166
50	200	200	50	300	25	400	100

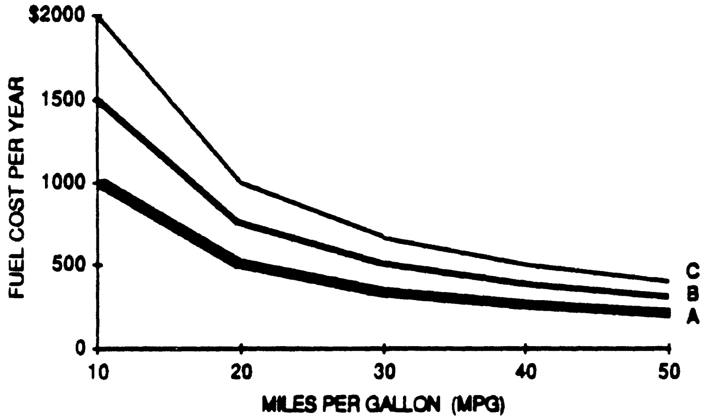

FIGURE M-1. The Declining Value of Incremental Gains in Fuel Economy

MAT-2. In general (excluding inertia-weight-class crises), what is the value (in current dollars) per pound of weight saved to a vehicle manufacturer? What will it be in 1990 and 1995? *(In constant dollars; that is, without adding anything for inflation.)*

Value per Pound Saved

	Median Response	Interquartile Range
Today	$0.50	$0.25/1.00
1990	0.55	0.33/1.25
1995	0.75	0.36/1.75

Selected Edited Comments

Value (excluding the crises) seems to be declining.

Except for pilot purposes we do not remove weight within an inertial test weight (ITW) at a cost penalty.

Primary goal is to meet inertia-weight-class. Meeting this goal at lowest possible cost seems to be main thrust.

Pure weight reduction has no savings for the manufacturer. Component reduction and manufacturing improvement techniques will reduce costs.

Value saved per pound is really dependent on actual size of vehicle. Savings per pound on large cars is greater than for small cars.

Discussion

The value to vehicle manufacturers of weight saved is estimated at $0.50/lb. today and forecast to increase to $0.55/lb. in 1990 and $0.75/lb. in 1995. The interquartile ranges are very broad indicating a substantial diversity of opinion regarding the value of weight reduction. However, both the present comments and previous Materials forecasts from Delphi III support this panel's forecast which suggests a significantly lower value to vehicle manufacturers of weight saved than do the forecasts of the Technology panel.

Discussion of Panelists' Comments

The comments, in general, support the median responses.

Comparison of Vehicle Manufacturers and Supplier Panelists

The forecasts of the manufacturer and supplier panelists for the value per pound of weight saved to a vehicle manufacturer for "Today" and 1990 were identical and in agreement with the combined medians. For the year 1995, the manufacturer panelists forecast $0.50 and the suppliers forecast $0.85.

Comparison of Replies to TECH-9

The following table illustrates the difference in opinion between the Technology panelists and the Materials panelists regarding value to the vehicle manufacturer of weight saved.

	Value per Pound Saved — Median Response: Technology Panel	Materials Panel
Today	$1.25	$0.50
1990	1.50	0.55
1995	1.75	0.75

Trend from Previous Delphi Surveys

As illustrated in the table below, the Materials panelists have been historically consistent in forecasting a lesser value per pound saved to vehicle manufacturers. The interquartile ranges for Delphi III forecasts were very tight.

Forecast Year	Value Per Pound Saved — Median Response: Materials Panel: 1983 Delphi III	1986 Delphi IV
1983	$0.40	N.A.
1986/1987	0.50	0.50
1990	0.60	0.55
1992	0.67	N.A.
1995	N.A.	0.75

Strategic Considerations

If the value of a pound of weight saved becomes too low to be significant, the impact on the use of substitute materials could be very large. The declining value-per-pound trend appears to correlate with moderating expectations for the use of lightweight materials and consumers' reduced concerns for fuel economy. Of course CAFE standards still place an important burden on the manufacturers to improve fuel economy. Lightweight materials must still be considered. Question TECH-3 provides a view of the relative importance of fuel economy improvement factors, including lightweight materials.

The past importance of meeting CAFE inertia weight classes is still true today although there has been a change in the size of the classes. If a manufacturer is just above a given weight class boundary, the value of a pound of weight saved can be considerably more than if the weight is just below it.

MAT-3. Rank order (from 1 to 5) the following materials according to weight-savings potential in automobiles in 1990 and 1995 (highest potential = 1, lowest potential = 5).

Ranked Weight-Savings Potential

Percent Total Responses for each Variable

Materials	1	2	3	4	5
1990					
Plastics	38%	40%	19%	3%	0%
HSLA Steel	31	17	25	19	8
Aluminum	16	22	38	16	8
Advanced Composites	17	14	11	30	28
Other Steel (low carbon, alloy, laminated)	0	4	7	30	59
Other: Magnesium	0	25	0	50	25
1995					
Advanced Composites	46%	32%	14%	3%	5%
Plastics	38	32	19	8	3
HSLA Steel	14	14	23	32	17
Aluminum	5	14	38	35	8
Other Steel (low carbon, alloy, laminated)	0	4	0	19	77
Other: Magnesium	25	0	50	0	25

Selected Edited Comments

There will be increased use of HSLA steels for body skins and increased use of composites after 1990; use of more plastic bumpers over the next few years. Continued down gauging of carbon steel and use of tubular steel components will replace steel bar.

Injection molded structures will allow the modular fabrication of vehicles utilizing aerospace frame structures. A single carline could be sourced at three different plants.

Plastics and composite technology will move these materials to the forefront of auto composition.

Discussion

For the year 1990, the Materials panelists expect plastics and HSLA steel to be the primary materials contributing to weight-savings potential in automobiles. By 1995, the primary potential for weight savings is forecast to shift to advanced composites and plastics. By 1995, the rank-order position of HSLA steel is expected to drop from second position to third, with the advanced composites advancing from a rank-order position of fourth to first.

Discussion of Panelists' Comments

The comments address the forecast pre-eminence of advanced composites and plastics as weight-saving materials.

Comparison of Vehicle Manufacturers and Supplier Panelists

For 1990, the OEM panelists ranked HSLA steel significantly lower than both the supplier panelists and the combined median with only 10% of this group ranking HSLA steel in the highest potential category. The manufacturer panelists also ranked aluminum considerably higher than either the suppliers or the median with over 60% of the responses falling in the two highest categories. This is in contrast to the supplier panelists where only 26% ranked aluminum in the same categories as the OEM panelists.

For 1995, no OEM panelist ranked HSLA steel in the highest category for weight saving and only 11% placed it in category 2. In contrast, 35% of the supplier panelists ranked HSLA steel in the same two categories. With regard to plastics and advanced composites, approximately 65% of the manufacturer panelists considered plastics in the two highest categories versus 73% of the supplier panelists. With other advanced composites, 90% of the OEM panelists and 80% of the supplier panelists ranked it in the two highest categories.

Trend from Previous Delphi Surveys

In terms of weight-saving potential for 1990, the relative rankings of plastics, HSLA steel, and aluminum in this Delphi are consistent with the rankings of the Materials Panel from Delphi III.

Strategic Considerations

It is evident that materials experts have particularly strong expectations for plastics and composites in the years ahead. However, caution should be exercised with regard to these expectations. While plastics would appear to have an excellent future, we are still at an early stage of the learning curve for plastics and there are still some important uncertainties. It is not clear at this point what the long-range potential of plastics will be. Also, it is becoming clear that significant progress is becoming possible with traditional materials when competitive forces are elevated as they are today. Steel, in particular, represents a challenging target for all competing materials because of its low cost on a dollar-per-pound basis. Furthermore, it is essential to begin considering materials not just in a singular way, as we often do, but to begin to think in terms of materials systems; that is, how various materials (plastic, steel, aluminum, etc.) can be effectively combined in some form to optimize performances as installed in a system. At this point, there is still a great tendency for industry engineers to think in terms of single individual materials and not how they might be combined in an effective manner.

MAT–4. Indicate two possible breakthroughs in automotive materials technology in the next ten years.

Leading Material Breakthrough Areas Suggested	Percent Total Responses
New polymeric materials and structural composites for automotive body parts	26%
New ceramic materials for powertrain components	17
Advances in sheet metal and steel forming technologies	15
New adhesive bonding technologies	7
Molded-in color plastics	7
Fiber-reinforced aluminum	7

Other responses each accounting for less than 4% of the total are rank ordered as follows: plastic engine components, reduction in cost of composites, new processing technology.

Single responses are as follows: laser welding, zirconium plasma spray engine coating, increased temperature resistance of plastics, high temperature lubricants, lower cost carbon fibers, non-asbestos brake system with advanced binders, increased use of aluminum in engine blocks, metal matrix composites, abrasion-resistant polymer to replace glass.

NOTE: In order to provide as much insight as possible into the thoughts of the panelists, "Representative Responses" are provided here in lieu of "Selected Edited Comments."

Representative Responses

High volume auto body panels—reaction injection molded—new reactor chemistry, not polyurethane. Small parts will be injection molded, composite structural body parts. High-performance magnesium transmission cases and engine components.

Advances in sheet metal forming technology and improved formability of high-strength steels. Advances in joining technology (laser welding, increased use of adhesives), molded-in color for plastic outer body panels.

Advanced composite floor pan and all plastic body panels, plastics and advanced composites under the hood (ceramics and plastics), metal matrix composites in engines (intake manifolds, connecting rods, camshafts, pistons, etc.).

Low-cost ceramic materials and processing for complex parts, low cost ceramic fiber reinforced aluminum castings.

Composite structures utilizing resin transfer molding, and preforms having cycle times in the 1- to 5-minute range. Zirconium plasma spray coatings for high temperature engine. This technology is in use in aerospace engines. Will allow elimination of cooling system.

Rapid solidification rate alloys will be used in connecting rods, valves, and piston crowns. Superior properties at high temperatures, combined with light weight and high strength.

Reduction in breakeven point between plastic and steel body panels through advances in sheet metal forming technology.

Metal matrix composites (MMC). Aluminum and/or magnesium based with ceramic fiber and/or particular reinforcements. Applications: power plants and chassis components.

Stampable thermoplastics replacing sheet metal; compression moldable advanced (fiber reinforced) plastics replacing rolled steel for body structures.

Molded-in color for plastic exterior panels with marked reduction in painting of vehicles. Adhesively-bonded structural steel construction.

The fabrication and painting of advanced composites will become "standard" practice in the supplier community. Ceramics will make even greater gains under the hood.

Use of fiber-reinforced resin-based composites in body structural applications leading to modular vehicle construction.

Control of characteristics of HSLA steel and other steels, development of better manufacturing techniques with plastics.

Adhesive bonding of steel parts which will significantly reduce overall cost for the use of steel.

Advance composites will come down in price dramatically; aluminum systems approach a new forming technique.

Continued improvements in processing technology that will improve quality and productivity of materials (lower cost) and ultimately end products.

Cost-effective, highly-automated composite structures for auto body structures, plastic engine.

Dramatic reduction in tooling costs to stamp steel components. Increase temperature resistance of plastics.

Introduction of structural ceramics in certain engines, initially in a limited amount.

Polymer alloy for external vehicle, horizontal passenger car panels for injection molding, new fabrication techniques for processing new composite materials.

Abrasion-resistant polymer to replace glass.

Almost all engine cylinder blocks which are now made of cast iron will be made of cast aluminum.

Discussion

The three leading areas suggested by the panelists as possible breakthroughs in automotive materials technology are: (1) new structural materials for use in bodies, primarily cost-effective, temperature-resistant, plastic composites amenable to highly automated manufacturing techniques; (2) reliable, high temperature, wear-resistant ceramic materials for engine and underhood application; (3) advances in sheet metal technology and sheet metal forming technology.

A number of the "single responses" merit consideration as harbingers of future breakthroughs in automotive materials technology.

Strategic Considerations

There is strong support for more breakthroughs in the areas of plastic-based materials, ceramics, sheet metal, and steel-forming technology. As noted in the "Strategic Considerations" of MAT-3, we believe it is increasingly important to think of systematic interactions between materials and how optimized material systems might be developed. It seems clear that within the breakthrough areas that are suggested, we will have a further intensifying of the materials competition in the automotive industry. It will be critical to provide the designers and manufacturing experts with the proper knowledge to fully utilize new material technologies.

MAT-5. Forecast the material content, in pounds, and the total curb weight (dry, unloaded) for the average U.S.-produced passenger car for model years 1990 and 1995.

Material Content for U.S.-Produced Passenger Car

Materials	Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
STEEL				
Low Carbon Steel	1100 lbs.	875 lbs.	900/1100 lbs.	800/900 lbs.
HSLA Steel	310	330	250/340	300/400
Stainless Steel	15	20	15/30	15/35
Other Steels	100	100	80/160	80/180
TOTAL	1525	1325	1500/1570	1200/1440
Cast Iron	380	300	350/380	300/325
ALUMINUM Castings	110	130	100/125	125/150
Wrought Aluminum	35	40	30/35	30/40
TOTAL	145	170	135/170	160/182
PLASTICS				
Unreinforced (no fiber content)	120	120	80/125	100/140
Reinforced (<40% fiber content)	80	120	70/80	90/135
Structural Reinforced Composites (>40% fiber)	20	60	20/50	50/60
TOTAL	220	300	210/300	265/400
Copper	22	20	20/25	15/20
ZINC (exclude coatings)	10	10	10/12	10/11
Zinc coatings	15	15	15/17	12/17
Magnesium	2	2	2/2	2/5
Glass	80	80	80/83	80/85
Ceramics	2	3	2/2	3/5
Powdered metals	27	29	25/28	25/30
RUBBER				
Tires (include spare)	90	80	80/90	75/80
All Other Rubber	40	40	40/40	40/40
TOTAL	130	120	120/133	120/130
Total All Other (includes paint, pitch, cloth, fibers, sound deadener, and lead)	140	130	126/140	120/140
TOTAL VEHICLE	2698	2504		

Selected Edited Comments

Ceramics will find its way into powertrain applications, first in diesel port liners, pistons, and valve train components, and in limited applications in gasoline engines. Unreinforced thermosplastics will replace RIM and SMC in most horizontal panels. Roofs and hoods will continue in SMC.

Emphasis over next five years in OEMs will be focused more on cost reduction than weight reduction. Plastics and advanced materials will only be successful if costs are decreased. Process limitations and lack of an infrastructure will restrict the inroads of plastics/advanced materials. Also Japanese OEM transplants will spur domestic OEMs to radically improve their tooling and stamping efficiencies and hence cost of steel parts is likely to go down.

Metal matrix composites will be introduced into the automotive market soon.

Much depends on gasoline prices. Plastic versus steel depends on cost difference and also how plastic fits into manufacturing techniques.

Now that product plans have firmed up I believe median to max side may be more realistic. Ratios will change mid-1990s as oil prices escalate. Subject to process cost reduction: steel and process development—plastics.

OEMs need to work with aerospace firms to develop technology. Some guarantees of future business will be required to provide incentives for composite technology transfer to auto industry. Few firms possess design capability and as such are very guarded about "giving it away."

Plastics adoption will require parts consolidation to a larger extent than previously thought in order to be economical. Capital equipment expenditure requirements for plastics adoption will retard their introduction.

The breakdown could be significantly impacted by the mix of Japanese vehicles produced in the U.S. especially for 1990 and 1995.

The real issue is quality. If plastics do not make a major quality improvement, their usage will not increase. The next ten years will see process dictate design more than the stylist has the last twenty years. Costs to make steel parts should decline dramatically with tooling and CAD/CAM advances in the next ten years. Some increase in car size is possible from now to 1995.

There will be a possibility of making structural frames of aluminum beams in 1995. Some applications of rubber will be replaced with those of thermoplastic elastomer.

Zinc coatings usage will increase substantially due to increased use of electrogalvanized steel on both interior and exterior skins; but balanced negatively by increased use of plastic body panels.

Breakdown can be significantly impacted by Japanese/U.S.-produced vehicles, especially for 1990 and 1995.

For plastics, depends on selection of body panel materials—thermoset with glass versus thermoplastics—no fiber.

Parts integration (tooling cost) capability will drive market.

Discussion

The weight of the average U.S.-produced passenger car is expected to continue to decline from an estimated 2,872 pounds in 1985 to 2,698 pounds in 1990, and 2,504 pounds in 1995. The steel content of U.S.-produced passenger cars is forecast to continue declining to 1,525 and 1,325 in 1990 and 1995, respectively. The decreasing utilization of low carbon steel is the source of this decline. HSLA steel is expected to increase modestly from 310 pounds in 1990 and 330 pounds in 1995. The interquartile ranges for "Other Steels" and "Total Steel," particularly in the upper quartile, are broad enough to provide some uncertainty with regard to the total steel content.

Aluminum usage is forecast to experience a fairly steady increase to 170 pounds by 1995.

Plastic usage is expected to grow from an estimated 190 pounds in 1985 to 220 pounds in 1990, and 300 pounds in 1995. The upper interquartile range for 1995 indicates that 25% of the panelists expected total plastic use to be 400 pounds or more. The largest gains are in fiber-reinforced and structural-reinforced composites. It should be noted that the upper interquartile range for structural-reinforced composites indicates that 25% of the panelists expect U.S.-produced passenger cars to contain 60 pounds or more of structural-reinforced composites.

The cast iron and copper contents of U.S.-produced cars are forecast to continue to decline to 300 pounds and 20 pounds, respectively in 1995. Ceramics are forecast to increase to three pounds and powdered metals to 29 pounds per car by 1995.

Discussion of Panelists' Comments

A number of the comments address the issues of quality and cost reduction with respect to plastics/composites technology. Given that this is a question concerning material content in passenger cars, the fact that the panelists commented on the necessity for quality improvement and cost reduction in this area is an indication of the importance the panelists attach to those issues. Additionally, the impact of Japanese vehicles manufactured in this country on tooling and materials choice are the topic of several of the comments and further indicate a growing awareness and concern regarding "transplants."

Comparison of Vehicle Manufacturers and Supplier Panelists

Although the manufacturer and supplier panelists were in very close agreement on the total vehicle weight for U.S.-produced passenger cars in 1990 and 1995 (difference between each group and the median is less than 15 pounds), there was a significant difference in their forecasts for steels and plastics in those years. In general, the OEM respondents forecast significantly lower carbon steel and "other steels" content and a significantly higher "total plastics" content than did the supplier panelists. All other materials surveyed were within a 15% difference.

Comparison of Replies to TECH-6

The Materials panelists and the Technology panelists were remarkably close on their forecasts for material content for U.S.-produced passenger cars, being for the most part, within 10% of each other. Those forecasts that varied *more* than 10% are illustrated in the following table.

Material Content	Materials Panel	Technology Panel
HSLA Steel: 1990	310 lbs	250 lbs
Stainless Steel: 1990	15	25
Stainless Steel: 1995	20	35
Plastics:		
Reinforced <40% Fiber: 1990	80	100
Reinforced <40% Fiber: 1995	120	100
Structural Reinforced: 1990	20	43
TOTAL VEHICLES: 1995	2504 lbs	2569 lbs

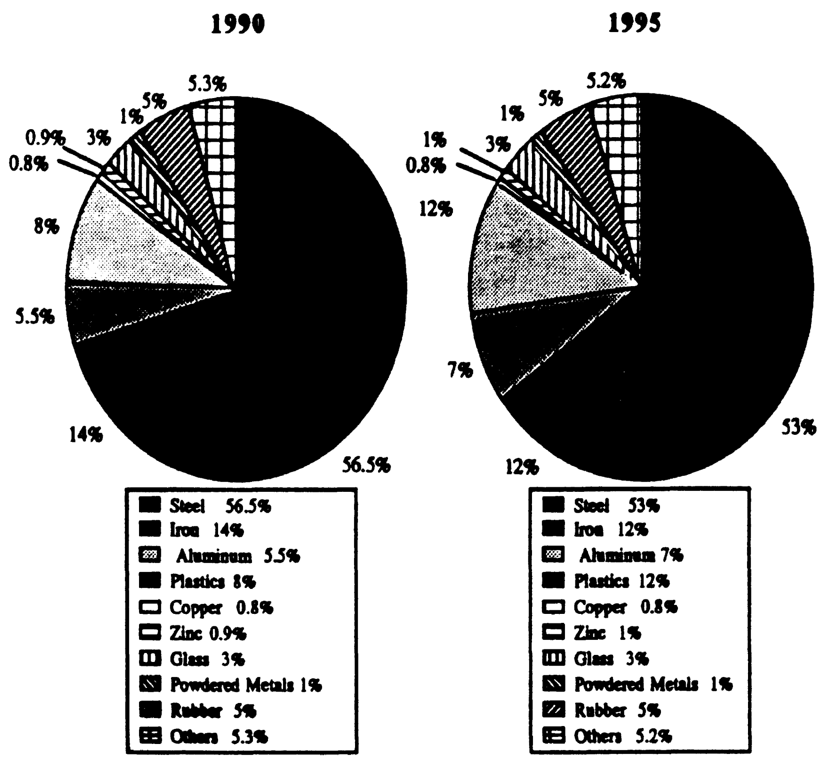

FIGURE M-2. U.S.-Produced Passenger Cars: Projected Use of Materials (based on material weight)

Strategic Considerations

What is most remarkable about these materials forecasts is their indication of a continual shrinkage in materials usage. Recent motor fuel prices, adjusted for inflation, are at pre-World War II levels and below what they were in the late 1960s during the great popularity of very large American-made passenger cars. This would suggest that a trend to larger vehicles could develop.

However, a major reason why this trend is not taking place is the uncertainty of long-term fuel availability. As discussed earlier, under the "Strategic Considerations" accompanying question MAT-1, manufacturers and consumers must consider not only the price of the fuel but the possibility that supplies can be arbitrarily disrupted at any given moment. Additionally, government controls such as CAFE standards are a barrier to larger cars.

However, and consistent with other related issues, the expected rate of vehicle weight reduction is slowing markedly from that forecast in earlier Delphis. Even though there is growing moderation in expectations for shifts in automotive materials for the future, there is strong support for lighter weight materials as evidenced by the forecast significant percentage growth in plastics and aluminum from Delphi III to Delphi IV.

In our judgment, materials and their processing will be one of the most exciting and volatile areas of technology in the coming decade. Developments must be watched closely. This is particularly difficult because of the diverse technologies and large number of potential sources of technology. Furthermore, many of the more conventional technologies are being reevaluated and may yield improvements well beyond the current "state of the art." Steel, for example, is experiencing renewed interest because of consideration of a far more systematic approach in the total process of converting the raw material to the finished product.

A true systems approach in automotive materials may emerge in which a hybrid set of materials are developed which use the best of metal and polymer technology. The seeds of this are beginning to germinate in some of the more creative automotive and material companies. One of the great uncertainties in the material competition is the relative infancy of "plastics" technology. Who really can forecast with great precision developments in the materials and their processing ten to twenty years from now?

MAT–6. Indicate the percentage of each of the following automotive components likely to be made in 1990 and 1995 from the materials listed. *Tables are on next two pages.*

Strategic Considerations

The expected increasing intensity of competition between various materials for a variety of automotive applications are evident in this question. In most cases there is a relatively broad interquartile range which is a measure of a high degree of uncertainty for these materials selections. One wonders what role some key external factors, ranging from changing energy prices to more assertive customers placing greater value on quality, will have on these developments. It is clear that the industry will increasingly be driven by consumer requirements which will place great emphasis on cost reduction while at the same time improving features. We anticipate that the aggressive competition between materials of all types will continue and perhaps intensify in the years just ahead.

This is apparent from numerous personal experiences where we have seen rather sudden shift in materials expectations based on waves of new thinking that flow through the industry. For example, just two years ago the prevailing view was that beyond 1990, plastics would be a significant exterior skin material. Today we find quite a different view and perhaps a more realistic understanding that plastics and steel are locked in a heated battle and the ultimate winner will not be defined in the next few years. It is generally evident from the long-range forecast that expectations for plastics penetration are substantial in a wide range of componentry. The general area of automotive materials is so fundamental that everyone associated with the industry needs to track trends very carefully.

1990 MODEL YEAR	Median Response: Percentage Made from				
	Steel	HSLA Steel	Aluminum	Reinforced: Plastics/Comp.	Nonreinforced: Plastics
Hood, Outer	86%	1%	2%	11%	0%
Hood, Inner	82	2	0	16	0
Roof, Outer	94	0	0	6	0
Doors, Outer	85	1	0	12	2
Doors, Inner	82	5	0	13	0
Fenders, Outer	81	1	0	9	9
Bumpers, Fascia	0	6	6	13	75
Bumper, Support	14	60	1	25	0
Gas (fuel) Tank	88	0	0	1	11
Floor Pan	97	1	0	2	0
Cylinder Head Cover	77	0	15	8	0
Seat Frame	79	16	0	5	0
Wheels	62	13	25	0	0
Radiator Support	50	10	0	40	0
Suspension Springs	89	0	0	11	0
Suspension Control Arms	53	47	0	0	0

	Interquartile Range: Percentage Made from				
	Steel	HSLA Steel	Aluminum	Reinforced: Plastics/Comp.	Nonreinforced: Plastics
Hood, Outer	65/91%	0/11%	0/5%	2/22%	0/0%
Hood, Inner	62/89	0/10	0/5	5/21	0/2
Roof, Outer	83/97	0/0	0/11	2/17	0/0
Doors, Outer	69/94	0/11	0/0	0/20	0/11
Doors, Inner	38/93	0/25	0/0	0/46	0/2
Fenders, Outer	60/88	0/11	0/0	0/22	0/25
Bumpers, Fascia	0/6	0/13	0/13	0/63	13/84
Bumper, Support	0/49	12/63	0/12	12/49	0/0
Gas (fuel) Tank	56/94	0/0	0/0	0/10	0/22
Floor Pan	60/99	0/20	0/0	0/10	0/0
Cylinder Head Cover	46/91	0/0	0/50	0/45	0/0
Seat Frame	33/84	0/82	0/16	0/33	0/0
Wheels	50/88	0/55	23/44	0/6	0/0
Radiator Support	0/86	0/60	0/0	12/63	0/0
Suspension Springs	78/95	0/0	0/0	5/22	0/0
Suspension Control Arms	11/95	0/90	0/10	0/0	0/0

Median Response: Percentage Made from

1995 MODEL YEAR	Steel	HSLA Steel	Aluminum	Reinforced: Plastics/Comp.	Nonreinforced: Plastics
Hood, outer	69%	1%	2%	28%	0%
Hood, Inner	62	6	1	31	0
Roof, Outer	81	5	0	14	0
Doors, Outer	74	8	0	15	3
Doors, Inner	61	8	0	30	1
Fenders, Outer	60	7	0	17	16
Bumper, Fascia	0	1	6	12	81
Bumper, Support	9	55	0	36	0
Gas (fuel) Tank	58	0	0	14	28
Floor Pan	86	0	0	14	0
Cylinder Head Cover	44	0	22	34	0
Seat Frame	33	40	0	27	0
Wheels	37	29	29	5	0
Radiator Support	30	35	0	35	0
Suspension Springs	63	0	0	37	0
Suspension Control Arms	47	47	6	0	0

Interquartile Range: Percentage Made from

	Steel	HSLA Steel	Aluminum	Reinforced: Plastics/Comp.	Nonreinforced: Plastics
Hood, Outer	42/95%	0/29%	0/4%	7/56%	0/0%
Hood, Inner	38/83	0/25	0/12	12/50	0/5
Roof	69/92	0/28	0/7	7/42	0/3
Doors, Outer	30/85	0/30	0/0	3/54	0/30
Doors, Inner	15/81	0/50	0/0	15/60	0/5
Fenders, Outer	27/80	0/27	0/0	0/27	0/47
Bumper, Fascia	0/0	0/12	0/12	0/35	50/94
Bumper, Support	0/36	18/70	0/18	0/55	0/36
Gas (fuel) Tank	43/72	0/0	0/0	0/28	0/60
Floor Pan	29/93	0/43	0/0	0/5	0/0
Cylinder Head Cover	0/65	0/0	0/44	0/60	0/0
Seat Frame	0/65	0/60	0/13	7/53	0/0
Wheels	0/43	0/48	19/38	0/9	0/0
Radiator Support	0/70	0/70	0/7	14/70	0/0
Suspension Springs	37/85	0/13	0/0	13/50	0/0
Suspension Control Arms	0/80	0/65	0/24	0/9	0/0

MAT-7. For the following engine components, please indicate possible materials/processes for their production by 1995.

Material/Process	Percent of Total Responses
Crankshaft	
Cast Iron	45%
Steel	
Forged	20
Cast	10
Powdered Metal	5
SUBTOTAL Steel	35%
Aluminum	
Cast	5
Forged	5
Al-Ceramic Fiber	5
SUBTOTAL Aluminum	15%
Composites	5%
TOTAL	100%
Camshaft	
Cast Iron	40%
Steel	
Forged	29
Steel-Ceramic: Composite	6
SUBTOTAL Steel	35%
Powdered Metal	25%
TOTAL	100%
Piston	
Aluminum	
Cast	23
Powdered Metal	4
Reinforced/Al-Composite	16
Al-Ceramic Inserts	4
SUBTOTAL Aluminum	47%
Ceramic	
Cast	25
Capped	4
SUBTOTAL Ceramic	29%
Plastics with Al-Ceramic crown	12%
Steel	4%
Magnesium	4%
"Super Alloy" Composite	4%
TOTAL	100%

Material/Process	Percent of Total Responses
Connecting Rod	
Aluminum	
Cast	21%
Forged	7
Reinforced	11
SUBTOTAL Aluminum	39%
Steel	
Cast	11
Forged	4
Other	4
SUBTOTAL Steel	19%
Composites	
Cast	11
Other	8
SUBTOTAL Composites	19%
Cast Iron	15%
Plastic	4%
Powdered Metal (unspecified)	4%
TOTAL	100%
Intake Manifold	
Aluminum	
Cast	40
Reinforced	8
SUBTOTAL Aluminum	48%
Plastic	
Injection Molded	36
Reinforced	12
SUBTOTAL Plastic	48%
Steel	4%
TOTAL	100%
Exhaust Manifold	
Cast Iron	32%
Iron-Ceramic Coat	4
Steel	
Cast	8
Stamped	12
Tube	4
SUBTOTAL Steel	24%
Stainless Steel	
Cast	4
Stamped	8
SUBTOTAL Stainless Steel	12%

Material/Process	Percent of Total Responses
Ceramic	16%
Aluminum	
Cast	8
Al–Ceramic Coat	4
SUBTOTAL Aluminum	12%
TOTAL	100%
Oil Pan	
Plastics	
Injection Molded	31
Reinforced	8
Plastic-Metal Laminate	7
SUBTOTAL Plastics	46%
Steel: Stamped	29%
Aluminum	
Cast	17
Reinforced	4
SUBTOTAL Aluminum	21%
Magnesium	4%
TOTAL	100%
Water Pump Housing	
Aluminum	42%
Plastics	
Injection Molded	38
Reinforced	8
SUBTOTAL Plastics	46%
Cast Iron	4%
Steel	4%
Magnesium	4%
TOTAL	100%
Air Cleaner	
Plastic	
Injection Molded	58
Sheet Formed	5
SUBTOTAL Plastic	63%
Steel: Stamped (Including pre-paint)	25%
Aluminum	
Stamped	8
Cast	4
SUBTOTAL Aluminum	12%
TOTAL	100%

Discussion

This question gives some indication of the use, in 1995, of various materials and processes for the production of eight major engine components. The replies are broken down by component so that the percentages forecast for each add to 100%.

Forecasts for possible materials and processes for the 1995 production of nine engine components exhibit a wide variety of predictions. Of all the components surveyed, the narrowest range of suggested materials for any component was three. The suggested use of magnesium in pistons, oil pans, and water pump housings is of considerable interest. See also MAT-47.

Comparison of Replies to TECH-40

The identical question addressed to our Technology panelists resulted in some significantly different replies, which are discussed below under component categories.

Crankshaft:	In addition to iron and steel, Materials panelists mentioned aluminum (15%) and composites (5%).
Camshaft:	Many detailed differences but probably not of major significance in a ten-year forecast.
Piston:	Technical panelists emphasized aluminum more (70% vs. 46% for materials panelists) and plastics less. However, the rich variety of forecast categories, with many combinations (aluminum/plastic, aluminum/ceramic, ceramic/plastic, etc.) make comparisons difficult.
Connecting Rod:	Greater Technical Panel emphasis on powdered metal (22% vs. 4% Materials panel) and less on aluminum (18% vs. 38%).
Intake Manifold:	Steel and cast iron (combined) was 12% among technical panelists and only 4% for materials respondents.
Exhaust Manifold:	Less iron and steel are forecast of Materials panelists.
Oil Pan:	Steel drops to 16% for Technical panelists and 29% for Materials panelists.

The rocker-arm-cover forecast was not asked of Materials panelists. Technology panelists were not asked about materials/processes for water pump housing and air cleaners.

Strategic Considerations

The purpose of a question of this type is to put some perspective in our future material thinking. What are materials engineers considering as possible technologies?

The wide variety of potential materials based on the expectations of the panelists in engine components is quite striking and should be expected when looking at the year 1995. In very few areas is there a singular material that appears to be the material of choice. As in the overall vehicle materials trends, this suggests that competition at the present time is heated and in that most component areas the race is too close to call. Obviously, cost, quality, and function will be major determinants in deciding the ultimate winners. In some cases, there may not be an ultimate winner but rather a variety of different materials may provide essentially equal and balanced performance in the various applications noted.

MAT–8A. An experimental engine with a metallic content of only 10% has been operated successfully. What is the potential in passenger cars for engines that are 50% or more non-metallic? Please comment.

Potential for +50% Non-Metallic Engine
Within a Year 1995-2000 Time Frame

	Percent of Respondents
Affirmative	64%
Negative	32
Undecided	4

Representative Responses

Affirmative

Potential is there but it may take some time. Development appears to be evolutionary rather than revolutionary. Would expect much less than 50% non-metallic at first.

A 50% non-metallic engine will be standard by 1995.

As ceramic structures become better understood and process controls provide parts with consistent properties, ceramics will be used in production. High volume critical engine parts for passenger cars are probably ten to fifteen years away.

Excellent. Higher operating temperature will require ceramics and composites.

Good possibility for success if control of thermal expansion of the different materials can be maintained for the life of the engine.

I believe this to be a strong possibility knowing some of the work going on at MIT and University of Illinois, Urbana. I think the change will be evolutionary, not breakthrough in nature.

Low metallic engines have a high potential for production usage but may be hindered by the relaxation of mandated CAFE standards and cost.

Not feasible by 1990. However, as engines become smaller and more efficient with simultaneous developments in new technology and processing, engines made from combinations of metallics and non-metallics are feasible.

Plastics and ceramics are potential candidates. Development of materials and processing techniques is essential to the development of non-metallic engine components.

Potential is good, but a new firm will need to emerge to commercially prove the process/engine before wide acceptance.

Potential is good! Problems would be considerable (repair, confusion, etc.), but costs are paramount and materials and fabrication are the keys.

The potential is high. Fracture toughness and some form of mass production are the main bottleneck.

Very high possibility. Work in race car engines which are non-cast fiber-reinforced point to mass production in next ten years.

Fifty percent on weight basis—no chance; 50% of components possible.

Metallic components comprised of metal matrix composites (MMC) will be in engines by 1995. Examples: connecting rod, piston, valves.

Negative

Considering production costs, engines could not be 50% or more non-metallic. Ceramics for combustion chambers, bearing surfaces, and turbine blades and plastics for covers are applicable.

Doubtful. Switch to aluminum more likely than use of plastics or ceramics.

I foresee that plastics, ceramics, and metal matrix composites will make great inroads into replacing metals in engines. I feel the head and block will be aluminum. All else is fair game. With most of the weight in block/head, I feel potential for more 50% non-metallic content to be low. Potential to reach 30–40% almost 100%.

No likelihood before 2000. Ceramics offer major advantages, but costs are high. Plastic applications are expensive and offer minimal advantage. Fifty percent non-metallic is a long way off.

No good. The technology in materials and processing is not ready to mass produce 50% non-metallic engines.

Potential in years past 2000 is reasonable for engines with 50% ceramic and 10% plastic.

Potential is low, because of unproven long-term durability of ceramics and polymers in engine environment. Application will be limited to selected components offering greatest advantage.

Discussion

Sixty-four percent (64%) of the panelists expect that the potential for a passenger car engine that is 50% or more non-metallic within a 1995-2000 time frame to be reasonably high. However, a significant percentage (22%) of the panelists within the affirmative category expressed concern that cost will continue to be a major impediment to volume production. Thirty-two percent (32%) of the panelists felt that the potential for production of such an engine within this century was very low or nonexistent. Again, the major inhibiting factors cited by this negative group are manufacturing and materials cost and unproven long-term durability of plastics and ceramics in an engine environment.

The representative responses of the panelists touch on both the positive and negative aspects of a successful commercially produced passenger car engine within this century and deserve very serious attention.

Strategic Considerations

Just a few years ago the concept of a non-metallic engine would have been considered too extravagant to even be suggested in an automotive study. However, in light of recent significant developments and because some interesting prototypes and specialty engines have been developed, it was decided to ask this question. It is interesting to note that there is an almost 2 to 1 belief on the part of the panelists in the potential for plastic engines based on 50% or more non-metallic content. Obviously, developments must be watched very closely considering the potential for a fundamental alteration of engine manufacturing and design technology. Engine component manufacturers, in particular, should pay careful attention to materials developments. It is clear from the comments, however, that we are far from being able to forecast commercial application with any precision. As evidenced by the data in MAT-8B, expectations for non-metallic components are generally rather high.

MAT-8B. What percentage of U.S.-produced passenger vehicles will be equipped with engines that consist of 50% or more non-metallic *component parts* and/or 50% or more non-metallic *by weight* in the years 1995 and 2000?

Percent U.S.-Produced Passenger Vehicles Equipped with Engines 50% or More Non-Metallic

	Median Response		Interquartile Range	
	1995	2000	1995	2000
Component Parts	5%	15%	0/15%	5/50%
By Weight	0	10	0/5	1/20

Selected Edited Comments

Costs high, benefits highly questionable.

Non-metallic engines have a long way to go to demonstrate long term durability and cost effectiveness.

Technical problems are too great to have more than an evolutionary, slow growth. Heavy equipment, diesel engines is the growth area.

Tend to more use of ceramic reinforced light metals instead of reinforced polymers.

To reduce the weight of a vehicle. To reduce the investment for casting shops. To reduce the noise and vibration generated by an engine.

The feasibility of high percentages of non-metallic component parts improves with the downsizing of engines, improvement in engine efficiency and development of new technologies and processing.

Discussion

The Materials panelists forecast that by 1995, 5% of U.S.-produced passenger vehicles will be equipped with engines that consist of 50% or more non-metallic component parts. This is expected to rise to 15% of passenger vehicles by the year 2000. The interquartile range for 1995 is fair; the interquartile range for the year 2000, however, is very broad indicating a considerable degree of uncertainty regarding the application of new material technologies in production passenger vehicle engines. It is worth nothing that based on the interquartile range for the year 2000, 25% of the panelists felt that 50% or more of U.S.-produced passenger cars would have engines that consist of 50% or more non-metallic component parts.

For a listing of likely polymer-based and ceramic engine components and their year of commercial application, see TECH-41 and TECH-46.

The panelists also indicated that by 1995 they expect no U.S.-produced passenger cars will be equipped with engines that are 50% or more non-metallic by weight. The forecast rises to 10% by the year 2000. This is supportive of the MAT-8A forecast in which 64% of the respondents said that there was potential within the years 1995-2000 time frame for engines that are 50% or more non-metallic. The interquartile ranges for this group are only fair.

Discussion of Panelists' Comments

The panelists' comments relate many of the diverse opinions regarding future development of non-metallic engines and components. The first three comments sum up the opinions many panelists also expressed in MAT-8A and MAT-8C. The last comment sums up the factors involved in creating a climate for extensive incorporation of non-metallic engine components.

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer panelists forecast that by the year 2000, 10% of U.S.-produced passenger cars would be equipped with engines that have 50% or more non-metallic component parts and that 5% will be equipped with engines that are 50% or more non-metallic by weight. OEM forecasts for 1995 and supplier forecasts for 1990 and 1995 were identical with the median values presented.

Strategic Considerations

Considering the nature of the materials involved, the expectations for non-metallic engines as measured either on the basis of number of component parts or by weight are surprisingly high. There is sufficient optimism to suggest that plastics and ceramics technology have made considerable progress and, at least at this point, are capturing the imagination of materials experts as potential engine materials. As noted in the "Strategic Considerations" of MAT-8A, these potentially significant forecasts demand very careful attention by all those engaged in engines and component production.

MAT-8C. What are the driving forces behind very low metallic content engines?

Driving Forces Behind Low Metallic Content Engines	Percent of Respondents
Lower engine weight	57%
Improved efficiency/performance	30
Higher operating temperatures	30
Lower cost	26
Fuel economy	17
Decreased vibrations, etc.	17
New materials developments	13
Wear resistance/durability	9

Representative Responses

Ability to mold parts (cheaper manufacturing processes). Ceramics will provide ability to operate at higher temperatures more effectively in diesels eliminating the need for cooling systems.

Improved operating efficiencies. With low volume the economies are less of a driving factor. Technology will drive.

More efficient, cleaner-burning engines: horsepower per pound will increase.

Low reciprocating mass for less vibration and improved performance. Cost will remain a challenge in the year 2000.

Lower reciprocating mass with non-metallic components; much benefit in smaller engine package. Can operate with higher combustion temperatures and possible radiator elimination with ceramic components providing insulation against heat.

Lower mass reduces need for counter balance shafts, etc.

Comparative reduction in weight versus cost to reduce weight in other areas of the vehicle.

The need to reduce weight of engine can and probably will be met by substituting aluminum for cast iron, hence need for extensive use of ceramics is decreased. Technical feasibility is real but manufacturing costs will be high for ceramics.

Discussion

Weight reduction, improved operating efficiencies, and the ability to function under higher operating and underhood temperatures are the leading forces driving the development of non-metallic engines. Lower cost was also indicated as an incentive to develop non-metallic engines. Within the lower cost group, approximately half of those panelists felt that a decrease in cost could be realized from less expensive mass production manufacturing processes. Nine percent (9%) of the panelists, however, felt that cost would remain a disincentive for non-metallic engine development well past the year 2000.

Within the panel group specifying higher operating temperatures, 29% suggested that low metallic content engines could reduce or eliminate the cooling system in some engine types.

A survey of engine components and possible materials/processes which could be involved in the development of low metallic weight engines can be found in TECH-40.

Strategic Considerations

The broad support for a number of key factors that will benefit from a low metallic content engine suggests that there are widespread concerns about present engine materials and their performance in the engine. Some of these factors such as reduced weight efficiency improvements and higher operating temperatures would suggest plastics and/or ceramic-type materials.

MAT-9. What application of ceramic materials do you foresee in spark-ignited and diesel engines? Do you foresee other non-engine automotive applications for ceramics?

Ceramic Components in Spark-Ignited Engines	Percent of Respondents for Each Variable
Exhaust system insulation: manifold and port liners, catalytic converter, beds, pipe lining	69%
Piston crown	61
Valve train components where severe temperature and/or wear is encountered: valves, lifters, inserts, guides, seats, tappets, camshaft, cam follower, roller follower, etc.	42
Turbocharger turbine	15
Piston pins	10
None	5
Other responses, each accounting for 4% or less of the total responses: block, cylinder heads, crankshaft, gears, sleeve liners, fuel injector nozzles, sealing elements, bearings	

Representative Responses

SiC-reinforced connecting rods using low cost SiC grinding media-type reinforcement. (can't see cost of SiC "whiskers" coming down).

I think there is a great possibility that certain areas of the engine can be totally made from ceramics.

Potential for ceramic-coated steels is great.

Main benefit would be light engines if cooling jacket can be reduced through the use of heat-resisting components.

Ceramic parts may find application in transmission wear applications later on.

Ceramic Components in Diesel Engines	Percent of Respondents for Each Variable
Piston crown	35%
Valve train components where severe temperature and/or wear is encountered: valves, lifters, inserts, guides, seats, tappets, camshaft, cam follower, roller follower, etc.	20
Exhaust system insulation: manifold and port liners	20
Combustion area insulation coatings: firedeck, pre-combustion chamber, combustion chamber	8
Turbocharger turbine	8
Cylinder liners	8
Piston pins	6
None	6
Other responses, each accounting for 4% or less of the total responses: adiabatic engine components, fuel system (injector) components, head shields, connecting rods, bearings, particulate traps, push-rod tip	

Representative Responses

Ceramic-coated piston heads, valves, and cylinders could improve heat retention in the engine thereby improving efficiency.
Combustion chamber, if fuel efficiency of adiabatic engine is really much greater than conventional engine.
Applications will be made; less obviously in the combustion chamber due to fracture issues being worked on.
Ceramics are a long way off.
Long range: fifteen to twenty years.

Other Non-Engine Automotive Applications

Bearings for suspension systems and steering
Heat protection areas
Transmission seals

Pulleys for A/C, power steering, alternator
Transmission case
Sensors, magnets, wave guides, and electro-optic relays

Discussion

This question provides a broad review of expectations for the commercial application of ceramic components for both spark-ignited and diesel engines. In addition, other non-engine automotive applications for ceramics are suggested. Also see TECH-46.

Comparison of Replies to TECH-46

The leading four ceramic components in spark-ignited engines forecast by the Technology panelists (piston crown, exhaust system insulation, valve train components, and turbocharger turbine) are identical with the leading four ceramic engine components forecast by the Materials panelists.

With respect to diesel engines, the five leading ceramic engine components forecast by the Technology panelists (piston crown, valve train components, combustion chamber, turbocharger turbine, and exhaust system insulation) are identical with the five leading components forecast by the Materials panelists.

Comparison with Previous Delphi Surveys

In the 1983 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?* Despite the difference in the wording of the questions in the two Delphis, the results demonstrate a striking concurrence, i.e., the top five engine components for both spark-ignited and diesel engines listed in Delphi IV are essentially the same top five components listed in Delphi III. The median year forecast in Delphi III for these components to achieve commercialization was 1990.

Strategic Considerations

There continues to be optimism for ceramic materials in a variety of engine components. Of course it must be recognized that the in-chamber insulation qualities of ceramics in gasoline engines may not be as attractive as in diesel engines because of engine octane requirement problems. It does appear that the applications are focused on relatively low-mass regions, although turbocharger turbine and piston crown are reasonably significant individual components. The major thrust seems to be in temperature control and friction/wear reduction. Obviously, manufacturing considerations are extremely important with regard to ceramic materials, as is the long-term durability capability. We sense that there is a somewhat more focused optimism than in the past.

MAT-10. What percentage of U.S.-produced, light-duty vehicles manufactured in model years 1990 and 1995 will use aluminum radiators?

	Percent U.S.-Produced Vehicles			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Passenger cars with aluminum radiators	50%	75%	30/80%	50/95%
Light trucks with aluminum radiators	40	60	33/50	50/80

MEDIAN FORECAST FROM THREE DELPHI SURVEYS
PERCENT U.S.-PRODUCED LIGHT-DUTY VEHICLES WITH
ALUMINUM RADIATORS IN 1990

	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Passenger cars with aluminum radiators	50%	25%	50%
Light trucks with aluminum radiators	40	20	40

Selected Edited Comments

A percentage of vehicles will utilize adiabatic engines and ebullient cooling.

Discussion

The panelists forecast that 50% of U.S.-produced passenger cars and 40% of U.S.-produced light trucks manufactured in 1990 will use aluminum radiators. This percentage grows to 75% of passenger cars and 60% of light trucks by the year 1995. The interquartile ranges for passenger cars are quite broad, whereas the interquartile range for light trucks indicates a fair consensus.

Discussion of Panelists' Comments

The single comment suggests the commercial development of new engine technologies that could have a profound impact on the radiator industry.

Discussion of Vehicle Manufacturers and Supplier Panelists

The manufacturer and supplier panelists are in agreement on the percentage of passenger cars and light trucks that will use aluminum radiators in 1990. For 1995, there also was agreement between the two groups with respect to passenger cars. For light trucks, however, the median forecast for the manufacturers was 80% with an upper quartile range of 100%. This indicates that 25% of the OEM panelists felt that 100% of the light trucks manufactured in 1995 will use aluminum radiators. The supplier panelists forecast a median of 50% with an upper quartile range of 70%.

Trend from Previous Delphi Surveys

The Delphi IV forecast for aluminum radiators in 1990 U.S.-produced passenger vehicles has returned to the earlier projections of Delphi II.

Strategic Considerations

Based on the data in this question there appears to be a clear trend to aluminum in radiators both in passenger cars and trucks. Recently, we have been engaged in a detailed study of copper use in vehicles and also conducted a similar study about five years ago. This study certainly supports the general trend to aluminum in radiators. However, the ultimate winner is very difficult to define. One automotive manufacturer is committed long term to copper. Another is committed to aluminum and is installing capacity to support that commitment. Yet another seems to have embraced a dual strategy. Both materials appear to have advantages and disadvantages in this application. Indeed, a key factor may be a long-range perception of the commodity pricing of the base materials.

MAT-11A. What percentage of light-duty vehicle engines produced in the U.S. in 1990 and 1995 will utilize aluminum cylinder heads and/or blocks?

	Percent U.S.-Produced Light-Duty Engines			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Aluminum Heads	50%	70%	40/60%	70/80%
Aluminum Blocks	20	40	10/20	20/50

Selected Edited Comments

Major weight-savings potential, proven technology.

I expect strong trend towards aluminum heads and/or blocks in the area of heavy-duty diesels by 1990-1995.

Relaxation of CAFE will slow switch to aluminum block.

Discussion

Median responses indicate a steady growth in the use of aluminum cylinder heads and blocks in U.S.-produced, light-duty vehicles with a forecast for aluminum heads of 50% and 70% for 1990 and 1995, respectively. Aluminum blocks are forecast to be 20% in 1990 and 40% in 1995. The interquartile ranges for aluminum heads in 1990 and 1995 and blocks in 1990 are very tight indicating a good consensus for this growth. The interquartile range for blocks in 1995 is somewhat broader indicating some degree of uncertainty on the lower end.

Discussion of Panelists' Comments

The first two comments support a steady growth potential in aluminum heads and blocks. The last comment presents an interesting possible inhibition to this growth.

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer and supplier panelists are in general agreement on the percentage of light-duty vehicles that will utilize aluminum heads in 1990 and 1995. As for the percentage of aluminum blocks, the suppliers are in close agreement with the median forecasts presented, whereas the manufacturer panelists' forecasts are one-half the median values for each year.

Comparison of Replies to TECH-39A

The Materials panelists forecast significantly higher utilization of aluminum heads and blocks than did the Technology panelists.

	Percent Aluminum Heads			
	Median Response		Interquartile Range	
Panel	1990	1995	1990	1995
Materials	50%	70%	40/60%	70/80%
Technology	35	60	30/40	40/65
	Percent Aluminum Blocks			
Materials	20	40	10/20	20/50
Technology	10	15	5/10	10/20

Trend from Previous Delphi Surveys

This is the first time the percent utilization of aluminum heads and blocks was asked of Materials panelists. Delphi trends from three previous Technology panels are presented in the following trend table.

MEDIAN FORECAST FROM THREE TECHNOLOGY DELPHI SURVEYS
U.S.-PRODUCED LIGHT-DUTY VEHICLE ENGINES WITH
ALUMINUM HEADS AND BLOCKS IN 1990

	1981 Delphi II	1983 Delphi III	1986 Delphi IV
Aluminum Heads	50%	30%	35%
Aluminum Blocks	15	10	10

Strategic Considerations

The substantial fraction of aluminum heads expected supports the high level of engine redesign noted earlier. Another key issue relates to the casting technology required to meet the demands of cost and more precise engine requirements.

The integral head/block engine may begin to emerge in the early 1990s and aluminum will be the material of choice in this design.

MAT-11B. Of the percentage of aluminum blocks (if any) forecast in MAT-11A, please distribute your forecast percentage for sleeving material among the following.

	Percent Aluminum Blocks			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Unsleeved	10%	30%	0/10%	20/30%
Cast Iron Sleeves	80	70	70/90	40/80

Other sleeving materials suggested by panelists include: aluminum-ceramic composite or high silicon aluminum alloy, ceramics, 390 aluminum, coated aluminum.

Selected Edited Comments

Cast iron sleeve will be largely replaced by other ways of providing adequate bore surface by 1995-2000.

Quest for lighter weight blocks will require shift to aluminum blocks and heads. Most aluminum blocks to be sleeved.

[In response to the following Round 1 comment: "390 aluminum is too expensive to make a complete block"]: . . . was in production for GM Vega and is still used in Porsche.

Discussion

Median responses indicate that cast iron sleeves are expected to remain the dominant sleeving material through 1995. The interquartile ranges for unsleeved and cast iron sleeves for 1990 are tight indicating a good consensus for those forecasts. The interquartile range for cast iron sleeves in 1995 is much broader, particularly on the low end. Given the broader low-end interquartile range for 1995 and the failure of the medians for 1990 to add to 100%, materials listed under "Others" deserve attention as possible future sleeving materials.

Discussion of Panelists' Comments

The first comment may be a harbinger of future developments in sleeving materials referred to in the "Discussion" above.

Comparison of Vehicle Manufacturers and Supplier Panelists

There are no significant differences in the forecasts of the two groups for the percentage of aluminum blocks that will be unsleeved in both 1990 and 1995. The manufacturer panelists forecast a 10% higher percentage of cast iron sleeves for each year than are reflected in the median values. The supplier panelists are in agreement with the median for 1990 but forecast only 50% cast iron sleeves in 1995.

Comparison of Replies to TECH-39B

The Materials panelists forecast a significantly higher use of unsleeved engine blocks than did the Technology panelists.

	Percent Unsleeved			
	Median Response		Interquartile Range	
Panel	1990	1995	1990	1995
Materials	10%	30%	0/10%	20/30%
Technology	5	10	0/10	5/20
	Percent Cast-Iron Sleeves			
Materials	80%	70%	70/90%	40/80%
Technology	90	80	80/99	60/90

Strategic Considerations

It is evident that some of the early problems with unsleeved engines have not been put aside despite the success some foreign manufacturers have had with this design. With "proving" of unsleeved technology, it might be expected that unsleeved designs could expand beyond the forecast percentage. Emphasis on quality and longer warranty period will definitely make manufacturers cautious about introducing uncertain technology.

MAT-12. Of all the steel used in the average U.S.-made light-duty vehicle, what percent of the following types do you foresee being utilized in the years indicated?

	Percent Steel Utilized in Light-Duty Vehicles			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Flat Rolled	75%	75%	70/77%	75/80%
Bar and Rod	10	10	10/10	8/10
Forgings				
Hot	3	2	2/3	2/3
Warm	2	1	1/2	0/4
Cold	1	2	1/1	2/2
Powdered Metals				
Normal density	1	1	1/1.5	0.6/2
High density	0.5	1	0.5/1	1/1
Forged	1.5	2	0.5/2	0.5/2
Other: Castings	6	6	5/12	4/10

Selected Edited Comments

Better controlled high strength steel will be available and will help maintain a steady demand for steel products. Stampings can replace some castings as in manifolds.

Steel forged camshafts, finish ground and then hardened will replace cast iron camshafts that are machined, hardened, and ground. However, composite camshafts (forged lobes on hollow tubes) will also enter market.

Some bar and rod products could be combined with forgings. Impact of Japanese-manufactured vehicles in U.S. and their use of materials could impact the 1995 percentage significantly.

Greater use of stampings to replace forgings. Greater use of tubing made from flat rolled to replace bar.

Discussion

Materials panelists' forecasts for the types of steel indicate little change between 1990 and 1995. The interquartile ranges for all the types of steels listed are very tight indicating a high degree of consensus among the panelists regarding the median percentages.

Discussion of Panelists' Comments

Some of the comments reflect a general opinion that stampings will gradually replace forgings/castings in some automotive components. Also, the impact of Japanese "transplants" on materials usage is reiterated.

Comparison of Vehicle Manufacturers and Supplier Panelists

The forecasts of the respondents representing the automotive supplier industry were in very close agreement with the median forecasts presented for types of steel that would be used in U.S.-produced, light-duty vehicles. The manufacturer panelists' responses are in some cases sufficiently divergent from the combined median forecast to warrant description in the table below.

Percent Steel Utilized in Light-Duty Vehicles

	Median Responses of Panelists Representing OEMs	
	1990	1995
Flat Rolled	65	55
Bar and Rod	10	5
Forgings: Warm	0	0
Powdered Metals:		
Normal Density	0.5	0.5
High Density	0.0	0.0
Forged	0.5	0.0

Strategic Considerations

As evidenced in the data, relatively little shift is forecast; although on a percentage basis significant changes are envisioned in such relatively minor areas of steel use as forgings. It is also evident, from other aspects of this study, that steel will continue to be overwhelmingly the dominant material in passenger cars through 1995 and that the character of steel will undoubtedly change with more electro-galvanized steel and a greater use of higher alloy content product. It is also clear from progress being made in the overall production system—from the ore pile to the metal fabricating plant—that the quality aspects of steel are being significantly improved to better facilitate the production of quality components. The relatively small forecast change in use probably reflects the substantial changes occurring in the overall production system.

MAT-13. Of the automotive plastic envisioned (weight basis) for 1990 and 1995, estimate the percentage falling into the following classes.

	Automotive Plastic Envisioned (Weight Basis)			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Thermoplastic	65%	65%	20/80%	50/80%
Thermoset	35	35	20/75	20/50
Filled	70	60	50/80	40/80
Unfilled	30	40	20/50	20/60

Selected Edited Comments

New, low cost, filler and processing will decrease cost of filled polymers.

Thermoplastic/Thermoset: The development of new materials and/or new processing methods will change the picture. Filled/unfilled: It depends on one's definition. Pigments are "fillers" too.

Discussion

This question was asked in an attempt to give some sense of direction between the competition among various plastic materials. Thermoplastic, for example, in both 1990 and 1995 is approximately viewed as a 2:1 favorite over thermoset. Similarly, filled plastic is almost a 2:1 winner over unfilled in the same time frame. However, the interquartile ranges are very substantial and would indicate that there is a high degree of uncertainty on these matters. One area of particular concern is the variety of definitions that appear to exist in the general area of the polymer materials thereby causing some uncertainty in the interpretation of these data.

Comparison of Vehicle Manufacturers and Supplier Panelists

The percentage of plastic on a weight-basis forecast by the manufacturer and supplier panelists are detailed in the following table.

	Median Response		Interquartile Range	
	Manufacturer	Supplier	Manufacturer	Supplier
1990				
Thermoplastic	80%	30%	80/85%	20/70%
Thermoset	20	70	15/20	30/70
Filled	60	70	15/80	50/70
Unfilled	40	30	20/70	20/50
1995				
Thermoplastic	80	50	75/85	50/80
Thermoset	20	50	15/25	20/50
Filled	45	65	40/50	50/90
Unfilled	55	35	20/60	10/50

As is evident from the above table, the panelists represent the OEMs and are in relatively good agreement with the medians for thermoplastics and thermosets in both 1990 and 1995. Additionally, there is a very tight interquartile range for both years. In contrast, the forecasts from supplier panelists are substantially less than the medians with a much broader interquartile range.

With respect to filled plastics in particular, the manufacturer panelists envision significantly lesser percentages than the median values. For both groups in both categories, the broad interquartile ranges indicate a considerable degree of uncertainty. In this case perhaps the last panelists' comment may be relevant.

Strategic Considerations

The responses to this question provide a sense of direction between broad classes of plastics. While the results suggest general consistency from 1990 to 1995, the pace of new developments could alter this forecast substantially. The huge disparity between manufacturers and suppliers in this forecast suggests that the results are inconclusive.

MAT-14. What is your forecast for the material mix of steel, aluminum, and polymer-based composites used in frame/structural members in integral body/frame and in space frame designs in the following years?

Median Response

	Integral Body/Frame		Space Frame	
Material Mix	1990	1995	1990	1995
Steel	95%	85%	90%	80%
Aluminum	4	10	7	10
Composites	1	5	3	10

Interquartile Range

Steel	90/95%	85/90%	80/92%	70/85%
Aluminum	3/10	5/12	5/10	5/15
Composites	0/2	3/10	0/3	5/15

Selected Edited Comments

Steel will remain competitive if processing costs can be reduced. Aluminum will score in engine compartment. Not in body/frame.

Flexible materials will be reasonably applied to horizontal panels, and the space-frame structure is suitable for attaching those flexible panels. Therefore, the space-frame might get more percentage than the integral body-frame.

Programs already in place will provide initial experience to produce future vehicles from composites. The driving factors of low tooling cost, design flexibility and the high potential for automation will make such vehicles an economic reality.

It depends on the development of new technology.

Metal matrix composites are a very effective way to reduce vehicle weight.

Steel will remain the dominant material in frame/structural applications due to cost, reliability, availability of processing equipment (stamping presses) and repairability.

Structural plastic composites are attractive for energy absorption in impact test. This could be additional "value-added" driving force for lightweight vehicles of 1990s.

Composites will replace steel in structures by the year 2000. Parts integration reduces tooling costs in the form of fewer tools needed and fewer tool setups. Space-frame structure will facilitate modular assemblies and allow purchasing of major systems from suppliers.

New fabrication and joining techniques will make steel very cost competitive with composites for structural applications as well as being performance competitive. Steel will remain the predominant material used in unibody construction due to material interfaces, joining problems, and the cost of redesign. Composites for structural applications will not be economically feasible until the early 1990s. Even then they will be used sparingly due to production changeover problems.

Plastics will require years of testing; liability too great, incentives (cost/weight) are very low.

Steel will remain the dominant material in frame/structural applications due to cost and reliability.

Discussion

The panelists forecast that between 1990 and 1995, an increasing utilization of aluminum and composites is expected to significantly impact the use of steel in both integral body/frame and space-frame designs.

Discussion of Panelists' Comments

It is of interest to note that although the median forecasts of the panelists for the material mix of integral body/frame and space-frame designs indicate an increasing utilization of aluminum and composites at the expense of steel, the comments are, generally, not in support of that conclusion. The predominate comment is that for a variety of reasons, steel will remain the dominate material in frame/structural applications.

Comparison of Vehicle Manufacturers and Supplier Panelists

There is no significant difference between the responses of the two panelist groups.

Comparison of Replies to TECH-17

In the integral body/frame material mix, the Technology panelists forecast a higher percentage for composites in both 1990 and 1995. The Materials panelists forecast a higher percentage of steel in space-frame designs for both years than did the Technology panelists. See table below.

	1990 Forecast		1995 Forecast	
Integral Body/Frame	Technology Panel	Materials Panel	Technology Panel	Materials Panel
Steel	90%	95%	80%	85%
Aluminum	5	4	10	10
Composites	5	1	10	5
Space Frame				
Steel	85%	90%	70%	80%
Aluminum	10	7	15	10
Composites	5	3	15	10

Strategic Considerations

Steel is expected to remain the overwhelmingly dominant material in the integral body/frame and space frame. However, there is surprising support for both aluminum and composites in these applications. Whether this means that steel will be interfaced with aluminum and composites in the same frame, or frames will be either aluminum or composite intensive, is not clear. In any event, these numbers suggest that this materials competition in structures must be watched very carefully. The strong optimism for these materials suggests that some of the key breakthroughs may already have been made in these areas.

MAT-15. What annual volume is the crossover point between plastic or steel exterior panels?

	Units Per Year: Plastic/Steel Panels	
	Median Response	Interquartile Range
Crossover point	80,000	60,000/100,000

Selected Edited Comments

Although plastic developments will tend to increase the crossover volume, the highly efficient practices of the Japanese in converting steel are likely to push the crossover volume to lower levels in future years as Japanese technology/procedures are adopted in North America.

Cost of dies and increased design flexibility will drive market.

Fabrication costs plus end-use performance are the drivers toward plastic skins.

In reality, it depends on the type of plastics and the processing method.

Lower cost stamping dies will drive breakeven down.

Plastic process development to shorter cycle times will have a major impact on this estimate.

Plastic panels will compete head-on with steel at virtually any volume whether as low as 5-10,000 for specialty vehicles or as high as 300,000+/year.

Plastic process development to shorter cycle times will have a major impact on this estimate.

Significant improvements can be made in reducing steel stamping costs.

The cost and number of steel stamping dies for a part will come down, but by using new plastics technology, one mold will produce over 150,000 parts and this mold will always be less costly than a line of steel stamping dies. Plastic material costs are competitive with steel costs on a part-to-part basis, and processing costs will become competitive in the future based on current developments.

We should add the cost of anti-corrosion treatment to the cost estimation of steel exterior panels.

20,000 if best steel die technology is used. 100,000 if we stick to our antiquated processes.

My volume estimate is due to steel die costs of double what they should be, and inefficient manufacturing of parts made of steel.

The volume varies significantly with the manufacturer and the type of dies used to process either material.

New technology (especially processing) will change the volume.

Discussion

Panelists' comments provide a fair analysis of the factors affecting the steel/plastics exterior panelists decision. Note particularly that steel forming improvements may be lowering the crossover point.

Comparison of Vehicle Manufacturers and Supplier Panelists

The responses of both the panelists representing the OEMs and the suppliers were identical and in agreement with the median forecast.

Strategic Considerations

Recent strong efforts by the steel industry and metal fabricators to slow these trends have, in our opinion, been quite successful. However, these data suggest that the struggle is far from over.

It is becoming clear from international data that the efficiency with which the U.S. fabricates steel is considerably less than it should be. That is, the relative costs of our steel fabrication are still too high. It is imperative that manufacturers not attempt to solve a management problem in steel processing with substitution of plastics if that will lead to a sub-optimum solution. Emphasis must be placed on comparing materials with world-class, state-of-the-art processing. An imponderable in the materials battle is the role of the customer. At the present time the consumer does not appear to be placing value on the particular materials used in today's products. However, this could change and could immediately skew the materials picture in the future.

MAT-16. The productive volume crossover point between plastic and sheet steel exterior panels is apparently based upon the upon the type of plastic. Please estimate the breakeven point for the following plastics today and what it will be in 1995.

Breakeven Point for Plastics *(Units)*

	Median Response		Interquartile Range	
	Today	1995	Today	1995
SMC	60.000	50.000	60,000/100,000	40.000/180.000
Thermoplastic	100.000	200.000	50.000/130,000	80,000/200.000
RIM	100,000	150,000	100,000/175,000	70,000/225,000

Selected Edited Comments

Depends upon specific raw material cost and process cycle time. Also depends on design and parts consolidation.

I disagree with the general statement—the complexity of the tooling, tooling cost and lead time to construct dies to stamp steel and the cost of automation equipment to handle stampings between die stages have a larger impact on crossover volume than the type of plastic.

It is doubtful that a meaningful estimate can be obtained without considering the design or complexity of the part.

The use of plastics and composites will make production plants smaller and easier to change over. Necessary volumes will be related to the amortization of tools. Molds will be manufactured differently in future (i.e., with higher powered CO_2 lasers). Each plate's hole will be cut out, then attached and welded, and final finished thereby reducing the time to rough cut molds.

The volume crossover point is highly dependent on the part in question as well as the plastic material. Developments in the areas of part design and tooling for the manufacture of steel parts will reduce the volume crossover point, or at least balance the developments in plastic technology.

These are volumes where steel panel costs equal the specific plastic. At higher volume, steel is less costly. At lower volume, plastic parts are less costly.

Discussion

From the responses to this question it is clear that volume trade-off between plastics and steel is a significant issue in the automotive industry and there is a relatively broad range of opinion on this important matter. In both thermoplastics and RIM the view is that by 1995 the breakeven point will have moved to substantially higher volumes than today, whereas for SMC the volume break point will be lower. The higher breakeven point is an indicator that plastics are becoming more competitive with steel. SMC exhibits a far lower breakeven point of 60,000 units per year and this is reduced in 1995 to 50,000 units. The comments offered in response to this question are very pertinent and should be looked at very carefully.

Comparison of Vehicle Manufacturers and Supplier Panelists

A substantial portion of the forecasts of the manufacturer and supplier panelists are sufficiently divergent from each other and the combined medians to warrant a tabular description for comparison. The data are presented in the following table.

	Today		1995	
	Manufacturer	Supplier	Manufacturer	Supplier
SMC	40.000	90.000	50.000	40.000
Thermoplastic	150.000	100,000	150.000	200,000
RIM	60.000	90.000	50,000	200,000

It should be noted that in some cases the median response of a particular panelist group may be either greater or less than the quartile ranges evidenced in the combined interquartile range. The upper and lower quartile ranges indicate that 25% of the respondents forecast a value that was either equal to or more/less than the median. As with the median values, it is possible that the upper and lower quartile may be either greater or less than the quartile ranges of a combined response. Such a difference demonstrated by a particular panelist group merits serious attention when considering the overall implications of the combined data.

Strategic Considerations

The issue of the plastics/steel tradeoff will continue to grow in importance as our knowledge concerning plastics increases and the steel production/fabrication system is better understood. It should be noted that Toyota, as an example of a major foreign manufacturer, suggested that the breakeven point between steel and plastics is approximately 10,000 units. This would infer that they are either very strong at producing components from steel or quite inferior at making them from plastic. We believe that their proficiency in utilizing steel is the key factor in this regard and suggests that steel is going to become a much more formidable and competitive target for plastics than was envisioned just several years ago. The issue is extremely complex and bears careful watching by all those that are associated with materials aspects of the automotive industry.

MAT-17. Other than volume, what factors are important in the selection of plastics or steel for body exterior applications?

In considering factors important in the selection of plastics or steel for body exterior applications, the following four factors accounted for approximately one-half of the total panelists' responses.

- Cost
- Surface quality, i.e., the ability to provide a Class A finish
- Weight reduction
- Styling/design flexibility

Other factors cited by the panelists are rank ordered as follows.

Corrosion
Ability to provide desired color at assembly-line speed
e.g., mold-in color or on-line painting
Lead time for tooling
Durability (damage resistance)

Speed of assembly
Repairability
Potential for parts consolidation
Consumer perception/acceptance

Strength
Capacity
Corporate considerations and attitude
Temperature flexibility

Number of manufacturing operations required
Dimensional stability
Recyclability
Fuel prices

The groupings of responses are the result of integrating the various responses of the panelists. Therefore, in order to provide as much insight as possible into the thoughts of the panelists, "Representative Responses" are presented in lieu of "Selected Edited Comments."

Representative Responses

Auto manufacturers' personnel attitudes, die cost, component part manufacturing costs, and material price.

Customer acceptance. Existing capacity for steel, limited capacity for plastics.

Repair in field, forming characteristics.

Total cost is still the bottom line. This is affected by parts integration, facilities amortization, tooling, etc.

Flexibility over wide ambient temperature range, resistance to hostile environments (sun, salt, snow, rain).

Ability to reduce manufacturing labor, parts consolidation potential.

Ability to obtain good surface finish for painting and good paint adherence. Resistance to dents and impact damage. Ease of repair.

Long-range design plans (i.e., face lifts).

First time through capability.

Color stability over time.

For plastic: design flexibility, lower tooling cost, light weight, rust protection, reduced number of operations, better quality, ability to mold "contiguous" where you want to use them. Potential cost savings.

Internal corporate political considerations, potential for part consolidation with plastic, potential for molded-in color with plastic, reduced tooling time, and cost for the production of plastic panels.

Lead time for tooling (less time required to tool for plastics than for steel).

Quality in terms of corrosion resistance and surface appearance, design flexibility in terms of form and function.

Model flexibility: Fiero plant produces three different models under 100K units a year. Cost of paint facilities.

Tool cost is lower for plastic versus steel. Timing: plastic tooling offers quicker turnaround. Design versatility: plastics are more easily styled, decorated, and parts integration is easier. Weight: plastics are 40% lighter than steel. Corrosion: no galvanizing required with plastics. Damage resistance: plastics don't dent.

Strategic Considerations

The most important factors supporting the use of plastics for body exterior applications are hardly new ideas but rather serve to reinforce generally held beliefs. Of course, other factors could materialize rather quickly that could alter this list. For example, if the ultimate vehicle customer perceived substantial added value in a ding-resistant plastic door, other factors could diminish very rapidly in importance. We fully expect fierce competition between steel/plastics during the next ten years. This will undoubtedly lead to very substantial improvements in overall vehicle cost, quality, and performance.

As noted earlier, because we are at a very early stage of development in many types of plastics, innovations in the plastics industry must be watched very carefully. This would suggest that future progress could move the industry along a learning curve, rapidly reducing costs and altering the priority of the list rather significantly. There is no question that this will be a very complicated and interesting issue to follow in the years ahead.

MAT-18. Indicate the influence of the following factors on the selection of steel and plastic exterior body panels.

Influence on Selection of Steel and Plastic Exterior Panels	Percent of Total Responses Per Variable: Steel			Plastic		
	High	Medium	Low	High	Medium	Low
Cost	82%	9%	9%	68%	32%	0%
Surface finish	78	18	4	70	26	4
Strength	57	13	30	9	56	35
Panel color	36	9	55	24	38	38
Durability	35	43	22	52	31	17
Plant capacity	35	22	43	35	35	30
Corrosion resistance	30	30	40	61	22	17
Repairability	23	41	36	30	40	30
Consumer acceptance	23	32	45	46	36	18
Styling	9	59	32	64	22	14
Styling flexibility	9	36	55	78	9	13
Recyclability	4	35	61	13	52	35

Selected Edited Comments

Part design and the resultant tooling complexity will play a key role in the material/process selection.

Discussion

Steel and plastics are selected, in part, for similar reasons. For example, cost and surface finish are high-ranking considerations for both materials. In contrast, styling flexibility, the highest ranking factor for plastics, rates near last place for steel; while strength, an important consideration in choosing steel, ranks last for plastics.

Other similarities and differences in factor ranking reflect the related characteristics of the two materials. But the meaning of the relative rankings is not always obvious. For example, corrosion resistance ranks higher for plastics than steel because plastics are better in this aspect; but consumer acceptance is higher in influencing the plastic choice because some consumer perceptions may be negative with regard to plastics.

Strategic Considerations

The response to this question strongly suggests that the materials selection process is, indeed, a systems problem that involves a number of important factors from cost and surface finish to durability and styling flexibility. Because of the present intensity of this competition, it is important to study these opinions carefully and to recognize that they are subject to change on relatively short notice. Two key factors are the rapid movement on the learning curve of plastics and the significant reformation occurring within the steelmaking and processing industry. The ultimate winner between these materials is too close to call.

MAT-19. Please rank order on a total scale of 100% the importance of the following factors in the competition between plastics and steel for body exterior application for the years indicated.

Percentage of 100% Scale

Factor Importance: Plastics/Steel for Body Exterior

Factor	Median Response 1990	Median Response 1995	Interquartile Range 1990	Interquartile Range 1995
Material cost	30%	20%	20/50%	13/30%
Surface quality, i.e., the ability to produce a Class A finish	20	20	15/30	15/20
Weight reduction	10	10	10/15	5/15
Corporate attitude and policy	10	5	8/10	2/10
Corrosion	8	8	5/15	5/20
Investment costs of tooling	5	10	5/30	5/16
Styling/design flexibility	5	8	5/15	5/15
Capacity	5	5	2/10	1/10
Lead time for tooling	3	3	0.5/10	0.5/12
Repairability	2	5	0.5/5	1/5
Recyclability	1	5	0/1	2/5
Mold-in color	1	1	0/3	0/5
TOTAL	100%	100%		

Selected Edited Comments

Quality and investment will dictate ratio. Plastics must standardize to really compete with steel.

The ranking may be significantly different for foreign car manufacturers since "material" decisions will still be made offshore even for transplant operations in the U.S.

This subject has not been studied rationally, many decisions being made without care and thorough study. This is changing mainly because of Japanese competition.

Strategic Considerations

It is evident that a wide array of factors have a very strong influence on the competition between plastics and steel. Although diminishing slightly as a factor by 1995, material cost is expected to remain an extremely important factor for the foreseeable future. Of course, improvements in both steel and various basic plastic materials technology, as well as processing technology, will undoubtedly continue to make the choice between sheet steel or plastic difficult and highly volatile in the years ahead. In general, it has been interesting to note that some of the assumptions of only two years ago have changed rather dramatically in terms of the relative competitiveness of these two basic material types.

MAT-20. In what year will the first production vehicle with a polymer-based composite body *structure* be produced?

	Year of Production	
	Median Response	Interquartile Range
Vehicle with polymer-based composite body structure	1995	1992/1995

Selected Edited Comments

All major domestic producers (GM, Ford, and Chrysler) have ongoing programs and have investigated aerospace firms for design help. Resin transfer molding, with fiber preform, appears to hold great promise for the automotive requirements. This change in manufacturing will revolutionize manufacturing plants as we know them.

Composite body structure will require new technology.

I would expect about two to three total design cycles to be required.

Repairability may be a key issue.

Substantial work will be required on joint fatigue performance and crashworthiness.

Discussion

The panelists forecast that 1995 will be the year in which the first production vehicle with a polymer-based composite body structure will be produced. The interquartile range is tight, indicating a good consensus among the panelists for the median year indicated.

Additional information regarding composite-based body structures may be obtained by consulting TECH-16 (space-frame construction, impact on materials and design) and TECH-17 (material usage, frame and structural members).

Discussion of Panelists' Comments

The first comment reflects the enthusiasm held in some sectors of the automotive industry for the future of polymer-based composite body structures. The remaining comments address the reservations held by others and note some of the remaining impediments to a greater utilization of composites in body structure.

Strategic Considerations

The forecast for the 1995 introduction of polymer-based composite structure appears to be quite optimistic. However, there is rather tight and strong consensus that this will occur by the middle 1990s. Obviously, development of a vehicle of this type could have a dramatic impact on the overall trends and vehicle design should it be successful and broadly applicable to a range of vehicles. Developments must be watched very closely in this area because of the potential impact on so many different aspects of the vehicle.

MAT-21. **What components do you believe will be produced completely or in part from thermoplastics in the years 1990 and 1995?**

1990 Thermoplastics

Sheet Applications	Percent of Respondents
Exterior body panels (includes quarter panels, fenders, doors, and hoods)	86%
Bumpers	14
Others (each less than 8% total responses): Moldings, grills, cowl vents, fluid housings, rear parcel shelf, trunkliner, interior trays	18

Representative Responses

Body panels in some models.
Skins of all specialty vehicles.
Vacuum formed body panel skins (doors).
Bumper backup beam, glazing, fenderliners, trunkliner, headliner adhesive.

Structural Applications	
Bumper assemblies	91%
Radiator support brackets	45
Springs	36
Wheels	36
Transmission support brackets	36
Driveshaft	27
Seat assemblies	27
Others: Headlamp body, floor pans, underbody panels, load floors, door interior	36

1995 Thermoplastics

In general, the sheet and structural applications of thermoplastics forecast for 1990 are extended and amplified for 1995 with some new applications.

Sheet Applications	Percent of Respondents
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 Application	
Bumper assemblies	40%
Doors	40
Floor pans	20
Others:	
Springs	20
Firewalls, underbody panels, intake manifold engine frame, seat frames, wheels	70

Selected Edited Comments

I believe thermoplastics will be less important than thermosets like reinforced RIM.

Discussion

It is clear that the primary sheet application of thermoplastics through 1995 will be heavily concentrated in exterior body panels and bumper fascia. Although it is forecast that the major structural application of thermoplastics will be in bumper assemblies, a number of other automotive components are also suggested. It should be noted that there appears to be a fair amount of overlap between what the panelists consider to be sheet application and structural application.

Strategic Considerations

One of the major segmentations in plastic materials is between thermoset and thermoplastic materials. The very substantial technical resources of major companies are being directed at each and it is evident from the data in this question that thermoplastics appear to have a substantial potential for a number of key vehicle components. The wide variety of parts suggested are a clue that thermoplastics are considered to be very much a part of the future automotive materials race and developments must be closely watched.

It should be noted that technical advances in any number of materials could significantly alter this list.

MAT-22. What factors limit the automotive industry's ability to use increasing amounts of the following plastic materials in light-duty vehicles?

Limiting Factors	Percent of Total Respondents
Sheet Molding Compound	
Paintability: the difficulty of obtaining an acceptable, reliable surface quality and a Class A finish	74%
Cost	26
Labor content: the necessity for post-molding. hand-trimming	17
Recyclability	17
Cycle time	17
Others (each cited by 10% or less total respondents): Problems associated with fabrication, strength, property variability, process complexity; manufacturing capacity	35
High-Glass SMC Plastics	
Paintability: the difficulty of obtaining an acceptable. reliable surface quality and a Class A finish	34%
Cost	34
Predictability and consistency of material properties	22
Others (each cited by 10% or less total respondents): Low cycle time, formability, fabrication, manufacturing capacity and productivity, post-molding labor, and machinability	39

Selected Edited Comments
For non-show surfaces there are few limitations except capital required and expertise.
Controlling pattern of glass matrix.

Limiting Factors	Percent of Total Respondents
Oriented Glass Reinforced	
Cost	53%
Insufficient manufacturing capacity	18
Lack of process/fabrication technology	18
Cycle time	18
Paintability	12
Others: Inconsistent properties and reproducible results, durability, weight/strength ratio, insufficient process/manufacturing data and engineering	26
Carbon-Fiber Composites	
Cost	100%
Lack of fabrication technology and engineering data	23
Others: Carbon fiber brittleness, performance/durability	10

Limiting Factors	Percent of Total Respondents
RIM Urethane	
Lack of structural strength	32%
Problems associated with paintability and appearance (e.g., surface waviness, etc.)	23
Low resistance to paint baking temperature	18
Cost	18
Post-molding labor (requires hand finishing)	18
Others (each cited by 10% or less total respondents): Dimensional stability, cycle time, quality, strength/elasticity modulus, styling requirements, manufacturing time	32

Selected Edited Comments
Must reduce operation of post-curing.

Limiting Factors	Percent of Total Respondents
Reinforced RIM	
Cost	21%
Surface quality/finish	21
Thermal resistance to painting	21
Lack of structural strength	16
Others (each cited by 10% or less total respondents): Dimensional control, processing cycle time, manufacturing capacity, labor content, number of operations, styling requirements, cold impact, and fiber readout	47

Limiting Factors	Percent of Total Respondents
Structural Foam	
Surface appearance and finish	41%
Slow cycle time/productivity	35
Performance at temperature extremes	18
Structural strength	12
Others (each cited by 10% or less total respondents): Long-term durability, reliability, cost, structure design, brittleness	29

Selected Edited Comments
Surface appearance not acceptable for many show surfaces.

Limiting Factors	Percent of Total Respondents
Compression-Formable Reinforced Plastics	
Inability to achieve a Class A surface appearance	41%
Forming and manufacturing technology	18
Cost	14
Others (each cited by 10% or less total respondents): Manufacturing capacity, properties of the material/technology parts complexity, material development, joining techniques	31

Selected Edited Comments

Cost versus injection molding tooling cost.

Crease line.

Metal-Plastics Laminated

Cost	34%
Assembly problems/lack of expertise in welding/joining material	34
Formability	20
Lamination problems	20
Lack of engineering data and technological development	20
Manufacturing productivity	20
Lack of defined need/product	13

Thermoplastics

Moldability	31%
Cost	25
Thermal properties	25
Dimensional stability and strength/structural stability	19
Engineering experience	13
Engineering facilities	13

Selected Edited Comments

Lack of good molders; major breakthrough of new resins with high temperature resistance and durability.

Selected Edited Comments

Some of the disadvantages of plastic materials apply to many types of materials. However, a primary disadvantage of one type may be a smaller disadvantage to another. Many of these disadvantages apply to several types of plastics: availability, cost, heat sensitive, shrinkage, not recyclable, repairability after crashes, paintability, other environmental.

The overriding problem with all these plastics is lack of production and engineering experience.

For plastics, in general, limiting factors are low-paint baking temperature capability and compatibility with engine environment.

Strategic Considerations

In practically every plastic suggested, cost ranked near the top as a limiting factor. Consequently, cost reduction factors as applied to these various plastic materials must be deemed critical to their ability to make further inroads as an automotive material. All in all, from the broad list for each plastic type, there is a clear indication that there are many challenges for each material as they are examined closely for various automotive applications. Improvements in steel processing capability add to the challenge polymer-based materials face.

MAT-23. If you were planning to invest in one or more plastic suppliers, how would you divide your investments based on their sales prospects in automotive applications?

	Investment Percentage	
	Median Response	Interquartile Range
Sheet Molding Compound (SMC)	25%	5/30%
Thermoplastics	20	5/30
Reinforced RIM	15	5/20
RIM Urethane	15	0/15
Oriented Glass Reinforced Plastics	10	0/10
Carbon Fiber Composites	6	0/10
Compression Formable (Stampable) Reinforced Plastics	6	0/10
Structural Foam	3	0/5
High Glass SMC	0	0/5
Metal Plastics Composites	0	0/5

MEDIAN FORECAST FROM THREE DELPHI SURVEYS
AUTOMOTIVE PROSPECTS FOR PLASTICS

	Forecast at the Time of the Survey		
	1981 Delphi II	1983 Delphi III	1986 Delphi IV
RIM Urethane	20%	14%	15%
Sheet Molding Compound (SMC)	20	10	25
Compression-Formable (Stampable) Reinforced Plastics	10	14	6
Oriented Glass Reinforced Plastics	10	14	10
High Glass SMC	10	11	0
Structural Foam	10	7	3
Metal Plastic Laminates	10	3	0
Carbon-Fiber Composites	5	4	6
Reinforced RIM	0	23	15
Thermoplastics	N.A.	N.A.	20
Other:			
Molded Polycarbonate	5	N.A.	N.A.

N.A. = Not applicable.

Selected Edited Comments

Metal-plastics composites appear to hold much benefit.

Investments should be based on need for technology. The need does exist to develop fiber-reinforced composites not available today. RIM and SMC are old stagnant technologies.

RIM should be the preferred method for auto body skins.

Discussion

Responses to this question indicate that sheet molding compound (SMC) and thermoplastics, individually, have the greatest potential for automotive applications. RIM and RRIM were considered to have the next largest investment potentials. Since RIM usually implies "urethane," the RIM plus RRIM total median of 30% can also be considered a vote for investment in urethane. Despite their promise for engineering applications, carbon-fiber composites and stampable reinforced plastics received only 6% each of the responses; the remaining plastics/composites received 0%–3% of the responses.

The interquartile ranges are all quite broad. The leading choice, SMC, has an interquartile rating that indicates 25% of the panelists would put 5% or less of their investment into SMC. The majority of the materials rated have a lower quartile rating of 0%. If one conclusion can be drawn from these forecasts it is that there is no clear consensus in these projections of automotive potential for the many types of plastics.

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer and supplier panelists were in generally close agreement, with three exceptions listed below.

	Investment Percent	
	Manufacturer	Supplier
Thermoplastics	30%	10%
RIM Urethane	5	14
Carbon-Fiber Composites	0	9

Trends from Previous Delphi Surveys

Significant alterations in investment strategies with regard to automotive plastics application have occurred since Delphi III forecasts were made in 1983. Many plastics/composites expected in 1983 to have significant investment potential demonstrate diminished or negated potential in the current survey. High glass SMC and metal plastics laminates, both considered to have relatively significant investment potential in 1981 are currently considered to have zero potential. SMC is the only plastic to have significantly increased its investment potential since 1983. However, thermoplastics were not included in the previous forecasts.

Strategic Considerations

Sheet molding compound (SMC) appears to be a clear winner with a number of materials in the runner-up spot. Examination of the past Delphi results suggest that this is a volatile area and that thinking could change rather dramatically. Of course new developments in the relatively early history of plastics could lead to substantial alteration of this list and distribution of results in a short time. Stability is not likely to be a virtue of the plastics business with respect to the competition between various materials and processes.

It must be emphasized that because of the highly speculative and qualitative nature of this question, the results should be considered only as a guide to current thinking in the area.

MAT-24. What percentage of fuels will use the following for octane enhancement by 1990?

Octane Enhancement	Percent Usage: Median Response	Percent Usage: 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.

Selected Edited Comments

I believe a combination of MTBE and methanol will increase as an octane enhancer while ethanol and additional refining will decrease.

There is no need for octane enhancement.

Water-hydrogen engines will become common by 1995.

Discussion

The panelists forecast that 20% of fuels will use additives for octane enhancement by 1990. The leading additive, ethanol, is expected to be used in 10% of the fuels, with methanol used in 5% of the fuels. The additives mentioned in "Others" also merit attention for future octane enhancement.

Discussion of Panelists' Comments

The first two comments presented here represent two divergent schools of thought regarding additives for octane enhancement.

Comparison of Vehicle Manufacturers and Supplier Panelists

The OEM panelists forecast that 90% of fuels will use no additives for octane enhancement; 2% will use methanol, and 3% will use ethanol. The supplier industry panelists project that 10% of fuels will use methanol for enhancement of octane.

Comparison of Replies to TECH-47

The two panelists are in agreement on the percentage share of fuels that will use additives for octane enhancement.

Strategic Considerations

We were surprised at the modest expectation for methanol and ethanol as fuel additives for octane enhancement in gasoline because there is a generally substantial supply of alcohols, particularly methanol, in the world market and we expect continued pressures for its use as both a fuel extender and octane enhancer. Also, it is likely that the use pattern could vary substantially with geography in the country. We are convinced that this will be a very interesting development to watch. With even a modest fraction of fuel using methanol. manufacturers will have to produce fuel system components that will withstand the rigors of methanol exposure.

MAT-25. 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?

Likelihood of Production *if* Interruption in Petroleum Supplies	Percent Total Responses for Each Variable			
	Very 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	17	22	44	17
Petroleum-like fuels derived from coal liquids	11	28	44	17
Liquid petroleum gas (LPG)	11	22	50	17
Hydrogen	0	0	44	56

Selected Edited Comments

Water to hydrogen will become common by 1995: no change in technology or production facilities by 1990. We are being lulled back to sleep by the current glut.

Fuels from natural gas is desirable because of low initial costs and large North American capacity. Fuels from coal are undesirable because of high initial costs and environmental concerns.

Discussion

Materials panelists forecast that methanol from either coal or natural gas and/or ethanol would be the most likely to be put into production for automotive fuels in the event of a major and continuing interruption in international petroleum supplies. Coal-derived petroleum-like fuels, natural gas, and LPG each received significant responses. Only hydrogen was considered to be highly unlikely.

Discussion of Panelists' Comments

Considering the responses presented above, the first comment is noteworthy. The second comment presents pertinent insight into the cost factors affecting natural gas and coal liquid fuels.

Comparison of Replies to TECH-48

The Technology and Materials panelists are in agreement on the predominance of methanol fuels as an alternative automotive fuel in the event of a continuing interruption of international petroleum supplies. The Technology panel considered natural gas a strong moderate alternative, whereas the Materials panelists considered the significance of natural gas low. The Technology panelists also considered ethanol to be in the moderate to low range; Materials panelists considered the likelihood for ethanol to be high to moderate.

Comparison of Replies with Previous Delphi Surveys

In Delphi III, Technology panelists were asked to rank possible alternative automotive fuels on a scale from 1 to 4, with 1 equal to the most likely. In spite of the differences in ranking procedures, it is evident that both Delphi III and Delphi IV panelists consider methanol derived from coal or natural gas to be in the very high to moderate range. Whereas Delphi III panelists considered the likelihood of ethanol to be in the very low range, the current Delphi IV Materials panelists considered ethanol to be in the high to moderate range.

Strategic Considerations

Methanol either derived from coal or from natural gas appears to be the most highly favored alternative fuel if there is a major and continuing interruption in petroleum supplies. There would appear to be a growing consensus for methanol throughout the automotive industry and it would indicate, at least subtly, that there is a growing confidence in the long-range energy supply picture. All of the fuels that were suggested in this question are adaptable to spark-ignition engines with relatively minor modification, although in some cases, fuel handling requirements are quite different and in several instances very sophisticated. There is still modest support for ethanol and therefore it would rank second to methanol as a likely future fuel. In all probability, we are not likely to have a multiple fuel strategy because of the complexities in both vehicle design and distribution system. This support for methanol does not suggest that all the problems have yet been resolved, although none of them appears to be of a fundamental nature.

MAT-26. What are the principle advantages and disadvantages of *methanol* 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
		Lower BTU value per gallon	11
		Others: None, Cold weather start-up problems	15

Methanol: Vehicle Perspective

Advantages	% Total Responses	Disadvantages	% Total Responses
Availability at a reasonable/ lower cost	53%	Corrosive nature of methanol/ materials incompatibility	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.

Volatility control economics, water tolerance/handling properties, incompatibility with synthetic materials.

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.

Discussion

The responses to this question are rather predictable and self-explanatory. From a fuel perspective, the principle advantage of methanol is availability at a reasonable cost, i.e., it is a low-cost resource that can be manufactured from a variety of sources and, in addition, contributes to a reduction of this country's dependence on oil/petroleum. Octane enhancement is also an important advantage of methanol from a fuel perspective. The fact that methanol is efficient, clean burning, and easy to blend were also considered by the panelists to be advantages of methanol.

An important challenge to methanol is what can be best described as volatility control economics, i.e., the cost involved with special handling and storage systems. The corrosive nature of methanol, i.e., an incompatibility of methanol with materials used in fuel management systems, also presents a formidable challenge.

From a vehicle perspective, low cost availability is cited as the primary advantage of methanol. The potential for reduced exhaust gas emissions and the ability of methanol to increase power output through octane enhancement also received a significant percentage of the total panel responses.

Almost one-half of the panelists considered the corrosive nature of methanol the most important disadvantage of methanol from a vehicle perspective. This was followed by cold weather starting problems. Engine performance/vehicle driveability and lower mpg and decreased range of the vehicle were also considered significant disadvantages as was evaporative emission problems if volatility is not controlled.

Comparison of Replies to TECH-49

The only difference between the two panels was in the advantages of methanol from a vehicle perspective. Whereas the Technology panelists were nearly unanimous in considering octane enhancement and power improvement the principle advantage, it was considered so by slightly over one-half of the Materials panel.

Strategic Considerations

Based on the views of the panelists, there are a number of areas with respect to both the fuel and vehicle where problems are evident. However, none of these problems would appear to be fundamental, and therefore should not preclude expanded use of methanol as a fuel supplement, at least up to approximately a 10% level. The feasibility of using neat methanol or high concentration methanol mixtures have been established. The trend of availability and cost of petroleum will largely govern the future role of methanol. At present, methanol is widely available principally from waste natural gas. It is in oversupply on the world market and is consequently quite inexpensive.

MAT-27. What percent of light-duty engine oil will be synthetic in 1990 and 1995?

	Percent Synthetic Light-Duty Engine Oil	
	Median Response	Interquartile Range
1990	5%	5/20%
1995	10	10/20

Discussion

Five percent (5%) of light-duty engine oil is forecast to be synthetic by the year 1990. This percentage is expected to rise by 1995. Interquartile ranges for 1995 are fairly close. The interquartile ranges for 1990 are rather broad indicating that one-quarter of the panelists expect 20% or more of light-duty oil to be synthetic in 1990.

Comparison of Vehicle Manufacturers and Supplier Panelists

The panelists from the supplier segment are in agreement with the median forecasts for the percent of light-duty engine oil that will be synthetic in 1990 and 1995. Panelists from the OEM, however, were higher than the median forecasts with projections of 10% for 1990 and 15% for 1995. This is in contrast to the forecasts of the manufacturer and supplier Technology panelists (see TECH-50) where the manufacturer forecasts were significantly lower than the suppliers' and the combined medians.

Comparison of Replies to TECH-50

The Technology panelists forecast 10% of light-duty oil will be synthetic by 1990. Their respective responses for 1995 were identical.

Strategic Considerations

The difference in forecasts between manufacturers and suppliers may be significant. The manufacturers, because of their primary design responsibilities for engines, should be reasonably close to lubricant requirement trends. A systems approach in the design of lubricants and engines together could yield a different concept of future lubricants than is envisioned today.

MAT-28. In light of increased usage of new powertrain technologies such as turbocharging, four-valve and fast-burn engines, increased compression ratios, etc., what new requirements will oils for future light-duty vehicles have to address?

Future Oil Requirements	Percent of Total Respondents
Higher operating temperatures	76%
Improved viscosity stability	32
Increased oxidation resistance	32
Improved detergency capability	12

Others:
- Longer lubrication life
- Decreased sludging tendencies
- Increased acid problems
- Higher tolerance between mating parts
- Effect of oil on fuel efficiency (friction modification)
- New additive technology for alcohol-fueled engines
- Improved foam control

Representative Responses

Higher temperature for adiabatic engines.

Continued higher temperatures. good lubrication to a wider variety of substraits. longer lubrication life, greater problem of acids.

Higher temperatures, anti-wear characteristics improvement.

Retention of properties at very high temperatures.

Stable viscosity, improved oxidation control, better detergent/dispersant package.

Discussion

Panelists forecast that higher engine operating temperatures would be the major new requirement that oils will have to address for future light-duty vehicles. Improved viscosity stability, increased oxidation resistance, and improved detergency capability were additional future oil requirements receiving a significant panel response. The responses listed under "Others" illustrate the broad thinking of the panelists as well as addressing a number of additional future oil requirements. Additionally, some of the response categories are interrelated.

Comparison of Replies to TECH-51

The two panels were in agreement that tolerating higher operating temperatures would be the major new requirement for future light-duty vehicle oils. Although the percent of respondents varied somewhat, they were also in general agreement regarding the remaining requirements cited.

Strategic Considerations

It is clear that panelists expect new engines to be more demanding of lubricants. This fact may be the key factor prompting increased expectations for synthetic oils. Higher specific power, longer oil-change intervals, tighter underhood packaging, higher load factors, and added accessory loading are some of the other factors that could require improved engine lubricant quality. It would appear that additive packages will be particularly important to meeting the objectives of higher lubricant stresses and longer oil change intervals.

MAT-29. In light of expected technological changes in engines and transmissions, and problems with current designs, indicate three lubricant additives (based on type of problem) that you would like to see developed.

Engine Problem	Lubricant Additive
Catalytic converter poisoning	Lower phosphates
Oxidation stability	New anti-oxidant
High temperatures	More thermal stable additive
High temperature shear/viscosity stability	More shear stable viscosity index improvers
Increased ORI	Deposit modifier/reducer
Much higher top ring contact temperatures	Thermal stability optimizer
Drift of ATF friction characteristics with service and higher underhood temperatures	Chemical/thermally unreactive friction modifier
Manual transmission wear	Anti-wear additive
Engine wear (methanol-fuel vehicles)	Anti-wear additive
Engine oil sludging	Anti-oxidants
Turbocharging	Improved cc/cd performance
High performance diesels	Soot control
Diesel emission control	Oil consumption

Discussion

Several lubricant additives have been suggested by the panelists to meet various powertrain problems.

Strategic Considerations

There is a wide range of problems that our panelists would like to see addressed with improved lubricant additives. Significant opportunities for new and improved products are indicated. In general, forecast powertrain trends are based in part on the expectations for improved lubricant properties.

MAT-30. What minimum lubricant viscosity will be practical for 1995 light-duty vehicle engines?

	Median Response	Interquartile Range
Viscosity	5W30	5W20/5W30

Selected Edited Comments

No drive for yet lower viscosities at extremely low ambient temperatures. Volume will be limited by base stock availability and cost.

Discussion

The minimum viscosity practical for light-duty vehicle engines in 1995 is forecast to be 5W30. The interquartile range is very good, over 50% of the respondents forecast 5W30.

Comparison of Replies to TECH-53

The two panels were in agreement that 5W30 will be the minimum viscosity practical for light-duty vehicles in 1995.

Comparison of Replies with Previous Delphi Surveys

This same question was asked of the Technology panelists in Delphi III and the response was also 5W30.

Strategic Considerations

It is evident from this Delphi forecast that there is a general and extremely tight consensus that the oil specification will be 5W30. There is little or no support for a less viscous oil. It is important to note, as observed in the comment, that other criteria related to the viscosity issue may be important in addition to assuring basic lubrication. Based on this tight consensus, this question may be put to rest for a while, though we should be watchful for new developments.

MAT-31. Do you foresee new lubricants for light- or heavy-duty engines that will extend:

Temperature Range: The panelists were unanimous in forecasting the development of new lubricants for projected higher engine operating temperatures.

Oil Change Intervals: The panelists were nearly unanimous in forecasting longer oil change intervals, although there is uncertainty as to when and how the decision will be made.

Engine Life: The overwhelming majority of the panelists forecast extended engine life, although opinion was mixed regarding the necessity for new lubricants.

Representative Responses

Temperature Range

Increased range on high end.

Synthetics may enhance thermal stability and allow lower temperature operation.

We anticipate higher engine operating temperatures—improved lubricants will be required.

Temperature range will become higher due to high engine rpms of new engines.

Higher for heavy duty engines.

Extension above 150 degrees C is needed and should be available. No extension of low temperature range.

Improvement in the high temperature for oxidation control will be needed. The low temperature is in good shape.

Oil Change Intervals

Heavy duty—yes, 200,000+ miles.

Intervals will be subject to interpretation by on-board computer maintenance systems. May extend under ideal conditions.

Oxidation and acid neutralizer additives.

See little change before 1990.

Yes, to satisfy proposed "maintenance-free" vehicle programs.

It will be an OEM decision.

Slight extension possible only if contamination sufficiently reduced.

Toxicological properties of drain oils may actually bring about a reduction.

Engine Life

Have already achieved sufficient engine life cycles, therefore no changes to lubricants are necessary.

Cleaner engines (light and heavy) through more cc/cd oils.

With the increasing cost of vehicle, extending engine life should be an automotive priority.

Lubricant additive technology already exists should OEM influences initiate their commercial support. More frequent oil changes may be needed to optimize engine life.

Yes, especially for future alcohol fueled engines.

Discussion

The panelists were practically unanimous in forecasting the development of new lubricants for projected higher engine operating temperatures, longer oil change intervals, and extended engine life. The "Representative Responses" illustrate many details associated with the forecasts.

Comparison of Replies to TECH-54

The Materials panelists were in agreement with the Technology panelists in their forecasts for lubricants associated with extended temperature range, oil change intervals, and engine life.

Strategic Considerations

In this question there is almost a general consensus that new lubricants would be developed to handle projected higher engine temperatures, oil change intervals would increase, and engine life would be extended, although, in the latter case, there were some mixed views with regard to the role of lubricant technology on enhanced engine life.

Even though opinions were strongly supportive, there are still negative views. For example, in terms of oil change intervals, one rather direct comment was that they would not be extended, whereas others said extensions in intervals could be substantial. There is no question that there is an overpowering emphasis on improving the overall quality of the vehicle as perceived by the customer. Furthermore, with the intense competitive pressures, manufacturers searching for advantage will undoubtedly push the technology.

We believe there will be increasingly strong emphasis on the engine lubricant system as a "system" which could lead to lubricants designed with the engine in mind and engines designed with the range of lubricant properties in view. This could lead to significant improvements.

MAT-32. With expected changes in engine technology and fuel characteristics, what range of compression ratios do you expect for light-duty vehicle, spark-ignited engines in 1990 and 1995?

	Median Response		Interquartile Range	
	1990	1995	1990	1995
Maximum Compression Ratio	9.5	11.0	9.5/10	9.7/12
Minimum Compression Ratio	8.0	8.5	8/8.5	8.5/9

Selected Edited Comments

Depending on what fuel or blend is being used, compression ratios may increase significantly.

Japanese engine developments for 1990 and obviously 1995 are unknown but could set either limit.

Discussion

The maximum compression ratio for light-duty vehicle, spark-ignited engines is forecast to be 9.5 in 1990 and rise to 11.0 in 1995. The minimum compression ratios are forecast to be 8.0 and 8.5 in 1990 and 1995, respectively. With the exception of the maximum ratio for 1995, the interquartile ranges are very tight.

Discussion of Panelists' Comments

The last comment addresses the continuing impact of Japanese technological development on U.S. and possibly future worldwide powertrain design.

Comparison of Vehicle Manufacturers and Supplier Panelists

The two panelists groups are in complete agreement for maximum and minimum compression ratios in 1990. For the year 1995, the suppliers forecast a 10.5 maximum compression ratio, while the manufacturers forecast a 8.0 minimum ratio.

Comparison of Replies to TECH-55

The Technology panelists are in agreement with the Materials panel's minimum compression ratio forecasts for 1990 and 1995. However, the Technology panel forecast a higher maximum ratio for 1990 and a lower maximum ratio for 1995 than did the Materials respondents.

Trends from Previous Delphi Surveys

A somewhat similar question regarding the *average* compression ratio for 1990 was asked of Technology panelists in Delphi III. The forecast was for an *average* compression ratio of 9.2. Delphi IV forecasts are in line with this 1983 projection and indicate a trend towards progressively higher compression ratios.

Strategic Considerations

Panelists expect fuel economy and performance demands to increase. The technology to support the increase should be rather broadly available in new engine designs. Fuel octane increases could also support higher compression ratios.

One obvious uncertainty relates to customer demand for fuel economy and performance and the cost/benefit tradeoff between fuel cost and octane number.

MAT-33A. What *increase* in octane number (if any) do you foresee in the years indicated?

	Octane Increase			
	Median Response		Interquartile Range	
Gasoline	1990	1995	1990	1995
Regular Unleaded	0	2	0/2	0/5
Premium Unleaded	1	2	0/1	1.5/5

Discussion

Materials panelists expect a modest increase in premium unleaded fuel octane number but no change in regular unleaded for 1990. However, by 1995 both grades are expected to be increased by two octane numbers. The interquartile range is relatively broad and suggests that there is a substantial degree of uncertainty, although the general conclusion would be that we will see an improvement in overall fuel quality based on octane number.

It is suggested that the reader consult TECH-56A which forecasts the octane numbers for the present grades of gasoline in 1990 and 1995.

Comparison of Vehicle Manufacturers and Supplier Panelists

While in accord with the median increases for premium unleaded, the manufacturer panelists forecast a greater increase in octane number for regular unleaded for both years—2 and 3, respectively. Conversely, the supplier panelists were in accord with the forecast increases for regular unleaded but were lower for premium unleaded, forecasting no increase for 1990 and an increase of 1.5 for 1995.

Strategic Considerations

Increased octane number of the fuel should permit improved overall thermal efficiency and increased power from higher compression ratios. Additionally, somewhat greater flexibility is possible in optimizing other engine variables with higher quality fuel. Furthermore, a number of technological advancements such as more advanced computer control and fast-burn combustion should further lead to improved overall thermal efficiency. The net effect between fuel and engine improvements could be a reasonably significant efficiency improvement in the next few years and gives support to the expectations that the engine will continue to be a very important factor in fuel economy gains.

The expectations for greater fuel octane rating support the preceding forecast in MAT-32 of higher compression ratios. New engine technology and high-octane fuels could support sufficient increases in compression ratio to yield significant fuel economy and power gains.

MAT–33B. For light–duty vehicles to be *sold* in the U.S. in 1990 and 1995, what is the expected segmentation between fuel grades required by these vehicles?

	Expected Segmentation Between Fuel Grades			
	Median Response		Interquartile Range	
Gasoline	1990	1995	1990	1995
Regular Unleaded	80%	75%	75/90%	70/85%
Premium Unleaded	20	25	10/25	15/30

Discussion

The panelists forecast that 80% of light–duty vehicles sold in 1990 will require regular unleaded gasoline; by 1995 the forecast is for 75%. Premium unleaded is expected to take up the remaining share. The interquartile ranges are fair, indicating a reasonable degree of consensus.

Comparison of Vehicle Manufacturers and Supplier Panelists

There is no significant disagreement between the two panelist groups with regard to the expected segmentation between fuel grades for the year listed.

Comparison of Replies to TECH–56B

The Technology panelists forecast a larger market segment for regular unleaded gasoline than did the Materials panelists.

Strategic Considerations

The expectations for greater fuel octane rating support the forecast of higher compression ratios. New engine technology and high–octane fuels could support sufficient increases in compression ratio to yield significant fuel economy and power gains.

MAT-34. Estimate the number of years before panel penetration will occur due to corrosion in a severely corrosive environment (such as Detroit, Pittsburgh, etc.) for U.S.-manufactured passenger cars produced in the following years.

	No. Years Before Panel Corrosion Penetration	
	Median Response	Interquartile Range
1990	7	7/8
1995	10	9/10

Selected Edited Comments

Ten years is the goal for most companies by 1990.

Assume good design of components and proper use of materials (avoidance of galvanic cell potentials).

Designs need to be improved. Bad production—cleaning, phosphating, and painting systems—needs to be eliminated.

Key issues are exposure due to repairs and road inflicted damage. Database is too small and unreliable.

Some products now have ten year performance. This is adequate for most owners.

We may be at seven now.

Possibly never with polymers.

Assumes good design of components; [on a specific high volume, low cost station wagon the] tailgate is an example of a bad design. Materials used in tailgates (1981-85 models) had a two to three year life while the same materials used in doors and other components last longer—possibly twice as long.

Improvements seen in the change from zinc coatings to zinc alloy coatings.

All manufacturers will have 10-year goals, but probably not warranties by 1990. Ninety-five percent of individual panels will survive for ten years, but as many as 80% of all vehicles will experience perforation of one or more panels.

Discussion

The panelists expect that through the 1990 model year, the number of years before panel penetrating corrosion occurs will be seven years. The number of years that automotive vehicle panels will be expected to withstand corrosion is forecast to rise to ten years by the 1995 model year. The interquartile range is very tight. It is noteworthy that fully three-quarters of the panelists forecast the number of years before panel penetration to be ten years or more by the 1995 model year. This is an important consideration when one takes into account the Delphi IV Marketing 1995 forecast of a twelve-year average life of new cars and six-year length of ownership by new car buyers (see MKT-39).

Discussion of Panelists' Comments

The first comment expresses a majority opinion that ten years is a 1990 *goal*. Remaining comments reflect another dominate opinion that there is a need for design improvement and better utilization of materials. The last comment may provide the most succinct exposition of the opinion of the majority of the panelists.

Comparison of Vehicle Manufacturer and Supplier Panelists

Although the two groups of panelists are in agreement on the median forecast for the number of years before corrosive panel penetration, it is interesting to take note of the lower interquartile ranges for supplier panelists' forecasts for both years. For 1995, 100% of the manufacturer panelists and 75% of the supplier panelists forecast ten years or more; 25% of the panelists representing the supplier industry forecast five years or less for 1990 and seven years or less for 1995.

Trends from Previous Delphi Surveys

Previous Delphi II and Delphi III surveys forecast eight years before panel penetration occurs on 1990 model year cars. Delphi III panelists also forecast ten-year resistance to corrosion for 1992. Given the interquartile range, this opinion was shared by three-quarters of the Delphi III panelists.

Strategic Considerations

The general increase in quality expectations are clearly driving the corrosion issue. This may be one of the primary forces behind the longer life expectancy forecast for vehicles in 1990 and 1995. Corrosion resistance, as indicated in this forecast, would tend to support the panelist's comment that suggests that corrosion will cease to be an issue. It also suggests that steel is expected to be improved in terms of corrosion protection; therefore, corrosion may not be a major factor in the choice of plastic over steel to the extent that was once expected. Improved design and production practice is critical to the proper utilization of any automotive material. We expect great strides in this area in the coming years.

MAT-35. What will be the duration in years for corrosion warranties in model years 1990 and 1995?

	Corrosion Warranty in Years			
	Median Response		Interquartile Range	
	1990	1995	1990	1995
Warranty duration	5	10	5/7	6/10

Selected Edited Comments

A warranty of 10 years is generally an acceptable time period and will be dictated by public/political pressures.

Add miles. Warranties are limited, interwoven with limiters such as Chrysler's 5-year/ 50,000-mile exterior perforation only; does not cover inner panels, underbody structure, etc.

Plastics don't ever corrode.

Ten-year perforation warranties are technically feasible, but counterproductive for both automaker and customer. Bullet-proofing a vehicle against perforation at 10 years will necessarily involve costly overkill on anti-corrosion protective measures because of uncertainties in the long-term perforation performance of new materials. These new materials, necessary to meet other automaker goals, i.e., fit/finish, surface quality, structural reliability, or vehicle corrosion tests, have serious limitations.

Discussion

Duration of corrosion warranties are forecast to be five years in 1990 and ten years in 1995. The interquartile range for 1990 is very good, for 1995 fair to good. While 25% of the panelists forecast six years or less for the duration of corrosion warranties in 1995, 75% forecast ten years or more.

Discussion of Panelists' Comments

The four comments presented reflect different perspectives on corrosion warranties. Because the questions are so closely related, the reader is advised to also note the comments for MAT-41.

Comparison of Vehicle Manufacturers and Supplier Panelists

The two groups are in agreement on five-year corrosion warranties for 1990; for 1995 the supplier panelists forecast an eight-year corrosion warranty, the manufacturers ten years.

Strategic Considerations

With warranties in the area of five years in 1990 and ten years in 1995, the perception of quality in the eyes of the customer should improve dramatically. It is important to note that the cost-benefit aspects of this level of warranty must be considered carefully. The last comment bears careful reading in that it suggests some of the major trade-off issues that are a part of key future materials decisions. With long-term warranties, corrosion will probably cease to be an issue in the buying decision because essentially all manufacturers will have outstanding levels of performance.

MAT-36. Which of the following *coated steels* do you foresee being used and in what amount (in pounds) in the average U.S.-produced passenger car in the following years?

	Use (in pounds)			
	Median Response		Interquartile Range	
Coated Steels	1990	1995	1990	1995
Hot-Dipped Galvanized				
Two equal sides	200 lbs.	200 lbs.	180/200 lbs.	150/200 lbs.
One-Sided	20	20	5/20	0/20
Differentially Coated	50	40	40/50	20/50
Electrogalvanized				
Two equal sides	100	120	100/115	100/150
One-sided	50	35	50/55	30/50
Differentially coated	50	80	40/50	70/90
Terne Coated				
Long terne	10	5	10/10	5/5
Nickel-terne	10	5	5/12	5/15
Aluminum Coated	10	10	10/10	10/10
Zinc-Aluminum coated	5	6	2/10	2/10
Tin Coated	5	3	1/5	1/5
Prepainted				
Zincrometal	30	0	30/40	0/5
Paint	10	15	10/15	10/30
TOTAL POUNDS	550	539		

Selected Edited Comments

Developments will occur in producing better surface quality hot-dip galvanized steels at a competitive price.

Electrogalvanized and hot dip will compete for price and quality in 1990s. Both will continue to improve.

Methanol fuel may require increased use of stainless steel and modified terne plate in fuel system by 1995.

Who needs pre-prime with E-coat? E-coat works, pre-prime has unknowns. The industry will stay with lower cost known results.

We are ignoring impact of Japanese transplants which so far are buying more than the reported fifty-percent levels.

Zincrometal will recover by 1990 as a "piggyback" topcoat over electrogalvanized steel to solve formability shortcomings of the latter.

Projecting the impact of local content on U.S.-produced Japanese vehicles could make a significant change in response to this question. Some of the prepainted tonnages will be a combination of preprimed steel or zincrometal over a differentially coated metallic (free zinc or alloy zinc).

Discussion

It is evident that coated steels will be an increasingly important factor in future vehicles. It is also interesting to note that there is expected to be a reduction in the volume of coated steels in 1995 compared to 1990. This may in part be due to lower overall vehicle weight and concomitant reduction in steel usage. Clearly, there is a broad array of capability in coating steels to provide enhanced corrosion protection and expectations are high for its use. Overall, the interquartile ranges indicate a reasonably good consensus as to the application of these various coating technologies.

Discussion of Panelists' Comments

The panelists' comments address a number of subject areas of importance to the selection of coated steels. It is clear from the comments that they expect continued competition between hot-dipped galvanized and electrogalvanized steel in terms of both price and quality. Zincrometal or other zinc alloy coatings are also expected to play a role in this area. (Also see "Comments," MAT-37.) The impact of Japanese transplants, as noted in the comments for several other questions, is not lost on these respondents either.

Strategic Considerations

The broad array of steel coating technologies suggest the possibility of a "shake out" if some prove to be more cost effective. Of course, some applications such as exterior class A surface requirements can narrow the choices. Generally, zinc coatings, either electro-deposited or dipped, appear to be the big winners.

MAT-37. **Coated steels may be used more extensively in vehicle panels and components. Please indicate what supplemental corrosion protection will be required and the relative distribution of each supplement for the indicated components.**

	Distribution of Supplement			
	Median Response		Interquartile Range	
Supplemental Corrosion Protection	Body Panels	Structural Components	Body Panels	Structural Components
Chemical barrier spray	55%	70%	20/80%	0/90%
Waxes	25	0	0/40	0/20
Plastic laminate film	15	10	5/40	0/15
No supplemental protection	5	20	0/80	0/100

Other supplemental corrosion protection suggested by single panelists are: electropaint, 100% on body panels and structural components; urethane anti-chip primer on lower 12 inches.

Selected Edited Comments

Zinc and zinc alloy coatings are sufficient to provide the required corrosion protection. Improved paints may eliminate the need for zinc coatings on the exposed side of exterior body panels.

Plastic body panels will gradually replace all steel panels. Last areas to go to plastic will be roof and hood.

Discussion

The relative distribution for several types of supplemental corrosion protection is forecast. Chemical barrier spray is the most preferred for both body panels and structural components. The interquartile ranges indicate a wide variation of opinion regarding the actual distribution of these coating techniques. Several coatings are forecast with a lower quartile of either zero or close to zero, suggesting that a substantial group of panelists feel that no supplemental protection will be required on various body panels and structural components.

The results indicate that there is a wide range of opinion and considerable uncertainty concerning supplemental coating technology in future automotive applications.

Discussion of Panelists' Comments

The two comments, from panelists who felt that no supplemental corrosion protection will be required, address the reasons for their forecasts.

Comparison of Vehicle Manufacturers and Supplier Panelists

There are no significant differences between the two groups. The interquartile ranges for each group are also very broad.

Strategic Considerations

The main point to be made is the wide opinion expressed in this question. For those that are impacted by these technologies, trends must be closely followed.

MAT–38. In your opinion, how would OEMs and suppliers rank (from 1 to 12) the value of the following services offered by material suppliers (most important = 1).

Material Supplier Services

Rank Ordered by:

OEM	Supplier
Design/development cooperation	Design/development cooperation
Design/development from concept	Visits by technical reps
Applied research	Visits by salespeople
Prototype parts production	Applied research
Visits by technical reps	Prototype parts production
Sample materials	Sample materials
Basic research	Design/development from concept
Computer data bases	Visits to customers' plants
Visits to customers' plants	Basic research
Data handbooks	Data handbooks
Visits by salespeople	Computer data bases
Other: Price/cost reduction*	

*Four panelists ranked price #1 for OEM; three panelists ranked price #1 for supplier; one panelist ranked price #9 for supplier.

Selected Edited Comments

Both OEM and supplier rankings will vary depending upon the specific activity the respondents are involved in. Respondents working in advanced engineering would rank these items much differently than someone working in purchasing or plant manufacturing operations.

Importance of "prototype parts production" would depend to a great extent on the type of material and the part production process. The less familiar they are to the customer, the greater is the value of prototype parts production.

Price still overshadows service and quality by the OEM.

They better be the same! For plastics, the need is for systems technologies and product design—feasibility.

Discussion

The four in common top-ranked materials supplier services are: (1) design/ development cooperation; (2) applied research; (3) prototype parts production; and (4) visits by technical reps. Although not a service *per se*, price was considered by several panelists as the most important concern for both the OEMs and the suppliers. Even though the OEM/supplier rankings of the services more or less coincide, there exists sufficient difference to allow for meaningful insight into how the two groups perceive the importance of each service. All factors considered, however, the first panelists' comment best sums up how these rankings should be interpreted.

Strategic Considerations

It is clear that much closer and cooperative relations between manufacturers and suppliers are necessary and this is supported by results to this question. In general, both parties must become sensitive to the needs of the other and increasingly cognizant of market demands if the enormous competitive challenge is to be met. Far richer communications are required.

MAT-39. The OEMs are moving in the direction of considering factors in addition to price in the purchase decision. In your opinion what relative percent value is actually assigned to each factor listed, and what should it be?

	Percent Value Assigned by OEM			
	Median Response		Interquartile Range	
Factors Considered in Purchase	Actual	Should Be	Actual	Should Be
Price	55%	25%	40/60%	15/28%
Quality	15	35	10/20	20/40
Reliability of delivery	10	10	5/15	10/18
Manufacturability	5	10	2/10	5/20
Research and design assistance	5	10	0/10	10/20
Supplier location	5	5	0/5	0/5
Other:	5	5	1/20	0/5
Prior relationships				
Quality improvement programs				

Selected Edited Comments

These values assume no change in materials requirements or in parts manufacturing and design. If any of these would be expected to change occasionally, the relative importance of research and design assistance would increase.

Discussion

It is evident from the results that most panelists believe that excessive value was put on price in the purchase decision and insufficient weight on other key factors including quality and manufacturability. Quality, in fact, is viewed as more important than price although in reality it is believed that price is more than three times more important than quality in the present buying decision. It should be noted that the interquartile ranges are quite broad but generally the relative ranking based on the quartile are similar to that of the median.

Strategic Considerations

As the automotive industry goes through a major transformation, there is reasonable emphasis on major material attributes in addition to price. Quality, manufacturability, delivery, and so forth are generally improving, but as indicated in the data there is belief that there is still some distance to go. As the customer is increasingly concerned about quality, this suggests that quality is going to become an increasingly dominant factor for all successful manufacturers and suppliers. The choice, in fact, is being made by the international competition which has apparently given quality a very high rating. Until the *actual* and the *should be* lists are the same, it is evident that the industry still has some distance to travel.

MAT-40. Popular opinion suggests that statistical process control (SPC) is widely used in the automotive industry. In existing manufacturing processes with which you are familiar, what approximate percentage of the production work actually utilizes SPC in the manner indicated?

	Percent Production Work Utilizing SPC			
	Median Response		Interquartile Range	
Manner Used	OEM	Supplier	OEM	Supplier
Used Properly	35%	25%	10/50%	10/30%
Misused	20	20	10/30	10/20
Not Used	45	55	25/80	40/70

Selected Edited Comments

Most SPC systems do not give data/understanding to the machine operator so he can control his process.

Many operations are not being monitored: many are only utilizing SQC (statistical quality control) techniques.

Misuse includes such items as: properly constructed charts but no action taken when special causes are indicated. calculation and reporting of capability indices for a process that is not statistically in control.

About 80% of our plant uses it now and is moving beyond it to designed experiments.

Discussion

The panelists estimate that 35% of the OEMs and 25% of the suppliers use statistical process control properly, 45% of the OEMs and 55% of the suppliers do not use SPC, and 20% of both groups misuse it. The interquartile ranges indicate a rather broad spread for all manners of utilization. It should be remembered that in this particular question the interquartile range takes on a different relevance than in other questions because in this question the responses represent a *perception* of fact.

Discussion of Panelists' Comments

The first three comments reflect various perceptions regarding the misuse of statistical process control.

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer panelists felt that 15% of OEM production work utilized SPC properly, 30% misused it, and 55% of production work did not utilize SPC.

The supplier panelists expressed the opinion that 45% of OEM production work utilized SPC properly, 20% misused it, and 35% of the production work did not use SPC.

Both groups were in general agreement on the utilization of SPC by suppliers.

Comparison of Replies to TECH-81

The following table compares the response of the two panels.

Percent Production Work Utilizing SPC

Median Responses

Manner Used	Materials Panel OEM	Materials Panel Supplier	Technology Panel OEM	Technology Panel Supplier
Used Properly	35%	25%	50%	50%
Misused	20	20	20	20
Not Used	45	55	30	30

The Technology panelists felt that 50% of the manufacturing processes of both the OEMs and the suppliers properly utilized SPC. This is significantly higher than the percentages suggested by the Materials panelists. Both panels were in agreement that SPC was misused in 20% of both OEM and supplier production work.

Strategic Considerations

It is evident from the results that while statistical process control is important to the development of effective high-quality manufacturing, it still is in a growing phase. One would suspect that the progress will be rapid toward applying SPC in the future, whereas with the Japanese it has become a given in the basic formulation of a production system. With the enormous pressures on product quality today, the driving force is strong to implement mechanisms to ensure the quality of both components and finished vehicles. Any manufacturer or supplier that cannot meet the growing quality expectations will have a very difficult time being competitive in the years ahead. Inherent in an effective quality strategy is the necessity to prevent problems at each stage in the process by ensuring that every process is under control.

MAT–41. 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 Techniques

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 joined 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.

Selected Edited Comments

Adhesive bonding and new welding techniques are too general—too many changes in these fields exist to rule out discussion for 1990.

Discussion

It is evident that expectations are rather significant for both advanced mechanical fastening techniques and adhesives as applied to both body joining and panel attachment. In addition, laser welding was viewed as an expanding technique for use in body joining.

Strategic Considerations

With emphasis on the competitive pressures and the apparent considerable advantage experienced by the many foreign manufacturers in producing the "body in white," great emphasis will be placed on improving manufacturability in this sector. It is likely that new joining techniques will be a part of this. Those that lead to automated assembly could be very much a factor in the joining technique selection. Furthermore, it is evident that a whole new major thrust from a number of suppliers of new fastening systems could have an impact on trends in body fastening.

MAT–42. What percentage of the following manufacturing processes will be performed by robots in your company's manufacturing facilities in 1990 and 1995?

	Percent Performed by Robots			
	Median Response		Interquartile Range	
Manufacturing Processes	1990	1995	1990	1995
Welding	60%	90%	50/90%	80/100%
Painting	60	90	50/80	80/100
Stamping	40	80	20/50	50/90
Other (single responses):				
Pumps/pipes	100	100		
Adhesives and sealers	40	75		
Parts handling	20	25		

Discussion

It is expected that 60% of welding and painting processes and 40% of stamping will be performed by robots in the year 1990. This percentage is forecast to increase to 90% for welding and painting and 80% for stamping. The interquartile ranges for 1990 are fair, while the ranges for welding and painting in 1995 are very close.

Comparison of Vehicle Manufacturers and Supplier Panelists

The panelists representing suppliers forecast significantly lower percentage of robots in their respective facilities. They project that by the year 1990, 30% of the welding, 50% of the painting, and 25% of the stamping in their facilities will be performed by robots. By the year 1995, 75% of welding, 80% of painting, and 50% of stamping processes are expected to be robotized.

In contrast, the OEM panelists were either, as in the case of stamping processes, in agreement with the median forecasts or were 5% to 10% higher. It is worth noting that a significant portion of the manufacturer panelists expect 100% robotization of painting.

Strategic Considerations

There is a clear indication that in less than ten years the more mundane, and potentially hazardous, manufacturing processes such as welding, painting, and stamping will be either completely robotized or very close to it in many manufacturing facilities. The production areas most completely under robot control, such as the paint booth, are decidedly the least desirable, and potentially most health threatening, of the manufacturing and assembly procedures. However until technological breakthroughs are achieved in the fields of machine vision or artificial intelligence, the human component in the more complicated and intricate procedures will be a necessity. Additionally, the need for control and maintenance of the in-place robots will continue to be a factor throughout the foreseeable future.

MAT–43. What percentage of the present workforce will be replaced by robots in the years 1990 and 1995?

	Percent Workforce Replaced by Robots	
	Median Response	Interquartile Range
1990	15%	10/20%
1995	25	20/40

Selected Edited Comments

Expect a major share of workforce will be involved in keeping robots working.

Discussion

It is expected that 15% of the combined automotive manufacturer and supplier workforce will be replaced with robots by the year 1990. The percentage is expected to rise to 25% by 1995. The interquartile ranges for both years are reasonably close. indicating a good consensus.

Discussion of Panelists' Comments

The single comment makes a very important point regarding the replacement of workers with robots. See "Strategic Considerations," MAT–42.

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer panelists forecast that a higher percentage of their workforce would be replaced by robots with projections of 20% in 1990 and 40% in 1995. The suppliers were somewhat lower than the median with forecasts of 10% in 1990 and 20% in 1995.

Strategic Considerations

Expectations for displacement of workers with robots appears to be significant. The implication of the forecast is highly significant in terms of the overall labor force as well as the ability to be competitive with the international competition in the years ahead.

MAT–44. When robots are used, will they be fixed-function units or part of a flexible manufacturing system?

	Median Response		Interquartile Range	
Robots used as:	Today	1995	1990	1995
Fixed Function	80%	50%	75/95%	20/75%
Flexible	20	50	5/25	25/80

Discussion

It is estimated that 80% of the robots used today are fixed-function units and 20% are part of a flexible manufacturing system. The distribution for 1995 is expected to be 50% fixed and 50% flexible. The interquartile range for the present estimation of fixed-function is fairly tight, indicating that 80% is a reasonably dependable estimate. The interquartile range for flexible is somewhat greater, indicating a broader range of application for automated flexible systems. The interquartile range for both systems by 1995 is very large, indicating considerable uncertainty regarding the future rate of application of robotic systems.

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer panelists estimate that the ratio of fixed to flexible function robots is, at present, 50%:25%; for supplier, 80%:10%. The forecast distribution of fixed to flexible function units by 1995 is manufacturers 20%:80%; suppliers 50%:50%.

Strategic Considerations

One of the most important dimensions in this particular question is the dramatic increase expected in flexible systems. Important changes occurring in the marketplace such as more varieties of products with lower volumes, and the increasing complexity of the manufacturing processes demand flexibility. Furthermore, because of the necessity to shift models and deal with a variety of models in a given assembly system, whether at the component stage or in the final vehicle, flexible systems would appear to be better suited to accommodate this shift. However, fixed-function systems are by no means disappearing but are only decreasing as more flexible arrangements increase. They both have an important place in the automotive manufacturing plant of the future.

MAT–45 If the Japanese yen were to stabilize at 150 Y/$ and the German mark at 2.2 DM/$, what percentage of steel utilized in the manufacture of North-American-produced passenger vehicles would be purchased overseas?

Percent of Steel Purchased Overseas	
Median Response	Interquartile Range
20%	15/20%

Selected Edited Comments

Depends on quality of steel and availability of the required products.

Doesn't matter. Korea or Brazil would supply steel at even lower cost.

Overseas steel would be used for special applications where domestic steel unavailable—overseas steel sourcing—too many days in transit—balance out and engineering change difficult—little control over supplier. Quality including consistency only plus.

The foreign content will be reduced from Germany and Japan in this scenario. However, the factor which is overlooked is the impact of third world steel producers (Brazil, Korea, etc.) on foreign content.

There has been little investment in steel in the U.S. The Korean, Chinese, and Taiwan position is still strong. It will take any position lost by Japan and Germany and the U.S. will continue to lose.

This depends very strongly on the particular vehicle manufacturer.

U.S. producers now have the quality and galvanizing capability to supply automakers. Most steel will come over in the form of parts. It also depends on what currency's not based on the dollar (Canada, Korea).

Comparison of Vehicle Manufacturers and Supplier Panelists

The panelists from the supplier industry forecast that if the yen and DM stabilized at the rates indicated in the question, 15% of the steel utilized in North-American-produced passenger cars would be purchased overseas. The OEM panelists were in agreement with the median value shown above.

Strategic Considerations

Basic economics, technology, quality, and loyalty will largely determine international sourcing. We would suspect that even if an advantage exists, there will be a diminished role for off-shore purchases as long as the negative balance of payments continues at the present level. While some third-world producers that have a currency more directly tied to the dollar (e.g. the Korean won) will have a relative advantage, political forces will probably become formidable in limiting off-shore sourcing in the years ahead. With respect to exchange rates, it is likely that further strengthening of key international currencies could occur. For example, there are some that would suggest that the yen may approach 90–100 yen per dollar level which indeed would create a strong economic incentive to not purchase Japanese steel. On the other hand, forces could emerge that may reverse the exchange rate trend and introduce an acute competitive problem. Banking exclusively on exchange rates to achieve competitiveness is dangerous policy.

MAT–46. What percent of steel used by "transplants" (i.e., foreign–owned automotive manufacturing facilities in North America) will be sourced from domestic suppliers *within* the U.S. and Canada?

Percent of "Transplant" Steel Sourced within U.S. and Canada

Median Response		Interquartile Range	
1990	1995	1990	1995
30%	50%	20/50%	30/60%

Selected Edited Comments

Balance of trade and rate of currency exchange will increase domestic steel content in foreign–owned auto facilities.

Big opportunity to maintain existing sales level if yen equals 160–170.

Issue is quality in U.S. steel industry—cost is secondary in many cases. Hopefully, U.S. steel industry will get its act together by 1990s.

Last steel to be sourced domestically will be exposed panels. Unavailability of products such as bake hardening steel will slow the adoption of U.S. suppliers.

The third world country steel plants continue to grow.

The reported 50% domestic/Japanese sourcing for one of the existing transplants is more like 30% U.S. and 70% Japanese. A further shift in the yen/dollar relationship will have an impact on the percentages as well as the financial health of the Japanese steel industry and union pressure for local content within the U.S.

Discussion

It is forecast that 30% of the steel used by North-American-based transplants will be sourced from domestic steel suppliers within the U.S. and Canada in 1990. This percentage is expected to rise to 50% by 1995. The interquartile ranges for these projections are only fair.

Discussion of Panelists' Comments

The comments reflect the opinion of the panelists on the issues of quality and rates of currency exchange, two of the major issues affecting the sourcing of domestically produced steel by transplants. Costs, availability of certain steel products, as well as the continuing growth of third-world steel production facilities are also discussed.

Comparison of Vehicle Manufacturers and Supplier Panelists

For the year 1990, OEM panelists forecast 20% of the steel used by transplants will be domestically sourced; for the year 1995, the forecast is 30%.

Strategic Considerations

The general expectation is that "transplants" will continue to extensively source basic materials, particularly steel, outside of North America. However, with the rapid pace of quality improvements in the North American steel industry, a continued strengthening of international currencies, and recent trends by transplants, we believe that this forecast for North American sourcing may be low. Based on conversations with representatives of foreign manufacturers, we observe an increasing attempt on the part of the transplants to source within the United States and Canada for both parts and basic materials.

MAT–47. 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 trucks, and (b) what components do you foresee will be manufactured utilizing magnesium?

	Median Response		Interquartile Range	
Magnesium	Passenger Cars	Light–Duty Trucks	Passenger Cars	Light–Duty Trucks
25% Premium	20 lbs.	25 lbs.	7/30 lbs.	5/50 lbs.
75% Premium	3	5	1/5	1/9

COMPONENTS UTILIZING MAGNESIUM AT 25% PREMIUM

Component Parts	Percent of Respondents
Engine components (connecting rods, pistons)	39%
Transmission housings	39
Cast wheels	23
Engine heads	23
Engine blocks	15
Others: Transmission parts, brackets, bumpers, decorative parts, intake manifold, oil pumps, fuel pumps, die–cast headlamp, door hardware	65

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 degrees F.

Heads, die–cast headlamp doors, possible engine block.

Matrix metal in composites for chassis and engine parts.

Decorative applied parts.

COMPONENTS UTILIZING MAGNESIUM AT 75% PREMIUM

Die–cast specialty parts	43%
Brackets	43
No significant penetration	15
Others: Covers and housings, connecting rods, headlamp doors, wheels	57

Representative Responses

Die–cast specialty parts (brackets, valve covers, etc.)

The real issue is price stability of secondary aluminum.

Only castings on specialty cars.

Selected Edited Comments

Magnesium is an unknown material with durability to be established, therefore very slow introduction on small components.

Assured supply at lower price is a concern. Corrosion still remains an issue for internal engine parts.

Discussion

It is evident that with a modest premium of 25%, the forecast of 20 pounds per passenger car and 25 pounds per light truck for magnesium use is rather substantial in comparison to today. However, with a 75% price premium the response is much less: about 3 pounds for passenger cars and 5 pounds for light trucks. The interquartile range for the 25% scenario is very broad indicating a high degree of uncertainty with respect to applications for magnesium.

Comparison of Vehicle Manufacturers and Supplier Panelists

At a 25% premium, the manufacturer panelists foresee 10 pounds of magnesium being used per passenger car and 30 pounds per light-duty truck. At a 75% premium, the manufacturer panelists foresee 1 pound per passenger car while the suppliers foresee 5 pounds. There are no significant differences among the other parameters.

Strategic Considerations

Price is not the only determinant in the potential application of magnesium. Material properties as well as the long-term availability and pricing of the material are also of critical importance in any automotive decision. An increasing emphasis on product integrity and quality would undoubtedly be of paramount concern in any material substitution. Furthermore, the incentives to reduce weight may be less than several years ago because of overall improvements in fuel economy and engine and drivetrain efficiency and generally reduced expectations for long-term fuel pricing.

MAT–48. What application of metal matrix composites (MMC) do you foresee in spark-ignited and diesel engines? Do you foresee other non–engine automotive applications for MMC?

MMC Application in Spark-Ignited Engines	Percent Respondents
Pistons	73%
Connecting rods	73
Others:	37
Cylinder liners/inserts	
Camshaft lobes	
Rocker-arm tips	
Rocker arms	37
Valves	
Push Rods	

Representative Response

Rotating components which will reduce shake/inertia/friction.

MMC Application in Diesel Engines	
Pistons	89%
Connecting Rods	78
Others:	34
Chambers	
Rocker Arms	
Push Rods	

Non–Engine Applications

Frame Members
Fly Wheels
Chassis components, transmission internal parts, brackets, levers, etc.

Strategic Considerations

Metal matrix composites appear to be a promising new technology for application in engines and a few other areas of the vehicle. They promise to reduce mass which is particularly critical in rotating and reciprocating internal engine components. For both diesel and gasoline engines, pistons and connecting rods are viewed as very attractive application points for metal matrix composites. For non–engine applications a random selection from frame members and transmission components are suggested. This technology must be watched very carefully in the years ahead, particularly with respect to its cost/benefit tradeoffs. Time and technological developments are necessary to better define the role of MMC.

MAT-49. What percentage of aluminum-ferrous castings utilized in U.S.-produced light-duty vehicles will come from U.S. suppliers and what percent will be sourced off-shore? For the percent off-shore, what are the likely source countries?

Percent Aluminum-Ferrous Castings Utilized in U.S.-Produced Light-Duty Vehicles

	Median Response	Interquartile Range
U.S. Suppliers	75%	60/80%
Off-Shore	25	20/40

Source Countries for Off-Shore	Percent Total Responses
Korea	28%
Japan	13
Germany	13
Taiwan	9
Brazil	9
Italy	5
Other Asian Countries	4
South America	4
Mexico	4
France	4
United Kingdom	4
China	3

Discussion

It is expected that 75% of the aluminum-ferrous castings utilized in light-duty vehicles will be sourced from U.S. suppliers and 25% will be sourced off-shore. Korea and other Asian countries are considered the most likely source countries collectively receiving over 50% of the total responses; they are followed by European countries with over 25% of the total responses, and Mexico and South America with 17%. The interquartile range is fairly tight indicating reasonably good consensus.

Comparison of Vehicle Manufacturers and Supplier Panelists

Both the manufacturer and supplier groups were within 10% of the median response.

Strategic Considerations

With the increase of major aluminum powertrain castings and the general emphasis on improvement in both aluminum and ferrous casting quality, the international sourcing of these items becomes an important factor. Of course, trends in exchange rate can have a profound impact on these sourcing decisions as well. The expectation that 75% will stay in the U.S. is significant but represents a substantial reduction from traditional levels. A key factor would be the development in this country of precision casting technology that could produce high quality raw castings requiring a minimum of machining operations. Quality seems to be such a dominant factor in the industry today that unless quality levels can be maintained at the world-class level, the casting business is likely to move where quality levels are regularly obtainable.

MAT-50. It has been suggested that there will be a transition by North-American-based automobile manufacturers from solvent-based lacquers and enamels to water-based base coatings. Other than environmental considerations, what are the major advantages of this emerging paint technology and what major factors exist that could continue to inhibit its expanded use? In 1990 and 1995 what percentage of U.S.-produced vehicles will utilize a water-based base coat?

Percentage of Water-Based Base Coat Used

Median Response		Interquartile Range	
1990	1995	1990	1995
10%	15%	5/15%	10/20%

Major ADVANTAGES of Water-Based Coatings	Percent of Respondents
Better appearance on metallic coatings	88%
Lower cost	68
Ease of application	22
Others:	
Less hazardous, potential styling advantages, lower brake temperatures, virtually none	

Major DISADVANTAGES of Water-Base Coatings	Percent of Respondents
Capital costs to convert existing facilities	38%
Need for humidification control	38
Energy requirements	25
New technology problems	25
QC/Reliability	25
Additives required for emulsification	12

Representative Responses

Advantages

Reduces the cost of solvent.

Lower curing temperatures equals cost savings.

By 1995, assembly plant paint systems may be very different from today's systems.

Difficulties of coating metallic-coated substrates, more plastics and concept of prepriming metal prior to forming could force a total change in paint systems.

Lower insurance rates, less hazardous to employees.

Water-base coatings would allow lower solids content to be used, resulting in improved flow and appearance.

Lower bake temperatures will be breakthrough for lower cost plastic panel material to be used.

Disadvantages

Energy requirement. Reactive systems with recycle of volatiles is likely long-term winner.

Plant facilities to control temperature and humidity. Again, it depends on technology development, e.g., competitive materials, new processes, etc.

Heat required for evaporating water—additives required for emulsification.

Paint installations that exist today that are costly and incompatible with water-base technology.

Discussion

It is expected that 10% of U.S.-produced vehicles will utilize a water-based base coat in 1990 and 15% in 1995. The interquartile ranges for both the median values are very tight indicating a good consensus. A majority of the respondents felt that a better appearance on metallic coating was a major advantage of water-based coatings. Lower cost and ease of application were cited as other principal advantages. The major disadvantages are basically the problems generally associated with the implementation of a new technology and the capital costs necessary to convert existing facilities to accommodate the new technology.

The groupings of responses for both advantages and disadvantages are the result of integrating the various responses of the panelists. Therefore, in order to provide as much insight as possible into the thoughts of the panelists, "Representative Responses" are presented above in lieu of "Selected Edited Comments."

Comparison of Vehicle Manufacturers and Supplier Panelists

The manufacturer and supplier panelists both forecast identical percentages which are in agreement with the combined median values.

Strategic Considerations

One of the most important costs in any assembly plant is the paint shop. It is not only a very expensive part of the plant but has recently been faced with added challenges with respect to health and other environmental issues. One of the paint technologies that has been gaining momentum is the water-based base coat. The advantages were rather clear in terms of better appearance, metallic coatings, lower cost, ease of application and, of course, less difficult environmental problems. Disadvantages of significance included capital costs in a very expensive part of the manufacturing operation. The need for humidification control, energy requirements, and general problems with new technology, quality control, and reliability factors are also disadvantages. Because of the newness of this technology, the relative balance between advantages and disadvantages appears to be too close to call at this time and developments must be watched very closely. A 10% penetration by 1990 and 15% penetration and application by 1995 must be deemed as significant when the interquartile range is relatively narrow indicating reasonable consensus that we will see application of more water-based base coat paint systems in the future.

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G. Manufacturing-Related Trends and Issues