Delphi VIII

FORECAST AND ANALYSIS OF THE NORTH AMERICAN AUTOMOTIVE INDUSTRY

Marketing • Technology • Materials

Materials

VOLUME 3

Office for the Study of Automotive Transportation

University of Michigan Transportation Research Institute

DELPHI VIII

Forecast and Analysis of the North American Automotive Industry

VOLUME 3: MATERIALS

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FOREWORD

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

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

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

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

The Delphi method: general background

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

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

Process

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

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

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

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

Panel characteristics and composition

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

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

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

Presentation of Delphi forecasts and analyses

Data tables. When a question calls for a response in the form of a number, responses are reported as the median value and the interquartile range (IQR). The median is a measure of central tendency that mathematically summarizes an array of judgmental opinions while discounting extremely high or low estimates; it is simply the middle response. The IQR is the range bounded at the low end by the 25th-percentile value, and at the high end by the 75th-percentile value. For example, in a question calling for a percentage forecast, the median answer might be 40 percent and the IQR 35-45 percent. This means that one-quarter of the respondents answered 35 percent or less, another one-quarter chose 45 percent or more, and the middle half of all responses ranged between 36 percent and 44 percent, with 40 percent as the middle response. That narrow interquartile range would indicate a fairly close consensus among the respondents.

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

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

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

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

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

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

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

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

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

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

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

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V. BODY/CHASSIS

VI. RECYCLING

EXECUTIVE SUMMARY

The North American Automotive industry stakeholders face a decade of challenge and change. Manufacturers and suppliers must work to develop affordable vehicles that continue to meet customer expectations and government regulations. Nowhere is the challenge more intense than in the selection of automotive materials. *The Delphi VIII Forecast and Analysis of the North American Automotive Industry: Materials Volume* identifies many of the challenges and opportunities facing industry participants. In doing so, the Materials volume presents an opportunity for companies to benchmark their vision of the future with that of an industry consensus.

The Materials volume of Delphi VIII is divided into six sections addressing Strategic Planning Factors, Strategic Materials Considerations, Total Vehicle, Powertrain/Drivetrain, Body/Chassis and Recycling. This summary is intended to highlight key results from the 1996 Delphi VIII Materials Panel.

I. STRATEGIC PLANNING FACTORS

The panel forecasts regular and premium gasoline to be $1.25 and $1.50, respectively, by 2005. The forecast of 3.3 percent and 3.0 percent annual price increases for regular and premium gasoline, respectively, over the coming decade suggests that the panel does not expect significant supply disruptions. However, panelists do suggest that increased fuel taxes will affect the price of gasoline. Further, the panel expects reformulated gasoline to account for 25 percent of all sales by 2005.

For at least the next decade, the gasoline-fueled internal combustion engine is forecast to remain dominant. Therefore, the implementation of alternate fuel sources and power plants is expected to be driven by public policy rather than consumer choice. The panel forecasts as less than moderately likely that some form of federal legislation regarding alternate fuels will be enacted by 2000. It does consider it likely that there will be federal legislation requiring alternate fuels by 2005.

The electric vehicle will present the automotive industry with many materials challenges and opportunities. The panelists see meeting mass, cost and performance criteria as among the most difficult challenges. However, it may take the development of key technologies as well as a paradigm shift by both consumers and industry for electric vehicles to gain acceptance.

The panel forecasts increased federal legislation and regulation pertaining to emissions, crashworthiness, occupant restraint/interior safety, fuel economy, alternate fuel and recyclability in the coming decade.

II. STRATEGIC MATERIALS CONSIDERATION

The panel forecasts cost to continue to be the most critical material selection attribute in the coming decade. It expects weight to be the other strong determinant over that period. The industry has traditionally relied on high weight, low-cost materials such as cast iron and steel. However, as pressure to reduce weight increases, the industry is looking more closely at lower weight but higher cost materials. By rating cost and weight as the most critical attributes, the panel suggests that this cost/weight dilemma will continue for at least the next decade.

The panelists rate steel body panels as having significant advantages over aluminum and plastic in the raw materials cost, component processing, assembly and vehicle disposal stages of the life cycle. Steel, thermoplastics and thermosets are viewed as equally advantageous in the design and field use stages of the life cycle.

III. TOTAL VEHICLE

The panelists believe the industry has made significant strides in reducing cosmetic and perforation corrosion. However, they strongly suggest there is the continued need to increase corrosion protection. The median forecast for panel penetration for 2000 and 2005 is 10 years.

Panelists believe vehicle weight will decrease by 5 percent by 2000 and 10 percent by 2005. Given the recent trend of increasing vehicle weights, the forecast of a 5 percent weight reduction by 2000 is rather noteworthy. Recent years have seen formidable weight reduction programs at the component and systems level. However, overall average weight has increased slightly, due to both increased content levels, and the slight up-sizing with model redesign.

The panelists estimate that for passenger car CAFE of 27.5 mpg, 30.0 mpg and 35.0 mpg, the manufacturers value a pound of weight saved at $1.00, $2.00 and $3.00, respectively. They also estimate for light truck CAFE of 20.0 mpg, 20.6 mpg and 24.0 mpg, that manufacturers value a pound of weight saved at $1.00, $1.00 and $2.00, respectively. The panel forecasts manufacturers may be willing to pay $23.50 per vehicle to improve fuel economy by one mpg by 2005, given a CAFE of 35 mpg. The wide interquartile ranges of this question suggests that many companies have not formulated a strategy regarding CAFE goals.

It is essential that manufacturers use a systems approach that appropriately balances all factors in the search for an optimal design. Clearly there is significant incentive for low-cost weight reduction. Good systems engineering may make higher cost materials vulnerable to improved designs using current materials.

Passenger car and light truck material changes were addressed for the coming decade. The relative direction of material choice was similar for both segments. However, the panelists forecast a more significant reduction of steel and cast iron, and a larger increase in plastics, for passenger cars than for light trucks. If CAFE increases, movement toward lighter weight materials is likely at the expense of traditional materials such as cast iron, steel, copper and zinc.

With polymers, panelists forecast substantial growth for polypropylene (16 percent), TPO (15 percent), and polyester thermoset (10 percent) and a decreasing usage of PC/PBT (-10 percent), SMA (-5 percent), and urethane (-2 percent) in the next 10 years. A steady growth rate of approximately 4 percent is expected for plastics in the coming decade compared to the almost phenomenal growth over the past 20 years. Although the 1996 Delphi VIII panel's forecast may not be as optimistic for plastics as recent growth rates, it does suggest continued new applications for plastics.

The panel forecasts several new application/technologies, most of which are intended to reduce weight and increase component life. The responses may indicate significant opportunity for suppliers, especially those with expertise in high volume manufacturing of lightweight materials. However, the panelists expect cost will likely remain a major hurdle for lightweight materials.

IV. POWERTRAIN/DRIVETRAIN

Aluminum is forecast to be used for 90 percent of cylinder heads and 50 percent of cylinder blocks on passenger cars by 2005. For trucks, aluminum is forecast to be used for 60 percent of cylinder heads and 20 percent of cylinder blocks by 2005. The substitution of aluminum for cast iron in engine blocks and cylinder heads is a significant source of weight reduction, apparently with an acceptable value/price trade off. Panelists forecast that 75 percent of aluminum cylinder blocks cast in 2005 will be utilized cast iron sleeves.

The panel also forecasts a trend toward lightweight materials for engine components in the coming decade. Cast iron and steel will see decreased usage and aluminum and plastics will see increased penetration.

Ceramics continue to face cost, manufacturability and durability concerns. A decade ago there was modest support for a ceramic-intensive engine but support appears to have subsided. It is more likely that ceramics will gain acceptance on a "part by part" basis.

Panelists anticipate significant growth of powdered metal engine components in the coming decade, particularly in valve guides but also including piston rings and piston crowns.

Aluminum is predicted to further increase penetration in heat exchanger components with higher penetration rates in passenger cars than in light trucks for engine oil coolers, heater cores and radiators.

The panel forecasts increased usage of plastic gasoline tanks in the coming decade. The panel expects 60 percent of all passenger cars and light trucks will be manufactured with plastic fuel tanks by 2005.

Material developments in powertrain applications are expected to lead to provide better acceleration, driveability and fuel economy in the coming decade. Many of these gains will come from increased usage of aluminum, magnesium and composites.

V. BODY/CHASSIS

Panelists forecast little change in frame construction for passenger cars and pickup trucks. However, an increase of 10 to 15 percent for unibody construction of both sport utility vehicles (SUVs) and minivans is expected.

Presently, in North America, steel is the primary material utilized for frame/structural components. Steel is forecast to remain the dominant material, through 2005, but aluminum is expected to be used to a limited extent in both unibody and space frame construction.

The panelists expect steel to continue to be the dominant material for body panels, suspension control arms and springs in the next decade. Although there will be a continued effort to reduce weight, the forecast is for aluminum and plastic to make only small gains in body panel usage in the coming decade. Aluminum and HSLA steel are expected to gain increased penetration in suspension control arms. They also forecast aluminum to experience continued growth for wheels. Styled wheels for both passenger cars and light trucks are forecast to be made predominately from aluminum.

Current styling themes continue to promote large glass surfaces. As more glass is used, it becomes more of a candidate to be at least partially replaced by lightweight alternatives such as polycarbonates. However, panelists forecast no application of polycarbonate as an alternative window material by 2000 and only modest usage by 2005. Special coatings and interlayers are expected to increase in usage through the coming decade.

The panel forecasts aluminum usage to increase significantly by 2005 for the following brake components: drums, drum backings, calipers, caliper housings, and pistons. Aluminum matrix composites are expected to see initial application in brake rotors.

The panelists forecast increased use of lead-free electrocoat, powder and waterborne primer surfacers, waterborne base coats, and powder and waterborne clear coat technology in the coming decade. In the past 20 years, industry has reduced paint shop emissions of VOC by nearly 80 percent. It may, however, be necessary to eliminate the remaining 20 percent to meet future environmental regulations. Panelists forecast paint oven temperatures will decrease approximately 10°F for both electrocoat and top coat applications in the coming decade.

Developments are expected for interior and exterior body components to improve dent resistance, corrosion resistance and durability in order to achieve increased customer satisfaction.

VI. RECYCLING

For decades the industry has been actively working to produce more environmentally friendly products. Much of this work has been focused on the manufacturing and operational stages of the product's life cycle. Recent years have seen an increased interest in the impact of the product at retirement. Even though the automobile is one of the most recycled consumer products, the industry faces continuing pressure to further increase recyclability. Material selection is expected to see some influence from recycling concerns. The panel forecasts that many barriers will present significant challenges for plastics/polymers. According to the panel, nonferrous metals will face several somewhat important barriers in the coming decade while the panel expects no significant barriers to recycling for ferrous metals.

Recyclability/disposition of thermoplastics and thermosets continues to present a significant challenge to the industry. The panelists expect closed loop recycling of thermosets to present the biggest challenge. Conversely, the panel does not expect the recycling issues facing ferrous and nonferrous metals to present significant challenges.

Manufacturers are expected to take action restricting the number of plastics in a vehicle, restrict plastics viewed as uneconomical to recycle and pass through recycling requirements to suppliers. However, they see the substitution of lightweight metals for plastics and restriction of the amount of plastics as less likely.

Conclusion

The panel has listed many opportunities and challenges for the industry. Comments regarding recyclability and cost reduction were most frequently given as challenges. The use of lightweight materials, specifically plastics and aluminum, were the most common opportunities given, but cost is a significant barrier. To be competitive in the coming decade, automotive industry participants will need to develop pro-active strategies that enable them to be prepared for change.

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

Unleaded Gasoline	1994*	Median Response		Interquartile Range	
		2000	2005	2000	2005
Regular	$1.10	$1.25	$1.50	$1.20/1.42	$1.30/1.75
Premium	$1.30	$1.50	1.73	1.45/1.65	1.55/2.00

*Source: U.S. Energy Information Administration

Selected edited comments

- After 2000, increasing global energy use will start to put pressure on supply.
- Alternative fuels and/or energy sources (such as electric vehicles) will begin to be competitive.
- Assumes no major disruption in Mid-East.
- Government need for tax revenue and desire to encourage alternate fuels will affect prices.
- Government taxes and increased demand will contribute to the rise in prices.
- I believe taxes will account for most of the increase.
- I would expect gasoline to eventually be taxed to balance the budget or reduce the debt (i.e., an untapped source of revenue). This assumes no political or cartel disruptions.
- Oil prices will remain fairly stable. I would expect a short-term oil glut once Iraq re-enters the market and Russia struggles for cash.
- Some new fuel formulation (not the current version) could make the above estimate wholly meaningless.

Discussion

The panel forecasts regular and premium gasoline prices to increase by 3.3 percent and 3.0 percent respectively annually in the coming decade.

Manufacturer/supplier comparison

The manufacturers forecast higher prices than do the suppliers. This may be in part due to the manufacturers greater awareness of impending fuel tax increases.

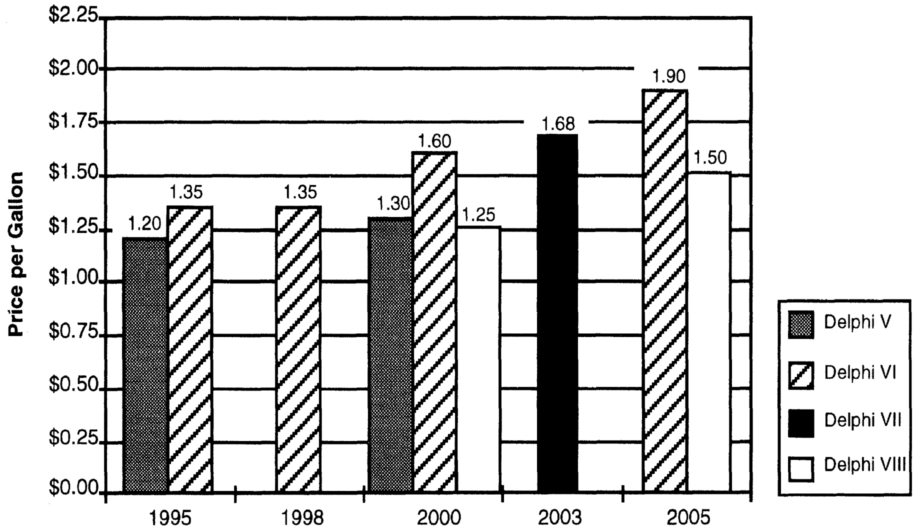
Comparison of forecasts: MKT-3 and TECH-1

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

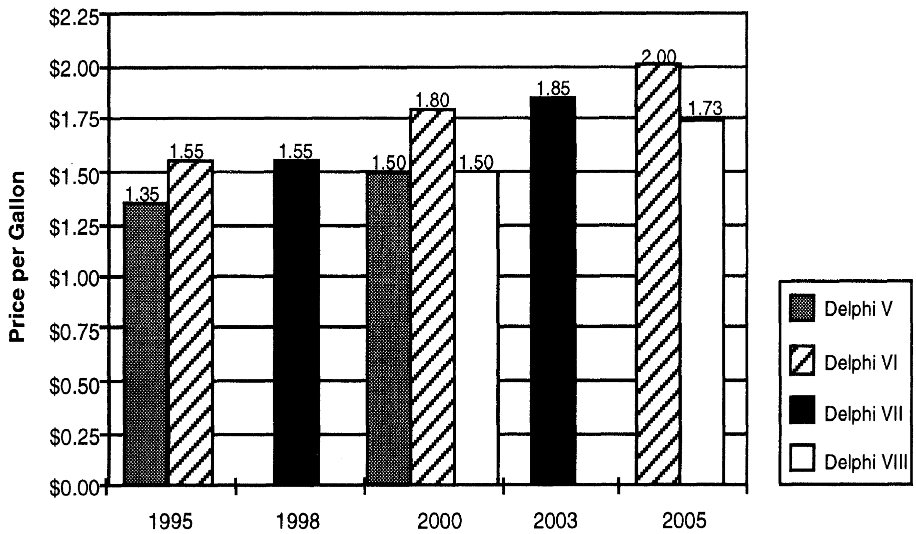
Trend from previous Delphi surveys

The 1996 Delphi VIII panel forecasts a slightly slower growth rate for the price of both regular and premium gasoline than did the 1992 Delphi VI and 1994 Delphi VII panels. Although there is a slight difference in forecasted growth rates between the panels, there may be a major shift in the expected drivers of any price increase. The Delphi VIII panel appears fairly confident that there will be no major oil supply interruptions. Several comments suggest price increases will be the result of political pressure to raise fuel taxes. The previous two panels were less confident about oil supply continuity.

Forecast Price of Regular Gasoline



Forecast Price of Premium Gasoline



Strategic considerations

The forecast of 3.3 percent and 3.0 percent annual price increases for regular and premium gasoline over the coming decade suggests that the panel does not expect significant supply disruptions. However, the comments strongly infer that increased fuel taxes will affect the price of gasoline.

Early Delphi surveys forecasted 1990 gasoline prices in the $2.50 to $3.00 range. Obviously these forecasts did not come to fruition. The Delphi process can best be described as what panelists believe will happen, which occasionally is far different from what does happen. Each forecast must be referenced by many outside factors. The early Delphi forecasts were made in a period of severe gasoline shortages and rapidly increasing prices. In the context of the early 1980s, the forecasts of $2.50 to $3.00 appeared to be very reasonable.

The supply of crude oil is expected to remain stable in coming years. However, the world-wide demand for crude oil may drastically increase, especially after 2000. Many newly industrialized countries (NIC) are rapidly moving toward the development of infrastructures capable of handling vast increases in automotive usage. As automobile usage in these countries increases, the demand for crude oil may increase. The long-term supply-demand equation for crude oil may not be as balanced as some might expect.

Finally it is important to note the environmental challenges facing gasoline. Concerns over global warming, smog and other related problems continue. Although automobile emissions in North America and Europe have been reduced, increased automobile usage in NICs present potential dangers. As automotive industries develop in these NICs, there will be strong temptation to limit costs. Although it may not be realistic, or necessary, for NICs to meet emissions standards of developed countries, it is essential for these newly developed markets to use cost-effective technology to limit emissions.

MAT-2. What percentage of 2000 and 2005 U.S. gasoline sales, in gallons, will be reformulated in accordance with 1990 Clean Air Act Requirements amendments?

Reformulated Gasoline				
1994*	**Median Response**		**Interquartile Range**	
	2000	2005	2000	2005
0%	15%	25%	5/21.3%	15/50%

* Source: Environmental Protection Agency estimate

Selected edited comments

- Corrosion concerns will inhibit wide-scale use.
- Depends upon success (or lack) of the Republicans to hold office.
- Once the public discovers the problems, the regulators will back off.
- Reformulated fuels will not be a major factor.
- The current uproar will result in political pressure to abandon the current fuel blend.
- The legislative drive should be joined by growing consumer acceptance.
- Too expensive. Eye irritant.

Discussion

The panel forecasts reformulated gasoline to account for 25 percent of all sales by 2005. The wide interquartile ranges and the comments suggest that there is still much uncertainty about the future of reformulated gasoline.

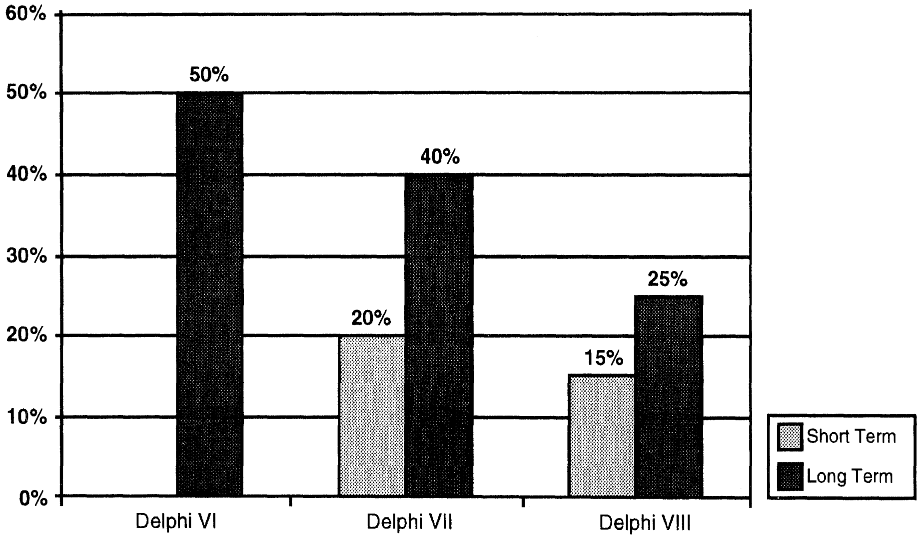
Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is significantly more pessimistic than the 1992 Delphi VI and 1994 Delphi VII panels about the future usage of reformulated gasoline. Much of this pessimism can be attributed to the initial negative consumer response to the new fuel blend.

Future Usage of Reformulated Gasoline



Strategic considerations

The Clean Air Act has mandated the use of reformulated gasoline for regions that do not meet air quality standards. The manufacturers and oil companies have supported this program in an attempt to reduce negative environmental affects of emissions in these regions. However, initial consumer response has been negative in some areas. There are concerns about eye irritation, odor, corrosion and price associated with the use of reformulated gasoline. If these consumer "irritants" are not addressed, they could result in political pressure to abandon or scale back this formulation. This is especially true if the proposed positive effect on the environment is not achieved.

MAT-3. What is the likelihood of federal legislation mandating some degree of alternative fuel capability in retail sales, excluding fleets, by 2000 and 2005? Please include electric vehicles in your forecast.

Scale:	
	1 = extremely likely
	3 = moderately likely
	5 = not at all likely

Year	Mean Rating
2000	3.5
2005	2.6

Selected edited comments

- Even with Republicans making the laws, I think that pressure for alternative fuels is a growing force. There will be at least one more oil crunch and perhaps some major oil spills to intensify the drive to alternative fuels. The government will follow.
- I don't believe electric vehicles will be as prominent as we thought a few years ago.
- Legislation by states is more likely.
- Republican-controlled Congress keeps the probability low for at least the next two years.

Discussion

The panel forecasts as less than moderately likely that some form of federal legislation regarding alternate fuels will be enacted by 2000. However, the panel views it as likely that there will be federal legislation requiring alternate fuels by 2005.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with previous Delphi panels.

Strategic considerations

The panel expects the federal government to enact some form of alternate fuel legislation regarding non-fleet vehicles in the coming decade. California, and 11 northeastern states have already passed some form of alternate fuel legislation. The potential for differing federal, regional and state emissions or alternate fuel regulations presents a difficult challenge. To industry participants, these differing regulations represent, among other things, a splintering of the market. It will be interesting to see if any federal legislation supercedes existing state and regional laws.

The automotive industry has strongly opposed the implementation of legislation such as the California law requiring manufacturers to sell vehicles classified as zero emissions vehicles (ZEV). The industry fought such legislation not only because of technical and economic barriers, but also in an attempt to maintain a common market throughout the United States—California and its special circumstances being the exception. A well thought out, technically feasible, federal alternate fuels strategy—as opposed to a hodgepodge of state and regional laws—is significantly more appealing to both the industry and the consumer.

MAT-4. What percentage of North American-produced passenger cars and light trucks (including fleets) will use each of the following alternate energy sources in 2000 and 2005?

Energy Source	Median Response			Interquartile Range	
	1994*	2000	2005	2000	2005
Passenger Cars					
Alcohol or alcohol/gasoline (>10% alcohol; includes flex fuel or variable fuel)	<1%	3%	5%	1.9/5%	3/10%
Diesel	0	0	1	0/1	0/3
Electric	0	1	2	0/1	1/3
Electric/gasoline hybrid	0	0	2	0/1	1/5
Hydrogen	0	0	0	0/0	0/0
Natural gas	0	1	2	0/2	0/5
Propane	0	0	0.1	0/1	0/3
Light Trucks					
Alcohol or alcohol/gasoline (>10% alcohol; includes flex fuel or variable fuel)	<1%	2%	5%	1/5%	2/10%
Diesel	0	5	5	4/6	4/10
Electric	0	0	1	0/1	0/3
Electric/gasoline hybrid	0	0	1	0/1	0/3
Hydrogen	0	0	0	0/0	0/0
Natural gas	0	1	2	0/3	0/5
Propane	0	0	0	0/2	0/5

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

Other Single Responses:

Fuel cell/hybrid; 2005 - 2 percent

Selected edited comments

- All except hydrogen should see some use.
- Concern about small-particle emissions will slow re-emergence of diesels.
- Fleets for city use will lead the way.
- Much depends on government funding for development.
- Propane is not a viable alternative. Domestic production is in decline as refiners reduce production to meet clean air requirements for cleaner gasoline. If demand increases for home heating and the chemical industry, the United States will have to rely on Middle East imports to meet demand. The trendline wholesale price for propane increased by 49 percent between 1987 and 1994.
- The big question to me is "other." Will an attractive alternative formula be found? The current alternatives appear either unattractive or incapable of sufficient development (i.e., hybrid) for wide use by 2005.
- The impact of globalization of car and truck platforms will turn around the current anti-diesel attitude with fuel efficient diesel offerings.

Discussion

The panel forecasts very little penetration for any of the listed alternate fuels or power plants. However, the usage of alcohol and alcohol/gasoline mixture fuels is expected to reach 5 percent by 2005.

Manufacturer/supplier comparison

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

Comparison of forecasts: MKT-42 and TECH-11

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

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

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with previous Delphi panels.

Strategic considerations

For at least the next decade, the gasoline-fueled internal combustion engine is forecast to remain dominant. Therefore, the implementation of alternate fuel sources and power plants will be driven, not by consumer choice, but by policy.

However, even if legislation is enacted, acceptance of alternative-fueled vehicles will likely be slow. Poor performance, range, cost, infrastructure and other factors are significant barriers.

Alcohol and alcohol/gasoline mixtures are expected to gain some acceptance despite some renewed concerns, mainly because they can be used with only minimal change to the current internal combustion engine.

The panelists forecast that diesels, common throughout much of the rest of the world, will see continued light truck application in the United States. Although there have been recent advances in diesel technology which may make it a more viable alternative, concerns over environmental factors associated with diesel engines, specifically NO_x and particulates, will likely continue.

Each of the other listed alternate fuels is not expected to see acceptance beyond limited application levels. It is important to note that stakeholders involved in the development of each alternate fuel are making substantial efforts to assure the success of their interests. It is essential that public policy take into account the technical and economic realities together with the environment.

MAT-5. What material issues will present the most significant challenges or opportunities in the development of the electric vehicle?

Challenges	Percent of Responses
Battery issues	72%
Lightweight economical materials	16
Other	12

CHALLENGES

Selected edited comments

Battery Issues:

- Battery development for increased range; lower total vehicle weight due to inherent battery weight.
- Battery technology—new materials are needed to further enhance performance and at a lower mass/smaller package size.
- Energy storage devices-batteries; high weight—must be reduced; recharging technology—availability and rate.
- High capacity electric storage (batteries); fail-safe, lightweight containment vessels for said batteries.
- I do not know that you can consider them material issues, but all available batteries have one or more of the following faults: 1) inadequate energy density, 2) inadequate power density, 3) inadequate durability, 4) excessive cost, and 5) lack of safety.
- Need a breakthrough in battery technology only; change thinking: electric vehicles may be valid only for short city use and as a second vehicle.
- Recyclability of battery materials.

Lightweight Economical Materials:

- Achieving required weight reduction at a viable cost while meeting other requirements such as manufacturability, appearance, crash, etc.
- Dramatic weight reductions for body-in-white (40-60 percent) to offset battery weight and improve overall driveability/performance.
- Integration of aluminum, magnesium and composites; hybrid structures based on customer and therefore vehicle requirements; battery technology and materials to reduce mass.
- Lightweight conductors (replace copper).
- Lightweight materials including body and structural panels.
- Lightweight materials to keep inertia low.
- Material weight reduction at a reasonable cost.

Other:

- Performance including crashworthiness.
- Resistance to change or innovation in U.S. auto industry.
- Shrinking the propulsion system.
- "Simple" styling to allow use of best material choices; people packaging.
- Total life cost of system vs. initial part cost.

Opportunities	Percent of Responses
Lightweight economical materials	42%
Battery issues	27
Composite material	17
Hybrid vehicles	8

OPPORTUNITIES

Selected edited comments

Lightweight materials:

- Allow for high value on mass reduction which will open the door for new ideas. These ideas may not be as costly as first thought.
- Development of nonferrous components such as aluminum- and/or -magnesium—based products will likely accelerate these materials being implemented into gasoline vehicles.
- Joining hybrid materials; fabricators who can break out of all-steel, all-aluminum and all-composite vehicles and offer hybrid designs (aluminum outer with composite inner or vice versa).
- Lightweight design with steel—at low cost.
- Lightweight motor materials and design.
- Lightweight, cost-effective aluminum extrusions.
- Opportunity for extruded and cast aluminum; opportunity for cast magnesium.
- Validate mass savings innovations on low-volume electric vehicles (e.g., aluminum and composites in body structures, aluminum, magnesium in suspension/powertrain, polymers in glazing).

Battery Issues:

- Battery disposal, quick change battery, lightweight battery.
- Long life synthetic energy battery.

Composite Material:

- Low-cost carbon fillers for composites.
- Lower tooling cost of composites vs. metal bodies.

Hybrid Vehicles:

- Hybrid electric/combustion energy sources.
- New electrical technologies; solar cells.

Other:

- Marketing claims as environmentally responsible company; demonstrate leadership in an emerging arena; systems approach to demonstrate increased vehicle recyclability.
- Redesign (optimization) through computer programs.
- Won't have to deal with fuel tank/fuel lines/fuel filler tube coatings.

Discussion

The electric vehicle will present the automotive industry many materials challenges and opportunities. The panel expects electric batteries to present a significant materials hurdle. It also sees meeting mass, cost and performance criteria as a challenge.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Electric vehicles currently lack many of the attributes needed for market acceptance. While there are certainly an array of substantial materials barriers to the development of electric vehicles, it is a certainty that developmental work will continue. However, it may take a paradigm shift by both consumers and industry for electric vehicles to gain acceptance. Most early electric vehicles, primarily made to meet California Air Resources Board (CARB) regulations, will likely be based on internal combustion engine platforms. Major changes in materials, manufacturing, technology and consumer attitudes are needed for electric vehicles to become competitive.

The panelists' comments suggest the development of lightweight, economical materials for storage batteries presents the greatest hurdle for electric vehicles that resolve issues of energy and power density, life, weight and more. Although electric vehicle batteries have received a great deal of attention in the past several years, there have been few major breakthroughs. Economically viable battery materials (and technologies) are still unable to meet most consumer requirements. It is highly unlikely that electric vehicles will succeed unless there are significant advances in battery materials and technology.

The development of materials that meet mass, cost and performance criteria will be critical to the success of electric vehicles. Current manufacturing strategies and materials decisions are based on compatibility with the internal combustion engine paradigm. Electric vehicles will only become broadly viable if they are given a clean sheet approach. There is extensive work being done inside the industry to develop materials for electric vehicles, and some important material and processing advancements will come from non-traditional suppliers. However, it is important to note that processes developed for non-automotive manufacturing applications may not be easily transferable due to the high volume and short cycle times required for automotive production. Any possible paradigm shift to electric vehicles is a long-term event, and it is important to monitor a wide variety of sources for materials technology advances.

MAT-6. Please indicate your view of the trend in U.S. federal regulatory and legislative standards over the short term (1996-2000) and long term (2001-2005). Also, please list any likely new areas of legislative and/or regulatory activity.

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

Legislation/Regulatory Activity	Mean Rating	
	SHORT TERM 1996-2000	LONG TERM 2001-2005
Fuel economy standards (CAFE)		
Passenger car	2.6	1.9
Light truck	2.5	2.0
Vehicle emission standards		
Passenger car	2.4	1.9
Light truck	2.4	1.9
Alternate fuel use		
Passenger car	2.8	2.0
Light truck	2.8	2.1
Occupant restraint/interior safety		
Passenger car	2.4	2.0
Light truck	2.3	2.0
Vehicle integrity/crash worthiness		
Passenger car	2.5	2.1
Light truck	2.4	2.1
Anti-theft		
Passenger car	2.9	2.6
Light truck	2.9	2.6
Product liability		
Passenger car	3.0	2.7
Light truck	2.9	2.7

Short Term: New areas
Vehicle identification, 2

Long Term: New areas
Assembly plant emissions, 1
Vehicle identification, 1

Selected edited comments

- Assumes anti-regulatory trend evident in Congressional elections continues at least two elections.
- Consumer preference will drive changes. Government initiative will be tempered by budget concerns.
- Depends on which group controls Congress.

- Some of the current requirements, such as Zero Emissions Vehicles and "clean fuels" will hurt the voter directly and, eventually, will be modified to pacify the voter.
- The federal government, juries and Congress are populated with liberals who do not understand the laws of physics.
- The government will insist on card reader technology for identification of vehicles which can be read by the traffic light sensors. These are currently being installed throughout Oakland County, Mich., at federal expense. Their supercomputers can track vehicle location on a real time basis.
- There will probably be an over-relaxation in the next few years, but moderation to some sensible compromise in the long term.
- Will depend upon success of state and regional initiatives.

Discussion

The panel forecasts increased federal legislation and regulation pertaining to emissions, crashworthiness and occupant restraint/interior safety in the short term. Panelist forecast increased likelihood for activity in each of the listed legislation and regulation areas by 2005.

Manufacturer/supplier comparison

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

Comparison of forecasts: MKT-42 and TECH-15

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

SHORT TERM 1996-2000			
Legislation/Regulatory Activity	**TECH**	**MAT**	**MKT**
Fuel economy standards (CAFE)			
Passenger car	2.2	2.6	—
Light truck	2.1	2.5	—
Vehicle emission standards			
Passenger car	1.9	2.5	2.3
Light truck	2.0	2.4	—

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

Trend from previous Delphi surveys

Forecasts from the 1994 Delphi VII panelists indicate a slightly more restrictive environment for all regulatory activities than was predicted by panelists from the 1996 Delphi VIII.

Strategic considerations

The panel expects federal policy to continue pursuing a strategy of regulation. The recent trend in Congress has been away from stricter industry regulation and more toward a cooperative effort with industry. Many panelists may see this as a short-term shift and expect that Washington will soon resume driving change through regulation.

This is an obviously volatile issue, and uncertainty is likely for sometime to come. Manufacturers desire long-term predictability of regulation. To its credit, industry may be developing a much more pro-active attitude than previously.

The panel expects legislators to subject light trucks to the same level of scrutiny that passenger cars receive. In fact, the panel expects that trucks may receive slightly more legislative attention than passenger cars over the next five years.

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MAT-7. Do you expect federal or state government legislations and regulations to require the recyclability of automotive materials in the following areas? Please give your forecast for 2000 and 2005.

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

Regulatory Issues	Mean Response	
	2000	**2005**
Establishment of uniform identification/coding standards for materials to facilitate separation	2.7	1.6
Specific regulation for disposal of automotive fluids	2.7	1.6
Specific regulation for disposal of used tires	2.8	1.6
Ban on some current automotive materials	3.4	2.2
Specific regulation for recyclability of plastics	3.5	2.2
Required minimum recycled content	3.8	2.9
Financial penalties/incentives based on recycled content	4.0	3.1
'Take back' regulations making manufacturers responsible for final product disposition	4.2	3.4

Other single responses:

Incineration codes: 2000; 3, 2005; 2

Electric vehicle battery recycling: 2000; 3, 2005; 1

Selected edited comments

- Cost is king. Recycling will be driven by automakers in anticipation of legislation.
- European community OEMs likely will be under greater pressure to meet more stringent regulatory requirements.
- I still think a few health risk materials will be banned by 2005.
- It's too late to ban materials or require minimum recycled content. Government understands lead times. This also applies to the recyclability of plastics.
- Local municipality (especially large urban areas) regulations may be more stringent.
- Many of the above issues, especially recycling of plastics, are heavily influenced by design. Designs are already underway for model year 1999-2000 and that may affect these numbers.
- Recyclability is more important than recycled content.
- Recycling will continue to receive both consumer and government attention. However, I believe that it will be more economically justified rather than decreed like safety and CAFE.
- Regulation will be dependent on party in office. Regulation will also be influenced by OEM activities; if OEMs continue to be pro-active and recycle voluntarily, there will be no need for costly regulations.

- The automotive industry needs to look at the source of raw materials for future vehicles (2010) coming primarily from our current fleet.
- The current moves in Congress are but a temporary block to more environmental responsibility in the private sector.
- The major drivers of new technology for both product and process are quality, cost, responsiveness; plus environmental: emissions, fuel economy, noise, alternate fuels, electromagnetic interference, recyclability.
- The politicians have taken too long to start downsizing the federal government and making them economically accountable. The 1996 elections will continue "business as usual."
- There will be bans on a few toxic materials.

Discussion

Panelists forecast increasing activity on the part of the federal government with material recycling and life cycle management. They expect federal regulations regarding automotive material recycling in the coming decade. The panelists view all of the listed regulatory actions as at least somewhat likely by 2005.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-41

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

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with previous forecasts. However, the Delphi VIII panel views as more likely the establishment of coding standards (1.6) than did the 1994 Delphi VII panel (2.3).

Strategic considerations

Even though the automobile is one of the most recycled consumer products available, (nearly 100 percent of all vehicles and 75 percent of each vehicle by weight), the industry faces continuing pressure to further increase the recyclability of its product.

The need to increase recyclability is driven by at least three forces. First, the amount of plastics is rapidly increasing in vehicles. Second, German regulation has been setting the standard for automotive recycling worldwide. Third, customer environmental awareness is increasing.

Much of the recent interest in automotive recycling is due to the increasing amount of plastic used in vehicles. Unfortunately, plastics are difficult to reclaim, and they increase the amount of automotive shredder residue (ASR) going to landfills.

The German government has, for several years, been the leader in the regulation of automotive recycling. Germany has enacted a number of laws pertaining to the final disposition of the automobile, including a so called 'take back' law requiring the manufacturers to be responsible for the disposal of the vehicle. It is important to note that the issues surrounding the implementation of the German laws are significantly different from those found in North America.

Consumers are more aware of the environment, and the products they purchase need to reflect this increased awareness. Although it is unlikely new car shoppers will soon make recyclability a major purchase criterion, they will become increasingly aware of the environmental impact that their vehicles will have upon final disposition. Companies must pro-actively position themselves to be perceived as environmentally conscientious.

Currently there are guidelines and regulations for the disposal of some automotive fluids. The panel expects expanded requirements in the coming decade. The disposal of used tires has also been an area of interest for regulators in recent years, and the panel also expects that the federal government will further regulate the disposal of tires.

The development of coding standards to facilitate the identification of materials is an excellent example of industry acting pro-actively to guide future regulation. Future federal regulation regarding the coding of materials will likely be based on industry-developed standards.

The implementation of a plastics recycling strategy presents the industry with many significant challenges and few easy answers (see MAT-42 and MAT-43). The greatest challenge may not be the technical capabilities to recycle plastics but rather the infrastructure to reclaim the plastics and secondary markets for the reclaimed materials.

Finally, if recycling is indeed forced via regulation, it is critical that manufacturers begin to include recycling in their materials selection, design and manufacturing processes (see MAT-8).

MAT-8. **The automotive manufacturers base their material decisions on many criteria, including a number of attributes and characteristics of competing materials. Please indicate your view of the importance of each of these attributes and characteristics in the material selection process over the next decade.**

Scale: 1 = extremely important
3 = somewhat important
5 = not at all important

Attribute/Characteristic	Mean Rating
Cost of materials and processing	1.2
Weight	1.5
Safety considerations	1.7
Corrosion resistance	1.9
Field experience	1.9
Cost of warranty	2.0
Design/styling requirements	2.2
Formability	2.3
Environmental issues	2.7
Preference of vehicle purchaser	2.8
Cost of disposal	2.9
Recyclability	2.9
Ease of final disposition	3.1

Other single responses:

Overall manufacturability and utilization of current investment.

Fuel economy/mass; 2

Assembly feasibility; 1

Selected edited comments

- A disconnect between marketing and engineering exists for steel on safety and environmental issues.
- As OEMs perfect corrosion protection, consumers may forget what a problem it was for body systems. Exhaust systems will need improvements.
- Automotive preference will evolve over the next 10 years from "price per pound" to "cost per system" and from "cost out the door" to "cost to consumer over vehicle life." Therefore, most of the factors will increase in importance over the next decade.
- Corrosion resistance is being caught between two opposing forces: overall desire to increase longevity of the vehicle vs. cutting back corrosion protection for cost savings and weight savings. Which will win out in the end?
- Cost-effective low mass solutions will prevail.

- Cost-out will continue to be the dominant theme. Reinvestment requirements will become a barrier to product or material innovation as suppliers offer incremental improvements from current technologies.
- Major factors in materials selections are also based on company politics, globalization hysteria (Europe won't accept it so we can't either), and lack of common collection, identification and distribution systems for used materials in the United States.
- Recyclability will increase in relative importance. Detroit is risk averse; demonstration projects are required. Modular construction will increase.
- Satisfying customer wants and needs is important. Customers don't care about material selection.
- The weight vs. cost balance can change dramatically for high-end, heavy vehicles where premiums can be absorbed or if vehicle exceeds weight-class limits.
- Use of non-hazardous materials and recyclability will be strong drivers. Material selection is key to environmentally compatible product and process design.
- Vehicle mass drives and affects many issues, not the least of which is fuel economy. As CAFE requirements increase, materials that lead to a decrease in vehicle mass should become more desirable. Component approaches to recyclability will drive material choices.

Discussion

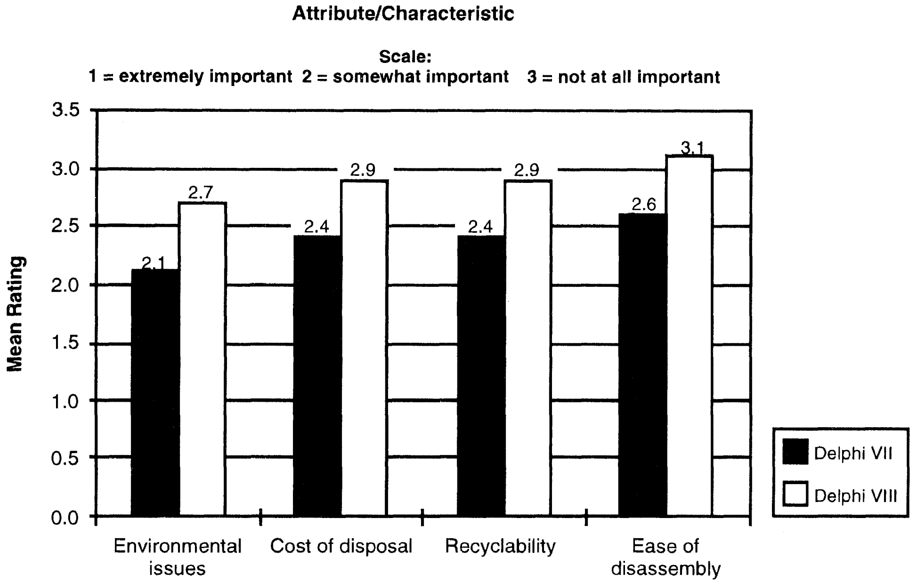
The panel forecasts cost to be the most critical material selection attribute in the coming decade. It expects weight to be the other strong determinant over that period. It is important to note that all of the attributes listed were viewed as at least somewhat important.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII. The 1996 Delphi VIII panelists are in general agreement with the Delphi VII panel, but there are some interesting differences. Although the rank order of the attributes is similar, the spread from top to bottom is wider for the Delphi VIII panel. This suggests material selection may face increased emphasis on cost and weight, and a decreased emphasis on environmental factors.



Strategic considerations

The material selection process includes a variety of often conflicting factors. The two factors rated as most important—cost and weight—are an excellent example of such conflict. The industry has traditionally relied on high weight/low cost materials such as cast iron and steel. However, as pressure to reduce weight increases, the industry is looking more closely at low weight/higher cost materials. By rating cost and weight as the most critical attribute, the panel suggests that this cost-weight dilemma will continue for at least the next decade. It is likely that those solutions that reduce weight while effectively addressing the cost issue will be the winners in the coming decade.

An interesting difference between the 1996 Delphi VIII and the 1994 Delphi VII is the apparent decreased importance of environmental attributes in the material selection process. The comparison with Delphi VII suggests that the traditional attributes such as cost, weight and safety will continue to drive the selection process while environmental factors may become less of a concern. This is at least partly due to the de-emphasis of environmental issues in Congress. This forecast is noteworthy, given the panel's expectation for federal regulation regarding recycling (MAT-7). Although there are many individuals at the manufacturers who are committed to making vehicles more environmentally friendly, it is likely that the implementation of recycling strategies may be slow given current corporate goals.

It is also important to note that each of the listed attributes is rated as at least somewhat important. While cost and weight will continue to be the main drivers in the selection process, materials must perform well on all attributes to be considered.

MAT-9. Please rate the relative advantages and disadvantages of each material for body panels over the specified stages of the vehicle life cycle.

Scale:	1 = an extreme advantage 3 = neither advantage nor disadvantage 5 = an extreme disadvantage

Material for Body Panels	STAGES OF VEHICLE LIFE CYCLE					
	Raw Material Cost	**Design**	**Component Processing**	**Assembly**	**Field Use**	**Vehicle Disposal**
Aluminum	4.2	3.5	3.2	3.5	2.9	1.9
Thermoplastics	3.4	2.2	2.9	2.9	2.5	3.5
Thermosets	3.3	2.3	3.3	2.9	2.6	4.1
Steel	1.3	2.4	1.9	2.1	2.4	1.5

Selected edited comments

- Aluminum material and processes used to fabricate aluminum have great potential but the wide swings in material cost are hurting implementation (i.e., an unstable situation).
- Assembly of thermoplastics and thermosets in typical assembly plant causes problems because of handling variation required and lack of experience. Vehicle disposal of steel is already established and therefore has an extreme advantage.
- Biggest disadvantage of steel is its mass. The comfort level with steel in the early stages of the product is still very high. Proper applications of the alternatives must be thought out well so as not to have any hint of failures to establish credibility of alternatives.
- Corrosion is real "Achilles heel" of steel. Thermoplastics offer best (longest) life cycle.
- Corrosion protection could be included as a category. Both thermoplastics and thermosets have an extreme advantage.
- Cost (material, process and assembly) will be predominant.
- Design: Plastics offer styling freedom over steel, and aluminum is least flexible. However, the mass saving potential of aluminum outweighs its disadvantages. Component processing: Maintaining consistent quality for plastic panels has proven difficult.
- Finish body panel cost premiums for aluminum will be cut in half compared to steel.
- If weight is not an issue, steel is the best, but aluminum is too volatile on price, and thermosets are not economically recyclable unless "waste to energy" or "pyrolysis" are politically acceptable.
- Mass should be a category here. Even though it is not related to the vehicle life cycle, it is an important driver. Infrastructure for recovery of plastics at vehicle disposal is not currently in place. Therefore, plastics suffer in this segment as they generally become automotive shredder residue. As the infrastructure evolves (and it is already beginning) these numbers will decrease.
- Raw material cost of thermoplastics is volume dependent.
- Regarding numbers given for vehicle disposal—thermoplastics and thermosets: For all the hoopla for recyclability of plastics, there is little chance that this will be implemented at final ve-

hicle disposal in the United States. The recycling industry is market driven and the cost to get the technology implemented for even thermoplastics is prohibitive. For this to happen, a great deal of government financial assistance (e.g., subsidies) will likely be required.

- Technology developments (polymer improvements, processing techniques, finishing systems) will improve cost effectiveness of thermoplastics at higher volumes. Thermoplastics should become dominant vs. aluminum for weight sensitive platforms and challenge steel on all lower volume, non-structural panels.
- The high scrap value of aluminum gives it a clear advantage for vehicle disposal.
- The raw material cost of aluminum is an extreme disadvantage, but should be an advantage if recycling were factored in.
- The unpredictable fluctuation in aluminum prices is the main reason for its limited use in body panels and other automotive applications. Its lower stiffness also limits weight savings over steel.
- Thermosets have been proven in a variety of body panel and structural applications. E-coat suitability is critical. Recyclability is improving. Designers are using some parts consolidation. Thermoplastics are not suitable for horizontal panels or E-coat. Aluminum not competitive at prices required for new investment ($1.50/lb.).
- Volume should be indicated because of tooling cost considerations. I assume 200,000 vehicles.

Discussion

The panelists rate steel as having significant advantages over the other listed materials in the raw materials cost, component processing, assembly and vehicle disposal stages of the life cycle. The panel rates steel, thermoplastics and thermosets equally advantageous in the design and field use stages of the life cycle.

Manufacturer/supplier comparison

The panels are in general agreement. However, the manufacturers rate steel as more advantageous at the vehicle disposal stage (1.2) than do the suppliers (1.8).

Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey, and the 1996 Delphi VIII panelists are in general agreement with that panel. However, the Delphi VIII panel rates steel and aluminum as slightly more advantageous than did the Delphi VII panel. Conversely, the Delphi VIII panel rates thermoplastics and thermosets as slightly less advantageous than did the Delphi VII panel.

Strategic considerations

According to the panel, steel, long the material of choice for body panels, continues to be the most advantageous material. In four of the six life cycle stages, steel is viewed as having a significant advantage over aluminum, thermoplastics and thermosets. In the other two stages, steel is seen as nearly equal to the competing materials. We believe that steel will remain the dominant material for body panels for the next decade (see MAT-32). However, it is important to note that these ratings assume current CAFE standards. If CAFE were to increase, it is possible that these ratings, especially for field use, may change.

Raw Material Cost: Steel is rated as significantly advantageous vis-à-vis the other materials at the raw materials stage of the life cycle. While raw material cost is seen as the strength of steel, it is the most disadvantageous attribute for aluminum. The continued price fluctuations of aluminum makes it a high risk material for many in the industry. Raw material pricing for thermoplastics and thermosets is viewed as neither an advantage nor a disadvantage.

Design: The panel views plastics and steel as nearly even, and aluminum as somewhat disadvantaged, in the design stage. Thermoplastics and thermosets allow designers versatility and creativity that is unmatched by other materials. Plastics also offer significant opportunities for part consolidation. Steel is design competitive in large part because of the familiarity of the industry with the material. What steel lacks in design flexibility, 100 years of industry experience is able to overcome. Many current materials engineers began their schooling with steel with little emphasis on other materials. Aluminum offers designers as much versatility as steel, yet is an unfamiliar material to many. As more design knowledge is gained, aluminum will be viewed as design competitive with the other materials.

Component Processing: The panel rates steel as significantly more advantageous than the competing materials for component processing of body panels. The automotive industry has also developed a century of steel-forming knowledge. Combined with that knowledge is a significant investment in tooling. Plastics suffer from cycle time disadvantages that may limit high volume application, and aluminum forming is still very much a new technology for the industry.

Assembly: Much like component processing, steel is viewed as the most advantageous material in the assembly stage. As several of the comments suggest, plastics and aluminum are at a severe disadvantage in the current assembly system. Traditionally, assembly facilities have been optimized for steel panels. Attempting to replace steel with plastics or aluminum inevitably leads to a less than optimal solution for current facilities. It may take a paradigm shift in component processing and assembly for any material other than steel to be competitive.

Field Use: The four materials are viewed as equal in field use. Steel suffers from corrosion but is extremely reliable for crash predictability. Plastics present significant durability and weight advantages yet may suffer from paint degradation. Aluminum saves weight, but it may present challenges for aftermarket repairs.

Vehicle Disposal: According to the panel, steel has a significant advantage over the other materials at the disposal stage. Steel's advantage lies not only in the properties of the material but also in the commitment of the steel industry to work diligently to develop an economically effective reclamation infrastructure. Aluminum also has a well-established recycling infrastructure that may help its acceptance environmentally for body panel applications. The lack of economically effective recycling puts thermoplastics and particularly thermosets body panels at a significant disadvantage.

Continued significant progress is expected in all areas for each material. As the Lightweight Steel Body Project by the auto-steel partnership suggests, steel is a moving target. Aluminum continues to see increased application for hoods and decklids, while Saturn has shown that plastic panels can be accepted by the consumer.

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MAT-10. A number of automotive industry experts suggest that the issue of corrosion has been satisfactorily resolved. For the following systems, do you agree or disagree with that analysis?

Scale: 1 = strongly agree
3 = neither agree nor disagree
5 = strongly disagree

System	Mean Rating
Cosmetic Corrosion	
Powertrain	2.3
Body	2.4
Chassis	2.4
Perforation Corrosion	
Powertrain	2.0
Chassis	2.1
Body	2.3

Selected edited comments

- A continuing issue exists with balancing appearance (cosmetics) with corrosion requirements (i.e., must be black or silver and meet 400 hours salt spray).
- Although significant progress has been made in nearly eliminating perforation corrosion failure within 5-7 years of vehicle life, cosmetic corrosion remains a problem within this time frame and beyond.
- Body damagability, including corrosion effects, is still a major source of consumer dissatisfaction.
- Body fasteners can still be a cosmetic concern. Panels themselves are okay.
- Both body and chassis show failure 2-3 years before any powertrain problems.
- Cosmetic corrosion at 5 and 6 years of age are still very high in the Detroit area (1993 survey).
- Cosmetically, the body is still not good enough for 100,000 mile, 10-year life.
- Even though I agree, the rules are being changed with the introduction of new materials, especially increased likelihood of coupled dissimilar metals, and less developed understanding of coatings for nonferrous metals and non-metals.
- Higher powertrain engine requirements mean higher operating temps, increased difference in thermal cycling extremes, etc. This requires more cost and engineering time to solve these issues, not value added in all cases.
- How long should a car last before the corrosion becomes a safety concern? I don't know, but with extended lifetime demands, it is likely to be an issue.
- I am considering "perforation corrosion" to include all corrosion that results in loss of function. Crevice corrosion of body hardware and chassis components has not been solved. Cosmetic corrosion of brake rotors has not been solved.
- I can't forecast impact of new technologies such as powder paint.

- In many cases we know what to do to meet the 10-year body cosmetic/perforation corrosion requirements/goals. We just don't want to spend the money. Wheels, brakes and exhaust systems have difficult-to-resolve cosmetic issues. I'm assuming under "Perforation Corrosion" you are including any corrosion that affects functional performance of the component.
- Most of the corrosion issues have been addressed by applying zinc coatings. Zinc is now being classified as a hazardous material. The corrosion issue may have to be revisited.
- Much work still needs to be done with regards to galvanized steel to protect from corrosion as more nonferrous components, especially magnesium, are integrated into the vehicle.
- Paint chipping on steel and aluminum is still a problem.
- Road salt in snow belt areas still badly corrodes body work.
- Steel has improved dramatically in 20 years but is still highly unacceptable.
- Steel rusts.
- The attention to the corrosion issue has had extremely good results; however, I don't think it has been completely resolved.
- The automakers think too short term. People are keeping their cars longer and corrosion problems have been postponed, not solved.
- The corrosion of aluminum body panels has been solved.
- The professionals that fill out this survey probably change cars frequently. For the large fraction of the population that purchases used cars, this is a serious issue. Corrosion—cosmetic or structural—should never be the cause of a car's demise. This is the goal; we are not there yet.
- The question does not define the failure criteria and/or the time element for acceptable performance.
- The technical issues probably have been satisfactorily resolved but for various reasons, including cost, the solutions are often not implemented.
- There are body problems with the few vehicles using metal bright trim (especially when trim comprises horizontal strip) due to galvanic action.
- There is a continuing conflict between cosmetics (for powertrain) and functional requirements. The use of conventional salt spray tests is typical but may not correlate with actual in-service conditions.
- This is an unfounded "lease car" owner's opinion: corrosion is a problem. People are expecting, and engineering is enabling, cars to last longer. Combining increases in cost due to regulations, body corrosion may be the first factor to cause a person to sell or dispose of a car.
- Underhood white corrosion.
- Use of two-sided electro-galvanized steel for outer body panels has given us a 5-year-plus cosmetic performance. Ten-year perforation life of the body is nearly in reach and is dependent on manufacturing/painting processes to achieve final results. Some cosmetic corrosion of chassis/powertrain will continue due to cost of solutions. Perforation of chassis/powertrain has not been an issue.
- Vehicles built after 1987 still show cosmetic corrosion.
- Vehicles still experience perforation with E-coat and hot dipped galvanized, especially after 10 years.

- While corrosion of steel body panels has been solved, corrosion is still one of the limiting factors in wider use of aluminum and magnesium.
- With regard to both cosmetic and perforation, the body has benefited due to visibility and has been given a lot of attention. The chassis and powertrain resist corrosion better because they are thicker, but surprises may occur.

Discussion

The panelists indicate that the industry has made significant strides in reducing cosmetic and perforation corrosion. However, they strongly suggest that there is the continued need to increase corrosion protection.

Manufacturer/supplier comparison

The two panels are in general agreement. But, the manufacturers view cosmetic corrosion as more of a continuing problem than do the suppliers.

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with previous Delphi panels.

Strategic considerations

Significant progress has been made in corrosion protection in the past decade. However, there are still significant gains that must be made before the corrosion issue can be satisfactorily resolved.

Effective corrosion protection involves a systems approach. It is critical to consider materials, process and design as fundamental to a successful corrosion protection strategy. Failure to adequately address any one of these elements will greatly increase susceptibility of a vehicle to corrosion.

Several panelists suggest that the technology and materials are available to extend corrosion protection, yet they are not used due to cost constraints. To remain at a competitive advantage, it is essential for those involved with metals prone to corrosion to continue to develop more cost-effective corrosion protection systems, particularly in this day of rising consumer expectations and concerns with affordability.

MAT-11. Please estimate the number of years before panel perforation will develop in a severely corrosive environment such as Detroit or Pittsburgh for North American-produced passenger cars and light trucks produced in 1995, 2000 and 2005.

	Median Response			Interquartile Range		
Years to Panel Penetration	**1995**	**2000**	**2005**	**1995**	**2000**	**2005**
	7.5 yrs	10 yrs	10 yrs	6/10 yrs	7/10 yrs	8.8/12 yrs

Selected edited comments

- Galvanized coating weight is being reduced on future models for cost savings.
- Polymeric coatings as opposed to electro-phosphate coatings may increase body panel life early in the next century.
- Possible reduction in electrogalvanized coating weights will take place as the material becomes less variable.
- Some panels will never perforate in "Green Belt."
- The auto industry should pat itself on the back for its win over corrosion (of steel).
- These figures represent average performance. There will always be car-to-car variation, and some customers will experience inferior performance.
- This meets customer demands and product life cycle. Most new car buyers do not keep their cars for 10 years.

Discussion

The panel forecasts that by model year 2000, the length of time for panel perforation will be 10 years. However, the interquartile ranges suggest that there is still significant concern that the industry standard may be less than 10 years. The median forecast for 2000 is also 10 years; however, the interquartile ranges suggest that there is more consensus that 10 years will be achievable by 2005.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with previous Delphi panels.

Strategic considerations

The current industry standard warranty for panel perforation is six years or 60,000 miles—a level that most cars meet. Volkswagen has significantly raised the standard to ten years or 100,000 miles. There is some question whether this will become the typical warranty. According to the American Automobile Manufacturers Association (AAMA), the average age of passenger cars in use in the United States is 8.3 years. However, the length of time that an average new car purchaser owns a new car is considerably less than that. For many new car buyers, and certainly individuals that lease vehicles, panel rust is only a consideration because it may effect used car prices.

According to the several comments, industry has the capability to design and manufacture panels that last for 10 years before perforation. However, manufacturers must weigh the benefits of longer lasting panels with the associated costs.

MAT-12. What percentage change in total vehicle weight do you anticipate by 2000 and 2005? Please also indicate plus or minus.

	Median Response		Interquartile Range	
Total Vehicle Weight	**2000**	**2005**	**2000**	**2005**
Percent Change:	-5%	-10%	-1/-6%	-12/-5%

Selected edited comments

- Americans like comfortable, soft riding vehicles; therefore, the weights are not going to change much.
- As long as petroleum real price stays extremely low and Washington waffles on CAFE, there is not much incentive for reducing vehicle weight.
- Assuming no major new add-on requirements for safety or crashworthiness.
- Average weight appears to be mostly influenced by end customer preference. Elimination of large passenger cars is being offset by an increase in sport utility vehicles and light truck sales. This trend will prevent realization of weight savings through design and engineering.
- CAFE regulations will drive vehicle weight issues; therefore, government regulations for CAFE should be tracked.
- Changes in material compositions are primary contributors.
- Depends on market segment, price of fuel and government CAFE targets.
- Depends on safety regulations.
- Fuel economy and thus emission reductions are important. However, we need to use an economic mechanism to solve the problem (i.e., higher fuel prices) and incentives to increase car pooling.
- Government regulations will still drive this issue.
- Magnesium is the next logical step to be used in the weight reduction trend. However, the world's capacity will have to increase for that to happen, and its price must drop. Total vehicle weight will be difficult to drop without magnesium as more components are being added for safety, fuel and clean air.
- Major efforts are underway to reduce weight but they will not be enough to reverse the current upward trend until after 2000.
- Major efforts are underway to reduce weight in passenger cars and light trucks. But the average weight will continue to increase with the trend to bigger vehicles and weight-adding features.
- Modular construction will help to reduce weight. CAFE will drive this reduction.
- My estimate assumes the current climate in Washington remains the norm for a while.
- Obviously, larger cars and trucks will contribute to this decrease in weight the most.
- The current trend of weight gain for new models (8 percent for '94 and 7 percent for '95) will prove very hard to reverse.
- This assumes that the fleet continues to downsize more than weight savings per vehicle.

- Total vehicle weight will go down due to perceived customer expectations (like in Europe) that higher mass vehicles are "wrong" and by OEMs showing social conscience actions (i.e., lower weight vehicles) to ward off additional government regulation.

Discussion

Panelists forecast vehicle weight to decrease by 5 percent by 2000 and 10 percent by 2005. The comments suggest that there are many factors that will determine the extent of weight change in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was asked differently in previous Delphi surveys, so direct comparison is not possible.

Strategic considerations

Given the recent trend of increasing vehicle weights, the forecast of a 5 percent weight reduction by 2000 is rather noteworthy. Recent years have seen formidable weight reduction programs at the component and systems level. However, overall average weight has slightly increased. This is due to increased content levels and the slight up-sizing with model redesign. This short-term forecast may be a case of the panelists failing to see the forest because of the trees. It is also important to note that with lead times of three years or more, there is a limit to the amount of newly designed models available by 2000. Therefore, a 5 percent change in the average weight of a vehicle may only be achieved by a change in model mix toward smaller, more fuel efficient vehicles.

Increased fuel economy can be achieved by a number of factors including powertrain modifications, design changes and mass reduction. Over the last two decades, the industry has made significant advances in the powertrain. Any significant future powertrain efficiency gains may be costly. Other alternatives to increase CAFE, such as aerodynamic designs, have been nearly optimized. Serious weight reduction such as the 10 percent forecasted by 2005 must include either significant downsizing (unpopular with the customer), increased use of lightweight materials (costly) or some combination of the two. It is likely that consumers will continue to view downsizing as an unacceptable alternative. Instead, the challenge will be for the industry to improve design of today's materials and develop cost-effective applications for higher cost, lightweight materials. It is also likely, even in light of the panelists' forecast, that vehicle weights could continue to increase slightly in the next five years due to shifts in model mix, feature content and other factors—unless CAFE is increased.

MAT-13. Assuming CAFE requirements as noted in the table below, what is the value today in current dollars per pound of weight saved to a vehicle manufacturer? What will it be in 2000 and 2005? Please do not adjust for inflation.

Passenger car							
Median Response				Interquartile Range			
1995	2000	2005	2005	1995	2000	2005	2005
Current Value CAFE= 27.5 mpg	CAFE= 27.5 mpg	CAFE= 30 mpg	CAFE= 35 mpg	Current Value CAFE= 27.5 mpg	CAFE= 27.5 mpg	CAFE= 30 mpg	CAFE= 35 mpg
$1.00	$1.00	$2.00	$3.00	$1.00/1.00	$1.00/1.50	$1.69/2.50	$2.50/3.63

Light truck					
Median Response			Interquartile Range		
1995	2000	2005	1995	2000	2005
Current Value CAFE= 20.0 mpg	CAFE= 20.6 mpg	CAFE= 24 mpg	Current Value CAFE= 20.0 mpg	CAFE= 20.6 mpg	CAFE= 24 mpg
$1.00	$1.00	$ 2.00	$0.50/1.00	$0.71/2.00	$1.19/3.00

Selected edited comments

- Costs assume the vehicle is at the top of its allowable weight class. Where CAFE is unchanged at 27.5 mpg, weight reduction gives added option flexibility.
- Dependent on inertial weight class and where vehicle is within it. Also dependent on where OEM's fleet is with regard to fleet average target. There is a significant difference between value and cost. Weight savings using holistic designs in steel will also result in cost reductions but still be of significant value to OEMs.
- Depends on how "overweight" the car is now.
- Despite what the OEMs say, the weight savings today are being achieved by using thinner metal, not using new technology. The price of magnesium must be lower and it must be available in strip form.
- Dollars per pound largely depends on how close you are to being over weight or dropping down a weight class. If you are midway in the weight class, the dollar per pound is much less.
- Even small increases in light truck CAFE are going to be very difficult to meet.
- It really depends on the type of vehicle and the weight class (Viper vs. Neon; Corvette vs. minivan).
- Most of the heat will be on light trucks to get over 25 mpg minimum.
- Must balance all deliverables (e.g., cost, fuel economy, etc.). May not be able to afford higher cost materials in a competitive market. Government will drive cost with CAFE mandates. Poor choice of methods to dictate fuel economy.

- OEMs have buried their overly aggressive cost reductions in their weight reduction demands with no cost credit. Under current domestic OEM rules, many moderate but not zero cost weight reduction opportunities are squandered.
- Reducing vehicle weight doesn't have to lose money. Consumers will not pay to decrease vehicle weight or improve fuel economy.
- The impact of mass on increasing CAFE is offset by overall powertrain efficiency gains and decreasing gasoline prices.
- The value of a pound of mass saved must be based on the customer's value (improved fuel economy equals less fuel cost), less mass can reduce tire size and replacement cost; performance acceleration and deceleration has a value. CAFE has done nothing as shown by the switch from cars to trucks where the product meets the customer's total requirements and cars do not!
- There cannot be effective mass reduction targets within programs with a value of mass that stays "fixed" no matter where vehicle is in inertial weight class. This is more important than ever since new platforms will last for years, and added features and regulations will add mass over their product life cycle.
- Value is established by nearness to target. If you are only a couple pounds off, you may elect to pay dearly.
- Varies widely by car line—should be based on customer value.

Discussion

The panelists estimate that for passenger car CAFE of 27.5 mpg, 30.0 mpg and 35.0 mpg, the manufacturers value a pound of weight saved at $1.00, $2.00 and $3.00, respectively. They also estimate that for light truck CAFE of 20.0 mpg, 20.6 mpg, and 24.0 mpg; the manufacturers value a pound of weight saved at $1.00, $1.00 and $2.00, respectively. However, the wide interquartile ranges, especially for light trucks, indicates some uncertainty. Several comments also point out the difficulty of estimating such a value.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-40

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

Trend from previous Delphi surveys

This question was significantly changed, and therefore comparison is not possible with previous Delphi forecasts.

Strategic considerations

The value of a pound saved is a function of many variables, including the price of the vehicle, the vehicle inertia weight class, CAFE and others. Vehicle programs that exceed either CAFE or inertia weight class goals are likely to place a high price on a pound of weight saved. Also, a luxury car program due to higher margins may have a higher value on weight savings than a compact car program.

It is essential that manufacturers use a systems approach that appropriately balances all factors in the search for an optimal design. There is tremendous incentive for low-cost weight reduction. Good systems engineering may make higher cost materials vulnerable to improved designs using current materials.

If CAFE increases, the value of a pound saved will rise significantly, according to our panel. However, it is likely the actual value of a pound saved will be largely dependent on the specific requirements faced by a program.

Light truck CAFE will likely create some interesting changes in the coming decade. If the government increases light truck CAFE significantly, it may change drastically the ability of companies to produce cost competitive light trucks. Therefore, any increases in light truck CAFE may have significant implications for the Big Three, since much of their recent success is attributable to their dominance of the light truck market.

MAT-14. How much additional cost per vehicle in current dollars would a manufacturer be willing to add to a typical mid-size passenger car to improve fuel economy by one (1) mile per gallon? This cost may be added for a new device, revised material, improved technology, etc. Assume CAFE requirements at 27.5 mpg in 2000 and 30 and 35 mpg in 2005.

Median Response				Interquartile Range			
1995	**2000**	**2005**	**2005**	**1995**	**2000**	**2005**	**2005**
Current Value CAFE= 27.5 mpg	CAFE= 27.5 mpg	CAFE= 30 mpg	CAFE= 35 mpg	Current Value CAFE= 27.5 mpg	CAFE= 27.5 mpg	CAFE= 30 mpg	CAFE= 35 mpg
$4.50	$5.00	$13.50	$23.50	$3.00/32.50	$4.00/45.00	$10.00/97.50	$15.00/115.00

Selected edited comments

- Assuming no major changes in the oil supply.
- Depends on gas cost and class of car (luxury vs. compact).
- Depends on what current CAFE is and penalties which may be imposed and what the customer perceived benefits will be.
- Depends too much on specific vehicle's position in a weight class.
- If manufacturers will pay $1-$3/lb. of weight saved, then the cost will be about $50-$200/vehicle.
- It relates to where a specific OEM's total fleet is relative to CAFE target. If it is under, there is no value. If it is over the target, the value varies by sales volume (e.g., increasing Viper's mpg does not have as much value as the same mpg change for LH).
- Manufacturer will only add cost to the extent that customers will pay for the value, thus the customer value calculation will provide the operational window. We are pricing ourselves out of business with government mandates not related to value. Improved quality/reliability/dependability on late model vehicles will result in used car dealerships providing the customer value at affordable prices.
- OEMs will be dragged kicking and screaming before they add costs. Engineers' intentions are honorable, but purchasing has a big say in the matter.
- Probably would accept cost increase to pay/equal fine.
- Recent reported shifts from plastic to steel show manufacturers are still not willing to pay much for lighter weight. Nor are they often willing to pay for development to achieve weight reductions.
- This would vary depending on the price range of the vehicle, where the economy of that vehicle was at the time and the yearly volume production of the vehicle. I could envision a company spending several 100 dollars per vehicle on a high-priced luxury vehicle with low volume.

Discussion

Panelists estimate that manufacturers are willing to pay $4.50 currently to improve fuel economy by one mpg. The panel forecasts manufacturers will be willing to pay $23.50 to improve fuel economy by one mpg by 2005 given a CAFE of 35 mpg. It is important to note the wide interquartile ranges for each estimate which suggest the industry has not institutionalized a strategy regarding CAFE goals.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

To gain an increase of one mpg, a weight reduction of 150-300 pounds is needed. According to MAT-13, the panel suggests that manufacturers are willing to pay $1.00 per pound of weight saved. Therefore, the value of a one-mpg increase is roughly $150-300. Even taking into account that the question does include technical solutions as well as weight reduction alternatives, there appears to be a severe disconnect between the responses for MAT-13 and MAT-14.

The values forecast by the materials panel are significantly lower than those of the technology panel. It is possible that industry has yet to develop a strategy for evaluating weight reduction and fuel economy gains. Currently weight reduction is very program specific. Many variables affect the need for weight reduction, and a corporate wide "rule of thumb" does not currently appear viable. Manufacturers likely will not seriously consider corporate guidelines until CAFE is raised to a level that forces such a strategy.

MAT-15. Please forecast the material content change in percentage for the typical North American-produced passenger car and light truck for 2000 and 2005, given the indicated CAFE scenarios. It is not necessary to enter a response for every material—just those with which you are familiar. Please indicate plus or minus and reference all percent changes to base year, where data has been provided (e.g., +5%, -3%).

Materials	Passenger Cars						
	Current Weight* 27.5 mpg	Median Response 2000 27.5 mpg	2005 30 mpg	2005 35 mpg	Interquartile Range 2000 27.5 mpg	2005 30 mpg	2005 35 mpg
STEEL							
Low carbon steel	1388 lbs.	-5%	-8%	-11%	-5/-2%	-15/-4%	-25/-6%
HSLA steel	263	5	9	10	0/10	2/20	3/30
Stainless steel	45	1	2	3	1/5	0/10	010
Other steels	42	0	0	0	-5/0	-5/1	-5/5
TOTAL STEEL	1738	-3	-6	-10	-8/-1	-12/-3	-20/-4
CAST IRON	406	-10	-15	-20	-10/-5	-25/-10	-40/-13
ALUMINUM							
Castings	n/a	10	15	20	2/18	5/21	9/38
Forgings	n/a	3	5	6	1/5	3/10	5/19
Sheets	n/a	5	10	18	2/10	4/20	8/48
TOTAL ALUMINUM	182	10	15	25	5/24	9/40	12/56
PLASTICS							
Thermosets	n/a	3	5	6	0/10	3/10	-5/10
Thermoplastics	n/a	6	10	15	4/13	5/15	10/20
TOTAL PLASTICS	245	5	10	15	1/12	5/20	5/26
COPPER (including electrical)	42	-1	-5	-10	-5/0	-10/-3	-10/-5
ZINC							
Zinc coatings	17	0	0	0	0/0	-1/0	-2/0
Zinc parts	16	-5	-10	-12	-10/-1	-20/-5	-30/-10
TOTAL ZINC	33	-2	-5	-6	-5/0	-10/1	-15/1
MAGNESIUM	5	50	90	175	10/80	19/163	38/225
GLASS	89	0	0	0	0/0	0/0	0/0
CERAMICS	2	0	8	10	0/6	0/25	0/25
POWDERED METALS	27	5	10	12	4/10	8/20	10/20
RUBBER							
Tires (include spare)	94	0	-2	-3	-1/0	-5/0	-7/0
All other rubber	40	0	0	0	0/0	0/2	0/4
TOTAL RUBBER	134	0	0	-1	-2/0	-3/1	-5/0

*Source: *Ward's Automotive Yearbook* 1992 and OSAT estimates. n/a–not available.

Materials	Light Trucks				
	Current	Median Response		Interquartile Range	
	Weight*	2000	2005	2000	2005
	20.2 mpg	20.6 mpg	24 mpg	20.6 mpg	24 mpg
STEEL					
Low carbon steel	n/a	-5%	-6%	-5/2%	-14/-5%
HSLA steel	n/a	4	5	1/11	2/21
Stainless steel	n/a	1	1	0/5	0/5
Other steels	n/a	0	0	-2/0	-3/3
TOTAL STEEL		-2	-5	-5/0	-12/-1
CAST IRON	n/a	-5	-10	-10/-3	-20/-5
ALUMINUM					
Castings	n/a	8	15	2/10	4/28
Forgings	n/a	2	5	1/6	2/10
Sheets	n/a	2	5	1/10	3/15
TOTAL ALUMINUM		9	15	3/18	6/30
PLASTICS					
Thermosets	n/a	3	6	-2/9	-3/10
Thermoplastics	n/a	10	15	4/18	7/23
TOTAL PLASTICS		8	10	4/19	4/24
COPPER (including electrical)	n/a	0	-4	-4/0	-11/2
ZINC					
Zinc coatings	n/a	0	0	0/0	-1/0
Zinc parts	n/a	-2	-5	-5/0	-15/-1
TOTAL ZINC	n/a	0	-2	-3/0	9/0
MAGNESIUM	n/a	20	90	6/50	36/175
GLASS	n/a	0	0	0/0	0/0
CERAMICS	n/a	0	3	0/2	0/10
POWDERED METALS	n/a	5	10	5/10	10/25
RUBBER					
Tires (include spare)	n/a	0	0	0/0	-4/0
All other rubber	n/a	0	0	0/2	0/0
TOTAL RUBBER	n/a	0	0	0/1	-3/0

Other Single Responses:

Aluminum: Extrusions Passenger Cars: 2000 - 30 percent; 2005 (30mpg) - 58 percent; 2005 (35mpg) - 87 percent Light trucks: 2000 - 40 percent; 2005 - 80 percent

Selected edited comments

- Assumes HSLA includes all types of high strength sheet steel. Total steel figures are based on AISI/IISI projects targeted at holistic design using sheet steel. Makes excessive usage of expensive alternative materials unnecessary. All of this assumes 1994 type model mix.
- Changes will have decreasing importance. Only major changes will be an increase in the use of plastics and ceramics. The use of aluminum in engines will also increase.
- Copper should begin giving way to fiber optics. Aluminum and magnesium should take over cast iron and some steel. Zinc coatings should decrease as zinc coated steel panels are replaced by aluminum or plastic. Zinc die castings are heavy; they should go away to be replaced by aluminum, magnesium or plastic.
- My focus is on engine (within) powertrain. Aluminum will increase in usage within engines by 25-30 percent.
- Percentage of plastics might be increasing when economical recycling technologies for them are developed.
- Stainless steel will increase in exhaust systems. Magnesium will expand its usage as product engineers and manufacturers become familiar with its mass advantages and as the magnesium raw material market expands.
- The median response for aluminum is much too low. Aluminum weight per car has increased 36 percent from 138 lbs. in 1985 to 188 lbs. in 1995 (American Metal Market).
- Zinc coatings - alloys of zinc (e.g., Zn/Fe) have better corrosion protection capabilities than free zinc (Zn) so lighter coating weights will be used.

Discussion

The panel was asked to forecast passenger car and light truck material changes in the coming decade. The relative direction of materials was similar for both segments. However, the panelists forecast a more significant reduction of steel and cast iron, and a larger increase in plastics for passenger cars than they did for light trucks. Although this forecast may reflect the current environment, severe CAFE increases for light trucks may have a significant effect on material selections.

For passenger cars, the panel was given one CAFE scenario for 2000 and two CAFE scenarios for 2005. The forecast for 2000, with a given CAFE of 27.5 mpg, shows significant material substitution. The panel forecasts steel and cast iron to decrease 3 percent and 10 percent by weight, respectively, by 2000. Aluminum and plastic are forecast to increase by 10 percent and 5 percent, respectively.

The two CAFE scenarios for 2005 present further evidence of reduction achieved through material substitution. For the 30.0 mpg CAFE, the panel forecast steel and cast iron to decrease by 6 percent and 15 percent by weight, respectively. Conversely, the panel forecasts aluminum and plastics to increase by 15 percent and 10 percent, respectively. For a 35.0 mpg requirement in 2005, steel and cast iron are forecast to decrease by 10 percent and 20 percent, respectively, while aluminum and plastic are forecast to increase by 25 percent and 15 percent, respectively.

For light trucks, the panel was given a 20.6 mpg CAFE for 2000 and a 24.0 mpg CAFE for 2005. For 2000, the panel forecasts a reduction of 2 percent and 5 percent by weight for steel and cast iron, respectively. The panel forecasts an increase of 9 percent and 8 percent for aluminum and plastics, respectively. For 2005, the panel forecasts a reduction of 5 percent and 10 percent for steel and cast iron, and an increase of 15 percent and 10 percent for aluminum and plastics, respectively.

For both passenger car and light truck, magnesium and powdered metals are expected to experience major percentage increases in the coming decade. However, because of the low current usage levels of both materials, these high percentages may be somewhat misleading.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-36

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

Materials	Passenger Cars					
	Median Response 2000		Median Response 2005 30 mpg		Median Response 2005 35 mpg	
	Tech	Mat	Tech	Mat	Tech	Mat
Aluminum	—	—	—	—	20%	25%
Cast iron	-5%	-10%	-10%	-15%	-15	-20
Copper	-1	-2	-5	-4	-5	-10
Magnesium	5	50	10	100	15	200
Powdered metals	4	5	5	10	5	13
Steel	-5	-3	-10	-6	-15	-10

The responses between the two panels were in good agreement with the exception of magnesium. The materials panel forecast a tripling of the use of magnesium by 2005 as compared to only a 15 percent increase forecast by the technology panel. It should be noted that 13 of the technology panelists forecast that the use of magnesium would at least double by 2005 at a CAFE of 35 mpg. It should be further noted that the total magnesium used in a passenger vehicle in 1993 was only 5 pounds.

Trend from previous Delphi surveys

This question was changed to ask for percentage change instead of actual pounds as in the 1994 Delphi VII survey. Therefore direct comparison with Delphi surveys prior to Delphi VII is not possible.

The 1996 Delphi VIII panel is in general agreement with the Delphi VII panel. However it does differ in the forecast of magnesium. The Delphi VIII panel forecasts significantly higher usage of magnesium than did the Delphi VII panel.

Strategic considerations

In order to meet potential increases in CAFE, a slow movement toward lightweight materials is likely. Increased penetration by lightweight materials will come at the expense of traditional materials such as cast iron, steel, copper and zinc. Even with the materials shifts forecast, it is likely that, to meet a CAFE of 35 mpg, the industry will have to drastically change model mix to include more small cars.

Usage of steel is expected to decrease by 1-1.5 percent per year. There are at least two drivers of this reduction: the direct substitution of lightweight materials for steel and a very pro-active steel industry. The auto/steel partnership has diligently worked to develop cost-effective weight savings designs using HSLA steels and better design and processing methods.

Cast iron will likely see substantial reduction in automotive application over the coming decade. Manufacturers are replacing cast iron with aluminum for cylinder heads and blocks (MAT-20). Cast iron will also continue to see reduced penetration in camshafts, crankshafts and connecting rods (MAT-22).

Aluminum will continue to make inroads in radiators (MAT-25), suspension control arms (MAT-33), brake components (MAT-35) and body panels (MAT-32) in the coming decade.

Plastics, both thermoplastics and thermosets, are also forecast to experience increased automotive applications. Thermoplastics are expected to experience larger increases than thermosets, due at least in part to the perceived recyclablity of thermoplastics vis-à-vis thermosets. The panel forecasts TPO, polypropylene and polyester thermoset to see the largest increases on a percentage of weight basis (MAT-16).

Copper and zinc are forecast to experience decreased application in the coming decade. Copper faces significant challenges from aluminum in radiator applications and may be closed out of that application entirely over time. Multiplexing of electronics also presents a challenge for copper. Magnesium will see increased application in many interior applications and non-critical structural components (MAT-17). Powdered metal will see increased usage in critical engine components (MAT-24).

MAT-16. **Assuming the same market size (13,357,000 passenger cars and light trucks) as in the base year 1994, please consider the following list of plastic materials and forecast change in plastic usage for 2000 and 2005. Please indicate plus or minus.**

Material	1994 * millions of pounds	Consumption per vehicle	Median Response		Interquartile Range	
			2000	2005	2000	2005
ABS	273	20	0.0%	0.0%	-5/4%	-14/9%
Acetal	27	2	4	4	0/9	0/20
Acrylic	48	4	0	0	0/8	0/0
ABS/PC(pulse)	29	2	5	10	2/18	5/20
PC/PBT (Xenoy)	43	4	-8	-10	-25/5	-50/10
PPO/nylon	43	4	5	5	-25/10	-25/17
PPO/styrene	29	2	0	0	0/2	-5/10
Epoxy	7	1	0	0	-5/0	-5/8
Ionomer	19	1	3	10	0/44	0/200
Nylon	212	16	4	6	1/10	5/10
Phenolic	48	4	0	0	-5/0	-11/0
Polycarbonate	93	7	4	7	2/10	0/10
Polyester elastomer	11	1	3	5	0/10	0/23
Polyester thermoplastic	88	7	10	15	5/20	10/50
Polyester thermoset	175	13	5	10	0/8	-3/10
Vinyl ester - TS	13	1	0	3	0/4	0/10
Polyethylene	209	16	5	5	1/5	2/10
Polypropylene	456	34	10	16	5/15	10/34
TPO	172	13	10	15	5/10	10/20
Polyurea	21	2	0	0	-10/5	-28/10
PVC	286	21	0	-5	-5/0	-10/0
SMA	60	4	0	0	0/0	0/0
Urethane	531	40	0	-2	-5/0	-10/1
Total	2,932					

* Source: Best Market Research estimates

Selected edited comments

- ABS interior applications will be replaced by PP.
- Focus on design/engineering to total customer requirements will continue plastics growth as "same way" engineering disappears and value of plastics is documented on a total cost and systems basis.
- Higher performance polymers such as PPS and fluropolymers will begin to make inroads.
- Polycarbonate will decrease long term because of its low environmental stress cracking resistance. It will be replaced (in non-clear applications) by blends and other high heat materials.

- Polyester thermosets will increase in body panel and structural applications. Urethanes in S-rim parts.
- Thermoset polyesters are expected eventually to be replaced by thermoplastic materials due to faster cycle times for the plastics.
- TS polyester as flex SMC. Nylon as high performance high heat NY4:6.

Discussion

Panelists forecast substantial growth for polypropylene (16 percent), TPO (15 percent) and polyester thermoset (10 percent) in the coming decade. The panelists forecast usage of PC/PBT (-10 percent), SMA (-5 percent) and urethane (-2 percent) to decrease in the next 10 years.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1994 Delphi VII and 1996 Delphi VIII forecasts are in general agreement. However, the Delphi VIII panel forecasts larger percentage increases for polypropylene, SMC, polycarbonate and polyester thermoplastic than did the Delphi VII panel. The following table compares the Delphi VII and Delphi VIII forecasts. Only those forecasts that differ have been included.

Comparison of Delphi VII and Delphi VIII Forecasts
Plastics: Percent Change in Usage

Material	Short term		Long term	
	1998 Delphi VII	2000 Delphi VIII	2003 Delphi VII	2005 Delphi VIII
Urethane	2%	0%	2%	-2%
Polypropylene	8	10	12	16
Polyethylene	5	5	8	5
Polyester thermoset (SMC)	2	5	3	10
Polycarbonate	2	4	2	7
Polyester thermoplastic	3	10	2	15
PC/PBT (Xenoy)	0	-8	0	-10
ABS/PC(pulse)	1	5	2	10
Acetal	0	4	0	4
Polyurea	0	0	-1	0

Strategic considerations

The panel forecasts a steady growth rate of approximately 4 percent for plastics in the coming decade compared to the almost phenomenal growth over the past 20 years. Although the 1996 Delphi VIII panel forecast may not be as optimistic as recent growth rates, it does indicate continued new applications for plastics.

For many applications, plastics will continue to face a pound-for-pound cost disadvantage compared to steel. However, plastics will remain competitive through parts consolidation, weight reduction or consumer preference.

The coming decade will be filled with challenges for the resin industry. Although it is likely that resins will continue to be seen as an advantageous material for many applications, environmental concerns may put increased pressure on plastics in the material selection process (MAT-41, MAT-42, MAT-43). Many manufacturers are developing strategies that markedly limit the number of different types of plastics in a vehicle program. The ability to develop entire component systems using one family of plastics may represent the most environmentally acceptable application of plastics in the future.

Polypropylene and TPO are forecast to exhibit the largest percentage gains. Polypropylene will likely see increased usage in interiors and bumper fascia. The increased usage of polypropylene will likely come at the expense of ABS, for interior applications and urethanes in the bumpers. Manufacturers view polypropylene as a material that may be a strong candidate for complete interior systems.

The recyclability of plastics will continue to present a dilemma for the automotive industry in the next 10 years. Although the Delphi panel expects increased regulation regarding the recyclability of plastics in the coming decade (MAT-7), it rates recyclability as only somewhat important in the materials selection process (MAT-8). It will be important for manufacturers to develop material selection processes that adequately meet recyclability challenges while concomitantly allowing for reduced vehicle weight. Given recent activity in new applications for plastics, the industry seems committed to developing a long-term strategy that includes plastics.

MAT-17. What percentage of North American-produced passenger car and light truck components will utilize magnesium alloys in the next decade?

Components	Median Response	Interquartile Response
Steering wheel	39.4%	5/75%
Airbag canister	33.7	4.3/63.8
Steering wheel components	33.6	5/50
Electric car transaxle	31.3	0/75
Seat frames	29.4	10/50
Brackets	28.4	5/45
IP components	24.6	1.8/50
Transmission cover	20.0	4/20
Engine covers	18.8	5/25
Transmission cases	18.1	8/20
Support braces/beams	17.5	2.3/31
Housing	14.6	0/23.8
Wheels (styled)	13.9	2/20
Oil filter adapter	12.6	0/17.5
Brake pedal	12.5	0.1/20
Door hardware	8.7	0/10
Oil pan	8.4	0/10
Intake manifold	8.3	0/15
Trim	4.8	0/5
Door frame	3.6	0/5

Selected edited comments

- I suspect magnesium will have substantial growth for castings and extrusions.
- Magnesium has many problems that need solving before you see wide usage: corrosion, high temp strength also with fasteners, creep, cost, fluid compatibility (oil, glycol, gasoline, etc.); castability; recyclability.
- Magnesium use will increase but actual amount is too dependent on future price relationships to predict how much.
- Magnesium will make major inroads. I see 1000 percent increase but don't know distribution. Parts that will see increases are brackets, engine covers, IP components, oil filter adapter, oil pan, seat frames, steering wheel, transmission cover.
- Primarily for forgings and some castings where plastics are not viable.

Discussion

Panelists forecast magnesium usage to increase significantly in the coming decade. Anticipated applications are concentrated in the interior and non-critical structural panels. The wide interquartile ranges suggest a high level of uncertainty regarding the future of magnesium and differing strategies between the manufacturers.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, there are three components that the manufacturers view as having greater potential for magnesium usage than do the suppliers:

Components	Median Response	
	Manufacturers	Suppliers
Oil filter adapter	22%	3%
IP components	38	12
Seat frames	40	16

Trend from previous Delphi surveys

This question was substantially changed for 1996 Delphi VIII so direct comparison is not possible.

Strategic considerations

Lightweight materials present many enticing characteristics for manufacturers. However, these materials usually also present significant challenges. The panel's forecast and comments suggest that magnesium may have a bright future for specific automotive applications—especially if CAFE standards are increased.

Before magnesium gains widespread acceptance, several hurdles must be cleared. Cost, supply, manufacturability and corrosion are significant concerns that need to be addressed. Magnesium usage in the automobile industry is still in its very early stages, and much could happen in the decade. However, it is likely that magnesium will experience continued long-term growth in the automotive industry.

MAT-18. Please indicate significant new material applications/technologies that are likely to emerge within the next decade for each of the following vehicle systems.

New Material Applications/Technologies	
POWERTRAIN	
ENGINE	**Number of Responses**
Plastic Fuel delivery: manifold Valve covers Engine dress, water pumps, pulleys, sound deadening belt covers	 3 each 2 1 each
Aluminum Blocks, blocks without liners Composite powder metals, engine casting durability improvement	 2 each 1 each
Magnesium Blocks, Base MMC, covers, brackets	 1 each
Titanium Powder metals, extruded silicon gaskets, connecting rods, valve train	 1 each
Ceramics In combustion chamber, in valve train, more ceramics	 1 each
Composite Pistons, water pumps, fuel pumps	 1 each
Nylon Induction systems, covers	 1 each
Stainless Steel Exhaust systems	 1 each
Other Powder metals, coatings for gaskets, high-temperature silicone compounds, super alloys, inter-metallics, hollow camshafts, hydrogen powered fuel cells, lower mass friction drivetrain, more sound deadening	 1 each
TRANSMISSION/FINAL DRIVE	
Aluminum Increased use, castings, housings	 1 each
Magnesium Cases More use, housings, covers	 3 1 each
Other Composites - increase use, continuously variable transmission, fiber reinforced drive shafts, increased use of powder metals, increased sound deadening	 1 each

BODY	
EXTERIOR	**Number of Responses**
Aluminum	
Closure/body panels	5
Body structures	2
Deck lids, doors, hydroforming, alloys, more use, stamped	1 each
Plastic	
Thermoplastics	8
Alloys	3
Lightweight SMC and TPO	3
Increased use	2
Colored, unpainted panels; thermoset body panels; resin transfer molded composites; body-match colors for weatherable resins; thermoplastic/carbon fiber structural composite	1 each
Steel	
Medium strength/highly formable, bake hardenable, high strength, dent resistant	1 each
Lighting	
Holography, neon	1 each
Coatings	
Powder coatings	1
Other	
Hybrid components, improved vehicle design, holistic vehicle design, better paint systems, thinner sheet metals, more use of zinc coating	1 each
INTERIOR	
Aluminum	
Structural sub-assembly	1
Steel	
35-40 dual phase, pre-phosphated; tailor welded blanks for inner body panels	2 each
Magnesium	
Cast, instrument panel, seat frames	2 each
Large one-piece divider/barriers, I.P. supports and brackets	1 each
Plastics	
Thermoplastics	6
Polypropylene interior trim, TPO	2 each
Compatible for recycling, polyolifin skins/foams, PP, urethane, more GRU/S-Rim materials, polyester seats, instrument panels, seats	1 each
Metal Matrix Composite	
Composites	2
Seats, injection molding, alloys	1 each
Other	
Subsystems requiring structural components; structural trim, more sound deadening, thixo molded components, gel technology to absorb impact, fewer materials	1 each

CHASSIS	
BRAKES	**Number of Responses**
AMC/MMC	
Brake	6
Increased usage	3
Drums	2
Calipers	1
WHEELS	
Aluminum	
Alloys, more use; cast; forged	2 each
Sheet	1
Other	
Steel wheels	2
Magnesium wheels, MMC, plastic	1 each
SUSPENSION	
Aluminum	
Increased usage	3
Castings	2
Control arms, steering knuckles, cross members, engine cradles, extrusions	1 each
Other	
Stainless steel exhaust	2
Ceramic, high temperature coating; more corrosion resistance	1 each

Discussion

The panel lists several likely new application/technologies, most of which are intended to reduce weight and increase component life. The responses suggest significant opportunity for suppliers, especially those that have expertise in high-volume manufacturing of lightweight materials. However, the panelists expect cost will likely remain a major hurdle for lightweight materials.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with previous Delphi panels. The responses suggest emphasis on the development of lightweight materials and technologies. Similar to the 1994 Delphi VII survey aluminum, magnesium and plastics continue to be the materials most frequently mentioned for future application.

Strategic considerations

The variety and breadth of the panel's responses are significant. There is the suggestion of rapid development of both materials and processes. Many of these developments could quickly change the status quo. The emphasis remains on cost-effective material applications. However, the industry is continually exploring nearly all potential materials. As weight reduction pressures increase, materials previously viewed as too expensive may become viable. But cost is still a key factor in materials decision.

Several of the mentioned materials/technologies are not new. Many have been used in very low-volume applications for several years, with acceptance being delayed due to cost, durability or manufacturing concerns. Many of these applications may remain applicable for low volume. However, others will may become widely accepted in the next decade.

Manufacturers are increasingly relying on a systems-oriented approach in the development of products. Individual parts must be designed to optimize the component system. Decisions made to optimize an individual part may not be the optimal solution at the system level. Only materials that maintain the system-level optimization will likely be considered in the future.

The industry will likely continue to benefit from the increased cooperation with government agencies such as the Department of Energy National Laboratories (DENL). Many of the gains will likely be in the area of materials. It is becoming critical for all companies to leverage the resources of the DENL, universities and other technical centers. It is prudent for both manufacturers and suppliers to maintain close connections with centers of material/processing expertise.

Material developments in all vehicle systems must be closely monitored. There is an unprecedented amount of effort being devoted to materials and processing development, and the likelihood of breakthrough is strong. It is also possible that some materials innovations may have a ripple effect, spreading rapidly through the industry.

MAT-19. Please indicate significant new developments that are likely to emerge within the next decade for each of the following fluids:

Brake fluid:

- Long life
- Longer life, higher temperature oils requiring fewer changes
- Reduced reliance on fluids, more electromechanical

Engine oil:

- Higher temperature stability and wear protection at elevated temperatures
- Improved, longer lasting additives; measurement of oil breakdown with use
- Longer times between oil changes
- Low friction additive that cut mixed mode by up to 50 percent
- No change
- Use of synthetics

Radiator fluid:

- Extended life fluids - use of recycled fluids
- Increased use in "environmentally friendly" fluids
- Long (lifetime) coolants with no change required
- Organic acid coolants
- Polypropylene glycol without water
- Should be research and development of fluids to allow more plastic development to increase
- Switch from ethylene glycol to less toxic polypropylene glycol base

Rear axle fluid:

- Low friction

Power steering fluid:

- Improved oxidation stability, shear stability
- Long life

Transmission fluid:

- Electro-rheological fluids
- Long life

Discussion

Panelists forecast longer life and extended time between fluid changes in the coming decade for all listed fluids.

Manufacturer/supplier comparison

These comparison are not made for open-ended questions.

Trend from previous Delphi surveys

This question was asked differently in previous Delphi studies, so direct comparison is not possible.

Strategic considerations

It is likely that automotive fluids will see only incremental improvements in the coming decade. But by 2005, each of the listed fluids is forecast to be significantly superior when compared to today's standards. It is also likely that some fluids will eventually be engineered to last for the lifetime of the vehicle.

The current standard for radiator fluid consists of approximately 50 percent ethylene glycol and 50 percent water. Because of environmental concerns, a 100 percent polypropylene glycol fluid is beginning to be used as a replacement for the ethylene glycol mixture. The replacement formula does not have the heat rejection/control properties of ethylene glycol mixture, but does meet or exceed manufacturer requirements. Because of its higher cost, the polypropylene glycol fluid will initially be marketed to environmentally concerned buyers. However, it is likely that the environmental advantages of the new fluid will eventually out-weigh the cost concerns, and it will gain wide acceptance.

Oil companies will continue to make incremental improvements in motor oils leading to better anti-oxidants, anti-wear, friction modifiers, viscosity index improvers and longer life. Use of synthetic motor oil will also continue to increase, but it is likely that the higher cost of synthetic oils will prevent wide spread application.

Recyclabiltiy of all automotive fluids will become increasingly important. The automotive service industry has been working to develop recycling infrastructures for many automotive fluids (e.g., radiator fluid and motor oil), and will likely continue to refine the process.

MAT-20. What percentage of North American-produced passenger car and light truck engines in 2000 and 2005 will utilize cast iron or aluminum cylinder heads and blocks?

Passenger Car Material	1994*	Median Response 2000	Median Response 2005	Interquartile Range 2000	Interquartile Range 2005
Heads					
Aluminum	78%	85%	95%	85/90%	90/100%
Cast iron	22	15	5	10/15	0/10
Blocks					
Aluminum	13%	30%	50%	21/40%	40/60%
Cast iron	87	70	50	60/80	40/60

Light Truck Material	1994*	Median Response 2000	Median Response 2005	Interquartile Range 2000	Interquartile Range 2005
Heads					
Aluminum	20%	40%	60%	30/48%	50/68%
Cast iron	80	60	40	52/70	33/50
Blocks					
Aluminum	5%	10%	20%	10/20%	16/43%
Cast iron	95	90	80	80/90	58/85

* Source: Ward's Automotive Reports, December 19, 1994 and various OSAT estimates

Selected edited comment

- Aluminum in this application is a most effective mass reduction. Technology is now proven. It is simply a matter of human and capital resources to convert to 100 percent aluminum. The only exception is trucks because of durability image of cast iron for large trucks.
- Diesels stay iron.
- I have no doubt aluminum will increase in use but I can't accurately predict.
- Light truck CAFE will drive change to aluminum.
- Price of aluminum is the most important factor here.
- Switching to aluminum is an easy way to reduce significant weight. Manufacturing capacity already in place will be the biggest hindrance.

Discussion

Aluminum is expected to be used for 90 percent of cylinder heads and 50 percent of cylinder blocks on passenger cars by 2005. For trucks, aluminum is expected to be used for 60 percent of cylinder heads and 20 percent of cylinder blocks by 2005.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-60a

There is a statistically significant difference in responses between the technology and materials panelists for the items shown in the following table.

Material	Passenger Cars				Light-Duty Trucks			
	Mean Response 2000		Mean Response 2005		Mean Response 2000		Mean Response 2005	
	Tech	Mat	Tech	Mat	Tech	Mat	Tech	Mat
Heads								
Cast iron	16%	12%	9%	5%	68%	53%	53%	38%
Aluminum	84	88	89	94	33	47	47	63
Blocks								
Cast iron	74%	67%	56%	43%	—	—	—	—
Aluminum	26	33	42	56	—	—	—	—

Materials panelists forecast a higher use of aluminum than is forecast by technology panelists.

Trend from previous Delphi surveys

This question was changed to separate passenger car and light truck forecasts for the 1994 Delphi VII. Therefore direct comparison with Delphi surveys prior to Delphi VII is not possible.

The 1996 Delphi VIII panel forecasts somewhat higher penetration rates for aluminum cylinder heads and blocks on passenger cars than did the Delphi VII panel. The Delphi VIII panel also forecasts a larger penetration rate for aluminum cylinder heads on light trucks than did the Delphi VII panel. However, the two panels are in agreement on the material mix for light truck cylinder blocks.

Strategic considerations

The substitution of aluminum for cast iron in engine blocks and cylinder heads is a significant source of weight reduction with an acceptable cost penalty. The industry has developed a comfort level with aluminum heads and is slowly gaining confidence in aluminum block applications. However, questions remain regarding noise suppression, durability and cost—especially for light truck applications—that may continue to slow penetration for aluminum blocks. Cast iron sleeves are currently used in all aluminum blocks to control noise and increase durability (MAT-21a, MAT-21b). The 1996 Delphi VIII panelists do not expect a significant portion of aluminum blocks to be sleeveless in the next decade.

The reduced weight of aluminum cylinder heads and blocks, especially in the case of a major redesign for a vehicle, can allow for further weight reduction. This is because weight savings can cascade into numerous other parts of the vehicle. For example, if the decision is made in the design of a new vehicle to use an engine with an aluminum cylinder block rather than a cast iron cylinder block, it is likely that many other components can be made lighter. These may include the engine cradle, front suspension, brakes, tires and possibly integral frame sections. As these additional components are made lighter, the fuel economy of the vehicle increases, thus possibly allowing a smaller fuel tank which saves additional weight. A total analysis of the vehicle is thus required to determine the total weight savings obtained by substituting a lightweight material for a heavier material.

MAT-21a. What percentage of the aluminum blocks forecast in MAT-20 will be sleeved, unsleeved and coated, and unsleeved in 2005?

Aluminum Block Engines	1994*	Median Response 2005	Interquartile Range 2005
Sleeved	100%	75%	73/86%
Unsleeved and coated	0	20	12/25
Unsleeved (aluminum 390 type alloy)	0	0	0/5

* Source: OSAT estimates

Selected edited comments

- Sleeved blocks will have 60 percent iron sleeves, 40 percent nonferrous. Nonferrous will be aluminum 390 extrusions, MMC extrusives and others.
- What about cast-in-place fiber pre-forms?

Discussion

Panelists forecast that 75 percent of aluminum cylinder blocks cast in 2005 will be sleeved. The remaining 25 percent are expected to be unsleeved and coated. The panel shows little confidence in unsleeved, uncoated cylinder block technologies.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-60b

In the materials survey, this question was asked only for 2005. There is no statistically significant difference in responses between the technology and materials panelists for that year.

Trend from previous Delphi surveys

The long-term forecasts of the past four Delphi panels show an interesting trend regarding unsleeved technology. The long-term forecast by the 1989 Delphi V panel was the most optimistic with forecasts by the 1992 Delphi VI and the 1994 Delphi VII panels becoming increasingly pessimistic. The 1996 Delphi VIII panel has reversed this trend and is somewhat more optimistic than the previous panel.

Long-term Forecast for Unsleeved and Coated Aluminum Cylinder Blocks				
	Delphi V 2000	**Delphi VI 2000**	**Delphi VII 2003**	**Delphi VIII 2005**
Unsleeved and coated	30 %	20%	10%	20%

Strategic considerations

Manufacturers are comfortable with cast iron sleeved aluminum cylinder blocks. Due to quality and durability concerns, it is likely that manufacturers will continue to predominately use cast iron for sleeve material in the coming decade. It is probable that the General Motors Vega experience of the 1970s will assure that movement toward sleeveless technologies in North America will be extremely slow, with manufacturers moving very cautiously in implementing these technologies. Although it is essential to monitor all manufacturers, there are currently several offshore manufacturers—mostly performance and luxury brands—that currently use sleeveless technology. If the processes used by these offshore manufacturers become more cost effective, the move to sleeveless technology could accelerate.

MAT-21b. What percentage of the sleeved aluminum blocks forecast in MAT-21a will use the following sleeve materials in 2005?

Sleeve Material	1994*	Median Response 2000	Interquartile Response 2005
Aluminum 390 type alloy	0%	0%	0/5%
Ceramic	0	0	0/2
Metal matrix composites	0	5	0/10
Thermal spray	0	5	1/10
Cast iron	100	90	79/90

* Source: OSAT estimates

Selected edited comments

- Electrolytic deposition 5 percent.
- Flame spray technology is being applied to pistons with good results. Plastic coated pistons offer potential compatibility in nonferrous blocks.
- Material matrix composites too expensive. Aluminum manufacturing process expensive and not robust.
- Material matrix composites: High silicon material - 10 percent.
- Thermal spray is not used as sleeved material but applied directly to aluminum bore.

Discussion

Panelists forecast the industry will continue to utilize cast iron as the predominant material for sleeves in aluminum cylinder blocks in the coming decade. Panelists also forecast metal matrix composites and thermal sprays applied directly to the aluminum bore to gain some initial penetration as replacement materials for cast iron sleeves.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However the manufacturers forecast a higher usage rate for thermal spray application (11 percent) than do the suppliers (2 percent).

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Due to quality, reliability and manufacturability issues, it is unlikely that any material will replace cast iron as the predominant sleeve material for aluminum cylinder blocks in the coming decade. Because the integrity of the engine block is vital to engine functionality, it is likely that manufacturers will be cautious when substituting any of the listed materials for cast iron. Although ceramic, metal matrix composites and aluminum type 390 alloy present many enticing attributes, manufacturers believe these materials have significant drawbacks and may not present a satisfactory substitute for cast iron, at least presently. The incentives remain high, however, to eliminate sleeves.

Recent activity in powdered metal sleeve technology is significant. Although the panelists did not forecast any usage of powdered metal sleeves, it is important to monitor all potential materials for breakthroughs that may signify an impending change.

MAT-22. For the following North American-produced passenger car and light truck engine components, please indicate what percentage is likely to be made from the listed materials currently and by 2000 and 2005.

Component Material Internal	Median Response			Interquartile Range		
	Current Est.	2000	2005	Current Est.	2000	2005
Camshaft						
Cast iron	58%	55%	48%	50/70%	43/63%	35/50%
Composites (e.g., steel/powdered metal combination)	10	17	25	5/20	15/21	20/40
Steel	30	30	25	15/35	18/35	15/30
Crankshaft						
Cast iron	80%	70%	62%	80/85%	70/79%	60/70%
Steel	20	30	38	15/20	22/30	30/40
Connecting Rod						
Aluminum	0%	0%	0%	0/0%	0/0%	0/0%
Cast iron	28	20	10	10/30	10/25	1/20
Metal matrix composites	0	0	5	0/0	0/2	0/5
Powdered metals	30	45	53	30/35	40/50	46/70
Steel	40	35	28	35/54	25/46	16/32
Fuel Rails						
Steel	90%	80%	64%	90/95%	75/87%	50/74%
Plastic	10	20	36	5/10	13/25	26/50
Piston						
Aluminum cast	100%	90%	75%	91/100%	80/97%	70/86%
Aluminum reinforced	0	5	8	0/2	0/10	0/15
Hybrid (e.g., plastic skirt/ceramic crown)	0	0	0	0/0	0/4	0/8
Metal matrix composites	0	1	13	0/0	0/8	0/16
Valves						
Steel	100%	100%	90%	100/100%	95/100%	80/97%
Aluminum matrix composite	0	0	0	0/0	0/5	0/10

Fuel Rails:

Aluminum: Curr. Est. 5%; 2000-10%; 2005 - 20%, Aluminum: 2000 - 10%

Piston:

Forged: Curr. Est. - 10%; 2000 - 10%; 2005 - 10%,

Valves:

Ti-alloy; Curr. Est. - 0%; 2000 - 0%; 2005 - 5%, Ti: 2000 - 3%, Titanium: 2000 - 10%, Ceramic-niche market only: 2000 - 2%; Ceramic/Ic-aluminides: 2000 - 10%, Titanium aluminum: 2000 - 10%

Component Material Engine Exterior	Median Response			Interquartile Range		
	Current Est.	2000	2005	Current Est.	2000	2005
Air Cleaner Housing						
Aluminum	10%	5%	0%	6/15%	0/10%	0/5%
Plastic	68	83	95	56/73	78/91	83/100
Steel	23	10	0	15/30	0/16	0/5
Exhaust Manifold						
Cast iron	90%	70%	50%	90/90%	60/80%	50/70%
Stainless steel	10	30	50	10/10	20/40	30/50
Front Cover						
Aluminum	75%	85%	95%	75/80%	84/90%	90/100%
Cast iron	25	15	5	20/25	10/16	0/10
Intake Manifold						
Aluminum	60%	60%	50%	60/68%	50/68%	43/60%
Cast iron	20	10	0	20/30	5/20	0/8
Plastic	10	30	50	10/15	25/35	33/55
Oil Pan						
Plastic	5%	14%	30%	4/5%	10/20%	18/40%
Steel	95	85	70	95/95	80/90	60/80
Rocker Arm Cover						
Aluminum	50%	45%	30%	38/60%	31/50%	30/40%
Magnesium	10	10	15	5/10	6/15	10/23
Plastic	16	28	40	10/21	20/38	25/50
Steel	27	17	10	15/31	10/24	3/18

Other Single Responses (Engine Exterior):

Exhaust: Composite - high heat: 2000 - 10%; 2005 - 15%

Front Cover: Plastic: Curr. Est - 10%; 2000 - 20%; 2005 - 50%, Plastic/magnesium (not using mag. currently): Curr. Est. - 5%; 2000 - 5%; 2005 - 10%, Composite: 2000 - 10%; 2005 - 20%,

Oil Pan: Cast aluminum: Curr. Est.-10%; 2000-20%; 2005-30%, Aluminum or magnesium: Curr. Est. - 5%; 2000 -30%; 2005 - 70%, Structured Aluminum: Curr. Est. - 50%; 2000 - 60%; 2005 - 60%, Cast aluminum: Curr. Est. - 20%; 2000 - 40% 2005 - 80%

Selected edited comments

- Cost is a major determiner even if function is rapidly deteriorated. Ford uses some semi-solid forged aluminum fuel rails.
- I believe there are already current alternate materials for front covers and oil pans.
- Plastic usage will increase markedly in all parts exposed to moderate temperatures (e.g., rocker arm covers, intake manifolds, etc.). I think there will be some increase in the use of ceramics, but still, as percentage of total engine weight, the amount will be small.

Discussion

The panel forecasts a trend toward lightweight materials for engine applications in the coming decade. Cast iron and steel will see decreased usage for most of the listed components. The wide interquartile ranges indicate some uncertainty regarding future material substitution patterns and different strategies by manufacturers.

Internal engine components

The panel forecasts moderately increased penetration for composite camshafts (15 percent), steel crankshafts (18 percent), powdered metal connecting rods (23 percent) and plastic fuel rails (26 percent) by 2005. The panel also forecasts increased usage of aluminum reinforced and metal matrix composite pistons in the coming decade.

External engine components

The panel forecasts moderate increased penetration for plastic air cleaner housings (27 percent), stainless steel exhaust manifolds (40 percent), aluminum front covers (20 percent), plastic intake manifolds (40 percent), plastic oil pans (25 percent) and plastic rocker arm covers (24 percent).

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, the manufacturers forecast higher penetration for aluminum intake manifolds for 2000 (64 percent) than do the suppliers (56 percent). Conversely, the suppliers forecast higher penetration for cast iron intake manifolds for 2000 (15 percent) than do the suppliers (7 percent). The manufacturers and suppliers are in agreement regarding the forecast for plastic intake manifolds for 2000.

Comparison of forecast: TECH-65

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

Polymer-based Components	Mean Response Current		Mean Response 2005	
	Tech	Mat	Tech	Mat
Fuel rails	5.1%	7.2%	—	—
Intake manifold	10.0	13.3	—	—
Oil pan	—	—	15.6%	29.4%

Trend from previous Delphi surveys

A comparison of the last four Delphi surveys presents an excellent example of the evolution of materials usage. Often forecasts of new materials are rather inflated as panelists, encouraged by early results, forecast rapid growth. These forecasts for rapid growth are often followed by the realization that significant hurdles remain. In time these hurdles are overcome, and the materials become accepted. A review of recent Delphi forecasts shows several such instances.

Comparison of Delphi V, Delphi VI, Delphi VII and Delphi VIII Forecasts Component Material: Selected Internal Engine Components						
	Short term		Long term			
Component Material Internal	**1998 Delphi VII**	**2000 Delphi VIII**	**2000 Delphi V**	**2000 Delphi VI**	**2003 Delphi VII**	**2005 Delphi VIII**
Camshaft						
Cast iron	70%	55%	55%	50%	60%	48%
Composites (e.g., steel/powdered metal combination)	10	17	10	40	15	25
Steel	20	30	35	10	20	25
Crankshaft						
Cast iron	80%	70%	70%	70%	80%	62%
Steel	20	30	30	30	20	38
Connecting Rod						
Aluminum	0%	0%	5%	5%	0%	0%
Cast iron	20	20	25	25	20	10
Metal matrix composites	0	0	n/a	4	5	5
Powdered metals	10	45	n/a	45	15	53
Steel	50	35	60	20	47	28
Piston						
Aluminum cast	90%	90%	70%	70%	73%	75%
Aluminum reinforced	10	5	20	20	15	8
Hybrid (e.g., plastic skirt/ceramic crown)	0	0	10	5	0	0
Metal matrix composites	3	1	n/a	n/a	10	13
Valves						
Steel	98%	100%	90%	90%	95%	90%
Aluminum matrix composite	2	0	n/a	n/a	5	0

Comparison of Delphi V, Delphi VI, Delphi VII and Delphi VIII Forecasts Component Material: Selected External Engine Components						
	Short term		Long term			
Component Material Engine Exterior	1998 Delphi VII	2000 Delphi VIII	2000 Delphi V	2000 Delphi VI	2003 Delphi VII	2005 Delphi VIII
Air Cleaner Housing						
Aluminum	10%	5%	n/a%	n/a%	15%	0%
Plastic	35	83	n/a	n/a	50	95
Steel	50	10	n/a	n/a	30	0
Exhaust Manifold						
Cast iron	80%	70%	75%	55%	70%	50%
Stainless steel	20	30	20	35	25	50
Intake Manifold						
Aluminum	60%	60%	60%	60%	70%	50%
Cast iron	20	10	10	10	10	0
Plastic	5	30	30	20	15	50
Oil Pan						
Plastic	5%	14%	15%	10%	15%	30%
Steel	92	85	70	50	80	70
Rocker Arm Cover						
Aluminum	15%	45%	15%	20%	20%	30%
Magnesium	5	10	5	10	5	15
Plastic	20	28	60	60	30	40
Steel	55	17	20	10	40	10

Strategic considerations

The industry is substituting lightweight materials for cast iron and steel in engine applications. Each of the listed components is likely to undergo significant changes in materials over the coming decade. As these components reach manufacturing scale economies, components made from these replacement materials could become the industry standard. It is important to note that, for many of the listed components, North American manufacturers may be behind the off-shore companies in converting to lightweight materials.

Internal engine components

Camshafts and crankshafts are forecast to increasingly be made from steel. The ability to forge these components to near net shape form saves significant time and cost, making steel camshafts and crankshafts a viable candidate to replace cast iron. Several manufacturers are in the process of converting or building facilities to manufacture steel forged camshafts and crankshafts. It is possible that crankshafts may see even higher penetration of steel than forecast. Camshafts, however, may not see higher than forecast penetration rates, due mainly to competition from steel/powdered metal composites.

Powdered metal connecting rods are rapidly becoming the industry standard. Each of the Big Three has used powdered metal connecting rods on significant new engine programs. By 1997, Ford is likely to have converted all of its engine lines to powdered metal connecting rods. Although there are certainly performance requirements unique to connecting rods, the competition between forged steel, powdered metal and metal matrix composites usage in connecting rods may be an interesting case study for other internal engine components.

Plastic fuel rails have recently made initial penetration into North American-produced vehicles. Although they may be more costly than steel fuel rails, plastics offer the opportunity to reduce weight.

External engine components

The panel forecasts aluminum and plastics to gain approximately equal shares of the intake manifold market. Based on recent material selections, both materials have proven to be viable contenders. However, plastics do present a performance advantage; i.e., plastic is very smooth, leading to improved volumetric efficiency. These developments should be watched closely. Slight improvements in either material or improved manufacturing processes may make a significant difference in future materials selection.

Plastics will likely see strong gains in the listed covers and housings. It is likely that weight reduction and design flexibility will provide plastics with strong advantages over current materials.

The future material selection of both internal and external engine components will be fiercely contested in the coming decade. Material selection will be based on many criteria. Manufacturers will likely develop different strategies regarding engine material selection. It will be important for suppliers to pay close attention to future materials developments and the strategies of individual manufacturers.

MAT-23. What percentage of spark-ignited engines in North American-produced passenger cars will use these ceramic engine components in 2000 and 2005?

Ceramic Engine Components	Median Response		Interquartile Range	
	2000	2005	2000	2005
Valvetrain components (includes valves, inserts, guide seats, tappets, cam, etc.)	5%	10%	0/5%	5/20%
Turbocharger turbine/rotor (based on % of engines equipped with turbochargers)	2	15	0/20	1/45
Exhaust manifold/port liner	0	5	0/5	0/10
Piston crown	0	4	0/5	0/10
Piston rings, coating	0	8	0/10	0/23
Seals	0	0	0/1	0/1
Wrist pins	0	0	0/5	0/9

Selected edited comments

- Ceramic industry may not be able to support production capacities.
- Seals—water pumps already are ceramic.

Discussion

Panelists forecast little penetration in all listed applications by 2000, and slow growth through 2005. However, the wide interquartile ranges indicate some uncertainty regarding the future penetration rates for ceramics.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-66

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

Trend from previous Delphi surveys

The short- and long-term forecasts for the 1996 Delphi VIII are similar to the 1994 Delphi VII forecast.

Strategic considerations

The automotive industry continues to pursue alternative lightweight materials, and ceramics remain a potential material for several engine applications. However, the panel forecasts that it will be a difficult challenge to gain significant penetration. Like many other alternative materials, ceramics face a struggle to overcome cost, manufacturability and durability concerns. A decade ago there was strong support for a ceramic intensive engine. Such talk has subsided, at least for now. It is more likely that ceramics will gain acceptance on a "part by part" basis.

It is important to note the wide interquartile ranges. The future of ceramics is far from certain. The industry will continue to develop lightweight materials because the incentives remain high. As manufacturing techniques are developed and a better understanding of the material and its interaction with the engine as a system is gained, there may be potential for substantially increased application rates. Component suppliers must monitor developments closely and recognize that ceramic applications could alter some fundamental aspects of the engine design and therefore influence more of the engine than just the parts that are replaced.

MAT-24. Which powertrain components for North American-produced passenger cars and light trucks will be made from various forms of powdered metals in 1995, 2000 and 2005?

Powdered Metal Components	Median Response			Interquartile Range		
	Current Est.	2000	2005	Current Est.	2000	2005
Connecting rods	25%	40%	55%	20/30%	36/40%	47/60%
Transmission gears	10	18	30	10/10	14/20	20/30
Bearing caps	5	20	35	5/5	10/25	23/50
Valvetrain components:						
Valve seat inserts	50%	75%	80%	40/60%	60/80%	76/90%
Valve guides	25	50	78	19/35	30/75	46/90
Camshaft lobes	9	16	25	5/10	15/20	23/38
Rocker arms	0	5	10	0/0	0/9	1/19
Tappets/lifters	0	10	20	0/0	0/10	2/25

Selected edited comments

- Not able to address - but certainly powdered metals will make inroads in this general area.
- Powdered metals components will continue to grow since it saves the OEM investment costs for machining.
- Rocker arms and tappets/lifters doubtful to be made of powdered metal in 2000.
- While I have no information on some of these components, I believe the powdered metals use for all will increase greatly. New technologies for powder binders to allow rapid machining of the green compact are being developed.

Discussion

Panelists forecast significant growth rates for powdered metal for all listed engine components in the coming decade. Most of the forecasted increases are in the 10 to 30 percent range from current usage rates. Powdered metal usage in valve guides is expected to see the largest percentage increase (53 percent). Although several forecasts include rather wide interquartile ranges, it is likely the industry will continue to rapidly expand powdered metal usage in the coming decade.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, the manufacturers forecast for valve seat inserts is approximately 15-20 percent higher than that of the suppliers throughout the forecast period.

Manufacturers and Suppliers Comparison			
Valve Seat Inserts	**Curr. Est.**	**2000**	**2005**
Manufacturers	61%	80%	89%
Suppliers	41	64	71

Trend from previous Delphi surveys

There are significant differences between the 1996 Delphi VIII forecast and previous Delphi forecasts. The Delphi VIII panel forecasts greater penetration of powdered metal for valve guide and valve seat insert applications than either of the two previous panels. The Delphi VIII panel also forecasts greater long-term penetration of powdered metal for connecting rods and tappet/lifters than did the 1994 Delphi VII panel. However, the Delphi VIII forecast for connecting rods and tappet/lifters is similar to the 1992 Delphi VI forecast.

Long Term Forecast for Selected Components			
Components	**2003 Delphi VII**	**2005 Delphi VI**	**2005 Delphi VIII**
Connecting rods	60%	20%	55%
Valve seat inserts	50	48	80
Valve guides	40	40	78
Tappets/lifters	0	0	20

Strategic considerations

Powdered metals continue to gain acceptance for many automotive engine applications. This trend should increase as the industry demonstrates and gains confidence in the characteristics offered by powdered metals. One characteristic that has proven to be of special importance to engine applications is the ability to achieve near net shapes with powdered metals. Cost savings associated with the need for only minimal machining make powdered metals a highly enticing material. Another important characteristic of powdered metal is the ability to achieve desired properties by controlling the alloys and densities of specific mixtures.

It is likely that powdered metals will continue to see rapid development and application for many engine applications. Therefore, it is critical to closely monitor the industry for further developments and new potential applications.

MAT-25. What percentage of the following components will be made of copper or aluminum in 2000 and 2005?

Passenger Cars Material	1992*	Median Response 2000	Median Response 2005	Interquartile Range 2000	Interquartile Range 2005
Engine Oil Cooler					
Aluminum	n/a%	60%	75%	55/60%	65/80%
Copper	n/a	40	25	35/45	20/35
Plastic	0	0	0	0/5	0/5
Total	100%				
Heater Cores					
Aluminum	68%	80%	90%	75/80%	80/90%
Copper	32	20	10	20/25	10/16
Plastic	0	0	0	0/0	0/0
Total	100%				
Radiators					
Aluminum	69%	80%	90%	75/80%	80/90%
Copper	31	20	10	20/25	10/20
Plastic	0	0	0	0/0	0/0
Total	100%				
Transmission Oil Cooler					
Aluminum	19%	25%	40%	24/30%	29/50%
Copper	81	75	60	69/76	50/71
Plastic	0	0	0	0/0	0/0
Total	100%				

* Source: OSAT estimates. *NOTE*: 1992 are the most recent estimates available.

Light Trucks		Median Response		Interquartile Range	
Material	**1992***	**2000**	**2005**	**2000**	**2005**
Engine Oil Cooler					
Aluminum	n/a%	50%	57%	40/60%	50/70%
Copper	n/a	50	43	40/60	30/50
Plastic	0	0	0	0/0	0/0
Total	100%				
Heater Cores					
Aluminum	46%	60%	80%	58/80%	70/90%
Copper	54	40	20	20/40	10/30
Plastic	0	0	0	0/0	0/0
Total	100%				
Radiators					
Aluminum	27%	50%	70%	49/50%	60/76%
Copper	73	50	30	50/51	20/40
Plastic	0	0	0	0/0	0/0
Total	100%				
Transmission Oil Cooler					
Aluminum	15%	25%	50%	20/30%	36/50%
Copper	85	75	50	70/80	50/64
Plastic	0	0	0	0/0	0/0
Total	100%				

Selected edited comments

- Aluminum prices are erratic but will remain cheaper than copper.
- Copper industry is putting an all-out fight to retain or regain market share but must come to grips with the weight issue.
- Distinctions between cars and trucks will disappear.
- Plastic should make inroads into radiators by 2005 if not 2000.

Discussion

Panelists forecast aluminum to further increase penetration in each of the heat exchanger components. Panelists expect aluminum to have higher penetration rates in passenger cars than in light trucks for engine oil coolers, heater cores and radiators. The panel does not forecast plastics to be used for any of the listed components in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question has undergone many changes over the past four Delphi surveys and therefore is not directly comparable. However, each of the panels is in general agreement on the continued increased penetration of aluminum for the listed components.

Strategic considerations

The recent trend to replace copper with aluminum in the listed components is forecast to continue in the coming decade. Aluminum offers the ability to meet weight reduction goals. Although the copper industry has worked diligently to develop new technology, with some significant success, it appears these advances are not sufficient to reverse the trend. Manufacturers have apparently accepted aluminum for these applications and have invested heavily in tooling to support that decision.

The panel forecasts no usage of plastics in any of the listed applications. However, it is possible that developments may lead to initial penetration in the coming decade. The plastic heat exchanger shown at the 1995 SAE Congress was very thought-provoking and represented a potential new paradigm. Again, it will be critical to monitor these initial attempts as they may be an early indication of future change.

MAT-26. What percentage of gasoline-fueled North American-produced passenger cars and light trucks will have fuel tanks made from steel, plastic or other materials by 2000 and 2005?

		Median Response		Interquartile Range	
Fuel Tank Material	**1992***	**2000**	**2005**	**2000**	**2005**
Steel	80%	60%	40%	50/65%	30/50%
Plastics	20	40	60	35/50	40/63
Aluminum	0	0	0	0/0	0/0
Total	100%				

*Source: Ward's Automotive Reports, August 1992

Selected edited comments

- Emissions from plastics is an issue.
- If plastic meets "enhanced evaporative emissions" standards, steel will become extinct eventually. This is likely. If plastic fails to meet "enhanced evap" or enhanced evap standards are increased, steel will dominate. This is less likely.
- Percentage given for steel in 2000: required to meet "running loss" emission standards.
- Provided low cost means capable of meeting "running loss" emission standards. Interesting to do a life cycle analysis on these products.
- Steel developments will begin a swing back to the lower-cost steel tanks.
- Steel will be zinc-nickel coated or galvanized.

Discussion

The panel forecasts usage of plastic gasoline tanks to increase in the coming decade. The panel anticipates that 60 percent of all passenger cars and light trucks will be manufactured with plastic fuel tanks by 2005. Aluminum is not forecast to be used for gasoline tanks in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel long-term forecast for plastic gasoline tanks (60 percent) was higher than the 1994 Delphi VII long-term forecast (40 percent). This may, in part, be due to recent advances in evaporative emissions control capabilities for plastic gasoline tanks.

Strategic considerations

Plastic gasoline tanks present significant weight savings, corrosion protection and design flexibility when compared to steel tanks. However, there is concern over their ability to meet stricter evaporative emissions requirements. Steel will continue to be used for gasoline tanks but likely at a decreased level. The panel does not forecast aluminum gasoline tanks to be a viable alternative in the coming decade, although there is apparently some activity in the industry.

Chrysler has recently begun application of a co-extruded fluorinated plastic gasoline tank that meets all California Air Resource Board (CARB) 1995 requirements. This manufacturing technique and other advances suggest that plastic gasoline tanks will be able to meet future evaporative emissions requirements.

MAT-27. **What percentage of <u>alcohol- or flexible-fueled</u> North American-produced passenger cars and light trucks will use the following fuel tank materials by 2000 and 2005?**

Alcohol- or Flexible-Fueled Gas Tank Materials	Median Response		Interquartile Range	
	2000	2005	2000	2005
Coated low carbon steels and painted	60%	40%	50/60%	30/56%
Plastic	35	50	29/40	38/60
Stainless steel	10	5	0/10	0/10

Selected edited comments

- Alcohol fuels being de-emphasized in favor of electric, and compressed natural gas fuels.
- Coated low carbon and painted steels will be functionally satisfactory and lowest cost.
- Percentage of plastics depend on regulations against penetration of fuels. If anti-penetration plastics are developed, its percentage might be increasing by 50 percent at 2005 models.
- Steel developments anticipate having to handle flex fuels for all tanks.

Discussion

Panelists forecast that plastic fuel tanks will gain 50 percent penetration for alcohol or flexible-fueled vehicles by 2005. Coated low carbon steel fuel tanks will account for 40 percent, and 10 percent will be made of stainless steel.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel continues the trend of the previous two Delphi surveys. The current panel forecasts further increased application of plastic and coated low carbon steel tanks, and a further reduction of stainless steel tanks.

Comparison Forecast for Alcohol/Flexible Fuel Gasoline Tanks			
Material	Delphi VII 2000	Delphi VII 2003	Delphi VIII 2005
Coated low carbon steel	30%	30%	40%
Plastic	—	45	50
Stainless steel	20	20	5

Strategic considerations

Early flexible-fuel tanks have been made from stainless steel. Although stainless steel meets the varied materials requirements, it does so at a weight and cost penalty. Coated low carbon steel tanks currently being validated present the potential for reduced cost when compared to stainless steel. However, the low carbon steel tanks do not resolve the weight issue. Plastic tanks present the opportunity to reduce weight and cost over stainless steel.

Two continuing concerns with plastic alcohol/flexible-fuel tanks is emission evaporation and material degradation. There is substantial research being conducted to resolve these concerns, and it appears the panel is confident that solutions will be found.

Finally, it is important to note that the volume of alcohol/flexible-fuel vehicles is expected to remain small (MAT-4). Therefore, overall volume of gasoline tanks that meet the requirements of alcohol/flexible-fuel may also be limited. Other alternatives, as noted in the comments, may be more attractive than alcohol which is currently heavily supported by tax incentives.

MAT-28. Please indicate how powertrain materials development will improve customer satisfaction over the next 10 years in regard to these vehicle attributes.

Selected edited comments

Customer Satisfaction Materials Developments	
Acceleration:	**Number of Responses**
Lighter weight reciprocating/rotating components.	5
Lightweight material usage	3
Smoother surfaces, better flow of fuels, gases, liquids, etc.;	1
Driveability:	
Engine design more than materials will improve this.	1
Faster warm-up from lower thermal mass of aluminum blocks and heads.	1
Increased emphasis on design will result in smoother running engines with better performance.	1
Lower inertia will make gear changes smoother.	1
Fuel Economy:	
Composites improve performance.	1
Improved by lower mass and faster warm up from aluminum.	1
Increased combustion design which will require new materials.	1
Lighter weight components and lower reciprocating mass should help improve fuel economy.	1
Lightweight materials	3
Noise/Vibration/Harshness:	
Aluminum has less damping capability therefore, NVH (noise, vibration, harshness) challenges will arise as more aluminum is utilized.	1
Composites will decrease NVH.	4
Engine design will be more important than materials.	1
Improved design—especially between engine and transmission	1
Improved NVH due to reduced mass of moving components.	2
Piston developments to reduce reciprocating mass.	1
Vibration deadening insulating properties will improve.	5
Quality/Reliability/Durability:	
Improved corrosion resistance should be big improvement.	2
Manufacturing process improvements	3
Simplified service, improvements or attainable design features can lead to QRD.	1

Safety:	Number of Responses
Improvements in fuel handling systems, shut off fuel line in case of fire.	2
Taking full advantage of physical properties of the material of choice in the design of safety features should be a big plus.	1
Ergonomics:	
Improved serviceability; anti-stick gaskets.	1 each
In 10 years we will have much more "drive by wire" this will improve ergonomics.	
Use of proper material and process to take full advantage of existing technology will result in improvements in packaging for serviceability, etc.	

Selected edited comments

- Composite materials will help enhance performance through lightweight, lower reciprocating mass.
- Material substitution will continue to reduce cost.
- Materials will play a big role in enhanced evaporation emission and pollution control issues.
- Perhaps some cost improvement/avoidance—primary goals of cost reduction.
- Some important gains in all attributes but due more to design than materials. Most significant material improvement will be reduction in reciprocating weight. Cost will be the biggest issue in the next decade as the national average income will decrease from about $30,000 today to $25,000 in ten years from now.
- Use of better powertrain material will give more power and torque per swept volume and weight which will contribute positively to most of the above attributes.

Discussion

Panelists forecast improvements in customer satisfaction in acceleration, driveability and fuel economy through materials related to weight reduction. However, engine design is a critical factor and may not be highly materials dependent. Additionally, some responses indicate material developments to lower friction and improve corrosion protection will also positively effect consumer satisfaction.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with the 1994 Delphi VII panel. Both panels forecasted that materials developments which reduce mass (including reduced rotating mass) and reduce friction will contribute to increased customer satisfaction with regard to powertrain in the coming decade.

Strategic considerations

Material developments in powertrain applications will lead to better acceleration, driveability and fuel economy in the coming decade. Much of these gains will come from increased usage of aluminum, magnesium and composites. These lightweight materials will allow for reduced overall vehicle mass, thus providing better driveability characteristics. A direct result of lower weight will also be improved fuel economy and performance. Lower component mass will provide reduced rotating and reciprocating mass leading to further performance gains. Panelists also suggest that materials gains will lead to reduced friction which will improve fuel economy and acceleration.

The increased application of many lightweight materials may be slowed by higher cost. The automotive industry is currently driven by cost reduction. The ability to use these more costly, lightweight materials present a constant challenge to the industry to develop cost-effective, lightweight components through advances in design and manufacturing. It is very much a systems engineering challenge.

MAT-29. What percentage of North American-produced passenger cars and light trucks will use an integral frame or other design in 2000 and 2005?

		Median Response		Interquartile Range	
Frame Construction	1994*	2000	2005	2000	2005
Passenger Cars					
Integral body/frame or unibody	91%	91%	90%	90/93%	85/94%
Separate body/frame	5	4	3	3/5	0/4
Space frame	4	5	8	4/7	4/12
Sport Utility Vehicle					
Integral body/frame or unibody	19%	25%	30%	19/25%	20/43%
Separate body/frame	81	75	70	75/81	54/63
Space frame	0	0	0	0/0	0/3
Pickup					
Integral body/frame or unibody	0%	0%	1%	0/4%	0/10%
Separate body/frame	100	100	93	95/100	90/100
Space frame	0	0	0	0/0	0/0
Minivan					
Integral body/frame or unibody	58%	65%	73%	60/70%	65/84%
Separate body/frame	31	25	14	20/30	10/22
Space frame	11	10	13	5/15	0/20

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

Selected edited comments

- Space frame design is not weight effective.
- Unibody is the most efficient structure.

Discussion

Panelists forecast little change in frame construction for passenger cars and pickup trucks. However, the panel forecasts an increase of 10 to 15 percent for unibody construction of both sport utility vehicles (SUVs) and minivans.

Manufacturer/supplier comparison

The manufacturers and suppliers are in substantial agreement. However, the manufacturers forecast lower usage of unibody construction for sport utilities (25 percent) in 2005 than did the suppliers (36 percent).

Comparison of forecast: TECH-44

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel is in general agreement with the 1994 Delphi VII panel with a few exceptions. The Delphi VIII panelists forecast a higher usage of unibody construction for sport utilities (30 percent) in 2005 than did the 1994 panelists (0 percent). Conversely, the Delphi VIII panelists forecast a lower usage of separate body/frame for sport utilities (70 percent) than did the Delphi VII panelists (100 percent). The Delphi VII panel also forecasts an application of space frame construction for sport utility vehicles (8 percent) in 2005, while the Delphi VIII panel forecasts no SUV application of space frames.

Strategic considerations

The forecast indicates a dominance of the unibody construction for passenger cars and minivans, and an increasing share of unibody construction in sport utilities in the coming decade. However, the panel forecasts little change for pickups, expecting them to continue to be separate body/frame construction.

Unibody construction is inherently an effective weight savings structure vis-à-vis the separate body/frame and space frame alternatives. It is likely that, as manufacturers experience increased pressure to reduce weight, unibody construction will continue to offer the most viable design for passenger cars and minivans. New developments could change this view.

The sport utility market has entered a highly dynamic phase. Currently the Jeep Grand Cherokee is the only sport utility vehicle that uses unibody construction. As the distinction between sport utility vehicles, minivans and passenger cars blurs, it is likely that more vehicles labeled as sport utilities will be made with unibody construction. SUVs, traditionally built off pickup truck platforms, are reaching volume levels that may allow companies to justify unique platforms for the vehicles. In an effort to meet possible CAFE increases, manufacturers may need to develop unibody designed SUVs to take advantage of weight savings potential.

The panel's forecast for a slightly higher usage of space frame construction is very interesting. This suggests that either the panel is very bullish on the vehicle programs currently using space frame construction, or it may believe that there are impending advances in alternate space frame material methods. Of special interest is the forecast for space frame usage in minivans. Currently General Motors is the only company using space frame construction for a minivan. This van is likely to be converted to steel unibody construction by 1998. The panel could either be expecting a new product featuring space frame construction or is unaware of the demise of the GM space frame minivan program.

There are many hybrid frame designs throughout the industry, and there will likely be many more in the future. Although the panel forecast calls for the design mix to remain relatively stable over the next decade, it will be important to remain informed on the variations that develop. These hybrid frame designs might prove to be the initial steps in subsequent significant changes in design and manufacturing. An excellent example of this are the new developments for the lightweight body structure by Porsche engineering for the steel industry.

MAT-30. Please forecast the material mix of steel, aluminum and plastic frame/structural members in both integral body/frame and space frame North American-produced passenger cars in 2000 and 2005.

Frame Materials	1994*	Median Response		Interquartile Range	
		2000	2005	2000	2005
Integral Body/Frame or Unibody					
Steel	100%	99%	90%	95/100%	85/99%
Aluminum	0	0	5	0/5	0/10
Plastics	0	0	0	0/0	0/5
Space Frame					
Steel	100%	95%	80%	90/100%	70/95%
Aluminum	0	5	10	0/10	5/20
Plastics	0	0	0	0/0	0/10

*Source: OSAT estimates

Selected edited comments

- Aluminum could replace steel for some space frames for expensive niche vehicles. But I don't see much future for space frames.
- More basic development is needed in use of "transition" materials to allow welding steel and aluminum.
- Plastics: depends on recycle technologies. Aluminum: spaceframes might be a disadvantage when safety regulations are more restrictive.
- Space frame will make aggressive gains in 2002-2004.

Discussion

In North America, steel is the primary material presently utilized for frame/structural members. The panel forecasts steel to remain the dominant material through 2005, but they expect aluminum to be used to a small extent in both unibody and space frame constructions. They forecast no applications of plastic frame/structural members over the same period. However, the upper quartile data for plastics suggest that there may be some interesting development work under way.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement with one notable exception. The manufacturers forecast higher usage of steel for space frame construction (86 percent) in 2005 than do the suppliers (73 percent).

Trend from previous Delphi surveys

The 1996 Delphi VIII panel and the 1994 Delphi VII panel are in general agreement.

Strategic considerations

Steel suffers from a weight disadvantage compared to aluminum and composites but will continue to be the material of choice for both unibody and space frame structure in the coming decade. The automobile industry has over 100 years of experience with steel frames. Steel provides low cost and a high level of comfort that is hard to match. However, the panel expects aluminum to gain initial acceptance, likely starting with high priced niche vehicles.

There are two basic designs for steel space frames: stamped steel and tubular steel. Stamped steel is currently the only viable design for mass production. Tubular steel space frames are reserved for low volume, high priced niche vehicles such as Ferrari. New technologies such as hydroforming could alter the forecast, however.

Several manufacturers are working intensively to develop aluminum frame technology. Much of this effort has focused on extruded space frame designs. However, significant cost, bonding and manufacturing issues remain. There are no aluminum intensive vehicles manufactured in North America, although Honda (NSX) and Audi (A8) produce such vehicles elsewhere. Interestingly, these manufacturers have vastly different designs for their aluminum intensive vehicles. The NSX is an aluminum integral frame construction with aluminum body panels, while the A8 is an extruded aluminum space frame with aluminum panels. The lessons learned from these programs will be instrumental in developing confidence in aluminum.

The panel foresees no usage of composite frame designs in the coming decade. USCAR Automotive Composite Consortium has had some success in developing composite frame manufacturing processes, but many major hurdles remain. Safety may also present a barrier for composite frame usage, although there is considerable disagreement on this point. Unlike steel, and more recently aluminum, finite element models are not as readily available for composite frames. Until there is some comfort with the predictability of composites during a crash, it is unlikely that manufacturers will use composites for critical structural applications.

MAT-31. What are the most significant challenges for the increased usage of structural composites? Please consider all aspects of the vehicle/component life cycle.

Challenges for the Increased Usage of Structural Composites	Percent of Responses
Cost	24%
Design expertise/comfort	18
Recyclability	17
Manufacturing concerns	13
Crashworthiness/safety	11
Joining in other materials	10
Assembly	4
Field use	3

Selected edited comments

Cost:

- Cost of high performance carbon fiber.
- Cost of manufacturing for composites (cycle time, complexity, variability).
- Cost of material and manufacture (system cost).
- Material cost may hinder use initially.
- Processing costs compared to steel or aluminum.
- Unless there is a breakthrough on price, it is difficult for me to see greater use of plastic frame materials.

Design expertise/comfort:

- Composites need to develop cure systems that are competitive and compatible with variable thickness of part sections; variable section thickness could result in unique challenges for design.
- Designer education; successful demonstration projects.
- Developing design expertise to effectively use the material.
- Development of structure designs that have a good balance of safety performance and weight reduction: Development of utilization of new materials such as honeycomb structures.
- Existing infrastructure for metal vehicles.
- Making upper management comfortable with using a different-from-the-normal type material.
- Risk aversion of auto industry: Captive investment in metal forming.
- Short-term testing that will give confidence in long-term performance of composites.
- Sunk investment in current steel tooling (stamping, welding, painting).

Recyclability:

- Disposal at the end of vehicle life will be an obstacle if there is no economic reward for the auto dismantler, be it landfill cost avoidance or getting money for the part(s).
- Life cycle/environmental.
- Recycling concerns based on the absence of facts and objectivity.

Manufacturing concerns:

- Cycle time is too long.
- Cycle time to mold.
- Economical high speed manufacturability.
- Processing and fabrication technologies need to be improved.
- QRD (how do I make and know I make 100 percent good ones?).

Crashworthiness/safety:

- Design for energy management in structural applications (i.e., design to accommodate low elongation to failure).
- Energy management upon crash.

Joining of other materials:

- Fastening (especially composite cross members to steel rails).
- Galvanic corrosion between aluminum and carbon fiber reinforced composites.
- Joining is largest technical challenge.
- Reliability at joints or bonds, especially with dissimilar materials.

Discussion

The use of composites for structural applications faces many challenges. The panel views cost, design expertise/comfort, recyclability and manufacturing concerns as the most significant challenges.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

The use of composites for structural applications presents many potential advantages and at least as many challenges. Composites offer the opportunity to significantly reduce weight and eliminate corrosion while potentially increasing design flexibility. Increasingly, there are examples of composites being used in weight bearing structural applications such as instrument panel beams and radiator supports. The USCAR Automotive Composites Consortium has been diligently working to develop manufacturing techniques that may lead to the adoption of composites for major structural components. However, a paradigm shift may be required to allow for significant increases in structural composites.

The panel views cost as the most significant challenge for structural composites. It is likely that high-cost materials such as carbon fiber may be needed to meet strength requirements in several critical structural applications although other reinforcement materials hold considerable promise. The inclusion of such materials would further add to the cost of vehicles for an industry already facing an affordability problem. Processing costs also present significant barriers.

The automotive industry has developed a century of experience with steel structural components. This comfort level presents at least two significant barriers for expanded structural composite application. First, the industry has developed manufacturing strategies based on steel, and the shift to composites would require significant new investment in tooling. Second, individuals that control the material selection process have reached a comfort level with steel. They understand characteristics of steel and are highly skilled in the design and engineering of steel structural components. It is unlikely that these individuals would easily accept a change to a new material.

Panelists view composites' perceived lack of recyclability as another challenge to increase usage. Panelists rate reinforced thermoplastics and thermosets as having many significant barriers to successful recycling (MAT-41). It is interesting to note that the Automotive Composites Consortium has suggested a paradigm shift that would promote long-lasting composite structure combined with replaceable exterior components, thus drastically lengthening the span of the structural part of the vehicle.

The panel also expects continuing challenges regarding manufacturing, crashworthiness and joining technology to impede the use of composites for structural applications. As CAFE pressures increase, composites could become a strong candidate for structural applications. It will be important to closely monitor activity in this area in the coming decade.

MAT-32. Consider the following list of automotive body components. Please indicate the percentage of each likely to be made from the listed materials in 2005. It is not necessary to enter a response for every component, just those with which you are familiar.

Median Response					
Passenger Cars	Vertical exterior panels*	Horizontal exterior panels**	Floor pan	Bumper, fascia	Bumper, support
Steel	60%	60%	80%	0%	25%
HSLA steel	5	5	10	0	30
Aluminum	10	10	0	0	10
Reinforced plastic					
Thermoplastic	7	5	0	10	10
Thermosets	8	10	0	0	5
Non-reinforced plastic					
Thermoplastic	0	0	0	80	0
Thermosets	0	0	0	0	0

Interquartile Range					
Passenger Cars	Vertical exterior panels*	Horizontal exterior panels**	Floor pan	Bumper, fascia	Bumper, support
Steel	52/75%	50/68%	80/90%	0/0%	20/50%
HSLA steel	0/15	0/15	5/20	0/0	16/60
Aluminum	3/15	9/20	0/5	0/0	0/17
Reinforced plastic					
Thermoplastic	1/10	0/10	0/0	0/60	0/20
Thermosets	5/10	5/15	0/5	0/14	0/10
Non-reinforced plastic					
Thermoplastic	0/5	0/0	0/0	20/94	0/0
Thermosets	0/0	0/0	0/0	0/0	0/0

* door, fender, quarter, ** hood, deck lid

Light Truck	Vertical exterior panels*	Horizontal exterior panels**	Floor pan	Bumper, fascia	Bumper, support
Median Response					
Steel	75%	72.5%	90%	15%	50%
HSLA steel	5	10	10	0	33
Aluminum	5	5	0	0	0
Reinforced plastic					
Thermoplastic	5	0	0	15	0
Thermosets	5	5	0	0	0
Non-reinforced plastic					
Thermoplastic	3	0	0	60	0
Thermosets	0	0	0	0	0

Light Truck	Vertical exterior panels*	Horizontal exterior panels**	Floor pan	Bumper, fascia	Bumper, support
Interquartile Range					
Steel	66/84%	61/83%	85/90%	0/40%	30/64%
HSLA steel	0/15	0/15	5/15	0/10	20/50
Aluminum	0/5	0/10	0/0	0/0	0/10
Reinforced plastic					
Thermoplastic	0/5	0/5	0/0	0/23	0/14
Thermosets	0/10	0/10	0/0	0/1	0/10
Non-reinforced plastic					
Thermoplastic	0/0	0/0	0/0	20/80	0/0
Thermosets	0/0	0/0	0/0	0/0	0/0

* door, fender, quarter, ** hood, deck lid

Selected edited comments

- 2000 is too soon to change anything.
- As weight reduction escalates, composites win.
- Bake hardenable steels will be widely used. If these should not be included under HSLA steels, then HSLA use would be 5-10 percent.
- Highly dependent on discipline to meet mass reduction goals to meet fuel economy goals.
- The terms "HSLA" as applied to high strength steel (HSS) is becoming obsolete. The strength level (e.g., >30 ksi) is more important than the method (LA=low alloy) of achieving the strength.

Discussion

The panelists forecast steel to continue to be the dominant body panel material. Although there will be a continued effort to reduce weight, the forecast is for aluminum and plastic to make only small gains in body panel usage in the coming decade.

Bumper fascias are expected to be made almost exclusively from nonreinforced thermoplastic. However, the panel expects several materials to be viable alternatives for bumper supports. It is important to note the wide interquartile ranges for bumper fascia and bumper support for they suggest a great deal of uncertainty or differing strategies of the manufacturers.

As with many material substitutions decisions, the panel expects passenger cars to experience earlier and greater application of lightweight materials than light trucks.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement, except for the forecasts listed below. It is important to note that all of the differences involve aluminum, and in each case the manufacturers forecast higher usage rates than do the suppliers.

Long Term Forecast for Aluminum Usage: Selected Applications			
Passenger Car	**Vertical exterior panels**	**Horizontal exterior panels**	**Floor pan**
Manufacturers	13%	18%	6%
Suppliers	6	11	0

Trend from previous Delphi surveys

For passenger cars, the 1996 Delphi VIII panel long-term forecast is for slightly lower application rates for steel horizontal and vertical panels than was forecast by the 1994 Delphi VII panel. This is offset by higher usage of nonreinforced plastics for bumper fascias with concomitant reductions in steel, HSLA and aluminum. These trends are repeated to a lesser extent for light trucks.

Strategic considerations

Steel will likely remain the material of choice for vertical and horizontal body panels, and floor pans in the coming decade. Manufacturers and suppliers have worked diligently to develop competitive manufacturing processes for alternate materials with only limited success. Even as advances are made in other materials, steel continues to present a moving target. Advances such as tailored blanks and HSLA steel make steel increasingly competitive.

Aluminum has experienced recent growth in horizontal panels, especially in hood applications for low-volume, high-priced luxury cars. However, the highest volume vehicle in North America, the Ford F-150 pickup, will use aluminum for hood application starting in the 1997 model year. This program will be a critical test for aluminum. The panel expects limited usage of aluminum for horizontal body panels, although there may be the potential for increased acceptance. Currently there are two aluminum intensive vehicles marketed in North America—the Acura NSX and the Audi A8. Although neither of these vehicles are manufactured in North America, and therefore are not included in the survey, their success, and the lessons learned from these programs, will be critical to the future success of aluminum body panels.

SMC, the most commonly used thermoset for body panels, continues to see increased application, usually for lower volume programs. The panel forecasts slow growth for thermosets in the coming decade. Reinforced thermoplastics have recently gained acceptance as a vertical body panel material (e.g., Saturn). Thermoplastics are perceived as being more recyclable than thermosets, and therefore viewed as more environmentally friendly. Generally thermoplastics have been seen as not acceptable for horizontal application. However, the panel forecast some application of thermoplastics for horizontal panels by 2005. Due in large part to customer response, Saturn has committed to plastic horizontal panels in current and future products.

It is likely that steel will continue to be the dominant material for body panels in the coming decade. If CAFE is increased, or if alternate fuel legislation is enacted, aluminum and plastics could see higher than forecasted levels of application.

MAT-33. Consider the following list of automotive chassis components. Please indicate the percentage of each likely to be made from the listed materials in 2000 and 2005. Leave blank any materials with which you are not familiar.

Passenger Car	**Median Response**			**Interquartile Range**		
2000 Chassis Components	Wheels	Springs	Suspension Control Arms	Wheels	Springs	Suspension Control Arms
Steel	25%	100%	55%	6/50%	75/100%	5/84%
HSLA steel	10	0	13	0/25	0/15	0/64
Aluminum	50	0	15	40/70	0/0	0/39
Reinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/1	0/0
Nonreinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/0	0/0

Light Truck	**Median Response**			**Interquartile Range**		
2000 Chassis Components	Wheels	Springs	Suspension Control Arms	Wheels	Springs	Suspension Control Arms
Steel	50%	100%	70%	12/70%	60/100%	0/93%
HSLA steel	10	0	23	0/23	0/36	0/85
Aluminum	35	0	3	20/55	0/0	0/16
Reinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/0	0/0
Nonreinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/0	0/0

Passenger Car	Median Response			Interquartile Range		
2005 Chassis Components	Wheels	Springs	Suspension Control Arms	Wheels	Springs	Suspension Control Arms
Steel	15%	90%	60%	10/20%	90/100%	40/70%
HSLA steel	10	0	20	9/16	0/10	8/30
Aluminum	70	0	18	60/75	0/0	5/36
Reinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/4	0/0
Nonreinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/0	0/0

Light Truck	Median Response			Interquartile Range		
2005 Chassis Components	Wheels	Springs	Suspension Control Arms	Wheels	Springs	Suspension Control Arms
Steel	30%	100%	63%	21/39%	90/100%	60/71%
HSLA steel	15	0	20	10/20	0/5	4/31
Aluminum	50	0	13	40/60	0/0	0/21
Reinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/0	0/0
Nonreinforced plastic						
Thermoplastic	0	0	0	0/0	0/0	0/0
Thermosets	0	0	0	0/0	0/0	0/0

Other single responses:

15 percent magnesium wheels and 10 percent hybrid-aluminum/plastic reinforced suspension control arms for passenger cars.

Magnesium: Passenger Cars: Wheels - 1 percent; Suspension Control Arms - 2 percent.

Magnesium: Passenger cars and light trucks: Wheels 15 percent.

Magnesium: Passenger cars: Wheels - 5 percent.

Selected edited comments

- Magnesium wheels for high performance. Titanium springs could come on stream if fuel cost or CAFE increases rapidly. Hybrid materials/processes may be right answer for some vehicles.
- Portion of steel wheel will be HSLA in both passenger cars and light trucks in 2000 and 2005.

Discussion

The panel forecasts steel to remain the dominant material for springs and suspension control arms in the coming decade. However, aluminum and HSLA steel are expected to gain increased penetration in suspension control arms. The panel also forecasts aluminum to experience continued growth for wheels. The wide interquartile ranges suggest some uncertainty regarding the implementation rates of aluminum and HSLA in the listed applications. It also may indicate different strategies for manufacturers.

Manufacturer/supplier comparison

The manufacturers and suppliers have significantly different long-term forecasts for suspension control arms in passenger cars. The manufacturers forecast significantly higher usage of aluminum for suspension control arms for 2005 (41 percent) than do the suppliers (13 percent). Conversely, the suppliers forecast a higher usage of steel for suspension control arms (63 percent) than do the manufacturers (42 percent). Manufacturers also forecast higher usage of aluminum for suspension control arms in light trucks for 2005 (26 percent) than do the suppliers (7 percent).

The manufacturers forecast a higher usage of aluminum wheels on passenger cars for 2005 (72 percent) than do the suppliers (61 percent).

Trend from previous Delphi surveys

The forecast by the 1996 Delphi VIII panel differs somewhat from earlier Delphi surveys. Delphi VIII does not forecast a decrease in steel usage for suspension control arms for passenger cars. Although the Delphi VIII panel does forecast increased usage of aluminum and HSLA steel, it also expects steel to remain competitive.

Passenger Car Suspension Control Arms								
	1995		1998	2000			2003	2005
Material	**Delphi V**	**Delphi V**	**Delphi VII**	**Delphi V**	**Delphi VI**	**Delphi VIII**	**Delphi VII**	**Delphi VIII**
Steel	75%	55%	70%	60%	35%	55%	60%	60%
HSLA steel	20	40	20	30	50	13	30	20
Aluminum	0	5	10	0	10	15	15	18
Reinforced plastic	5	0	0	10	5	0	0	0
Nonreinforced plastic	0	0	0	0	0	0	0	0

The Delphi VIII panel forecasts steel to remain the dominant material for passenger car springs. The 1989 Delphi V and 1992 Delphi VI forecast some usage of composites for springs, however the 1994 Delphi VII and Delphi VIII forecast no use of composites for the application.

Passenger Car Springs								
	1995		1998	2000			2003	2005
Material	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VIII	Delphi VII	Delphi VIII
Steel	85%	85%	n/a	80%	70%	100%	n/a	90%
HSLA steel	0	5	n/a	0	25	0	n/a	0
Aluminum	0	0	n/a	0	0	0	n/a	0
Reinforced plastic	15	10	n/a	20	5	0	n/a	0
Nonreinforced plastic	0	0	n/a	0	0	0	n/a	0

The forecast for passenger car wheels has remained constant over the previous four Delphi surveys. Low carbon steel is forecast to decrease, while HSLA steel remains constant and aluminum gains penetration. Although Delphi V and Delphi VI forecasted some application of composites for wheels, Delphi VII and Delphi VIII forecasts no usage of composites.

Passenger Car Wheels								
	1995		1998	2000			2003	2005
Material	Delphi V	Delphi VI	Delphi VII	Delphi V	Delphi VI	Delphi VIII	Delphi VII	Delphi VIII
Steel	55%	30%	40%	42%	20%	25%	25%	15%
HSLA steel	10	30	10	10	30	10	10	10
Aluminum	30	40	50	36	40	50	60	70
Reinforced plastic	5	0	0	12	10	0	0	0
Nonreinforced plastic	0	0	0	0	0	0	0	0

Strategic considerations

Manufacturers are diligently working to develop lightweight alternatives to steel for suspension components. Much of the effort has been focused on aluminum and composites. Many suspension components can be considered "hang on" parts, and therefore may present an opportunity to make changes on a part-by-part basis. However, the strict requirements for safety, cost and stiffness that suspension components must meet may make steel a difficult material to replace.

The panel expects some gains to be made by aluminum in suspension control arms. Several manufacturers have developed control arms made from aluminum. These components present a substantial weight advantage over steel control arms. However, cost remains a barrier. It is likely that aluminum suspension components will gain early penetration into luxury vehicles where cost may not be as critical. Manufacturers have also invested significantly in the development of suspension components using HSLA steel. HSLA steel may present the potential for lower weight than low carbon steel, and lower cost than aluminum.

The panel does not forecast any penetration for composite springs. This is especially interesting given the advances that General Motors' Delphi Chassis has made in this area. Composite springs have experienced great success in the heavy truck market, but so far have gained only limited acceptance in the passenger car and light truck markets. Recyclability, cost and durability concerns may impede future gains for composite springs in automotive applications.

Wheels, especially styled wheels (MAT 36), will continue to be made increasingly from aluminum alloys. The industry has accepted the cost—weight trade off that aluminum provides and is committed to developing further design using aluminum.

The industry is faced with the dilemma of achieving the proper balance between affordability and weight reduction. It is possible that, unless CAFE increases significantly, the aluminum control arm and composite spring may continue to be a technology that remains on the shelf due to cost concerns.

MAT-34. What percentage of North American-produced passenger cars and light trucks will use materials other than conventional glass for either windshields, side windows or rear windows in 2000 and 2005?

2000	Median Response			Interquartile Range		
Alternative Material for Glass	**Windshield**	**Side Window**	**Rear Window**	**Windshield**	**Side Window**	**Rear Window**
Polycarbonate	0%	0%	0%	0/0%	0/5%	0/1%
Polycarbonate-glass laminates	0	5	0	0/5	0/5	0/5
Special coatings and/or interlayers to:						
Reduce solar load	23	5	10	5/68	0/29	2/70
Provide defrosting capability	7	0	10	4/14	0/0	0/50
Provide abrasion resistance for plastics (e.g., diamond film glazes)	0	1	0	0/0	0/5	0/9

2005	Median Response			Interquartile Range		
Alternative Material for Glass	**Windshield**	**Side Window**	**Rear Window**	**Windshield**	**Side Window**	**Rear Window**
Polycarbonate	0%	4%	5%	0/0%	0/10%	0/6%
Polycarbonate-glass laminates	0	10	10	0/10	0/15	1/20
Special coatings and/or interlayers to:						
Reduce solar load	40	20	30	13/73	2/55	5/70
Provide defrosting capability	10	0	25	7/58	0/4	0/100
Provide abrasion resistance for plastics (e.g., diamond film glazes)	0	5	5	0/0	0/50	0/50

Selected edited comments

- 10 percent quarter glass. Bi-layer may be used—windshield thicker glass 3.0mm glass + 1.0mm PVB as opposed to laminated windshield with 8-10 percent reduction in mass.
- Expect side glass first (to use non-conventional materials), rear window next and windshield last due to 1) government regulation, 2) mass reduction versus noise reduction trade-off—polycarbonate does not absorb sound like glass does, and 3) abrasion resistant coating durability versus extended vehicle life.
- Glass will remain primary material.
- The regulation for the light trucks and passenger cars at present is different for the use of plastic in windows. The 2005 projection is based on future changes in regulation to allow the use of plastic in windows in passenger cars as well as trucks.
- Very small amounts in all applications shown.

Discussion

Panelists forecast no application of polycarbonate as an alternative window material by 2000 and only modest usage by 2005. Special coatings and interlayers are expected to continue to increase in usage through 2005.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel and the 1994 Delphi VII panel are in general agreement with regard to future usage of polycarbonate as an alternative to glass. However, the Delphi VIII panelists are less optimistic about penetration rates for special coatings and/or interlayers.

Strategic considerations

Current styling themes continue to promote large glass surfaces. As more glass is used, it becomes an increasingly attractive candidate to be replaced by lightweight alternatives such as polycarbonates.

Glass will continue to be the material of choice for all listed applications. It is expected that polycarbonates will initially be used for side and rear window applications. However, it is likely that these applications will only occur in situations where weight reduction is vital. Use of polycarbonate for windshield applications presents a significant weight reduction. However, polycarbonates have lower resistance to scratching, less sound dampening and are less forgiveness at impact than glass laminates.

The increased greenhouse effect presented by newer styling themes not only affects weight, but it also will likely lead to increased usage of coatings and interlayers to reduce the solar load on the interior with glass as the primary interior/exterior material.

There is creative work being done that could lead to new window material technologies and therefore alter the forecast considerably.

MAT-35. **For the following North American-produced passenger car and light truck brake components, please indicate what percentage is likely to be made from the listed materials currently and by 2000 and 2005. Please total each component to 100 percent. Leave blank any materials with which you are not familiar.**

Component Material	Median Response			Interquartile Range		
	Current Est.	2000	2005	Current Est.	2000	2005
Drum						
Aluminum	0%	28%	35%	0/5%	5/42%	13/68%
Cast iron	100	72	65	95/100	58/95	33/88
Drum Brake Backing						
Aluminum	0%	20%	87%	0/0%	8/50%	15/100%
Steel	100	80	13	100/100	50/92	0/85
Rotors						
Aluminum	0%	0%	0%	0/0%	0/20%	0/25%
Aluminum matrix composites	0	10	20	0/0	5/10	10/30
Cast iron	100	90	70	100/100	80/90	45/80
Caliper Housings						
Aluminum	0%	13%	40%	0/5%	9/20%	18/40%
Nodular iron	100	87	60	95/100	80/91	55/83
Plastic	0	0	0	0/0	0/0	0/0
Calipers						
Aluminum	0%	10%	25%	0/0%	0/18%	1/48%
Nodular iron	100	90	75	100/100	82/100	52/99
Pistons						
Aluminum	0%	8%	10%	0/0%	1/19%	5/35%
Composite	0	5	20	0/0	3/20	8/30
Steel	100	80	60	100/100	53/94	20/85

Other Single Responses:

Drum:

Aluminum/MMC: Curr. Est. - 0%; 2000 - 5%; 2005 - 30%.

Rotors:

Aluminum matrix composite: 2000 - 25%; 2005 - 50%, Aluminum/MMC: Curr. Est. - 0%, 2000 - 20%; 2005 - 40%, Metal matrix composites (alum.): 2000 - 10%; 2005 - 25%.

Caliper Housings:

Aluminum/MMC: Curr. Est. - 0%; 2000 - 5%; 2005 - 20%, Aluminum: 2000 - 20%.

Pistons:

Aluminum/MMC: Curr. Est. - 0%; 2000 - 0%; 2005 - 10%, Plastic: Curr. Est. - 20%; 2000 - 40%; 2005 - 50%, Plastic: 2000 - 50%; 2005 - 80%, Phenolic or aluminum: Curr. Est. - 2%; 2000 - 2%; 20005 - 2%, Composite: Curr. Est. - 10%; 2000 - 40%; 2005 - 60%.

Selected edited comment

- Aluminum is not the same as aluminum MMC.

Discussion

The panel forecasts aluminum usage to increase significantly by 2005 for drums, drum backings, calipers, caliper housings and pistons. This substitution will be at the expense of cast iron, nodular iron and steel for the listed components. Aluminum matrix composites are forecast to see initial application in brake rotors. The wide interquartile ranges may suggest some uncertainty regarding the future of aluminum for brake material applications and/or different strategies.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was changed significantly from previous Delphi studies, and therefore comparison is not possible.

Strategic considerations

The substitution of aluminum for current materials in brake components presents the opportunity for substantial weight reduction, but at a significant cost penalty. Each North American manufacturer has programs to advance manufacturing and engineering knowledge of aluminum brake components. Although each of these programs is in the early stages, it is likely that brake components made from aluminum could see increased penetration in the coming decade.

There are a few low volume programs that currently use aluminum alloy brake rotors. Although these are mostly higher priced vehicles, the advantages of aluminum alloy are already apparent. Aluminum alloy rotors are less than half the weight of the components they replace. Although rotors were the only brake component that were forecast to see aluminum matrix composites penetration, there is significant work being done in AMC for each of the listed components. Brake rotor material developments should be watched closely. It may give an early indication of the viability of AMC for other brake components.

Several of the forecasts have wide interquartile ranges. This may be due to some uncertainty regarding future CAFE regulation. The cost associated with the substitution of aluminum for current materials is a severe penalty. Panelists that do not forecast CAFE increases may expect cost considerations to slow the switch to aluminum brake components. Given the amount of effort devoted to aluminum brake components, it is likely that aluminum will continue to be viewed as a candidate for brake components in the coming decade.

MAT-36. Approximately 45 percent* of 1994 North American-produced passenger cars and light trucks had styled wheels. What percentage of styled wheels will be made from each of the following materials in 2000 and 2005?

Styled Wheel		Median Response		Interquartile Range	
Materials	**1994***	**2000**	**2005**	**2000**	**2005**
Passenger Car					
Aluminum	85%	85%	85%	80/90%	75/95%
Hybrid (steel and plastic)	0	0	0	0/1	0/2
Magnesium	0	0	0	0/0	0/5
Plastics	0	0	0	0/0	0/0
Steel	15	10	10	5/15	5/15
Light Truck					
Aluminum	68%	71%	75%	70/75%	70/85%
Hybrid (steel and plastic)	0	0	0	0/0	0/0
Magnesium	0	0	0	0/0	0/0
Plastic	0	0	0	0/0	0/0
Steel	32	25	20	25/30	15/29

* Source: *Ward's Automotive Reports*, December 26, 1994 and January 16, 1995

Selected edited comments

- Cost of aluminum wheels will limit growth.
- Move back to steel for cost-effective weight reduction.

Discussion

Styled wheels for both passenger cars and light trucks will continue to be made predominately from aluminum. Essentially no role is expected for magnesium or plastic in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel and the 1994 Delphi VII panel are in general agreement. This question was asked differently prior to Delphi VII, making direct comparison to earlier Delphi forecasts impossible.

Strategic considerations

Styled wheels are expected to continue to be a popular option for many vehicles. The 1996 Delphi VIII panel forecasts that, in the coming decade, aluminum will continue as the dominant material for styled wheels. Aluminum offers several advantages over its current competitor, steel. Aluminum wheels are lightweight, easily meet current styling requirements and, most importantly, have a good safety and durability history. The perceived ruggedness of styled steel wheels will allow steel to hold at least a small portion of the light duty truck market.

The panel forecasts little or no usage of plastic or magnesium for styled wheels in the coming decade. Plastic, or composite, wheels present significant opportunity for weight reduction, yet acceptance will be slow because of cost and safety considerations. Magnesium also presents weight and styling advantages but also has several drawbacks. Both of these materials are not likely to gain significant penetration in the coming decade without significant advances in both materials.

MAT-37. **What percentage of North American-produced passenger cars and light trucks will utilize the following bonding/joining technologies in body assembly by 2000 and 2005?**

	Median Response		Interquartile Range	
Bonding/Joining Technologies	**2000**	**2005**	**2000**	**2005**
Acrylics				
Body panels	4%	6%	0/6%	4/11%
Body reinforcement	4	5	0/5	4/9
Glass	0	0	0/0	0/2
Hem flanges	12	15	5/20	5/23
Ornamentation	45	55	24/61	33/71
Structural	5	10	5/11	5/10
Epoxies				
Body panels	15%	30%	15/30%	23/30%
Body reinforcements	28	40	15/40	15/60
Hem flanges	50	70	40/60	40/75
Structural	15	25	5/25	10/30
Foam Tape				
Exterior trim	90%	95%	90/93%	90/96%
Interior trim	25	30	12/50	20/55
Urethanes				
Body panels	10%	15%	5/20%	10/20%
Hems	10	10	5/20	5/25
Stationary glass	100	100	94/100	92/100
Structural	8	15	5/16	5/28

Selected edited comment

- I can't speak to the technologies, but there is no question that joining technologies which result in a continuous (as contrasted with a discontinuous, e.g., spot welding) joint will find much expanded application.

Discussion

The panel forecasts epoxies to see increased usage for each of the listed applications. Acrylics, foam tape and urethanes are forecasted to see only slight growth for the listed applications. It is important to note the wide interquartile ranges for several of the technologies listed in this question.

Manufacturer/supplier comparison

The manufacturers and suppliers are in statistical agreement except for two bonding/joining technologies. Suppliers forecast a higher application rate for epoxies in body reinforcements for 2000 (32 percent) than do manufacturers (15 percent). Suppliers also forecast a higher application rate for acrylics in hem flange joining for 2005 (23 percent) than do the manufacturers (10 percent).

Trend from previous Delphi surveys

The 1996 Delphi VIII panel and the 1994 Delphi VII panel differ in their forecasts. Given the wide interquartile ranges for both Delphi VII and Delphi VIII, the forecasts may not be as dissimilar as they appear, however. The following table compares the two forecasts.

Comparison of Delphi VII and Delphi VIII Forecasts				
	Median Response			
Bonding/Joining Technologies	1998 Delphi VII	2000 Delphi VIII	2003 Delphi VII	2005 Delphi VIII
Acrylics				
Body panels	0%	4%	5%	6%
Glass	5	0	10	0
Hem flanges	2	12	5	15
Ornamentation	5	45	10	55
Structural	0	5	0	10
Epoxies				
Body panels	15%	15%	15%	30%
Body reinforcements	10	28	15	40
Hem flanges	20	50	50	70
Structural	10	15	20	25
Foam Tape				
Exterior trim	30%	90%	50%	95%
Interior trim	30	25	40	30
Urethanes				
Body panels	10%	10%	20%	15%
Structural	5	8	20	15

Strategic considerations

It appears that manufacturers will not significantly increase usage of many bonding and joining techniques in the coming decade. Of the listed materials, only epoxies are forecasted to see even moderately increased penetration for the listed applications. The usage of adhesives to join body parts during assembly may be limited, depending on the role non metallic recycling has in the material selection process. The ease of disassembly is critical to a successful recycling strategy. It is possible that bonding/joining technologies may be limited to applications where the bonding and substrate materials are compatible.

Finally, it is important to note the wide interquartile ranges for several of the technologies listed in this question. The differences among panelists reflect uncertainty regarding the use of bonding and joining techniques, and different strategies at the individual manufacturers.

MAT-38. **What percentage of North American-produced passenger car and light truck manufacturing facilities will use the following paint systems in 2000 and 2005?**

Paint Systems	1994*	Median Response 2000	Median Response 2005	Interquartile Range 2000	Interquartile Range 2005
UNDERCOAT					
Electrocoat					
Current technology	100%	90%	50%	90/95%	50/60%
Lead-free	0	10	50	5/10	40/50
Total	100%				
Primer surfacer					
None	15%	10%	5%	0/15%	0/10%
Solvent-borne	80	60	50	50/68	40/60
Powder	5	20	30	15/26	25/40
Waterborne	0	8	10	2/10	5/15
Total	100%				
TOPCOAT					
Base coat/clear coat					
Base coat					
Monocoat/solvent-borne low solids	0%	0%	0%	0/0%	0/0%
Solvent-borne	90	70	40	60/75	40/60
Waterborne	10	30	60	25/40	40/60
Total	100%				
Clear coat					
Conventional solvent melamine	35%	20%	10%	15/30%	10/22%
Solvent-borne etch resistance	65	70	65	65/80	60/75
Powder	0	0	5	0/5	0/11
Waterborne	0	0	10	0/5	0/15
Total	100%				

* Source: Automotive Manufacturer estimate

Selected edited comments

- A lot depends on political climate and legislation.
- Dependent on government regulations.
- Waterborne clear coat/topcoat: 2005 - 20 percent. Japanese manufacturers will continue to have an advantage of choosing coatings based on cost and performance rather than emissions compliance.

Discussion

The panelists forecast increased usage of lead free electrocoat, powder and waterborne primer surfacers, waterborne base coats, and powder and waterborne clear coat technology in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel forecast is similar to the 1994 Delphi VII forecast. However, the Delphi VIII panel is slightly more aggressive in its forecast of most of the environmentally friendly paint technologies. This is likely due to increased governmental pressure to reduce volatile organic compounds (VOCs) and increased experience with the new technologies. The table compares Delphi VII and Delphi VIII forecasts.

Paint Systems	Short term		Long term	
	1998 Delphi VII	2000 Delphi VIII	2003 Delphi VII	2005 Delphi VIII
UNDERCOAT				
Electrocoat				
Current technology	90%	90%	70%	50%
Lead-free	10	10	30	50
Primer surfacer				
None	40%	10%	30%	5%
Solvent-borne	40	60	30	50
Powder	5	20	10	30
Waterborne	10	8	25	10
TOPCOAT				
Base coat/clear coat				
Base coat				
Monocoat/solvent-borne low solids	10%	0%	10%	0%
Solvent-borne	70	70	50	40
Waterborne	20	30	40	60
Clear coat				
Conventional solvent melamine	60%	20%	25%	10%
Solvent-borne etch resistance	30	70	30	65
Powder	0	0	8	5
Waterborne	0	0	10	10

Strategic considerations

Airborne chemicals or volatile organic compounds (VOC) have been a significant byproduct of traditional automotive paint systems. In the past 20 years, the industry has reduced paint shop emissions of VOC by nearly 80 percent. However, it may be necessary to eliminate the remaining 20 percent to meet future environmental regulations. The panel forecast reflects this increased regulatory pressure to reduce VOC emissions and thus decrease environmental problems associated with their use.

The removal of lead from the electrocoat process is another important environmental challenge for the industry. The panel forecasts continued implementation of lead free electrocoat systems, in large part due to tightening government regulation.

The task for the manufacturers and their paint system suppliers is not only to overcome the technical hurdles of these more environmentally friendly paint systems but to do so in a highly capital constrained business environment. The installation of a new paint system can cost hundreds of millions of dollars and considerable downtime.

The USCAR Low Emission Paint Consortium (LEPC) was established in 1993 to conduct joint research and development programs on paint-related technologies to reduce or eliminate solvent emissions from automotive paint systems. In Summer 1995, LEPC began construction of a facility to develop powdered paint technologies. The activities of this consortium must be closely watched. The potential for the development of cost-effective powdered paint technology will most certainly signal a major change for paint and paint system suppliers.

MAT-39. What are your expectations of oven temperature for 2005 for the following paint system oven?

2005	Median Response		Interquartile Range	
Paint Systems	**Current Estimate**	**Oven Temperature**	**Current Estimate**	**Oven Temperature**
Electrocoat	360°F	350°F	350°/378°F	278°/355°F
Topcoat	260°F	250°F	250°/295°F	240°/265°F

Selected edited comment

- Topcoat bakes likely to increase due to water base and powder coatings use. May be as high as 325°F.

Discussion

Panelists forecast paint oven temperature will decrease approximately 10°F for both electrocoat and top coat applications in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was changed significantly from previous Delphi studies, and therefore comparison is not possible.

Strategic considerations

The panel does not expect increased usage of lead-free electrocoat technology (MAT-38) to substantially alter the minimum electrocoat oven temperature. It forecasts only a minor change in current top coat oven temperature requirements. As powdered and waterborne paint system are implemented, there will likely be the need to increase top coat oven temperatures considerably.

There are several materials issues that are involved in establishing the lowest minimum electrocoat and top coat oven temperature. Plastics—materials that are central to the oven temperature issue—are currently engineered to meet the demands of top coat ovens now in use. Any significant change in oven temperature would greatly affect the performance of these materials. If, as the panelists forecast, top coat oven temperatures slightly decrease in the coming decade, plastics may experience less shrinkage and warpage and possibly allow for a better fit. However, if powdered and waterborne paint systems become commonplace, the higher temperatures required could create challenges for current plastics.

MAT-40. Please indicate how materials will influence the improvement of future customer satisfaction over the next 10 years for body and chassis.

Selected edited comments

BODY (EXTERIOR)

Quality/reliability/durability:

- Cannot be achieved at the expense of recyclability.
- Continued high quality paint finishes.
- Dent resistance and corrosion resistance from use of plastics.
- Dent resistant steel will help eliminate those shopping cart incidents.
- Eliminate corrosion as an issue.
- "Friendly fender" concept for all vertical panels.
- Improved chip, mar, fallout resistance will be required to be competitive.
- Improved fit and reduced mass doors will improve door opening and closing and operation.
- Improved weathering performance of coatings and plastics.
- More chip resistant paints and corrosion resistant panels.
- More formable, more consistent, coated steels will have positive effects.
- Move to more plastics will improve durability and repairability.
- New materials and paint technologies will improve all three categories at lower mass and cost.
- Plastic body panels eliminate corrosion.
- The introduction of aluminum which is inherently corrosion resistant will provide a major step forward in durability.

Appearance:

- Aluminum skin panels provide a high quality finish with dent resistance equivalent to that of bake hardened steel.
- Better painting systems will lead to better finishes along with increased stamping techniques and increased use of plastics.
- Damage resistant polymer panels keep vehicle looking new longer.
- Derivative niche vehicles at low tooling cost (plastics, composites).
- Etch resistance clear coats; improved chip resistant coatings.
- Even better surface finish of steel.
- Finishes will be more glossy. Decreased gaps between major panels will lead to "jewel effect."
- High gloss paint surface, improved fit and finish.
- Improved DOI, gloss retention. Improved color fastness and weathering.
- No-rust, no-dent thermoplastics with dyed in color.

- Paint systems/denting/chipping are important issues.
- Plastics eliminate dings and dents; no rust issues; styling features incorporated that can't be formed in metal; frequent restyling due to low investment tooling.
- Powder paint could limit use of (desirable) tinted clearcoats and colored primers.

Safety:

- All structural components including outer skins must be part of the energy absorbing system.
- Aluminum vehicles provide equal or better protection than steel.
- Astute uses of plastics and foams will enhance impact resistance.
- Higher strength steels with high strain rate sensitivity (i.e., the higher the strain rate, the stronger they are).
- Improved crashworthiness of materials and improved means of predicting through FEA.
- Improved occupant containment with polymer glazing.
- Increased design of materials with CAD will result in improved crash resistance per energy criteria.
- Lead, cadmium, chromium free phosphates, electrocoats, primers and top coats will be common.
- Materials and crash energy management systems must do much more than just "meet current safety standards."
- Plastic laminated side windows.
- Side impact technology with combinations of steel, aluminum and composites. Improved alloys will perform uniformly.
- Stiffness, strength, and ductility of steel will provide the best combination of properties for safety.

Other:

- Cost—customer satisfaction is linked to value. Materials must provide high performance at low cost.
- Enhanced structural performance improves handling and refinement.
- Increased use of steel/polymer/steel laminates for superior NVH.
- Lighter weight materials will help by permitting vehicle size to remain constant while achieving CAFE and safety goals.
- On body and chassis I believe customers 10 years from now will have a better appreciation for the comparative structural performance (safety) of various materials and the comparative life cycle costs—including costs associated with environmental impact.
- Sensitivity to cratering may adversely affect appearance of powder paint.

BODY(Interior)

Quality/reliability/durability:

- Better long term durability (i.e., 10 years) on coatings including chip resistance.
- Improved ultra-violet resistance interior materials fading, cracking, color change.
- Improved weathering performance of coatings and plastics.
- More formable, more consistent, coated steels will have positive effects.
- New materials and paint technologies will improve all three categories at lower mass and cost.
- Not much change.
- Replacements for PVC/ABS skins (IP, console, door) will lead to a more luxurious feel and increased levels of QRD.
- Use of TPO's, high crystalline polypropylenes, etc., to provide surfaces easy to clean, not subject to poor aging.
- Water base and other compliance coatings will make color and texture match more difficult.

Fit and finish:

- Demands made by customers for more uniform look (color, gloss, texture). Improved fit and finish can be achieved by material and component deproliferation.
- Improved squeak/buzz/rattle techniques; better structural integrity for instrument panel system.
- Longer term coatings color and sheen.
- More consistent steel properties will improve fit.
- More parts/components likely to be pre-painted or molded in color.
- Not much change.
- Use of polypropylene and various S-RIM, etc., with improved dimensional stability will result in better chance for improved fit and finish.

Ergonomics:

- Components are now being designed with consumer comfort in mind. Many tools are being developed especially for seating and instrument panel.
- Dials and buttons will have softer feel through either soft touch paints or soft material over mold.
- Paint systems will be highly automated with minimal human exposure to harmful fumes.

Safety:

- Airbags, dashboard material, interior space (survival space) will all have a measurable effect on customer satisfaction.
- Foam materials on pillows and headers.
- Impact force absorption with foam, gel technology, side airbags, honeycomb, etc.
- Improved protection through airbags and structures.

- Lighter weight, smaller packaging for airbags (door, steering wheel, seat, passenger). Investigating alternate technologies for occupant protection.
- Lower levels of safer solvents will reduce worker and environmental exposure.
- Side airbags.
- Stiffness, strength, and ductility of steel will provide the best combination of properties for safety.
- Use of foams, etc. to encapsulate the passengers will evolve for good packaging of people and things—and provide safety features necessary.
- Use of tailor welded steel blanks for inner body panels.

Other:

- Laminates and pre-paints likely to find wider acceptance.
- More recyclable materials will lower tax burden.
- More uniform (gloss) and improved mar resistance of interior plastics.
- Tailored blanks will improve NVH and reduce weight and costs.
- Tailored blanks will provide benefits in areas of NVH, performance and safety while reducing costs and weight.

CHASSIS

Quality/reliability/durability:

- Coatings on cast iron brake rotors or use of aluminum brake rotors will eliminate grinding noise from rust.
- Improved coatings resulting in longer life; improved temperature performance characteristics.
- In a changeover away from steel, quality will initially suffer, then improve greatly.
- Increased use of HSLA and metal/plastic composite will evolve.
- Increased use of statistical process control will result in increased material characteristics resulting in increased QRD.
- More formable, more consistent, coated steels will have positive effects.
- No corrosion on aluminum suspension components, stainless and titanium exhaust systems reduce replacement frequency.
- Would expect only minor continuous improvement.

Noise/vibration/harshness:

- Expect greater use of pillar foams and underbody coatings for noise. Adhesives may also help NVH.
- Increased use of steel/polymer/steel laminates for superior NVH.
- Increased use of structural aluminum castings will improve NVH.
- Materials and materials systems exist that will offer great improvements in this area. The technology must become competitive so the advantages can be taken achieved.
- Materials will drive new designs and architecture.

- Metal matrix composites in drive shafts and brakes (rotors/calipers).
- Nonmetallics will improve this area greatly.
- Stiffer structures will improve NVH.

Performance:

- Decreased mass through increased design and implementation of nonferrous materials.
- Engineering with materials technology to engineer in dynamic features such as dynamic rate systems and tuned systems.
- Extensive use of tailor welded steel blanks for weight reduction and energy absorption.
- Lightweight aluminum, magnesium, titanium and composite components improve acceleration and responsiveness.
- No significant influence expected.
- Overall performance will remain the same.

Safety:

- ABS, traction control and integrated chassis control (yaw and steering position sensors).
- Computer aided design of materials and subsystems will create safest chassis to date.
- Stiffness, strength and ductility will provide the best combination of properties for safety.

Other:

- Lighter weight materials will help by permitting vehicle size to remain constant while achieving CAFE and safety goals.
- More dimensionally stable manufacturing processes such as hydroforming and vacuum casting of aluminum cradles allow dimensionally current chassis component mounting and minimize alignment requirements.

Discussion

Panelists forecast material developments for interior and exterior body components to improve dent resistance, corrosion resistance and durability to achieve increased customer satisfaction. The panel also expects corrosion protection of chassis components to increase customer satisfaction.

The panel expects increased knowledge of current and new materials to lead to more advantageous designs and applications.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

Because of differences in coding, direct comparison can not be made. However, the comments of the 1996 Delphi VIII panel are similar to those of the 1994 Delphi VII panel.

Strategic considerations

The panel has identified a number of materials issues that represent potential for increased customer satisfaction. In many instances, technologies are available to significantly reduce or eliminate these problems. However, cost prevents them from being implemented. Future implementation of such technologies bears close watching.

Many comments suggest the industry has the capability to design and manufacture steel body panels that last for 10 years before perforation (MAT-11). However, the added cost may not be accepted by the customer. Paint, a critical element of the corrosion protection system, will also play an important role in customer satisfaction in the coming decade.

Environmental laws are forcing industry to radically change the methods used to paint vehicles (MAT-38). The conversion to powder and waterborne paints will create significant new challenges and opportunities. Corrosion protection will also play a critical role in customer satisfaction regarding chassis. The panel expects increased usage of coatings to protect steel while alternative materials, specifically aluminum, play critical roles in future chassis corrosion protection.

The body interior will also present significant opportunities for customer satisfaction in the next decade. Increased emphasis will be placed on achieving a luxurious feel while controlling costs and increasing recyclability. Lightweight materials such as magnesium (MAT-17) and composites may also see increased usage for some interior applications.

Weight reduction also appears to be significant to increasing customer satisfaction. Decreased weight can improve performance and fuel economy, leading to enhanced ride characteristics in some situations. However, manufacturers continue to struggle with the cost-benefits associated with weight reduction. In light of the affordability concerns, it appears that the use of higher-cost lightweight materials may be difficult to justify. Although the panel forecasts increased usage of lightweight materials, it is also likely that conventional materials will remain competitive through improved design techniques.

MAT-41. The recyclability of automotive materials and related environmental concerns will be significant issues confronting the entire industry in the upcoming decade. With regard to recycling, what factors do you think are or will become recycling barriers to the utilization of materials within the listed categories?

Scale: 1 = most important 3 = somewhat important 5 = least important

	Plastics/Polymers			Nonferrous metals			Ferrous
Potential Recycling Barriers	Unreinforced Thermoplastics	Reinforced Thermoplastics	Thermosets	Aluminum	Copper	Zinc	**metals**
Alloy content/contamination	2.2	2.1	2.5	2.7	3.7	3.7	4.4
Automated processing/ separation of materials, e.g., density gradient	2.5	2.5	2.9	3.5	3.6	3.5	4.7
Dismantling/ disassembly	2.0	1.9	2.2	3.0	2.7	2.8	4.5
Ease of materials separation	1.5	1.5	1.9	2.9	3.2	3.2	4.7
Economics of reclamation/recycling process	1.7	1.5	1.4	3.0	3.2	2.6	3.9
Energy required for recovery	3.0	2.8	2.6	3.6	3.5	3.8	4.2
Energy required to process raw material	3.5	3.4	3.3	2.5	3.4	3.7	4.0
Environmentally safe disposal	3.3	3.2	3.1	4.1	3.9	3.2	4.7
Industrial environment/ health issues	3.6	3.5	3.3	4.4	4.0	3.2	4.7
Labeling/identification	2.3	2.4	2.5	3.6	4.1	3.9	4.6
Lack of design for disassembly	2.1	2.2	2.3	3.5	3.6	3.8	4.3
Lack of labor skills for parts disassembly	3.7	3.6	3.7	4.2	4.2	4.3	4.7
Landfill availability and cost	2.7	2.6	2.3	4.2	4.0	3.8	4.4
Limited markets/uses for recommended parts and materials	2.4	2.2	1.7	4.6	4.7	4.5	4.8
Recycling infrastructure/logistics	1.6	1.5	1.5	3.6	3.9	4.0	4.5
Scrap value	2.1	2.0	1.6	3.6	3.7	3.5	3.8

Selected edited comments

- It is not obvious to me why the automobile must be further recycled. It is already the most recycled major product (75 percent), all nonsubsidized, and contributes less than one-half of one percent of landfills.
- Lack of design for disassembly is somewhat important for thermosets. Recycling for ferrous/nonferrous is established.
- Recycling infrastructure/logistics and scrap value dependent on dismantling/disassembly, ease of materials separation and economics of reclamation/recycling process.
- Recycling of plastics is still the biggest challenge in the United States. since our scrap stream is purely driven by economics. There are no plastics recycling systems which are even remotely close to being cost–effectively implemented. I do not think U.S. political environment will support dismantling as Europe has done.
- Separating all the aluminum and magnesium alloys from each other will probably become the biggest challenge for recycling metals. We need a set of codes for identifying, like the plastics are starting to use.
- Thermoset recycling schemes are not viable.
- Thermosets are hardest to recycle. Unreinforced thermoplastics are quite easy, but infrastructure is underdeveloped and automotive specifications severely restrict use of recycled materials.

Discussion

As industry becomes more aware of the final disposition of its products, material selection may be influenced by recycling concerns. The panel forecasts that a majority of the listed barriers will present significant challenges for plastics/polymers. According to the panel, nonferrous metals will face several somewhat important barriers in the coming decade while the panel expects no important barriers to recycling for ferrous metals.

Manufacturer/supplier comparison

Manufacturers and suppliers statistically differ over several issues. The manufacturers view landfill availability and cost as a more important barrier for thermoplastics than do the suppliers. Conversely, the manufacturers rate landfill availability and cost as a less important barrier than do the suppliers. The manufacturers also rate the scrap value of thermoplastics and nonferrous metals as less of a concern than do the suppliers.

The suppliers rate alloy content/contamination for thermoplastics a more severe barrier than do the suppliers. However, the manufacturers rate content/contamination for copper and ferrous metals as a greater barrier than do the suppliers.

The table shows the statistically different responses in the following form: Manufacturer/supplier.

Potential Recycling Barriers	Plastics/Polymers			Nonferrous metals			Ferrous metals
	Unreinforced Thermo-plastics	Reinforced Thermo-plastics	Thermosets	Aluminum	Copper	Zinc	
Alloy content/contamination	2.8/1.9	2.4/1.9	—	—	3.3/3.9	—	4.0/4.6
Automated processing/ separation of materials, e.g., density gradient	—	2.9/2.4	—	—	—	—	—
Dismantling/ disassembly	—	—	—	*3.4/2.8*	2.4/2.9	—	—
Ease of materials separation	—	—	—	—	2.9/3.5	—	4.3/4.9
Economics of reclamation/recycling process	1.4/1.9	—	—	—	*2.8/3.5*	2.2.3/2.8	—
Energy required for recovery	—	—	—	4.0/3.4	3.9/3.3	—	—
Energy required to process raw material	—	—	—	—	—	4.0/3.5	—
Environmentally safe disposal	—	—	—	—	—	*3.6/2.9*	—
Industrial environment/ health issues	—	—	—	—	4.3/3.8	*3.8/2.9*	—
Labeling/identification	—	—	—	—	4.4/3.9	—	—
Lack of design for disassembly	—	—	—	*4.1/3.1*	—	—	4.0/4.6
Landfill availability and cost	2.1/3.0	2.1/2.8	—	4.5/3.9	4.3/3.8	4.2/3.4	—
Recycling infrastructure/logistics	—	—	—	4.2/3.3	—	—	—
Scrap value	1.7/2.3	1.6/2.2	—	3.2/3.9	33.2/4.0	2.7/3.8	3.0/4.2

Trend from previous Delphi surveys

There are several areas of disagreement between the 1996 Delphi VIII panel and the 1994 Delphi VII panel. The most obvious is that the Delphi VIII panelists rate barriers facing ferrous metals as consistently less important than did the Delphi VII panel. Conversely, the Delphi VIII panel rates industrial environment/health issues as more important barriers than did the Delphi VII panel. **The table shows the statistically different responses in the following form: Delphi VII/Delphi VIII.**

Potential Recycling Barriers	Plastics/Polymers			Nonferrous metals			Ferrous metals
	Unreinforced Thermoplastics	Reinforced Thermoplastics	Thermosets	Aluminum	Copper	Zinc	
Alloy content/contamination	2.8/2.2	—	3.0/2.5	—	2.9/3.7	2.8/3.7	3.9/4.4
Automated processing/ separation of materials, e.g., density gradient	—	—	—	—	3.1/3.6	—	—
Dismantling/ disassembly	—	—	—	—	—	—	3.7/4.5
Ease of materials separation	2.0/1.5	—	—	—	—	—	4.1/4.7
Economics of reclamation/recycling process	—	—	—	—	2.7/3.2	—	3.4/3.9
Energy required for recovery	—	—	—	—	3.0/3.5	3.0/3.8	3.4/4.2
Energy required to process raw material	—	—	—	—	—	—	3.3/4.0
Environmentally safe disposal	2.4/3.3	2.3/3.2	2.2/3.1	—	3.4/3.9	—	3.7/4.7
Industrial environment/ health issues	3.6/3.0	2.8/3.5	3.3	3.6/4.4	3.2/4.0	—	3.7/4.7
Lack of design for disassembly	—	—	—	—	—	—	3.6/4.3
Lack of labor skills for parts disassembly	—	—	—	—	—	—	3.8/4.7
Landfill availability and cost	2.2/2.7	2.1/2.6	—	3.5/4.2	2.8/4.0	—	3.7/4.4
Limited markets/uses for recommended parts and materials	—	—	2.2/1.7	—	3.8/4.7	3.7/4.5	4.1/4.8
Recycling infrastructure/logistics	—	—	—	—	3.4/3.9	3.1/4.0	3.64.5
Scrap value	—	—	—	—	3.0/3.7	3.0/3.5	3.1/3.8

Strategic considerations

For decades, the industry has been actively working to make more environmentally friendly products. Much of this work has been focused on the manufacturing and operational stages of the product's life cycle. Recent years have seen an increased interest in the impact of the product at the retirement stage.

Presently 75 percent (by weight) of each vehicle is recycled. This is accomplished by the removal of resaleable parts, fluids and metals. The remaining 25 percent, comprised mostly of plastics, goes to the landfill as automotive shredder residue (ASR). Decreasing the amount of ASR is currently the focus of the industry's recycling strategy.

The panel expects the most severe barriers to automotive plastics recycling to be economic, not technical, in nature. Few, if any, plastics are not technically recyclable. However, the lack of an economically viable recycling infrastructure will continue to prevent large scale plastics recycling as well as technology to separate waste into the various components.

Ultimately, it is unlikely any important automotive material will be eliminated by life cycle/recycling concerns. Technology is likely to resolve most problems.

MAT-42. Recycling/disposition involves a complex set of stages and issues. Please indicate your view of the degree of challenge each of these methods presents to effective recycling/disposition.

Scale:	1 = extremely severe challenge 3 = somewhat severe 5 = not at all severe

Method	Mean Rating
Thermoplastics	
Closed loop recycling	2.4
Open loop recovery	3.0
Heat recovery	3.3
Thermosets	
Closed loop recycling	1.6
Open loop recovery	2.2
Heat recovery	2.7
Ferrous	
Closed loop recycling	3.8
Open loop recovery	4.5
Nonferrous	
Closed loop recycling	3.2
Open loop recovery	3.9

Selected edited comments

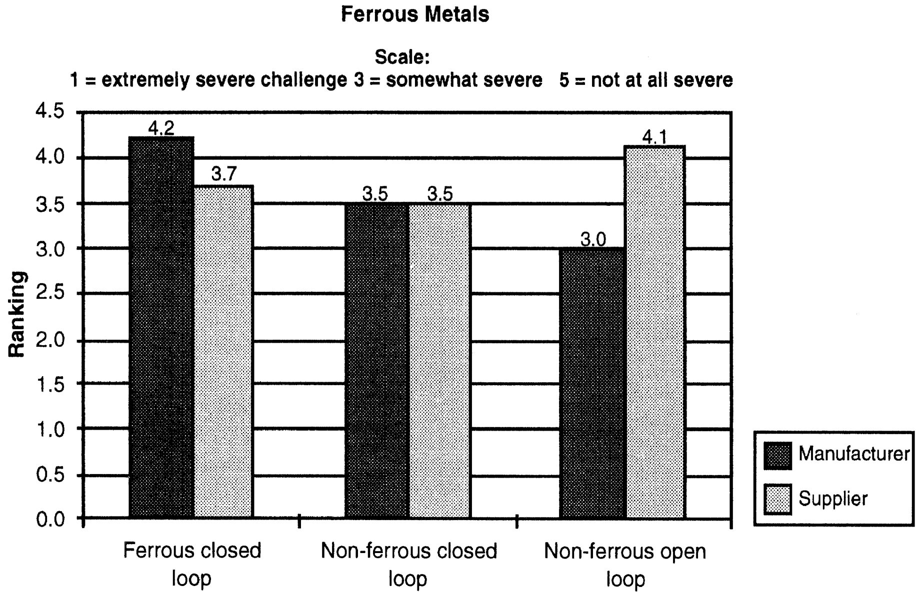
- Closed loop recycling of thermoplastics and thermosets varies with resin application. Technically, both thermoplastics and thermosets can be put back into their original applications. Cost is the issue for both. Plastics generally burn cleaner than coal with equal or more energy release. However, securing a permit to burn industrial scrap or automotive shredder residue is more difficult—especially with recent EPA rulings. Open loop recycling is technically feasible with most plastics from properly designed components. Cost is the issue.
- Heat recovery technically attractive, main issue is political.
- I believe there is a misconception that metals are truly closed loop recyclable when, in fact, very little can go back into high value applications.
- I would be extremely disappointed if the issue of open or closed loop recycling becomes important for metals—where the metals go is unimportant from an environmental point of view as long as they are used. Tracking would be almost impossible. Plastics are less clear in my mind. I would guess the auto industry may have to play the lead in reusing them to create an effective recycling infrastructure; therefore closed loop recycling may be more important.
- In 1994 more than 95 percent of all cars taken out of service were recycled. 100 percent of the ferrous content was recovered in the present open loop recovery system and sold back to steel mills.

Discussion

Panelists expect the recyclability/disposition of thermoplastics and thermosets to continue to present a significant challenge to the industry. The panelists expect closed loop recycling of thermosets to continue to present the biggest challenge of all listed alternatives. Conversely, the panel does not expect the recycling issues facing ferrous and nonferrous metals to present significant challenges.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement regarding the severity of the challenges facing thermoplastics and thermosets. However, there is some disagreement regarding ferrous and nonferrous metal.



Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII. The 1996 Delphi VIII panel is in general agreement with the Delphi VII panel with regard to the challenges facing thermoplastics, ferrous and nonferrous metals. However, the Delphi VIII panel views as somewhat more severe the recycling challenges facing thermosets than did the Delphi VII panel.

Strategic considerations

The final disposition of automotive plastics continues to present significant challenges to the industry. There are a few successful examples of reclaiming plastics from vehicles for reuse as the majority of plastics used in automobiles are landfilled in the form of automotive shredder residue (ASR). The 1996 Delphi VIII panel expects that there will be some form of federal regulation regarding automotive recycling in the coming decade (see MAT-7). In order to meet such regulation, the industry must move swiftly to resolve the challenges presented by recycling.

As one of the selected edited comments illustrates, much of the challenge facing plastics is economical rather than technical. Plastics recycling will not become viable until there is an economic incentive to develop an infrastructure and support technology. Until that happens, many plastics will continue to be viewed as unrecyclable.

Several comments also refer to the success of the ferrous metal recycling infrastructure. Two comments are of particular interest. First, approximately 100 percent of all ferrous metal used in the vehicle is currently recycled. Second, there is some uncertainty as to the applications of this recycled content. Until recently, class "A" steel surfaces contained no recycled steel; much of the steel recycled from cars and light trucks was used in open loop recycling (i.e., reuse for lesser applications). However, recent processing developments are now in place to close the loop for class "A" surfaces.

Nonferrous metals also have economically viable reclamation programs. An excellent example of this is aluminum. However, as alloy mixtures increase, it may reduce the success of current programs.

MAT-43. Relative to plastics usage in the next decade, how likely are the auto manufacturers to undertake each of the following actions?

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

Action	Mean Rating
Restrict the number of types of plastics in the vehicle	2.2
Pass-through recycling requirements to suppliers	2.4
Restrict the amount of economically unrecyclable plastics in the vehicle	2.4
Substitute lightweight metals for plastics	3.3
Restrict the amount of plastics in the vehicle	3.8

Selected edited comment

- The question is not what they'll attempt to do (undertake) but what they will be able to implement. Pass-through recycling is not likely to be successful. Automakers must accept responsibility for the product they integrate into their assembly sequence.

Discussion

Panelists expect manufacturers to take action restricting the number of plastics in a vehicle, restrict plastics viewed as uneconomical to recycle and pass through recycling requirements to suppliers. However, they see the substitution of lightweight metals for plastics and restriction of the amount of plastics as less likely.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1996 Delphi VIII panel and the 1994 Delphi VII panel are in general agreement.

Strategic considerations

Plastic is the material of choice for many automotive applications, and the panel expects it to remain a strong contender. However, the final disposition of plastics continues to present a challenge to the industry. All interested parties are diligently working to develop acceptable strategies. Several companies are developing requirements limiting the number of families of plastics per vehicle. The ability to have complete subassemblies made from the same family of plastics may allow for easier reclamation and recycling.

There continues to be a great deal of discussion about who is responsible for the recyclability of vehicles. Some suggest that, because their name is on the product, the manufacturers must assume final responsibility. Others believe that the material supplier should take responsibility. Although it is true that the manufacturers will be held accountable, we also see significant marketing potential for pro-active suppliers. System suppliers are attempting to create demand for their product by marketing directly to the final consumer. This may be a viable strategy for materials suppliers interested in becoming leaders in recycling.

MAT-44. What materials issues will present the most significant challenges or opportunities to the North American automotive industry in the coming decade? Please consider all aspects of the business, from concept design to manufacturing, use and disposal.

Challenges:

- Ability to continue product/application efforts in light of cost down pressure; changing political climate affecting regulations; lack of ability to understand "total value-in-use."
- Ability to lightweight the vehicle cost effectively (steel); lower material and manufacturing costs (aluminum and plastics); recyclability (plastics); long-term durability of composites.
- Achieving 10-year durability for vehicle interiors.
- Aluminum price volatility will continue to produce application resistance; thermosets and glass filled plastics will increase viability for recycling issues.
- Battery propulsion system that is commercially acceptable; tire disposal; chrome plating/disposal; cost-effective lightweight alternatives.
- Competitive vehicles from Japan and Europe usurp steel at low cost.
- Continued light-weighting with higher performance; repairability; processing and fabrication ease; disassembly and reuse.
- Cost (vehicles are becoming unaffordable); safety (becoming a much greater issue); fuel economy (still important).
- Cost vs. weight; weight vs. crashworthiness; cost reduction for composites.
- Cost; global standardization; developing multi-function capabilities for added value; recycling.
- Costs; processing; assembly at the plant.
- Design using "systems" approach to components using minimal types of plastics, minimizing number of parts in assemblies; ease of assembly and disassembly to initiate economic driver for recycling vehicle more thoroughly.
- Economic lightweight material applications; mass production of new concepts; consumer acceptance of change due to unfamiliarity of new product.
- Effective use of materials to up-integrate part function for cost reduction; develop an effective business structure for recycling the non-metal portion of the vehicle; effective use of material to reduce mass without significant downsizing of vehicle.
- Eliminating materials parochialism—all steel, all aluminum, and all composite proposals are ineffective and tunnel vision; setting up collection and distribution infrastructures for recycling all materials; eliminating hysteria, sales hype from the recycling programs and getting data.
- Government regulation, designer education.
- Insuring that supply and cost are world competitive. We are going to a world base of supply.
- Joining dissimilar materials; getting cost of magnesium down; developing infrastructure for recycling; more wear resistant materials—rotors, cylinders.
- Lightweighting; recycling; crashworthiness; mileage performance increase.
- Low cost!

- Lower mass and at same time increased safety and increased Q/R/D; substantial material changes/modifications will likely be needed to meet emission requirements. By 2010 recycling will be major factor and if disassembly of vehicles is not in place, the use of plastics could drop dramatically.
- Make an appealing car that the customer can afford that meets all safety, fuel economy, and air quality requirements.
- Offsetting cost driven by CAFE or EPA regulation.
- Paint emissions; painted plastic recycling; end of life automotive fluids.
- Processing cost reduction for aerospace materials (i.e., casting cost reduction, powder forming cost reduction, machining improvement and cost reduction).
- Purchasing decisions drive short-term actions/supply changes; lack of materials knowledge in all phases of auto design cycle; lack of consistent materials strategy at OEMs; threat of legislation on recycle content.
- Recycle methods; adequate financial return to justify investment in technology and equipment for the supply chain.
- Recycling of nonmetallic; lightweighting exterior body structure economically; electric vehicle battery technology.
- Recycling; judicious selections, designing to the material. The materials engineer must have a position in the auto organizations on par with the product and other top design and development managers.
- Reducing cost of the vehicle while maintaining the ability to meet quality, durability, weight and recycling objectives.
- Reducing product cost; recycling; reducing development time line.
- Reduction in weight for fuel economy and emissions while maintaining durability, safety and cost.
- Set up thermoplastic recycling infrastructure and thermoset incineration infrastructure; engineering and life cycle understanding of thermoset composite structures; bonding/joining dissimilar materials.
- The value of the scrap vehicles must be higher to drive processing and recycling.
- To develop electric vehicles that are acceptable to the consumer—batteries; lightweight materials that can withstand the operating environment; recyclable plastics.
- Trying to balance short-term cost pressures versus the need to introduce new technologies that aid weight and environmental issues.
- Utilizing the same material in the same part (recycled); improved safety; cost reduction.
- Vehicle cost reduction; quality perceptions and performance with plastic body vehicles; energy absorbing composite structures.

Opportunities:

- All materials suppliers have opportunities to help solve the above challenge problems by improving performance and application.
- Application of sophisticated design and test techniques to optimize component and structures.
- Ceramics; titanium-aluminide/titanium; aluminum; plastics.

- Coatings for lightweight metals for wear and heat resistance; die wear extensions for "plastic" ferrous deformation; development of powder metal and material matrix composites to reduce machining and increase tensile strength.
- Combining materials and processes to provide the most economical low mass solutions for meeting vehicle/company/customer needs; using the current fleet as a source of raw materials for 2005 and beyond programs; including the total process of getting raw material into a usable form, using it and recycling it. (For example, why is steel considered economically recyclable when the industry has contaminated Lake Superior with taconite tailings and all our harbors and lakes with steel plant toxins which the taxpayers are paying to clean up?)
- Development of stronger, more reliable adhesives; metal monolith converters—clean air; lighter rotors - aluminum, composite; aluminum engines, composite liners.
- Eliminate corrosion as cause of vehicle death; lighter, more fuel efficient cars; superior safety through new frames containing new materials.
- Ever increasing need for weight reduction.
- Forming and manufacturing methods such as hydroforming that can produce lightweight steel parts at rapid production rates; laminate products with high stiffness/insight ratio; adhesive bonding (assume 100 percent reliability of structural parts); expand strength.
- Growth for plastic composites, particularly thermoplastic; growing use of high performance, monolithic sheet such as biaxially oriented thermoplastic sheet.
- High quality, improved durability and reliability while using lighter weight, lower cost materials. Select materials which minimize impact on environment (cradle to grave).
- If Daimler-Benz goes to ceramic valves starting in 1997-1998, by 2000 there will be intense interest in this component in North America. New forming technologies for simpler construction.
- Increase of lightweight metals usage; advanced forming methods; metal matrix composites.
- Increased usage of lightweight materials.
- Innovative holistic designs using low-cost materials; design for cost-effective recycling; concurrent (simultaneous) engineering.
- Lightweight reciprocating components for internal engine friction reduction; faster light off times for catalyst with low thermal inertia; exhaust systems and higher temperature capable substrates.
- Lower cost metal processes; ingenuity in plastics reuse and separation.
- Lower weight; consolidation (value added operations).
- Market/advertise rewards for company that can attack successfully the above challenges.
- Math modeling or simulation on computer of sheet forming, SMC mold flow, or casting processes.
- Most weight/cost benefits of plastic still untapped.
- Plastics: improved timing to bring new products to market; lower costs; lower energy to make materials and to fabricate parts. Great possibilities for new composites and greater possibilities for metal/plastic composites. Most of the technologies exist. They must be shepherded intelligently to bring into general use.
- Reduce the complexity of polymeric materials on a global basis.
- Simplify the body structure with part consolidation and lightweight materials.

- The opportunities for increased usage's of aluminum in tomorrow's vehicles contribute in all areas including concept design to manufacturing and disposal. A holistic approach to the application of aluminum in automotives will produce cost-effective, structurally efficient, lightweight and recyclable vehicles.
- Tooling cost reduction with plastics; weight reduction/improved performance with plastics; low-cost niche vehicles with plastic bodies; low-cost entry level vehicles in Third World with plastic body vehicles.
- Weight reduction, parts consolidation.
- Weight reduction.

Discussion

The panel has listed many opportunities and challenges for the industry. Comments regarding recyclablity and cost reduction were most frequently given as challenges. The use of light weight materials, specifically plastics and aluminum were the most common opportunities given.

Manufacturer/supplier comparison

These comparisons are not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi survey.

Strategic considerations

Again, as with all of the open-ended questions, the breadth of response is significant—if not unexpected. The automobile industry faces many challenges, most of which affect the material selection process. The panelists list many significant challenges and opportunities that may be of critical importance to future material trends.

The most frequently mentioned challenge is recycling. Manufacturers are becoming increasingly aware of the difficulty in recycling automotive plastics. Technically, all plastics are recyclable, but the development of a cost-effective plastics recovery/recycling infrastructure appears to be a difficult long-term challenge (MAT-41). A viable solution to the recyclability of automotive plastics may be critical to the inclusion of plastics in future vehicle programs.

The industry continues to attempt to balance the desire to reduce vehicle weight through the use of higher-cost light weight materials and the need to maintain affordability. Total vehicle weight has been increasing in recent years with much of this weight increase due to increased safety, emissions and convenience accessories. Manufacturers have to some extent offset this added weight by increasingly using lighter materials. However, the increased vehicle cost due to more government and customer driven accessories has led to affordability concerns that may limit the ability to incorporate higher cost lightweight materials into future programs.

DEFINITIONS

FOREIGN NAMEPLATES Refers to all non-U.S.-headquartered vehicle manufacturers or dealership networks regardless of production location (i.e., Honda's U.S. production should be combined with it's import vehicles).

LIGHT TRUCK Includes sport utilities, vans and pickup vehicles.

NORTH AMERICAN-PRODUCED PASSENGER CARS AND LIGHT TRUCKS Refers to all vehicles produced in the United States and Canada.

TRADITIONAL DOMESTIC OR BIG THREE Refers to all U.S.-headquartered (parent company) manufacturers or dealership networks regardless of production location (i.e., forecast for General Motors should include NUMMI-produced Prizms and imported Metros).

QUALITY/RELIABILITY/DURABILITY (QRD) Encompasses any customer dissatisfaction for which a vehicle is taken back to the dealership.

Note: "year" refers to Model Year unless otherwise specified.

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KEY WORD INDEX

Key Words	Question Number		
	Materials	Technology	Marketing
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Efficiency, stiffness	-	-	-
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Key Words	Question Number		
	Materials	Technology	Marketing
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Lean burn	-	63	-
Lean NOx trap	-	65	-
Legislation	3,4,6,7,32,38,44	13,14,15,16,43	6,9
Lift control	-	60	-
Lightweight materials	5,9,12,15,17,18,20,22, 23,28,29,32,33,34,36, 40,43,44	-	-
Lithium-polymer	-	35	-

Key Words	Question Number		
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Loans	-	-	15,16,17
Magnesium	5,10,12,13,15,17,18, 22,28,33,36,40,41,44	-	-
Maintenance	-	-	23
Manufacturing	5,7,8,22,23,26,28-32, 35,38,41,44	-	1,5
Market segments	-	-	13,32
Market share	-	-	32,33
Market structure	-	-	4
Materials	-	10,43	-
Materials change	-	38	-
Message system	-	51	-
Metal matrix composite	21b,22,35,40,44	-	-
Metal substrate	-	64	-
Miller cycle	-	34	-
Modle niches	-	-	8
Motors, electric	-	79,80	-
Multiplexed	-	74,75	-
Nameplate offerings	-	-	4
Natural gas	4	11,12	42
Navigation	-	51	-
Nickel-cadmium	-	35	-
Nickel-hydride	-	35	-
Nodular iron	35	-	-
Noise cancellation	-	81	-
NOx catalyst	-	63	-
Nylon	16,18	-	-
Occupant restraint	-	14,15	-
Oil pan	17,22	67	-
Outsourcing	-	-	54
Owner loyalty	-	-	22
Ownership	-	-	19,26,35
Paint	9,18,27,31,38-40,44	-	-
Particulate controls	-	65	-
Parts	-	23,24	-
PC/PBT	16	-	-
Performance	28,40,44	20	-
Phenolic	16	-	-
Piston	18,22,23,28,35	67,68	-
PNGV (Partnership for a New Generation Vehicle)	-	7,8,9,10	-
Political trends	-	-	1
Polycarbonate	16,34	-	-
Plastic/composite	5,7,9,15,16,18,19,22, 25-28,30-36,39-44	38,39,40,67	-
Platforms	5,29	19	29
Polyester elastomer	16	-	-
Polyester thermoplastic	16	-	-
Polyester thermoset	15,16	-	-

Key Words	Question Number		
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Polyethylene	16	-	-
Polymer based	-	38,67	-
Polypropylene	15,16,18,19,40	-	-
Polyurea	16	-	-
Powdered metal	15,21b,22,24	38,62	-
Powertrain material applications	5,10,12,18,24,28	-	-
PPO/nylon	16	-	-
PPO/styrene	16	-	-
Prices	11	-	13,14,25
Procurement	-	-	55
Product design	-	21,22	-
Product liability	6	14,15	-
Production, volumes	-	-	5,36,37,38
Production development	-	-	27a,b,28
Production process	-	10	-
Propane	4	11,12	-
Push rod	-	55,62	-
PVC	16,40	-	-
QRD	28,31,40	20,37	-
Quality		-	23
Recyclability	5,7,8,16,31,40-44	43	49
Redesign	12,20	56	29,30
Reformulated gasoline	2	-	-
Regionalization	-	14,16	-
Regulation	3,5-8,16,35,38,42,44	13,14,15,16,17,43	6,9
Repair	9	-	19,21,22
Research consortia	-	-	7
Retail prices	-	-	13
Retail sales	-	-	18,30,31
Ride and handling	-	20	-
Ride/handling	-	47	-
Roller lifters	-	62	-
Rolling/resistance	-	4,9	-
Rubber	15	-	-
Safety	5,6,8,28,31,33,36,40, 44	20	7,24,25
Sales	-	-	2,5,18,30,32,33,34
Sales personnel	-	-	19,22
Sales procedures	-	-	19,22
Seals	23	68	-
Selection criteria materials	8,22	-	-
Selling	-	-	18,19
Service	19,28	83	-
Sharing	-	19	-
Skills	-	84,85	-
SMA	16	-	-
Social factors	-	-	2
Spark plugs	-	59	-
Springs	33	46	-

Key Words	Question Number		
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Stainless Steel	22,27	-	-
Standardization	-	32	7
Standards	-	14,15	-
Start-up catalyst	-	64	-
Steel	5,8,9,15,16,18,29,31, 32,33,35,36,41,42	38,39,40	-
Steering	17-19,40	47,80	-
Strategic planning	-	-	1
Stratified charge	-	34	-
Styling	-	-	22,29,30,52a,b
Sub-assemblies	-	23,24,25	-
Supercharged/ Super-charger	-	58,4	-
Suppliers	-	-	53-57
Suspension	5,15,18,20,33,40	46	43,48
Systems engineering	-	33	-
Taxes	1	1,12	9
Technology leadership	-	30	-
Thermoplastic	9,15,18,31,32,33, 40-42,44	-	-
Thermoset	9,15,16,18,31,32,42,44	-	-
Tires	7,15,20	4,9,49	51
Titanium	18,40	-	-
Toll collection	-	51	-
Tooling	5,9,25,31,40	26	-
Torte liability	-	17	-
TPO	8,15,16,40	-	-
Traction control	-	48	44,48
Trade	-	17	39,40,41
Transaction prices	-	-	14
Transmission	17-19,24,25,28	4,72,69	-
Transverse	-	70	-
Trends	-	-	1,2
Truck attributes	-	-	11,12,25
Turbocharger	23	4,58	-
Two-stroke engine	-	34	-
Urethane	16,18,37,40	-	-
Value of 1 mpg improve-ment	14	6	-
Value of pound saved	13	42	-
Valve covers	18	67	-
Valves per cylinder	-	54	-
Valvetrain	23,24	55,60,68	-
Vehicle attributes	-	-	10-12,25,48
Vehicle demand	-	-	2,31
Vehicle features	-	-	50
Vehicle integrity	-	14,15	-
Vehicle production	-	-	5
Vehicle servicing	-	83	19,21,23
Vehicle use	-	-	26

Key Words	Question Number		
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Vinylester TS	16	-	-
Voice activated	-	77	-
Voltage, system	-	78	-
Water pump	-	80	-
Weight reduction/weight	5,7-9,12-14,16,18,40, 44	4,5,9,41,42	-
Wheels	17,18,33,36	-	51
Wrist pins	-	68	-
Zinc	15,18,41	-	-

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