Delphi IX Forecast and Analysis
of the
North American Automotive Industry

VOLUME 3: MATERIALS

June, 1998

Published by

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

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Printed in the United States of America.
First edition published 1998. UMTRI-98-12-3.

ACKNOWLEDGMENTS

The authors wish to acknowledge the many team members whose efforts contributed to the completion of this report. Robert Andrei, with guidance from Bruce Belzowski, acted as project manager. Wendy Barhydt handled coordination for the Technology volume, and manuscript review for all three volumes. Betsy Folks provided data base support. Tina Jeminez and Cathy Rowe contributed essential graphics design and desktop publishing skills to the Technology and Marketing volumes, respectively; their efforts are greatly appreciated. Karen Shears provided secretarial support to the project manager. Bernard Swiecki provided the seemingly thankless, but ever so important, hours of baseline data gathering.

Diana Douglass contributed outstanding coordination, graphics design, and desktop publishing skills for the Materials volume. Diana also lent her expertise to the Technology and Marketing volumes to assure formatting and design consistency. Her patience, determination and skills added greatly to the overall quality of the Delphi IX, for which the team is appreciative.

The Delphi team would also like to acknowledge the efforts of our panelists who spent untold thoughtful, reflective and—we are sure—sometimes frustrating hours completing our detailed questionnaires. Finally, we would like to thank our initial financial supporters in the Delphi process—OSAT affiliates and Delphi IX subscribers. These companies are listed on the following pages.

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CORPORATE ACKNOWLEDGMENTS

The Office for the Study of Automotive Transportation (OSAT) would like to thank its Affiliates and Delphi IX subscribers for their generous support of this project. Our Affiliates provide annual, unencumbered funding for initiating nonfunded work and public service activities. Delphi IX subscribers contributed directly to this project by covering substantial start-up costs and suggesting potential questions and panelists. This project could not have been structured, initiated, or completed without their support.

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FOREWORD

Delphi IX 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 ninth 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, Delphi VII in 1994 and Delphi VIII in 1996.

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 IX 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 266 panel members are as follows: 21 percent of the Technology Panel was composed of CEOs, presidents, or vice presidents; 18 percent were directors; 37 percent were executives, managers or supervisors; 16 percent were engineers (chief, assistant chief and staff); and 8 percent of the panel was made up of academic specialists and consulting technical-engineering specialists. The Marketing Panel was composed of 33 percent CEOs, presidents, or vice-presidents; 30 percent directors; 29 percent managers; and 8 percent academic and consulting marketing specialists. Among Materials panelists, 6 percent were CEOs, presidents and vice presidents; 26 percent were directors; 41 percent managers and supervisors; 16 percent engineering specialists; and 11 percent academic and consulting materials specialists. Approximately 29 percent of the Delphi IX panelists were employed by vehicle manufactures; 63 percent by components and parts suppliers; and 3 percent were others (i.e. 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 IX 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 Manufacturers (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 IX 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.

MATERIALS CONTENTS

PAGE

ACKNOWLEDGMENTS iii

FOREWORD v

Introduction v

The Delphi method: general background v

Process v

Panel characteristics and composition vi

Presentation of Delphi Forecasts and Analysis vii

EXECUTIVE SUMMARY 1

I. STRATEGIC PLANNING FACTORS

1. Fuel prices, U.S. retail per gallon 7
2. Fuel prices, percent of increase due to taxes 10
3. Reformulated gasoline sales 12
4. Alternative fuels, federal legislation 14
5. Alternative fuels, North American-produced passenger vehicles 16
6. Electric vehicles, materials challenges 19
7. PNGV, materials challenges 25
8. Federal regulatory and legislative activity 31

II. STRATEGIC MATERIALS CONSIDERATION

9. Materials issues; new regulations/legislation 35
10. Recycling, regulatory areas of interest 38
11. Materials issues, decision criteria 42
12. Material selection, long-term strategic considerations 44
13. Material selection, departmental influence 51
14. Materials issues, challenges and opportunities 53

III. TOTAL VEHICLE

15. Corrosion issues, cosmetic and perforation corrosion 61
16. Corrosion issues, panel penetration corrosive environments 64
17. Total vehicle weight, percent change 66
18. Materials value, per pound of weight saved 69

19 Materials value, improved fuel economy by 1 mpg 72

20. Material cost savings in the next decade 75
21 Material issues, weight reduction, government regulations and recyclability 81
22. Material, percent change by type 86
23. Plastics, percent change by type 91
24. Magnesium, applications 94
25. Emerging materials, technologies, and applications 96
26. Automotive fluids, emerging developments 102

IV. POWERTRAIN/DRIVETRAIN

27. Engine head and engine-block materials 105
28. Aluminum engine-block sleeve technology 108
29. Aluminum engine-block sleeve materials 109
30. Engine components, material applications 110
31. Ceramics, engine component applications 116
32. Powdered materials, engine component application 118
33. Engine oil cooler, heater cores, radiator, transmission oil coolers 120
34. Fuel tank materials, gasoline fueled passenger cars and light trucks 122

V. BODY/CHASSIS

35. Vehicle frame construction type 125
36. Vehicle frame construction, material 128
37. Structure composites, challenges for increase usage 130
38. Body components, material 133
39. Body panels, specified stages of life cycle 137
40. Bumper components, material application 141
41. Interior components, material application 144
42. Chassis/suspension components, material application 149
43. Glass, alternative materials 152
44. Brake components, material application 154
45. Styled wheels, material application 157
46. Adhesive body joining technologies, barriers 159
47. Automotive paint technologies, penetration rates 162
48. Automotive paint oven, temperature 165
49. Customer satisfaction, body, and chassis materials improvements 167

VI. RECYCLING

50. Recycling barriers 175
51. Significant recycling barriers, actions 178
52. Methods to recycling, challenges 182
53. Manufacturer actions regarding recycling 185

DEFINITIONS 187

KEY WORD INDEX 189

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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 IX 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 IX 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 1998 Delphi IX Materials volume.

I. STRATEGIC PLANNING FACTORS

During the next decade, panelists forecast fuel prices for regular and premium to increase annually at a rate of 4.3 percent and 3.5 percent respectively. This forecast increase for regular and premium gasoline over the coming decade indicates the panel does not suggest any significant supply disruptions (MAT-1). Approximately 50 percent of the forecasted increase will be attributable to increased gasoline taxes (MAT-2).

The panel views it as likely there will be federal legislation requiring alternate fuels by 2007 (MAT-4). However, they expect the internal combustion engine to continue to be the dominant power source for the coming decade (MAT-5). The United Nations Convention on the World Climate in Kyoto, Japan has established targets for the reduction of carbon dioxide gases by 2010. This agreement will likely have significant impact on the global automotive industry. To assist in meeting these targets, the federal government will likely attempt to enact stricter fuel economy and emissions standards. It is also possible that, as a part of an attempt to reduce carbon dioxide gases, the government will choose to expand legislation regarding the use of alternate fueled vehicles. However, before new alternate fuel laws are implemented, cost, safety, and technological issues must be resolved.

The development of an effective electric vehicle presents many significant challenges for the automobile industry. The critical challenges most frequently mentioned by the panelists include the advancement of battery technology and the application of lightweight materials within the cost and performance standards established by the internal combustion engine (MAT-6).

The panel lists a vast array of challenges and opportunities faced in the development of a vehicle to meet the goals of the Partnership for a New Generation of Vehicles (PNGV) (MAT-7). In many regards, the material requirements to meet these goals are viable. Unfortunately, the ability to meet the material challenges, while remaining within the cost constraints, is not yet an achievable goal.

A new materials paradigm will likely be necessary for the industry to meet the goals of the PNGV. Current manufacturing and design strategies may not allow for the level of change necessary to meet the mass reduction requirements implied by the PNGV goals. The ability to deliver a vehicle capable of 80 miles per gallon may require all stakeholders to re-evaluate the materials and process currently used. Such a paradigm shift would be costly and potentially painful, especially in such a relatively short time period.

The panel forecasts federal regulation and legislation to become increasingly restrictive in the coming decade (MAT-8). The industry and government are at a critical juncture with regard to environmental regulation/legislation. The possibility of regional, national, and even international environmental regulation will present a continuing challenge for the industry.

II. STRATEGIC MATERIALS CONSIDERATION

The panel forecasts an increasing likelihood of legislative and regulatory activity by the federal government regarding the recyclability of the automobile. In view of the expected regulatory activity, manufacturers will likely need to re-evaluate their material selection process and make adjustments to allow for a greater emphasis on the final disposition of their vehicles (MAT10).

The cost of materials and processing is expected to be the most critical material selection criteria in the coming decade. Weight, safety considerations, cost of warranty, field experience, and design styling requirements are also expected to be critical elements of the material selection process (MAT-11).

The panelists most frequently list cost as the most critical long-term strategic consideration with regard to material selection. They also indicate that increased engineering requirements, manufacturability, environmental issues, and recyclability will also be important long-term strategic challenges (MAT-12).

The panel lists a wide array of material-related issues that will present opportunities and challenges in the coming decade. The responses can be placed into four general categories: cost reduction, design, environmental, and manufacturing. Throughout the Materials volume it is apparent that cost is a very important issue in material selection. However, it would be misleading to suggest that cost is the only important factor. To remain competitive in the coming decade, participants in the North American automotive industry must continue to develop efficient design, manufacturing, and environmental strategies that allow for cost-effective solutions (MAT-14).

III. TOTAL VEHICLE

Although the panel forecasts an increase in length of time before panel perforation, there appears to be little incentive to increase the current six year, 60,000 mile corrosion warranty. Effective long-term corrosion protection is dependent on a thorough systems approach. According to several comments, technology is available to increase the length of time before panel perforation; however, manufacturers must weigh the benefits of longer lasting panels with the associated costs (MAT-16).

Panelists forecast vehicle weight to decrease by 2 percent by 2002 and 5 percent by 2007. Government regulation is the most significant driver of vehicle weight reduction. The implementation of more stringent regulation would likely lead to an increased effort to reduce mass. If recently announced carbon dioxide reduction goals are to be met by internal combustion engines, the automotive industry will likely aggressively pursue lightweight materials. In light of these goals, the forecast of a 5 percent reduction by 2007 may be somewhat conservative (MAT-17).

The panelists indicate that North American automotive industry participants are increasingly viewing the automobile as a complete system and not merely a compilation of individual parts. Panelists comments also indicate that material selection and the competition between materials is more intense than ever—and is likely to get even more so in the coming decade (MAT-21).

The automotive industry is expected to continue the trend to lightweight materials in the coming decade. Increased penetration of lightweight materials will come at the expense of traditional materials such as low carbon steel, cast iron, copper and zinc (MAT-22).

Panelists forecast substantial growth for polypropylene, TPO, nylon, polyester thermoplastic, and polyethylene. The panel also forecasts significant decrease in usage for ABS, PVC, and urethane (MAT-23).

IV. POWERTRAIN/DRIVETRAIN

Panelists forecast 95 percent of cylinder heads and 50 percent of engine blocks for passenger cars will be made from aluminum by 2007. Panelists forecast 60 percent of cylinder heads and 25 percent of engine blocks for light trucks will be made from aluminum by 2007 (MAT-27).

The panel forecasts a continued trend toward lightweight materials for engine applications. The automotive industry has, for several years, been increasingly substituting lightweight materials for cast iron and steel in engine applications. As components made from alternative materials approach manufacturing scale economies, these materials may rapidly become the industry standard. Also, for many of the listed components, North American manufacturers may be behind offshore companies in converting to lightweight materials for the listed engine components (MAT-30).

Panelists forecast aluminum to further increase penetration in engine oil coolers, heater cores, radiators and transmission oil coolers. Panelists expect aluminum to have higher penetration rates in passenger cars than light trucks for engine oil coolers, heater cores, and radiators. The panel does not forecast plastics to be used in any of the listed components in the near future (MAT-33).

V. BODY/CHASSIS

In the coming decade, the integral, or unibody, frame construction will continue to be the dominant frame design for the North American passenger car industry. The panel also expects an increased number of sport utility vehicles to be built using unibody design (MAT-35).

Steel will likely continue to be the predominant material for all types of frame construction in the coming decade. Although steel suffers from a weight disadvantage vis-à-vis aluminum, it provides a significant cost advantage. Steel also benefits from having been the material of choice for nearly a century. The combination of a cost advantage and a high comfort level places steel in a very strong position (MAT-36).

The use of composites for structural applications presents many potential advantages and, at least currently, even more challenges. Composites offer the opportunity to significantly reduce weight while increasing design flexibility and eliminating corrosion. However, the panel indicates that there are numerous barriers to the implementation of structural composites. Cost, recyclability, crashworthiness/safety, bonding/joining, and manufacturability all appear to be very significant barriers. It is important to note that breakthroughs in one or two of these areas will not necessarily guarantee the increased application of composites for structural applications (MAT-37).

During the next decade steel usage for exterior body panels is forecast to decline only slightly. The panelists indicate that steel will likely remain the material of choice for all horizontal and vertical body panels. Manufacturers and suppliers have worked diligently to develop competitive manufacturing processes for alternative materials with varied success (MAT-38).

Steel is viewed as having an advantage over aluminum, thermoplastic and thermosets in the raw material cost, component processing, assembly, and vehicle disposal stages of the vehicle life cycle. The panel rates thermoplastics as slightly more advantageous than the other listed materials in the design stage, and thermoplastics, thermosets and steel as equally advantageous in the field-use stage (MAT-39).

Thermoplastic is forecast to increasingly become the material of choice for bumper/fascia. Thermoplastic gains are expected to be at the expense of thermosets for passenger cars, and steel for trucks. It is possible that much of the forecast increase in thermoplastic bumper fascias for light trucks may be due to the expected increase in the number of small sport-utility vehicle programs. Many of these vehicles are built from passenger car platforms, and therefore are more likely to use passenger car bumper systems (MAT-40).

The panel forecast decreased application of steel and increased application of lightweight alternatives for seat frames and instrument panel cross beams. They also forecast increased effort to develop the listed plastic components from similar plastic families (MAT-41). Plastic has created many opportunities to reduce weight, improve safety, and simplify component design and assembly for interior components. The need to increase commonality of materials for recycling purposes has led to increased interest in designing groups of components with similar materials. Weight reduction will also continue to drive interior component material selection. Steel is forecast to decline in usage at the expense of lighter weight materials.

The panel forecasts little change in material for most suspension components. Control arms and steering knuckles are expected to see the increased penetration of aluminum. The panel also forecasts the increased application of aluminum for light truck drive shafts and differential carriers (MAT-42).

The panel forecasts little or no application of polycarbonate as an alternative window material by 2002. The panel forecasts only small penetration rates for polycarbonate in side or rear window applications by 2007. They expect no use of polycarbonate for windshields in the coming decade. Special coatings and interlayers are expected to see increased usage through the forecast period (MAT-43).

VI. RECYCLING

Panelists see no significant barriers to recycling ferrous and nonferrous metals. However, with regard to plastics, the panelists view economics, ease of material separation, infrastructure, and value of reclaimed material as significant challenges (MAT-50). The panelists' comments suggest significant concern over the economic viability of automotive recycling, and more specifically, the development of an economically viable recovery and reuse technique for plastics (MAT-51).

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; however, the majority of plastics used in automobiles are landfilled in the form of automotive shredder residue (ASR). According to the panel, the degree of severity for the recycling of plastics depends on the method, material, and ultimate use of the material. Thermosets continue to be viewed as difficult to recycle—either via a closed loop or open loop method. Thermoplastics are viewed as a somewhat less severe challenge, yet still present significant barriers to the implementation of viable recycling programs (MAT-52).

Conclusion

The *Delphi IX Forecast and Analysis of the North American Automotive Industry: Materials Volume* has presents many challenges and opportunities for the industry. The materials panel has presented several factors that will likely drive the material selection process for the coming decade.

Panelists have stated that, in no uncertain terms, cost reduction will play a critical role, yet weight reduction will increasingly become a key element in the selection process.

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MAT-1. **Please estimate U.S. retail fuel prices per gallon for 2002 and 2007, including fuel tax. (Please use constant 1997 dollars without adjusting for inflation).**

Unleaded Gasoline	Est. 1996*	Median Response		Interquartile Range	
		2002	2007	2002	2007
Unleaded regular	$1.23	$1.48	$1.75	$1.40/1.50	$1.56/1.95
Unleaded premium	$1.41	1.65	1.90	1.55/1.75	1.71/2.18

*Source: US Energy Information Administration, National Average Jan. - Oct. 1996

Selected edited comments

- After 2000, increasing global energy use will start to put pressure on supply, and the price of crude will go up.
- By 2007, developing economies will be using more energy. This increased demand will increase the price.
- Demand and supply balance will be maintained during this time span by partly offsetting the increase of vehicle population with the improvement of fuel efficiency of the fleet. Price differences between regular and premium may become wider with expansion of the use of phase 2 reformulated gasolines.
- Energy reserves and refining capacity remain abundant, yet a political crisis/source disruption is inevitable, as will be the impact of environmentalists on Congress to extract a toll to encourage higher fuel efficiency.
- Expect federal and state taxes to increase for road maintenance and budget expenses.
- Fuel prices will remain constant (except for somewhat higher taxes) to pay for infrastructure and the cost of increased usage of reformulated gasoline.
- Global demand for energy will squeeze supply in the next 10 years.
- I agree with the following: Fuel prices will continue to rise (more people, more cars, more fuel needed) unless there is a dramatic increase in miles per gallon by those high-volume vehicles (i.e. light truck and mid-size cars). And, taxes will account for the majority of the increase.
- I am assuming there will be no major crisis in any of the major oil-producing countries.
- I do not anticipate a surge of fuel prices, just a steady increase in line with the consumer price index. Introduction of alternative energy vehicles, such as electric vehicles, compressed natural gas, liquid petroleum gas, and hybrid vehicles might work as a barrier against large increases in the price of gasoline.
- I do not believe alternate fuels will have any effect on the price of gasoline in a time span as short as 2010.
- I still expect state taxes (possibly federal taxes) to rise to address road and infrastructure repairs.
- Increased fuel economy standards for light truck/SUV will drive improved mileage, and therefore, less consumption. The only uncertainty would be federal and state gas tax increases and market impact.

- Increased taxes plus the use of more energy by the third world will cause significant increases in gasoline prices.
- New fuel deposits may be discovered in China. Increased consumer demand may be partially offset by better efficiency.
- New oil production in Russia will help keep competition high and prices down. New fuel economy standards will help with gasoline consumption and high-test premium needs will be reduced.
- OEMs will probably require fewer vehicles to use premium gas by 2007.
- Prices will continue to rise due to increasing global demand and a lack of ability to effectively control OPEC. Alternative technology won't be cost effective soon enough to put pressure on prices. Taxes for EPA reasons will drive prices up and force use of smaller cars.
- Taxes will account for the majority of the increase.
- Taxes will rise, with that money earmarked for road repair and improvement.
- The answer assumes no engine technology breakthrough to reduce/eliminate emissions. Taxes will raise the price of gasoline to combat "greenhouse" CO_2 emissions.
- The next ten years will see rising global demand and potential disruptions, as well as higher taxes.
- The spread in gasoline grades will increase as an alternative to an increase in gas-guzzler penalties.
- World crude production should keep up with demand during this period. Any crude price rise will be due to a political disruption. Taxes will rise to build and repair roads and, later, to fund increasing expenditures.

Discussion

During the next decade, panelists forecast prices for regular and premium fuel to increase annually at a rate of 4.3 percent and 3.5 percent respectively.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH 1a and MKT-3a

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

Trend from previous Delphi surveys

The 1998 Delphi IX panel forecasts a slightly larger increase in gasoline prices than did the 1996 Delphi VIII panel. The Delphi IX panels forecast is consistent with the 1992 Delphi VI and 1994 Delphi VII forecasts.

Strategic considerations

The forecast of 4.3 percent and 3.5 percent annual price increase for regular and premium gasoline over the coming decade indicates the panel does not expect significant supply disruption. However, the panel expects increased fuel taxes to affect the price of gasoline (MAT-2).

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 is occasionally 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 events of the early 1980s, the Delphi forecast seemed very reasonable. The challenge for the Delphi reader is to review these results and analyze external factors to determine the validity of the panelists' forecasts.

During the next decade, the energy requirements of developing nations are expected to increase significantly. The panel's forecast suggests that the increased demand will only marginally affect gasoline prices in the United States.

It is not yet clear how the recent global environmental agreement will affect gasoline prices. Even if the various governments do not ratify the agreement, it has set the tone for carbon dioxide reduction in the coming decade and will likely have an impact on the price of gasoline throughout the world.

MAT-2. What percent of the change forecast in MAT-1 will be attributed to state and federal taxes?

	Median Response		Interquartile Range	
	2002	2007	2002	2007
Percent Change Attributed to Taxes	50%	50%	34/50%	41/54%

Selected edited comments

- Although probably still unpalatable in 2002, by 2007 using gas tax to drive vehicle weight/efficiency issues will be accepted strategy.
- Despite the inefficiencies and unintended consequences involved, Congress will continue to indirectly tax (unfunded mandates to automakers, e.g., CAFE) car buyers rather than directly taxing fuel buyers (e.g. gasoline tax) in their misguided attempts to discourage fuel consumption.
- Gasoline taxes will increasingly become a viable alternative source of tax revenues for state and federal governments.
- Government will finally wake up to the fact that increased gas prices through taxation are key to pushing fuel economy.
- Government will lack the courage to increase gasoline taxes.
- If we consider the possible introduction of the so-called CO_2 Tax, a 5 to 10 percent addition of federal tax could be expected around 2002.
- No tax increase is thinkable under the current economic growth rate and time span through year 2002, but as far as 2007 is concerned (with some agreement at COP3) a marginal tax increase might be possible to suppress the fuel consumption.
- Taxation of fuel will include elements of carbon tax, usage tax and "penalty" tax for usage.
- Taxes in 2002 will be similar to today, but I expect an increase of 5 percent by 2007.
- Taxes will be the principal driver of higher fuel costs.
- The Big Three will finally "convince" the government to raise fuel taxes instead of raising CAFE.
- The cost should remain constant, as new available crude will come from Kazakhstan and the North Sea. Distillation costs will remain same.
- There is strong public sentiment that fuel tax increases are regressive and work hardships on the average consumer. This, plus the efforts of the American Trucking Associations, will keep Congress away from significant changes.
- With the deterioration of our road systems in the north and the increase in the population of southern states, there will be an increase in the fuel tax. This increase in tax will supply the needed funds for repair in the north and road construction in the south.

Discussion

Panelists expect that 50 percent of the forecasted change in gasoline prices (MAT-1) will be attributable to increased taxes.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-1b and MKT-3b

Responses from materials panelists are not statistically significantly different from technology panelists. There is a statistically significant difference in responses between technology and marketing panelists. Mean responses for the two panels are summarized in the following table.

Percent Change Attributed to Taxes		
	TECH	MKT
2002	47%	36%
2007	53	42

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

The panelists' forecast for MAT-1 and MAT-2 indicate that the panel believes the supply of oil will remain relatively stable in the coming decade. Based on the forecast in MAT-1, the panelists expect a 2.2 percent and 1.7 percent annual increase in regular and premium gasoline prices respectively before taxes and inflation. Given the trend in recent years for steady and even falling gasoline prices, the panels' forecast for minimal price increases is understandable.

However, there is potential for supply disruptions that may adversely affect that forecast. Developing nations are rapidly increasing their usage of oil. This increased global demand may exacerbate any future supply shocks. Also, recent agreements to reduce gases that are believed to cause global warming may lead to federal restrictions on gasoline consumption. Although significantly higher gasoline taxes are politically difficult to implement, it is likely that there will be pressure to increase gasoline taxes or raise the corporate average fuel economy in the coming decade. Either of these actions will have an affect on the MAT-1 and MAT-2 forecasts.

MAT-3. **What percentage of 2002 and 2007 U.S. gasoline sales, in gallons, will be reformulated in accordance with 1990 Clean Air Act Amendments Requirements?**

		Median Response		Interquartile Range	
	1996*	2002	2007	2002	2007
Reformulated Gasoline	25%	35%	50%	30/40%	35/60%

* Source: U.S. Energy Information Administration
(Estimate excludes area of California outside of Sacramento, San Diego, and Los Angeles)

Selected edited comments

- Any nonattaining region will mandate reformulated gasoline at an early stage because that is an effective and promising approach.
- As long as the costs are containable, refineries set up to produce reformulated gas will sell it in areas where it is not mandated, as well as in the areas where it is.
- Consumers already use reformulated gasoline and likely do not even know it. The EPA seems clear on its intent. Lower level pollution of the atmosphere is increasing and governments are likely to respond with counter measures.
- Consumers will resist reformulated gasoline.
- Designated nonattainment areas will shortly double, per the EPA.
- Global events (i.e. growing demand and another oil crisis) will be the macro drivers for alternate fuel use.
- Government regulations will drive this. As long as Democrats are in power, this should increase. There are health concerns with MTBE and methanol that seem to be ignored by the *environmentalist* lobby. If these are considered, oxygenated fuels may not look so good.
- Hopefully Congress will continue to reduce the amount of regulation imposed upon the American people, particularly when the regulation is not based on sound science. Measurement systems and norms for non-attainment have resulted in reformulated fuel being required in areas where real air quality problems do not exist, and where the move to reformulated fuel and the expected health outcomes cannot be correlated.
- I believe reformulated gas will be discontinued due to related problems with it.
- I do not see a very strong trend. Electric cars will grow in critical geographic areas.
- Primarily reformulated gasoline and clean diesel (rather than alternatives to petroleum) will meet Clean Air Act requirements for cleaner fuels.
- Reformulated gasoline will be mandated by government requirements.
- Reformulation formulas may change significantly by 2007.

Discussion

Panelists forecast reformulated gasoline to account for 35 percent of all gasoline sold by 2002 and 50 percent of all gasoline sold by 2007.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

This question was first asked in this form in the 1992 Delphi VI. The Delphi VI forecast for 2000 was 50 percent. The 1994 Delphi VII and 1996 Delphi VIII panels both forecasted significantly lower penetration rates for reformulated gasoline than did the 1992 panel. The long-term forecast by the 1998 Delphi IX panel is for 50 percent penetration, this time by 2007.

Reformulated Gasoline Usage			
	Short-term year/ Long-term year	**Short-term forecast %**	**Long-term forecast %**
1992 Delphi VI	NA/2000	NA	50
1994 Delphi VII	1998/2003	20	40
1996 Delphi VIII	2000/2005	15	25
1998 Delphi IX	2002/2007	35	50

Strategic considerations (new)

The Clean Air Act of 1990 has mandated the use of reformulated gasoline for regions that do not meet air quality standards. The initial reformulated gasoline blend produced some consumer dissatisfaction. However, it appears that the Environmental Protection Agency will continue to require reformulated gasoline as a part of its strategy to reduce pollution levels.

In the coming decade, the number of nonattainment areas will likely increase markedly. These areas that do not meet the air quality standards will be forced to use reformulated gasoline in an attempt to meet the more stringent standards.

MAT-4. **What is the likelihood of federal legislation mandating some degree of alternative fuel capability in retail vehicle sales, excluding fleets, by 2002 and 2007? Please include electric vehicles in your forecast.**

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

Year	Mean Rating
2002	3.4
2007	2.6

Selected edited comments

- A sure point; government will intervene.
- Among so-called alternative vehicles, everybody realizes that hybrids are most feasible and satisfying for everyday driving. This will encourage legislators to set a mandate.
- COP 3 at Kyoto, Japan this fall (1997) will clearly show the target level of CO_2 reduction and year of attainment and this will require the federal government to consider the mandated introduction of alternative fuel vehicles.
- I expect ethanol-type fuels to increase. There will be some electric vehicles, but not a significant amount.
- If scientific evidence continues to build in favor of the greenhouse effect, then legislation will come on strong. This is particularly true for Europe.
- It is one thing to mandate that alternative fuel vehicles be available for purchase, it is another thing entirely to mandate that someone actually buy them. This leads to premiums on gasoline-powered vehicles to subsidize alternative fuel vehicles, and/or other forms of federal foolishness in the marketplace. I would hope that we are past that, but perhaps not.
- Legislation by certain states will push federal legislation.
- Legislation by states is extremely likely.
- The EPA will continue to pressure manufacturers to improve emissions performance. Baby boomers, with a high impact on sales, have been reared on ecological issues and will largely support efforts to require lower emissions.
- The federal government's inability to do things easily would support a bureaucratic mandate and ensuing compliance enforcement.
- The near-term pressure for legislation will likely materialize in some sort of legislation; then time pressure will be reduced.
- The world has criticized the U.S. for not being sufficiently aggressive in reducing CO_2. The Clinton administration will push harder.
- This depends largely on whether the U.S. will submit itself to United Nations *environmental* dictates.

Discussion

The panel forecasts as less than moderately likely that some form of federal legislation regarding alternate fuels will be enacted by 2002. However, the panel views it as likely that there will be federal legislation requiring alternate fuels by 2007.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

The United Nations Convention on the World Climate in Kyoto, Japan, has established targets for the reduction of carbon dioxide gases by 2010. This agreement will likely have significant impact on the global automotive industry. To assist in meeting these targets, the federal government will likely attempt to enact stricter fuel economy and emissions standards. It is also possible that, as a part of an attempt to reduce carbon dioxide gases, the government will choose to expand legislation regarding the use of alternate fueled vehicles. However, before new alternate fuel laws are implemented, cost, safety, and technological issues must be resolved.

The challenge for meeting future fuel economy and emissions standards is complex. California and several northeastern states continue to develop state and regional regulations that will add further complexity to the challenge. A well-thought-out, technically feasible, federal-alternative fuels strategy (as opposed to a hodgepodge of state and regional laws) is significantly more attractive to both industry and the consumer.

MAT- 5. What percentage of North American-produced passenger cars and light trucks (including fleets) will use each of the following alternate energy sources in 2002 and 2007?

Energy Source	Passenger Cars					Light Trucks				
		Median Response		Interquartile Range			Median Response		Interquartile Range	
	Est. 1996*	2002	2007	2002	2007	Est. 1996	2002	2007	2002	2007
Alcohol or alcohol/gasoline (>10% alcohol; includes flex fuel or variable fuel)	<1%	1%	4%	1/5%	1/10%	<1%	1%	3%	1/5%	1/10%
Diesel	0	1	2	0/2	0/5	3.8	5	8	4/5	6/10
Electric	0	1	2	1/1	1/3	0	0	1	0/1	0/1
Hybrid-Electric/combustion engine	0	1	2	0/1	1/5	0	0	1	0/1	0/2
Natural gas	0	1	1	0/1	0/3	0	1	1	0/1	1/3
Propane	0	0	0	0/1	0/1	0	0	1	0/1	0/1

*Source: *Ward's Automotive Reports*, February 3,1997 and February 24, 1997.
Dates for 1996 based on production in U.S., Canada, and Mexico for the U.S. Market.

Selected edited comments

- A higher percentage of vehicles will use up to the mandated limit of oxygenated hydrocarbon, which in a practical sense means ethanol and/or methanol at less than 10%. Diesel fuel, in the short-term will be of restricted use because of its particulate problem. The advantage of nonaromatic hydrocarbon containing diesel, in not contributing to ground level ozone, would spur its legislative-induced use once the particulate issue is resolved.
- A variety of technologies will develop. The market and technology evolution will sort out the eventual mix. Government pressure will force experimentation.
- CAFE will probably have light trucks at the same mpg as cars by 2007.
- Even though the diesel has a (deserved) poor reputation in North America, the European experience with direct injection diesels will permeate the North American consciousness. Performance, noise, and cold-start problems have been materially improved and fuel economy is substantially better than spark-ignition.
- Gasoline price and emission improvements will lead to the use of other fuels. Selected urban areas will have electric cars legislated or local "owner tax" will favor electric cars.
- I do not expect internal combustion engines to be replaced with alternate energy sources to any significant degree.
- I do not see an immediate impact on electric vehicle production unless a hybrid is developed that will use electric/internal combustion with little inconvenience and cost to the buying public.
- I expect a generally increasing percent of diesel, natural gas and propane for light trucks. I also expect a generally increasing percent of natural gas and propane for cars.

- Market share depends on fuel economy and NOx legislation. NOx catalyst development may lead to a European mix of diesel and gasoline passenger cars.
- The cost and length of life for batteries will keep EV from wider application despite the California mandate of 10% ZEV by 2003. From the technological and economical point of view, EV/combustion (gasoline) hybrid E-ZEV will have higher potential. Also, natural gas has the same level of potential as hybrid because catalyst technology to treat methane properly will be developed to meet emission requirements.

Discussion

The panel forecasts market penetration rates for flexible-fueled vehicles to be 4 percent for passenger cars and 3 percent for light trucks by 2007. Diesel engines are forecast to reach an 8 percent share of the light truck segment by 2007. Minimal growth is forecast for all other listed alternate power sources.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-13

There is a statistically significant difference in mean responses between technology and materials panelists for the alternate fuels in passenger cars and light trucks in the years shown in the following table.

Alternate Fuels – Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Passenger Car				
Diesel	4.2	1.6	7.8	4.3
Light Truck				
Diesel	6.5	5.0	15.0	9.0
Natural gas	2.3	1.0	4.4	2.3

Technology panelists forecast higher use of diesel in passenger cars and light trucks and natural gas in light trucks than materials panelists.

Trend from previous Delphi surveys

This question was first asked in the present form in the 1994 Delphi VII. The Delphi IX panel is in general agreement with the previous two forecasts. However, current panelists are slightly more optimistic regarding diesel applications in light trucks than the previous panels.

Strategic considerations

The panelists expect the internal combustion engine to continue to be the dominant power source for the coming decade. The implementation of alternate fuels and engines will likely be driven, not by consumer choice, but by policy.

Recently there has been substantial effort given to the development of several alternate energy powertrains. The payoff for these efforts has been significant gains in technology. Yet substantial barriers still exist.

Panelists forecast that diesels, common throughout much of the rest of the world, will see increased light truck application in the United States. The development of an effective NOx catalyst would likely increase the application rate of diesel engines in both passenger cars and light trucks in the United States.

Each of the 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 environmental issues.

MAT- 6. What material issues will present the most significant challenges or opportunities in the development of the electric vehicle? *(Emboldened headings represent authors groupings of common ideas.)*

RESPONSES

Challenges (issues):

Battery Challenges

- Acid and lead hazards (2)
- Atomic/electrical power (3)
- Availability, time and ease of recharging (10)
- Battery - construction
- Battery - cost (initial and replacement) (6)
- Battery - disposal/recycling (3)
- Battery - efficiency (2)
- Battery - energy density
- Battery - life (7)
- Battery - materials (5)
- Battery - performance
- Battery - size
- Battery - technology
- Battery - weight (9)
- Battery issue – storage (3)
- Battery power density (2)
- Electric conductivity
- Long-term idle period (airport parking)
- Short duration driving distance

Cost Concerns

- Cost - lightweight materials and structure (13)
- Cost - materials (2)
- Cost (4)
- Cost of aluminum for body structures
- Cost of ownership

- Cost of production
- Cost/performance habits

Electric Motors

- Electric motor designs to be improved by reducing weight and size but increasing power output
- Lightweight propulsion systems
- Low energy loss motors
- Motor generator—higher conversion efficiency
- Motor materials

Materials

- Aluminum—cost, manufacturability, joining and repairability
- Exterior appearance improvements for composite body panels
- Fast cycle time and consistent composites
- FRC (Fiber Reinforced Composites) manufacturability, uniformity (crash energy management prediction)
- GrFRC (Graphite fiber reinforced composites), cost, manufacturability
- Inexpensive and light materials with as little secondary processing (machining and thermal) as necessary
- Interior materials, especially seat structures and restraints
- Joining of variety of materials
- Lightweight glazing and noise reduction through the glazing
- Lightweight materials for saving weight in higher volume vehicles
- Lightweight transparencies
- Lightweight yet traditional class "A" surface
- Lightweight, mechanically capable materials for structural, driveline, and body-skinning applications
- Low-cost polymer matrix composites
- Low-cost sheet aluminum
- Low-cost ultra light composites
- Overall weight reduction of vehicle materials
- Steel—density
- Strength
- Strength/weight
- Structural integrity

- Vehicle weight reduction—weight of battery itself and rack, body panel, chassis components
- Weight efficiency/reduction (4)

Other

- Cost and recyclability of high-tech materials (e.g., fuel cell, battery components)
- Crash protection and energy management (2)
- Frictionless technology
- Full-size vehicles
- Lower cost and resulting vehicle pricing of early version
- Manufacturability
- On-board power supply
- Package requirements
- Packaging/styling
- Recharge infrastructure/refuel infrastructure
- Recyclability (3)
- Reliability of electrical connections
- Safety
- Sharing of ideas between the OEMs
- Time constraints for product development and product validation
- Vehicle performance (2)

Opportunities (solutions):

Battery Opportunities

- Batteries with 500 mile range
- Better electrochemical batteries
- Development of advanced batteries and the needed materials
- High-energy density battery technology
- Lithium battery (3)
- Long-life batteries
- Long-life synthetic energy battery
- New battery technology
- New battery technology, high-tech, high-volume
- New solar cell technology

- Polymer-based battery (3)

Cost Opportunities

- Cost-effective method to join lightweight body structures to achieve required safety, durability and stiffness criteria
- Cost will be the overriding issue
- Structures redesigned for low-cost composite

Electric Motors

- Development of hybrid engines
- Functional flywheels
- Materials for higher energy density motors

Materials

- Additional improvements in primers/coatings (2)
- Aluminum for body, chassis and powertrain (2)
- Aluminum: DFM for aluminum to help with the lower ductility and more difficult joining; continuous casting and electric utility deregulation to help with the cost problems; nationwide training and education for repair
- Amorphous metals for lower magnetic losses
- Carbon/graphite fiber-reinforced composites; CEM design; material uniformity and cost (3)
- Coatings
- Combination of design and lightweight materials such as composites, magnesium, and titanium
- Composite materials (3)
- Develop lower cost manufacturing technologies for these materials
- Develop way to reduce feedstock costs of aluminum, magnesium, graphite fiber composites, titanium, etc.
- Heat-releasing and absorbing materials
- Improved manufacturing technology for mass reducing material
- Improved plastics that optimize strength and ductility; structural composites need to move from space industry to automotive industry
- Laminate or composite materials for broad structural application
- Lightweight aluminum alloy for body frame and chassis, stampable fiber-reinforced thermoplastics for battery rack and body panels, polyolefin-based integrated interior system
- Lightweight design using aluminum and magnesium
- Low-cost aluminum structural techniques
- Magnesium for seats, instrument panels, etc.

- Magnetic materials development
- Materials for higher energy density batteries
- Minimize joining of similar and dissimilar materials
- More aluminum and magnesium (2)
- More magnesium and aluminum
- Nontraditional applications of nonferrous materials due to "trickle down" effect of much lighter weight vehicle
- Plastic glazing (2)
- Semisolid molding of aluminum
- Significantly improved formability for aluminum alloys
- Stable reduced price for aluminum sheet alloys
- Steel: holistic design taking advantage of steel's unique properties and utilizing alternative architecture and design solutions for improved performance and reduced mass (i.e., improved efficiency in design)
- Structural and recyclable composites
- Use of lightweight materials like plastics
- Weight reduction based on design modifications (e.g., stiffening members strategically placed to reduce mass while retaining structural integrity)

Other

- All of the above are interrelated. A battery construction that has a higher efficiency will have an effect on each of the other parameters. As has been demonstrated by weak sales of the EV-1, the public desires a longer-range vehicle at a sensible price, not a novelty.
- Composite fabrication of frame/body
- Environmental impact—clean air
- Fuel cell development (5)
- Government-sponsored development of this infrastructure
- Hybrid solutions
- Increased design knowledge
- Legislative reality
- New computer models of component performance and durability
- No electrical finishing system
- None in the short-term (2)
- Onboard generation of electrical power with reciprocating magnets
- Reformer technology

- Smaller vehicles
- The development of rapid tooling

Discussion

The panel lists a wide range of material-related challenges and opportunities presented by the electric vehicle. The challenges/opportunities can be grouped into four basic categories: battery issues, mass reduction, cost and performance.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

The development of an effective electric vehicle presents many significant challenges for the automobile industry. The critical challenges include the advancement of battery technology and the application of lightweight materials within the cost and performance standards established by the internal combustion engine.

Although advancements continue in battery technology and performance, most initial electric vehicle offerings have relied on lead-acid batteries. These batteries are characterized by slow recharging properties, limited driving ranges, and short service life. Recently metal hydride batteries have been offered in some electric vehicles. Although they have increased range, and decreased recharging time they are also more expensive. The panelists indicate that battery technology and the material issues involved in battery technology will continue to hinder the success of the electric vehicle in the coming decade.

Current electric vehicle programs make it clear that plastics, aluminum, high-strength steels, and magnesium will play an important role in the development of electric vehicles. Cost-effective uses of these materials will greatly increase the likelihood of a successful electric vehicle.

Although some companies have shifted attention away from electric vehicles with increased developmental effort being given to hybrid vehicles, there continues to be significant effort to develop electric-powered vehicles. The lessons learned from these programs are a necessary, if costly, exercise that may lead to shifts in material processing paradigms within the industry.

MAT-7. What material issues will present the most significant challenges or opportunities in the development of PNGV Partnership for a New Generation of Vehicles? *(Emboldened headings represent authors groupings of common ideas.)*

RESPONSES

Challenges (issues):

Battery Challenges

- Cost-effective battery (2)
- Range
- Recharging time

Cost Challenges

- Affordable lightweight design
- Cost (3)
- Cost for using lightweight materials (aluminum, composite, or magnesium) (8)
- Cost of development
- Cost of product
- Cost-effective alternative production processes
- Cost-effective reparability of "advanced" materials in body panels, etc.
- Economics in producing an affordable vehicle (5)

Electric Motors

- Improved mechanical efficiency: energy recovery of IC engines, friction loss reduction of transmissions and wheels, tires etc.
- Low friction, durable lubricants
- Magnetic shielding

Fuel Cells Technology

- Fuel cells
- Fuel cells offer the best long-term approach to improved fuel economy, but they are ten times too expensive.

Materials

- 50 percent weight reduction in chassis, body and interior
- Cost of materials
- Cost of materials/manufacturing

- Cost/performance of lightweight plastic composites
- Cost-effective mass reduction (2)
- Developing cost-effective, lightweight body structures which can be manufactured at high volumes and which can be readily recycled
- Durability, taking into account temperature, humidity and UV exposure; developing appropriate accelerate test procedures
- Efficient high-volume processes
- End of life recycling
- Environmental issues: toxicity and recyclability
- Exterior appearance improvement for composite body panels
- Feedstock costs of lightweight materials
- High recycling rates and low-cost processing.
- Improved ceramic manufacturing capability for turbines
- Joining variety of materials (4)
- Lack of experience in designing with alternative materials—plastics and composites versus steel and aluminum always handicaps effective utilization of these alternatives in new designs. Properly utilized, these materials can help solve the most difficult problems the PNGV program faces, efficient with cost effectiveness.
- Lightweight transparencies
- Lightweight vehicle structure
- Lightweight vs. safety
- Low-cost polymer composite materials (2)
- Lower cost for higher volume production processes of nonferrous products
- Manufacturability
- Manufacturing and assembly issues
- Manufacturing processes with new materials
- Massive body weight reduction (50 percent) without dramatically higher costs
- Material requirements (e.g., increasing exhaust gas temperatures)
- Recyclability (4)
- Weight efficiency/reduction (9)
- Weight of ferrous metals
- Weight reduction: concept of vehicle usage (limited use or general use) and structure (frame and unitized)
- Weight vs. strength

Other

- "Not invented here" syndrome at the Big Three
- Catalyst so NOx can be met with high efficiency DI engines
- Commercially-viable PNGVs are assumed
- Competitive natures of the marketplace will eliminate any serious development
- Exhaust systems
- FRC: CEM (Crash Energy Management)
- Further weight reduction without harming crashworthiness or increasing costs to such an extent that customers will not be able to afford to purchase the vehicle
- Getting all parties to agree on direction
- Government safety regulations
- Maintain comfort level to that of current family vehicles
- Maintaining interest and focus when fuel costs are so low
- May need regulation changes
- Meeting fuel economy goal
- Part-making technologies that provide robust components at reduced costs
- Passive restraint
- Performance
- Power management: selection and control of electric power and combustion energy
- Reduction of reciprocating mass in internal combustion engines
- Resistance of Big Three to change
- Satisfying customer "lifestyle statement", vehicle cycling, and performance
- Sharing of ideas between the OEMs
- Supplier capability
- Supplier infrastructure
- Supply base

Opportunities (solutions):

Battery Opportunities

- High energy density battery technology.

Fuel Cell Technology

- Catalysts for fuel cells
- Fuel cell

- Fuel Cell Technologies: hydrogen storage alloys, methanol to hydrogen catalyst, high-efficient and durable membrane
- Improvement in fuel cell technology could have a great impact—on-board hydrogen formation has real promise
- Materials appropriate for fuel cell technology

Materials

- A steel/aluminum/composite (glass)/plastic/ultra-light composite (carbon) hybrid vehicle should give the best cost versus weight balance
- Aluminum mill products (3)
- Combination of design and lightweight materials such as composites, magnesium, and titanium (7)
- Higher volume cost, fiber performance process for PMCs
- Lightweight vs. safety
- Low friction materials (polymer, ceramics, alloys), oils for CVTs and automatic transmissions
- Material substitute for ferrous metals
- Materials for higher energy density electrical storage for hybrid powertrain
- More extensive use of high strength steel including stainless
- Steel—innovative design to reduce mass (2)
- Use of higher alloyed, more exotic metals/composites (e.g., use of more austenitic stainless grades in exhaust systems)
- Use of materials not usually associated with major automotive structural components (e.g., stainless steel for use in frames etc.)

Materials Cost

- Increased level of demand for lightweight materials such as aluminum and magnesium may help to stabilize prices.
- Low cost carbon fibers
- Low cost high strength steel
- Low cost polymer and aluminum body structures
- Low cost/high performance resins
- Need new methods for producing low cost aluminum and magnesium
- Structures redesign for low-cost composite

Materials Processing

- Application of the structural bonding system developed by Alcan for street-based body structures

- Composite joining
- High-speed plastics/composites fabrication and processing technique
- Hydroforming of steel/aluminum tubing
- Improved manufacturing technology for mass reducing materials
- Low-cost aluminum structural techniques
- Minimize joining of similar and dissimilar materials
- New forms and joining methods for aluminum structures

Other

- 100 percent recyclable
- By saving money due to pooled resources on precompetitive research development, companies may be able to afford to use some more costly materials.
- Design ignorance (lack of expertise) by OEMs
- Design optimization
- Extreme use of consolidated parts/function
- First to market will have a distinct advantage
- Fuel efficiency
- Large, integrated, structured light metal castings
- Life cycle costs
- Low capability by tier 1 suppliers in lightweight materials
- Mindset or existing mass production paradigm; sunk capital
- New manufacturing technologies (e.g., hydroforming)
- New part-making technologies such as castings and powder metallurgy
- Potential for increased recyclability (2)
- Recycling facilities
- Recycling infrastructure for nonmetallics
- Redesign of systems to reduce number of parts (consolidation)
- Re-engineer the assembly line to bypass 200° C e-coat (ELPO) primer ovens
- Same as today–not very good
- Technology awareness
- USCAR to force on (1) lower cost nonferrous raw material processes and (2) lower cost prices to form NNS components

Discussion

The panel lists a vast array of challenges and opportunities faced in the development of a vehicle to meet the goals of the Partnership for a New Generation of Vehicles. The comments suggest that the panelists foresee a significant effort to achieve the stated goals.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

In many regards, the material requirements to meet the goals of the PNGV are viable. Unfortunately, the ability to meet the material challenges, while remaining within the cost constraints is not yet an achievable goal.

A new materials paradigm will likely be necessary for the industry to meet the goals of the PNGV. Current manufacturing and design strategies may not allow for the level of change necessary to meet the mass reduction requirements implied by the PNGV goals. The ability to deliver a vehicle capable of 80 miles per gallon may require all stakeholders to re-evaluate the materials and process currently used. Such a paradigm shift would be costly and painful, especially in such a relatively short time period.

The use of composites for structural components presents an example of such a paradigm shift. Composites in structural components offer many potential benefits, yet barriers persist that make near-term acceptance unlikely. Manufacturing cycle time remains too long, and there is continued uncertainty regarding the reliability of finite element analysis modeling related composites.

The development of alternative powertrains also presents the potential for a new materials paradigm. The internal combustion engine has driven the industry for a century. However, much of the effort by the PNGV has been toward the development of alternate power sources, which may require new technology materials.

MAT- 8. **Please indicate your view of the trend in U.S. federal regulation and legislation over the short-term (1998-2002) and long-term (2003-2007). Also, please list any likely new areas of legislative and/or regulatory activity.**

Scale:	
	1 = much more restrictive
	2 = somewhat more restrictive
	3 = no change from 1996
	4 = somewhat less restrictive
	5 = much less restrictive

Mean Rating		
Legislation/Regulatory Activity	**Short-Term 1998 - 2002**	**Long-Term 2003 - 2007**
Fuel economy standards (CAFE)		
Passenger car	2.4	1.8
Light truck	2.3	1.7
Vehicle emission standards		
Passenger car	2.4	1.9
Light truck	2.3	1.7
Vehicle integrity/crashworthiness		
Passenger car	2.4	1.9
Light truck	2.3	1.9
Alternate fuel use		
Passenger car	2.6	2.0
Light truck	2.7	2.3
Occupant restraint/interior safety		
Passenger car	2.5	2.0
Light truck	2.5	1.9
Product liability		
Passenger car	2.7	2.5
Light truck	2.7	2.5
Antitheft equipment		
Passenger car	2.9	2.6
Light truck	3.0	2.7

New areas:

Mobile phones: Passenger car - 2; Light truck - 2

Selected edited comments

- A lot depends on who is president and who is in Congress. It's a political thing and cost is and will be a major issue.
- An intrusive misguided government can't resist meddling (and usually making things worse).
- Antitheft is likely to be installed per consumer demand, mitigating government mandate.

- Development of PNGV (if it comes to pass) will have a major effect on CAFE and alternative fuel legislation. With lighter weight materials used in the manufacture of these vehicles, there may be an adverse effect on vehicle integrity/crashworthiness.
- Elections in 2000 could result in changes.
- Global citizenship pressures, rather than the U.S. Congress, will be the stronger factor in moving to a somewhat more restrictive scenario.
- In the short-term there could be legislation by states on alternate fuel use. In the long-term, new requirements are possible for large vehicles to reduce the damage caused to smaller vehicles.
- Safety will be a major thrust the next 5 years. Occupant restraint and crashworthiness will be paramount. Reduction awards of product liability will take place, as personal responsibility will come into play. Daytime running lamps will become mandatory as their effect on accident prevention becomes more evident.
- The pendulum may be swinging back to a saner legislative mood.
- Trial lawyer lobby will have a large impact on legislation as well as liberal groups such as that run by Ralph Nader.
- Worldwide agreement for controlling CO_2 emissions will force the federal government to increase fuel economy requirements.

Discussion

Panelists forecast in the short-term that all listed areas will see somewhat more restrictive regulation/legislation. Fuel economy, emissions, and safety are forecast to have much more restrictive regulation/legislation by 2007. Regulation/legislation pertaining to light trucks is forecast to be similar to that of passenger cars.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question has been asked in the same format since the 1994 Delphi VII. Over that period, the forecast of the materials panels have been similar. However, the 1996 Delphi VIII panel forecast long-term regulation/legislation to be more restrictive than did either the 1994 Delphi VII or the 1998 Delphi IX panels, especially with regard to occupant restraint/interior safety, product liability, and vehicle emissions.

Strategic considerations

The panel forecasts federal regulation and legislation to become increasingly restrictive in the coming decade. The recent trend in Congress has been away from technology forced command and control and toward a more cooperative effort in a number of regulatory areas. However, the industry and government are at a critical juncture with regard to environmental regulation/legislation. The possibility of regional, national and even international environmental regulation will present a continuing challenge for the industry.

Over the past decade there has been a considerable amount of progress in the development of alternate powertrains. There is potential that the federal government may see these initial advancements and become overzealous with regulations which may force the use of technologies before they are market-ready. Conversely, the automotive industry has, on occasion, shown that the incentive of government standards may be necessary to encourage the development of critical technologies.

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MAT- 9. **What new regulation/legislation do you anticipate in the next decade that will significantly affect material selection?** *(Emboldened headings represent authors groupings of common ideas.)*

RESPONSES

Emissions and CAFE

- Additional increases in CAFE will drive long life or life of vehicle fluids (i.e. improved friction modifiers and lubricity of engine, transmission, gear/axle oils and coolant improvements) and have caused, and will continue to cause, compatibility issues with component materials as well as sealing materials.
- Alternate fuel mandates
- CAFE changes pushing lighter vehicles and lighter weight material, especially in trucks. (3)
- CAFE/CO_2 generation expectations for the SUV market—it is driving the environmental issue.
- CAFE/Safety will continue a push toward cost-effective mass reduction.
- CO_2 reduction requirement will be reflected into new CAFE standards.
- Fuel economy and emission are the areas where the further improvements will be required by new regulations. (3)
- Higher CAFE and/or fuel tax (while consumer expectations on performance will not be lowered)
- Higher fuel tax will steer consumers to higher fuel economy vehicles. Weight reduction through material selection will follow.
- Increased CAFE (8)
- Increased CAFE standard for light trucks (4)
- Lower NOx standards
- Reduced fuel consumption and CO_2 emissions will increase the pressure to reduce weight by using more lightweight materials.
- Some change in CAFE for light trucks such as redefining SUVs as cars

Stationary Source Emissions and Other Hazardous Materials

- Air quality from decorating operations (paint/trim)
- Banning of use of certain materials because of the environment—solvents, heavy metals, etc.
- Chemicals used in coating/plating restricted limiting coating/plating options
- Continued restriction (unwarranted) against incineration of plastics for energy; clean technology exists
- Fixed site emissions restrictions will force paint systems to continue to change(2)
- Further control of substances of concern
- Global (as opposed to local) regulations will influence U.S. manufacturers.

- Global warming related legislation is a possibility in the post 2000 time frame.
- I believe serious efforts will be made to restrict Americans "unlimited" driving.
- Intra-city restriction to assist ozone reduction in large cities
- Lead plating, now widespread, will be outlawed—good!
- More "heavy metals" restrictions in plating
- More regional emission standards (increasing)
- More restrictions regarding clean air and water could affect choices of paint and other coatings
- Particle size for particulate emissions

Recyclability

- Evolving recycling guideline from the Big Three will narrow the field of suitable plastics
- Ill-conceived plastics recycling
- Legislation to require recycling and/or dismantling
- RCRA (Resource Conservation and Recovery Act) will be more severe
- Recyclability (8), Recyclability of total vehicle (2)
- Recyclability (disassembly by capability) is making it easier for materials identification. (2)
- Recyclability for vehicles exported from North America
- Recyclability mandate (2005) vehicle returned to manufacturing and/or percentage recycled material
- Recyclability: ASR (Automotive Shredder Residue, or Fluff) disposal problems may generate sufficient popular support to engender legislation (a la Germany).
- Recycling of post-consumer nonmetals
- Regulations on bumper height to avoid light trucks overriding the bumpers of cars

Safety

- Belted occupant for FMVSS 208 testing
- Crashworthiness (2)
- Crashworthiness and CAFE will require lighter/stronger material, perhaps magnesium, titanium and ABS.
- Development and application of ITS will eventually reduce the number of fatal accidents and this makes the tighter regulation unnecessary.
- Harmonization of frontal and side crash tests between U.S. and Europe
- Head impact
- Improved crashworthiness for light trucks
- Increased emphasis on interior safety

- Interior safety requirements/durability will push the envelope in interior materials for occupant protection.
- Movement to the "cage" concept (i.e., NASCAR) for passenger safety
- Occupant restraint more stringent (3)
- Safety (2)
- Side impact (2)

Discussion

The panel forecasts that new, or more restrictive, regulations pertaining to fuel economy, emissions, air and water quality, and recyclability will significantly affect material selection in the coming decade.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

More restrictive CAFE regulations will likely move the industry toward significant mass reduction in the coming decade. Mass reduction will come from downsizing of vehicles, improved design efficiency, and the application of lightweight materials. According to panelists, plastics, aluminum, and magnesium are likely to see rapid growth in the automotive industry.

Also of note is the panels' frequent mention of stationary source emissions. It is likely that regulation regarding such emissions will become increasingly stringent. Increased regulation could have a significant effect on material selection. Close scrutiny will be given, not only to the materials attributes, but also to the environmental friendliness of materials-manufacturing processes.

There continues to be potential for regulation pertaining to the recyclability of vehicles (see Questions 10, 50-53). Any such regulation may have significant implications for the use of plastics, and therefore warrants close monitoring.

Increased safety regulation could also lead to material changes. More stringent occupant safety regulation may come in the form of technology (i.e., airbags) or new material applications.

MAT- 10. Do you expect federal or state government legislation and regulation to require the recyclability of automotive materials in the following areas? Please give your forecast for 2002 and 2007.

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

Regulatory Issues	**Mean Response**	
	2002	**2007**
Specific regulation for the following:		
Disposal of automotive fluids	2.6	1.6
Disposal of used tires	2.8	1.9
Recyclability of plastics	3.2	2.2
'Take back' regulations making manufacturers responsible for final product disposition	4.2	3.3
Establishment of uniform identification/coding standards for materials to facilitate separation	3.1	2.3
Ban on some current automotive materials	3.5	2.4
Required minimum recycled content	3.5	2.6
Financial penalties/incentives based on recycled content	3.8	2.8

Other regulatory issues responses:

Set limits on some current materials: 2002 - 3, 2007 - 2

Codes for identifying metal source of safety parts: 2002 – 3, 2007 – 1

Selected edited comments

- "Take-back" sounds a little too burdensome for all but the most radical legislation/regulations. Excepting CFCs, outright bans seem unlikely.
- Although an entrenched, liberal bureaucracy will continue to push for regulations of many kinds, the auto industry and its suppliers are well informed of the value of increasing recycling of materials (to their own benefit) and will wage a strong effort to maintain a sense of reason. Any regulation that negatively affects the bottom line will be fought.
- Bureaucrats, whether informed or ignorant, do not seem to be able to resist the temptation to interfere with market forces or people's choices.
- By 2007, regulatory action will be possible if related industries do not act as expected in terms of recycling and waste treatment.
- Economics and technology will tend toward recycling only where it makes sense, in concert with other options that minimize environmental impact like life cycle and incineration.
- Europe is moving aggressively towards recyclability and end-of-life requirements. The U.S. infrastructure is handling these issues effectively in the marketplace today without regulation.

- Fluids and tires are being recycled at a higher rate than other parts because technologies and reuse patterns already exist. Legislation which relates specifically to electric vehicles or hybrid electric vehicles is very likely because they contain hazardous chemicals.
- For the most part, the current attention to recycling of materials is largely a political issue with very little real environmental impact. Strong corporate environmental stewardship is very important now and in the future. Over the next few years, the majority of the industry and government will realize that the current recycling emphasis is good stewardship. In the end, total life cycle analysis will be the tool that decides what is the best thing to do for the environment
- Recyclability will continue to be economically driven. Government can change economics by impacting landfill costs.
- Recyclability will have to be economically viable on all fronts in order to be enacted. Requiring a minimum recycled content may have a positive effect if the price of recycled material is less than or equal to raw materials, with no decrease in quality. "Take-back" legislation will not occur due to the well-entrenched automotive dismantling industry currently in place.
- Recycling of ferrous metals from scrapped automobiles has been a for-profit business for about as long as the car has been around (>100 years)—it is the engine that drives automotive recycling. To promote the reuse, recycling, or recovery of embodied energy content of other materials, they too need to ensure that such activity is for-profit. At the present time, profits from the sale of the metallic fraction of the vehicle cover much of the cost of disposing of the nonmetallic fraction. Increases in the disposal cost for nonmetallics, and/or the percentage of the vehicle's mass made up of nonmetallics threaten the commercial viability of the automotive recycling business. Nonmetallics should pay their own way when it comes to end-of-life disposition, by whatever means.
- Selected state governments are more likely to impose recycling.
- The disposal of tires and plastics will be handled by specifying minimum recycled content.

Discussion

The panel expects the federal government to enact legislation or regulation in the coming decade regarding the disposal of automotive fluids and tires, the recyclability of plastics, the establishment of uniform standards to facilitate separation, and a ban on some current automotive materials.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, there are three areas where their responses are statistically different. Manufacturers view legislation/regulation requiring minimum recycled content, disposal of automotive fluids, and recyclability as less likely than do the suppliers. The table shows the mean responses for the manufacturers and suppliers.

Regulatory Issue	Mean Response	
Legislation/regulation	**Manufacturers**	**Suppliers**
Required minimum content by 2007	3.1	2.3
Regulation for the disposal of automotive fluids (2002)	3.0	2.3
Regulation for the recyclability of plastics (2002)	3.8	2.9

Comparison of forecast: TECH-42

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

Regulatory Issues – 2002		
	Technology	**Materials**
Ban on some current automotive materials	2.9	3.5
Establishment of uniform identification/coding standards for materials to facilitate separation	2.6	3.1
Financial penalties/incentives based on recycled content	3.5	3.8
Specific regulation for:		
Disposal of used tires	2.4	2.8
Recyclability of plastics/polymers	2.7	3.2
Regulatory Issues – 2007		
"Take back" regulations making manufacturers responsible for final product disposition	2.8	3.3

For all areas where there is a significant difference, technology panelists rate the likelihood of legislation and regulation higher than materials panelists. It should be noted that the largest difference in mean values is only 0.6 rating points.

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

The panel forecasts increasing likelihood of legislative and regulatory activity by the federal government regarding the recyclability of the automobile. In view of the expected regulatory activity, manufacturers will likely need to re-evaluate their material selection process and make adjustments to allow for a greater emphasis on the final disposition of their vehicles.

Germany has passed stringent recycling regulations that will make manufacturers responsible for the final disposition of their vehicles. Although the panel does not expect such legislation in the United States, it is likely there will be increasing pressure to develop more environmentally friendly vehicles.

MAT- 11. 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
Materials and processing cost	1.1
Safety considerations	1.7
Weight	1.7
Warranty cost	1.8
Design/styling requirements	1.9
Field experience	1.9
Corrosion resistance	2.0
Formability	2.1
Preference of vehicle purchaser	2.5
Environmental issues	2.6
Recyclability	2.7
Disposal cost	2.8
Ease of final disposition	3.0

Other attributes/characteristics:

Cost of noncompliance: 1

Customer service—die development, manufacturing, inventory, claim resolution, plant quality performance: 1

High-tech image: 1

Investment: 1

Supplier capability: 2

Selected edited comments

- Again, cost will be a major issue. Today we are pricing ourselves into smaller markets (affordability).
- As the automakers push more design responsibility down to the tier 1 suppliers, they also intend to push the legal/product liability responsibility to the tier 1 supplier. If this succeeds, suppliers will have more freedom to choose materials but will be responsible for recyclability, disposition, warranty, and environmental issues/compliance.
- Automotive manufacturers take vehicle purchaser preferences very seriously. Customers don't know or care about material selection; they care only about the attributes and performance of the product.
- Compatibility with current manufacturing system is extremely important.

- Cost dominates everything, including the cost of not meeting regulations such as CAFE and emissions.
- Cost is certainly the most important issue now and will continue to be unless there is an "oil crisis" or if the federal/state governments increase taxes on gasoline, which would increase cost and decrease availability.
- In order of priority, automakers have regulatory compliance at the top of their list followed closely by cost. Everything else is a poor third or below. To the extent that some of the issues listed may become the focus of regulatory activity, they would move immediately to the top of the list (e.g., recyclability or recycled content). Essentially, everything else is viewed through a cost framework. Every problem, be it safety, ease of disposition (or whatever) must be resolved in a cost-effective manner. Solutions that add cost need to be rethought.

Discussion

Panelists forecast that the cost of materials and processing (1.1) is the most critical material selection criteria in the coming decade. Weight (1.7), safety considerations (1.7), cost of warranty (1.8), field experience (1.9), and design styling requirements (1.9) are also expected to be critical elements of the material selection process. It is important to note that all attributes and characteristics listed are forecast to be at least somewhat important in the next decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII survey. Cost of materials and processing has been rated as the most critical factor in all three of the Delphi surveys. It is important to note that in the three surveys, materials cost and processing has increased in importance, both in comparison with previous forecasts and with the other attributes. All other attributes are consistent in the three surveys.

Strategic considerations

The material selection process is very complex and often presents conflicting goals. The Delphi IX panel has made it very clear that cost is expected to be the driver for material selection in the coming decade. However, two points are of importance. First, all of the listed attributes are noted as at least somewhat important. Even if, as the panel indicates, cost is the most critical factor, there is still an abundance of other attributes that must be accounted for in the material selection process. Secondly, there are external factors that may quickly change the importance of any of the listed attributes. Increased CAFE or CO_2 emissions regulation would certainly make weight a more critical attribute, while regulation regarding recycling or other environmental challenges would also change the rating of several attributes. Although cost is expected to be the critical factor, it is important to continually monitor external factors for changes that may have implications for the material selection process.

MAT- 12. What do you believe are the five major material issues and long-term strategic considerations associated with future material selection? *(Emboldened headings represent authors groupings of common ideas.)*

RESPONSES

Cost

- Continued cost pressures that require part/system cost reductions that can be impacted by material through material cost, design and/or processing, Cost—increase pressure with materials offering great potential for improvement
- Cost (16)
- Cost at high volumes
- Cost competitiveness
- Cost is still the most important factor in selecting materials because the vehicle price war becomes much more fierce in order to secure world share of sales.
- Cost of materials (relative to benchmark best current practice) to fabricate a part or subsystem (5)
- Cost of materials must be contained, and will be, as productivity increases continue.
- Cost of new light materials—current demands are low, causing high cost. Increasing the demand requires significantly higher fuel cost or taxes on vehicle mass.
- Cost of processing
- Cost of the component
- Cost of the raw material
- Cost reduction (2)
- Cost reduction due to improved manufacturing techniques
- Cost/flexibility of tooling used to process/fabricate materials
- Cost: the warranty cost to the automaker
- Cost-effective mass reduction, cost versus weight savings
- Cost-effective repairability of nontraditional material external components
- Cost will be handled through a combination of design, material selection, and advance magnesium process
- Decrease in cost while maintaining performance
- Establishment of an effective low-cost manufacturing system for using aluminum for body structures
- Long-term cost stability for materials and especially aluminum for body structures
- Low-cost manufacturing.

- Manufacturing cost, new processes, and optimization at various production volumes
- Material price, price stability
- More cost effectively utilizing materials in the manufacturing process (3), cost effectiveness—value
- Price (3)
- Price/cost ratio
- Relationships of tooling and investment costs to shorter product-development times and mega-platforms
- Systems costs
- The acquisition cost (or purchase price) of the raw material required to fabricate the part, sub-assembly, assembly and finally vehicle.
- The cost to the customer of purchasing, owning and maintaining, operating and repairing, and finally disposing of the vehicle. This includes the cost of insurance.
- The manufacturing cost required to produce the vehicle and its component parts, including yield (engineered scrap) and capital investment (tooling and production equipment)
- Tooling cost
- Use of existing capital
- Vehicle affordability (2)

Environmental Issues

- Balancing plastic recycling requirements with the separation of the multitude of different plastics used in a car
- Elimination of hazardous chemical from processing of materials (e.g., plating operations)
- Environment (2)
- Establishment of recycling systems that will ensure close-loop recycling
- Likelihood for legislative control due to recyclability
- Lower VOC levels
- Maintaining competitive cost of plastics in light of recycling/disposal pressures
- Reduce manufacturing site emissions
- What restrictions will be imposed in China for clean air, CAFE

Recyclability

- Recyclability issues pushing families of materials that can be recycled together
- Recyclability—government mandates requiring reuse/disposition
- Recyclability—if new material can be introduced at some cost
- Recyclability/recycling (19)

- Recyclability—concerns on shredder dust disposal (ease of treatment and cost) require careful selection of materials
- Recycling, both separation and reuse
- Sustainability material life cycle standards
- The technical (not practical, economical) feasibility to recycle

Manufacturing Issues

- Ability to lend themselves to modular component-manufacturing efficiencies
- Assembly cost, architecture, parts count, processes, and automation
- Availability of infrastructure to produce the materials and components from them
- Comfort level of taking some materials from low volumes to high-volume production
- Compatibility of alternative materials with existing assembly infrastructure.
- Composite joining and repairability
- Ease of assembly and disassembly
- Ease of forming: high degree of parts consolidation requires flexibility of processing/forming
- Ease of manufacturing
- Existence and/or establishment of appropriate infrastructures for the high-volume supply of materials
- Existing sunk capital forcing product design into a "Reform-Plus-Assembly" approach versus the option plastics bring of net shape production
- Flexibility of processes using selected materials
- For plastics, overcoming the resistance from OEMs to phase out investments in steel stamping
- Form stability
- Formability—we must revise manufacturing processing to stay competitive
- Formability of higher strength materials
- Hazardous materials (at any point in the supply chain)
- Joining of dissimilar materials to afford greater use of materials in specific locations
- Large use of carry-over parts limits the material selection
- Manufacturability—processes primarily developed by suppliers
- Manufacturability—robust
- Processability
- Processability/Productivity
- Processable in existing assets
- Reliable joining of lightweight materials for structures

Material Properties

- Performance requirement forcing a materials change
- Performance—new material development
- Temperature capability
- Thermal/mechanical properties
- Uniform property definition and characterization
- Updating specifications established over 50 years ago—ferrous and nonferrous chemical compositions; updated specifications would provide closer chemical tolerances that can be readily met today by most mills

Corrosion Issues

- Corrosion resistance (2)
- Corrosion resistance (long life for nonmetals)
- Corrosion resistance of the material or the process to make it so
- Increased warranty periods for anticorrosion
- Loss of function due to corrosion of structural and electronic materials

Safety

- Crash requirements (head impact)
- Crash/safety—lighter smaller cars and trucks requiring engineered structures

Familiarity

- Ease of getting new material properties (universal database)
- Educating OEM designers on overall advantages of plastics/composites
- Getting commercial experience for new materials
- Insufficient knowledge in the tier supply base (reoutsourcing more to a smaller number)
- Lack of education in alternative materials—materials science remains primarily metallurgy versus "generic" materials science. This lack of awareness and education is endemic though the entire engineering curriculum, and starts with the professors and their lack of experience and expertise.
- OEM engineering capability is limited and being transferred to suppliers who need more education and better modeling tools for design, manufacturing, assembly, and durability.
- Product designer competence to utilize these alternatives to their fullest extent
- Properly defining product requirements to chose "right" material
- Unknown liability risk for materials with failure modes that differ from today's materials

Increase in strength and stiffness

- Strength (2)

- Strength—stiffness and impact
- Strength-to-weight ratios (2)

Lightweight

- Ability to incorporate a material into a subsystem that lowers system weight (it is not the mass of the material itself)
- Lower weight materials to enhance emission or CAFE will normally only be introduced if new products come in with cost reduction—not likely to pay for weight swap with government weight class criteria
- Mass reduction (4), Weight reduction (15)
- Recognition of the value of materials and especially lightweighting on life-cycle cost
- Supply base has little experience in lightweight components and little interest in acquiring experience since OEMs won't pay, since customers do not perceive that low weight is a valuable vehicle attribute.
- Weight minimization
- Weight, fuel economy, and less CO_2 emission are the most important key words during the next decade.
- Weight—except in the U.S., auto designers have always strived for low weight. Real progress will only be made with lightweight materials.
- Weight—goes with cost
- Weight—important for fuel economy and emission strategy
- Weight—significant weight reductions will be required for fuel economy improvement.

Other

- Ability to consolidate parts
- Adhesive bonding of structured joints in the body structure
- Aesthetic design
- Alternate fuel requirement—battery technology, higher combustion temperatures—after treatment systems
- Appearance (2)
- Availability of materials (3)
- Availability of the materials over the world having the same materials at plants overseas makes the vehicle development process very simple.
- Availability—materials like magnesium
- Availability—must have multiple sources of supply (2)
- Ceramics for turbines
- Color ability

- Compatibility among materials/fluids/components/designs
- Compatibility with other materials
- Compatibility with other materials and surface treatments
- Computer modeling able to predict performance of selected materials
- Customer (internal and external) acceptance, durability, quality, reliability
- Customer preference/design and styling
- Design and analysis experience—for specific materials and processes, especially systems integration issues
- Development time
- Durability (4)
- Durability/reliability
- Evolution of a secondary magnesium alloy supply which meets current high performance ductility requirements
- Friendly interior materials that meet durability requirements for safety
- Global standardization of materials
- Government regulations forcing a material change
- Higher performance and longer term durability
- Long-term field history, especially fatigue behavior
- Material changes' impact on customer expectations (based on traditional materials)
- Material performance under expanding warranty targets and increasingly severe operating environments
- More aggressive/stylish designs demand change in materials due to material forming/processing/packaging limitations
- Multifunctionality—parts reduction
- One supplier base for all materials in the plant
- Performance—ability to function is a given—listing refers to ability to achieve improvements
- Reliability/warranty
- Risk averse nature of automotive company design and engineering staffs
- Same as today—manufacturability, process, durability, customer pleasability, cost, disposal, recyclability
- Technologies, such as GrFRC, may offer elegant engineering solutions, but their application within the design, manufacture, repair/service infrastructure of today's automakers make their broad application extremely difficult.
- Use of plastic in the fuel system because of susceptibility to loss of strength due to elevated temperature

- Value of scrap metal–Japan has done very well with no raw material.
- Warranty

Discussion

The panelists most frequently list cost as the most critical long-term strategic consideration for material selection. They also forecast increased engineering requirements, manufacturability, environmental issues, and recyclability as important long-term strategic challenges.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

Throughout the 1998 Delphi survey, the materials panel leaves little doubt that they believe cost will be the most important strategic challenge facing the industry in the coming decade. The challenge to maintain affordability will demand that industry participants continue to focus on cost reduction. However, those who concentrate on cost at the expense of other attributes do so at great peril. The potential of stricter CAFE and emissions regulations, combined with the work of the Partnership for a New Generation of Vehicles, has positioned the North American automotive industry on the edge of a new materials paradigm.

Recyclability presents a variety of challenges. Currently, technologies exist to recycle most plastics; yet, because the plastics-reclamation infrastructure and subsequent reuse of reclaimed materials is not economically viable, most plastics recycling projects continue to be less than successful.

Unless an outside force (government regulation, oil-price shock, recyclability requirements, etc.) directs the automotive industry, the material-selection process will continue to be cost-driven. Although there will be a continued effort to incorporate new materials applications, new materials will be considered a viable alternative only if they are cost competitive with current materials.

A wide variety of responses was given by panelists. We urge the reader to review the list carefully. Even a rarely mentioned factor may be a clue to new thinking in the industry.

MAT-13. Please indicate the level of influence that various departments or activities have on material selection in your company. Please respond for only the category (i.e., OEM, Component Supplier or Material Supplier) that applies to your company.

Scale: 1 = very influential	3 = somewhat influential	5 = not at all influential

	Mean Rating		
Departments/activities	**OEM**	**Component Suppliers**	**Material Suppliers**
Product engineering	1.2	1.8	1.9
Material engineering	1.7	1.7	1.8
Manufacturing	2.2	2.4	2.2
Safety	3.0	3.1	2.5
Purchasing	2.6	2.7	2.3
Environmental	3.3	3.0	2.6
Marketing/sales	4.1	3.3	3.0
Finance	3.6	3.5	3.7
Service	4.2	4.0	3.5
Government relations	4.3	4.1	3.5

Other departments/activities:

Corporate policy: 2

Customer satisfaction: 2

Suppliers: 2

Selected edited comments

- As a raw-material supplier, we attempt to influence all of the above areas at tier 2/tier 1/OEMs.
- Design and manufacturing planning clearly have the lead.
- For many components, material selection is the province of the Tier 1 suppliers.
- I assume this means the selection of materials that we wish to supply to OEMs and component suppliers.
- In many instances, safety can be handled by a variety of materials via good design. Interiors will require materials to be part of the design solution.
- In my company, sales/marketing personnel are also engineers dealing with customer purchasing and engineering groups. Sales and materials engineering decide what products are applicable with input from product engineers, manufacturing and (to a lesser degree) finance.
- It completely depends on who is responsible for the design of the part. For "black box" parts, the component supplier has practically all the influence on the choice of materials (i.e., we, as the OEM, have very little opportunity for input).
- Our products are highly specialized. We coil coat (steel or aluminum) with paint, adhesives, lubricants, and film laminates. It is the responsibility of field technical sales to ascertain

specification and product requirements from the customer and then work with materials engineers to select the product that will satisfy those requirements.

- Product engineering and material engineering play dominant roles in material selection, with strong recommendations or requirements from vehicle evaluation departments (durability testing) and purchasing departments.
- Product engineering and materials engineering are the most influential in selecting materials. They confer with others before proposing material candidates.
- Product engineering still must make final decision on all the trade-offs. Two key stakeholders are material engineering and purchasing. Purchasing brings in the raw-material cost factor and supplier ideas based on supplier's manufacturing/technology expertise.

Discussion

The panelists indicate that product and material engineering are the most influential functions in the material-selection process. The panel also views manufacturing and purchasing as very influential.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement. However, the manufacturers (1.2) indicate that product engineering is more influential than do the component suppliers (1.8) and the material suppliers (1.9).

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

Given the emphasis that the 1998 Delphi IX materials panel has placed on cost reduction, the fact that product and material engineering are rated as the most influential activities in the material selection process is somewhat surprising.

Conventional wisdom states that purchasing has a strong, even overpowering, dominance in the automotive industry. The results of this question indicate that purchasing's influence may be less than convention indicates. It does appear, at least in the view of the material engineers surveyed, that there are four activities that strongly influence the selection process.

Most materials are defined by the requirements of the part, which is in turn set by product engineering with support from materials and manufacturing experts. Where a premium price material is proposed, generally this must be approved based on a strong business case. Clearly many functions participate in the material-function process, yet it is clear that the dominant ones are product and materials engineering.

MAT-14. 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. *(Emboldened headings represent authors groupings of common ideas.)*

RESPONSES

Challenges (issues):

Cost Issues

- Affordable lighter weight vehicles
- Aluminum manufacturing—low cost
- Aluminum—cost
- Availability of stable, low-cost aluminum sheet for the high volume production of fuel-efficient vehicles, especially PNGV vehicles
- Cost (6)
- Cost (as a component of reducing vehicle cost)
- Cost and availability components by tier 1 supply base knowledge
- Cost of development
- Cost of lightweight materials
- Cost reduction
- Cost to purchase—price of vehicle
- Cost-effective designs
- Cost-effective mass reduction (2)
- Cost-effective use and disposal for nontraditional materials is based on designing with these goals in mind. When this fact is recognized, the realities with respect to both of these is changed drastically from the common perception.
- Cost-efficient lightweight structures for fuel efficiency.
- Designing for system cost, not dollars-per-pound. material cost
- Development of light-gauge, dent-resistant or bake-hardenable steel with good ductility
- Dimensional stability
- Keeping costs down while shortening the time for product development
- Low cost—component integration
- Materials manufacturing cost increases
- Minimize capital/labor utilization

- Overall cost effectiveness
- Reduce number of parts/more simplification in designs—reduce cost!
- Reducing the cost of lightweight materials
- Reducing the vehicle cost
- Solutions that are not cost-effective are nonstarters
- The cost of aluminum: material, fabrication, and service repairs
- The cost of thermal stability in plastics (painting and service)
- Use of existing capital

Environmental Issues

- Eliminating all hexavalent chromium—if the proposed EU directive to eliminate these materials by 2002 takes effect
- Eliminating all PVC
- Environmental issues in the production and processing of materials
- Environmental: Materials that present environmental/disposal problems (e.g., GFR thermosets) create one problem while solving another.
- More environmentally friendly and lower cost manufacturing processes
- More environmentally friendly material/vehicle
- Reducing emissions
- Removal of materials/processes that use harmful (real or perceived) chemicals
- Substitutions for materials of concern
- Tighter emission standards require (1) high efficiency catalyst to reduce NOx under lean condition, (2) improved fuel to assure proper combustion and catalyst activity.

Recyclability

- Maintaining value of recycled material from the new aluminum-alloy stream
- Meeting environmental demands for recycling such as using a limited number of plastic polymers while meeting design, styling, and competitive objectives
- Recyclability (9)
- Recyclability—reusability
- Recycling infrastructure
- Recycling—get the plastics issues solved
- Staying ahead of the environmental issue (disposal/recycling) to avoid legislative requirements
- Ultimate disposition
- Zero or minimal environmental impact

Materials/manufacturing issues

- As the North American auto industry becomes more global, issues of global materials sourcing, specifications, and regulations will arise.
- Catalyst development for high-efficiency engines
- Ceramics for engines
- Compatibility between materials processes
- Compatible materials used in the manufacture of component systems
- Competitive (to steel) high-volume costs
- Competitive foreign price pressure
- Complexity—understanding the cost of complexity is becoming increasingly important.
- Corrosion resistance in the presence of increasing severity of environmental conditions
- Formability (2)
- Formability of higher strength materials
- Forming nontraditional materials
- Improve ductility of aluminum alloys
- Joining methods for new materials and for different materials
- Joining–reduce spot welds, increase adhesive bonding
- Less energy-demanding materials throughout the whole life of vehicles, from raw material production to reclamation of the material
- Limited installed manufacturing base for nonferrous automotive components
- Magnesium—cost and availability
- Manufacturing process control
- Manufacturing with alternative materials is heavily constrained by existing mass production capitalization, which drastically curtails product design options for these materials. The opportunity to engineer cars and trucks cost-effectively with possible features and advantages that plastics can enable is lost due to this "structural" obstacle. A new company could "end run" existing companies and bring out dramatically new and different products since they wouldn't be constrained by this same self-imposed obstacle.
- Material changes impact on manufacturing capital investment
- Material consolidation
- Materials development that represents aerospace performance at auto pricing
- Metal—matrix composites
- Proving strength and durability of plastics
- Rapid tooling to meet 18 to 24 month design to manufacturing time lines

Design Issues

- Decrease vehicle mass reducing the vehicle weight (6)
- Design engineer knowledge of plastic alternative for system solutions
- Design guidelines for lightweight metals components
- Design optimization
- Educating/training/developing “plastics technologies” at the OEMs
- Engineering models for integrating and optimizing design and manufacturing for lightweight, durable components.
- Expertise in designing with alternative materials; ability to couple traditional and nontraditional materials in component and assembly design
- Learning curve with new material in product design and manufacturing
- Lightweight
- Systems design guidelines to accommodate lightweight metal components
- Weight efficiency
- Weight reduction to meet tighter fuel economy
- Weight reductions using essentially the same materials (e.g., carbon steels, stainless steels) with some exceptions

Other Issues

- Export opportunities
- Further minimizing effects of corrosion/environmental degradation
- Global availability of materials
- Global economic stability and growth
- Government restriction of some materials
- Governmental control
- Higher exhaust temperatures
- Higher vehicle durability—higher performance materials/products
- Increasing fuel economy (2)
- Longer-life catalysts
- Part consolidation
- Preference of purchaser—technical breakthrough could change entire market
- Repairing nonsteel components
- Supplier infrastructure
- Supply base changing/shifting
- Systems integration

- Versatility of application

Opportunities (solutions):

Cost Issues

- Accountability for system cost
- Aluminum manufacturing—low cost
- Cost–invest more time and energy developing solutions using materials that are cost-effective and reduce the R&D on materials that promise solutions, but always at some cost premium.
- Development of new structural materials, especially composites, that are cost-effective for automotive application
- Low cost—component integration
- Reduce raw materials cost; need new approach to cost raw materials supply. Reduce tier 2 supply cost.
- The potential for increasing aluminum sheet availability at competitive cost by using continuous casting

Environmental Issues

- Demonstrating safe, environmentally clean energy recovery from automotive shredder residue
- Development of recycling technologies
- Downsizing—fuel and emission improvements
- Environmental–avoid materials that bring environmental problems, either future or current, with them. With development time plus vehicle life in excess of 15 years, betting on technical solutions to environmental problems being available at recycling time is more of a gamble than is currently appreciated.
- Facilitate material disposal at end of life by having systems made from compatible materials, leading to an increase in material recovery and a decrease in materials being landfilled.
- Fuel economy and environmental legislation presents opportunities
- More creative processes/ideas that have "green" in mind from the beginning will allow for "cleaner" manufacturing and a "cleaner" vehicle.
- Recyclability (2)
- Recycling—get the plastics issues solved
- Redesigning components and systems for recycling and dismantling
- Vehicle dismantling

Materials/manufacturing issues

- A good method of joining/repairing polymer matrix composites
- Adhesive bonding of joints in body structures will result in lighter sections and improved body stiffness

- Advances in adhesive-bonding cure time
- Application of full life-cycle analysis (LCA) on materials is inevitable to gain the approval of the consumer.
- Change in method of design and assembly
- Custom analytical software programs for systems
- Develop families of solutions using materials that have application over a broad range of design and manufacturing problems/situation; avoid one-off niche solutions that proliferate special conditions/requirements.
- Eliminate painting or bypass high-temp paint operation; design molecular architecture.
- Fundamental research and improved processes to allow formability advances
- Improved heat treatment on steels, use of highly integrated parts design, easy-to-use joining (fastening) technology and highly controlled polymer structure contribute to the use of lighter materials.
- Improved manufacturing technology
- Joining with bonding, laser or E.B. welding
- Magnesium–strength through work hardening
- Manufacturing/process development—automation and artificial intelligence will escalate
- More research into ultra high-speed machining
- New bonding methods use of adhesives
- Rapid prototyping
- Rapid prototyping or alternative means to get to final tooling ASAP with minimum costs
- Reduce or eliminate assembly plant e-coat systems (new facilities, not existing equipment) by using preprimed steel/aluminum sheet and adhesive bonding or use of weldable primers
- Superior forming techniques for nonferrous metals

Lightweight Materials

- Decrease in mass (increased use of aluminum, magnesium, thermoplastics, and composites in lieu of ferrous materials)
- Development of cost-effective lightweight materials—feedstock and manufacturing
- Weight efficiency
- Weight savings

Material-Specific Responses

- Aluminum—flexibility of design, recyclability
- Ceramics, the materials of the future (for the last four decades)
- Families of materials that can be used for various applications in each vehicle will gain favor.

- Growth of HSLA steels, especially stainless
- High-strength steels and innovative designs
- Increase use of aluminum, magnesium, thermoplastics, and composites in lieu of ferrous materials
- More aluminum, plastic, precoated metal usage
- Plastics and lightweight metals (magnesium, aluminum) can capture market share from conventional materials.
- Use of higher alloyed stainless steel and aluminum as well as more coated materials

Other Issues

- Education
- Education/training in materials/material properties
- Electric car/fuel-cell car would have some new material requirements
- Emerging market entry (India, South America, etc.)
- Finite element analysis (2)
- Greater use of the predictive powers of computer analysis
- Higher performance nonfinancial products, especially for elevated temperature applications—fatigue will be a big area of development
- Improved/innovative design solutions
- Introduction of new concepts to keep the active site of catalyst from being deteriorated under lean conditions
- Longer useful life
- Long-term supply contract
- Material suppliers developing strong knowledge base to aid industry
- Materials that can be molded or formed into a few components, replacing many components with different functions, will gain favor.
- More effort to understand materials issues and construct models; lower cost computers.
- Must come from R&D. Overall efforts are now not enough.
- Neodymium for magnetic applications requires shielding not yet invented. Can be used for power generation.
- New catalyst formulations
- New designs utilizing novel approaches to achieve strength requirements using less material
- New suppliers investing in new technology
- Open-minded thinking to evaluate true opportunities and costs for alternative solutions
- Optimized structure designs to reduce amount of materials

- Plastic design/engineering programs needed at major universities
- Property data/material models for commodity materials
- RFG/RFD with much less polyaromatics and sulfur content
- Start up a new OEM to produce composite vehicles
- The existing unskilled capacity for the volume production of low-cost aluminum sheet
- Willingness to implement new solutions and not constrain their design by existing paradigms

Discussion

The panel lists a wide array of material-related issues that will present opportunities and challenges in the coming decade. The responses can be placed into four general categories: cost reduction, design, environmental, and manufacturing.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

The panel's responses to this question reaffirm the importance of cost to the North American automotive industry. Throughout the materials volume, it is apparent that cost is a very important issue in material selection. However, it would be misleading to suggest that cost is the only important factor. To remain competitive in the coming decade, participants in the North American automotive industry must continue to develop efficient design, manufacturing, and environmental strategies that allow for cost-effective solutions.

Many of the design and manufacturing concerns raised by the panel are due in part to the lack of comfort in the processes necessary to maximize the benefits of lightweight materials. This presents an outstanding opportunity for proactive suppliers. The development of information resources that allow for quick and reliable information transfer should be an integral part of any materials-awareness strategy. Concomitantly, assemblers must be willing to openly evaluate materials based on the merit of the material.

MAT-15. 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	2.4
Body	2.5
Chassis	2.5
Perforation Corrosion	
Powertrain	2.0
Body	2.2
Chassis	2.2

Selected edited comments

- Better chip-resistant paint is required.
- Brake corrosion is still a problem.
- Chassis and under-body parts still need to increase to match the body's performance level.
- Chassis corrosion in underbody systems is still a concern. Also, a replacement needs to be found for chrome plating for environmental reasons.
- Cosmetic and perforation corrosion for coolant, fuel, brake, and transmission components has not kept up with the protection of body panels.
- Dissimilar metals, such as magnesium vs. steel, and some aluminum alloys create problems.
- It is still very evident from the appearance of cars that are six years old or older that the corrosion of body panels is still a major cosmetic issue, especially in the northern areas of North America that are subject to snow.
- More corrosion-resistant materials are needed for mufflers.
- New coolants for powertrain are required.
- Once the protective paint/primer surface is cracked, exposing steel, it will start to corrode.
- Postpainted chassis and powertrain parts are done with inadequate cleaning and pretreatment systems. As a result, paint performance is compromised.
- Steel still rusts when paint is dipped.
- The average age of vehicles on the road is at an all-time high. The sales of used vehicles have increased and are projected to overtake new vehicles. There is a substantial segment of the

population that never buys new cars. Cars still "rust out". The "experts" that say corrosion is "resolved" probably all drive two-year lease cars.

- The cost of cars and trucks is high enough that it is reasonable to assume many people will be keeping their vehicles running longer without trading—thus lengthening the "corrosion protection window." I do not think existing systems will give that extended, greater-than-10-year life this will require. Consequently, I believe many of the newer vehicles that are just reaching that age now will be disappointing to many owners; it will be interesting to see the result.
- The cost to prevent corrosion is still too high.
- The inducement of galvanic corrosion by the introduction of aluminum will require extra steps and cost to prevent.
- The margin of safety and the length of protection could be longer were it not for cost limitations.
- The technical issues probably have been satisfactorily resolved but for various reasons, including cost, the solutions are often not implemented.
- The under-vehicle and under-hood cosmetic corrosion performance still lags the body in field performance. The true voice of the customer in this area has yet to be heard, and therefore the real value of improvement in these areas is questionable. The additional cost for improved under-vehicle and under-hood protection is often a tough sell in today's competitive market.
- The used car market will tell the good from the failed. Again, smaller sales volumes in the future are expected due to cost; therefore stronger used car markets will result.
- There needs to be continuous improvement in all areas, but solutions for traditional designs exist. As more aluminum and magnesium are used, there will be learning curves as we learn, using various new applications.
- Today's primers rely on materials of concern: lead, chrome, etc. Powertrain relies heavily on electronics, which are also subject to corrosion.
- Under-hood white corrosion is still a problem.
- We still see significant corrosion on body panels. Aluminum radiators and heater cores are still being replaced. Light truck frames are not adequately protected from corrosion.
- With the increased perforation warranty period, field surveys indicate that the warranty is not being achieved. Cosmetic corrosion is better but still a concern at five years.

Discussion

The panelists agree that corrosion avoidance has been improved; yet comments suggest that there is the need for further improvement.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

Significant progress has been made in corrosion protection in the past decade. However, significant work remains to be done before the corrosion issue can be considered satisfactorily resolved.

Effective corrosion protection involves a systems approach. It is critical to consider materials, process, and design as fundamental to a successful corrosion strategy. Failure to adequately address any one of these elements will increase the susceptibility of a vehicle to corrosion. As the use of a variety of dissimilar metals increases, the interaction between these materials will require increased attention. Also, the increased application of plastics will play an important role in overall corrosion protection.

The technology and materials are available to improve corrosion protection, yet many are not implemented due to cost concerns. 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.

The comment indicating service life is increasing is certainly due in part to improved corrosion protection. Panelists from the marketing volume forecast a continuing increase in the average age of vehicles, which suggests they foresee continued improvement in corrosion protection.

MAT-16. 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 1997, 2002 and 2007.

Years to Panel Perforation	Median Response	Interquartile Range
1997	8	6/10
2002	10	7/10
2007	10	10/12

Selected edited comments

- Anticorrosion treatments and selection of the materials based on electrochemical considerations on the fastening structure will take care of the corrosion problems.
- Current rust prevention technologies will be continued until 2002. On the other hand, from the standpoint of life-cycle analysis, countermeasure for perforation will be enhanced so that it is expected that more perforation-resistant cars will be seen.
- I do not expect much activity by U.S. companies unless pushed by foreign competition. Today's condition is fairly good.
- I see no change unless aluminum is adopted in which case the time to perforation will be greater than 10 years.
- It is impracticable to go beyond 20 years, but by 2007, it could probably be done.
- Many cost-saving measures are reducing the capability to achieve the targets.
- My answer reflects the increased use of less corrosion-susceptible materials such as aluminum and polymer composites.
- Requirements in this area continue to be 10 years minimum, but the performance lies in the proper execution of not only material selection, but also the design of the parts and the paint and sealing processes. Getting all three is necessary for meeting a 10-year goal.
- Seams, repairs, and chipping damage will improve–more uniform paint application is key
- The increase I note is due to the projected switch to plastic or aluminum panels raising the average, not an improvement in steel/coatings.
- There will be a continued effort to add other processing aids beyond galvanized steel.
- There will be continuous progress in improving perforation in panels. All designs/materials selections are at the same high level.
- These figures represent average performance; there will always be car-to-car variation, and some customers will experience inferior performance.

Discussion

The panel forecast that for both 2002 and 2007 the length of time before panel perforation will be 10 years.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

Although the panel forecasts an increase in length of time before panel perforation, there appears to be little incentive to increase the current six year, 60,000 mile corrosion warranty. Effective long-term corrosion protection is dependent on a thorough systems approach. According to several comments, technology is available to increase the length of time before panel perforation; however, manufacturers must weigh the benefits of longer lasting panels with the associated costs.

The forecast of a 10-year no-panel perforation may have its most significant affect on the used car market. According to the American Automobile Manufacturers Association (AAMA), the average age of a passenger car is 8.5 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, rust is only a consideration because it may affect used car prices.

MAT-17 What percentage change in total vehicle weight do you anticipate by 2002 and 2007? Please also indicate plus or minus (please reference all estimates to 1996 base).

	Median Response		Interquartile Range	
Total Vehicle Weight	**2002**	**2007**	**2002**	**2007**
Percentage Change	-2%	-5%	-5/0%	-8/-4%

Selected edited comments

- Although weight increase will be expected due to countermeasures for collision safety, improvement in design, adoption of high-strength steels and adoption of lighter materials will reduce the weight more than the weight gain.
- By 2002, there will be some reduction due to the dropping of large cars and the introduction of smaller SUVs and minivans. I believe there will be a reduction due to PNGV vehicles entering the marketplace by 2007.
- Consumer preferences will dictate, and by 2007, the SUV/truck boom will have long passed its peak, leading to a mix with lighter vehicles.
- Fuel economy will push mass reduction, and some vehicles will be downsized through improved packaging/design.
- Increased gas taxes will put downward pressure on vehicle weight for better fuel economy. There appears to be a dimming of interest in SUVs. If this is really a trend, car sales will increase which will enable engineering to focus on weight reduction on a larger platform base, perhaps generating faster results.
- Increased market share of heavier vehicles will result in increased weight by 2002; however, by 2007 increased vehicle fuel economy requirements will necessitate vehicle weight reduction.
- Large size demands from the marketplace continue to keep vehicle weight higher than in other areas of the world.
- The change will be driven mainly by improving fuel economy and emission MY requirements.
- The government will dictate vehicle weight in the future. Customer demands will continue to request heavier vehicles (more content, larger sizes).
- The increase in "world cars" will lead to pressure for weight reductions in cars sold in the U.S. Also, some lightweight actions will become more cost-effective and thus have widened implementation.
- The portion will depend on energy cost!
- The pressure for additional equipment will continue. Gas supply and pollution issues drive mass down after 2000.
- There exist no clear fuel economy targets to be integrated into new models scheduled before 2002. But for the vehicles beyond that, new targets will require more than a 10 percent increase in fuel economy, based on the agreement made on a CO_2 level.
- There is no consumer demand to reduce vehicle weight. No CAFE changes are anticipated unless an oil crisis occurs.

- There is not much incentive to lower weight as long as fuel prices remain low.
- There will be an incremental change to lightweight products by 2002 with improving technology moving that rate of change higher by 2007.
- These are averages for all vehicles. My estimate by major segment are: Passenger car: 2002, -10; 2007, -15; Light trucks: 2002, +5; 2007, +5.
- These numbers may vary if the PNGV is realized.
- This is driven by consumer tastes—not some big industry strategy, as is fuel economy.
- Total average vehicle weight will increase due to continued increase in (heavier) light truck sales.
- Trucks will see the most change to meet CAFE.
- Weight and size increases will turn back down in 2002 (especially SUV); performance and environmental impact will drive the 2007 change.
- Weight is continuing to climb for the North American fleet, despite selected increased use of lightweight materials. This is because of the increase in content and consumer selection toward heavier light trucks, vans, and sport utility vehicles. Also, an aging population has decreased the demand for lighter entry level vehicles. Political/social pressure on the environment plus products offered by European and Japanese OEMs will force longer-term weight reduction.
- Weight will continue to be reduced through new lightweight material and integrated design. Plastics will offer the most weight savings.
- With the increasing demand of RVs (including SUVs) and 4WD, total weight reduction will be partly offset, but the pressure of reducing CO_2 becomes more influential, resulting in the reduced size of body and larger use of lightweight materials.

Discussion

Panelists forecast vehicle weight to decrease by 2 percent by 2002 and 5 percent by 2007.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was first asked in this form in the 1996 Delphi VIII. The 1998 Delphi IX panel forecasts less drastic weight reduction than did the previous panel. The table shows the short- and long-term forecasts for the Delphi VIII and Delphi IX panels.

Weight Reduction Forecasts		
	Short-term	**Long-term**
1996 Delphi VIII	-5% (2000)	-10% (2005)
1998 Delphi IX	-2% (2002)	-5% (2007)

Strategic considerations

Government regulation is the most significant driver of vehicle weight reduction. The implementation of more stringent regulation would likely lead to an increased effort to reduce mass. If recently announced carbon dioxide reduction goals are to be met by internal combustion engines, the automotive industry will likely aggressively pursue lightweight materials. In light of these goals, the forecast of a 5 percent reduction by 2007 may be somewhat conservative.

It is important to note that the percent change in vehicle weight is a function of many factors. However, one of the most important factors is raised by the first selected comment. As asked, this question may be interpreted to be highly dependent on the sales mix of the fleet. The recent trend towards trucks has greatly increased the average vehicle weight of the total fleet. Barring an increase in light truck CAFE, or a significant movement by consumers away from trucks, the higher percentage of light trucks could continue to raise the average vehicle weight.

The factors involved in weight reduction are straight forward: improved design, lightweight materials, and size reduction. Manufacturers will seek to optimize the balance between these factors in order to achieve customer satisfaction at the lowest cost.

MAT-18. 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 in order to meet a vehicle's allowable weight class? What will it be in 2002 and 2007? Please do not adjust for inflation.

Passenger Car							
Median Response				Interquartile Range			
1997	2002	2007	2007	1997	2002	2007	2007
Current CAFE Value 27.5 mpg	27.5 mpg	30 mpg	35 mpg	27.5 mpg	27.5 mpg	30 mpg	35 mpg
$0.75	$1.00	$1.25	$2.00	$0.38/1.00	$0.50/1.10	$1.00/2.00	$1.50/3.00

Light Truck					
Median Response			Interquartile Range		
1997	2002	2007	1997	2002	2007
Current CAFE Value 20.7	20.7 mpg	24.0 mpg	20.7 mpg	20.7 mpg	24.0 mpg
$1.00	$1.00	$1.75	$0.25/1.00	$0.50/1.00	$1.00/2.00

Selected edited comments

- 27.5 mpg for both passenger cars and light trucks can be met by applying material replacement with a minor increase of the price. However a 20 percent increase will require more rigorous changes in the parts design and material selection, and thus cost much more.
- At current fuel economy levels, material selection/design/manufacturing opportunities still exist, so we won't need a directive on mass reduction. As standards increase we'll run out of cost-effective solutions and the premium will go up. Today there are premium material applications used, but they are still subject to replacement with alternative solutions (design, material).
- Cost increase of materials must be compensated with the reduction of other cost-through parts integration or process improvement and others, but the incentives for the weight savings should be offered.
- Even if an OEM said it was worth a certain amount, they still wouldn't pay it!
- Even small increases in light truck CAFE are going to be very difficult to meet.
- I don't think this is a meaningful question—a pound isn't worth anything unless the vehicle is ready for production and it exceeds the requirement. Then, for a short period of time due to the CAFE mandate, a pound is worth a lot, but only until a corrected design can be implemented that gets the weight down without having to pay for systems that are prohibitive.
- In September 1997, the CARB began discussion of a proposal to raise truck CAFE to 27.5 mpg by 2010.

- It appears that this group is overstating the benefits gained from most savings—to achieve the above mpg improvements in 2007 would result in very large mass reductions which would dramatically increase vehicle cost. Other means will be required to compliment mass reductions to meet the types of requirements anticipated above.
- OEMs are less likely to reward for weight savings ideas. It has now become an expected performance similar to quality standards.
- OEMs do not effectively reward suppliers for weight reductions.
- Passenger car (2007 - 35 mpg) may need 20-30 percent weight savings, and this may drive the incentive to smaller trucks/autos. This value will be dependent on the penalty dollars per vehicle as a fraction of how far the fleet is from the requirement. This estimate would be helpful in making a realistic estimate.
- The "step function" built into CAFE makes this question difficult to answer meaningfully.
- The values in dollars-per-pound are ambiguous. If the vehicle weight is in the middle of the weight class, then the dollars-per-pound value is low. However, if the vehicle is on the brink of moving up or down in the weight class, then the dollars-per-pound is much greater. The latter scenario may have a value of up to $5.00/lb., with the former having a value of $0.05/lb.
- There are always design options—downsize vehicle, better analysis etc. But more pressure will be in place, so premiums will be paid.
- There is no cost penalty (value for mass reduction) acceptable today due to cost pressures.
- We will only pay a penalty if we miss a weight class and have to get weight out at the last minute.
- Why would a vehicle manufacturer assume that taking weight out would cost money? The ULSAB project provides ample evidence that weight and cost reduction are possible together. Further, assuming that the vehicle manufacturer has now taken all of the weight out (cost-effectively with steel) that he can, and is still in trouble, the answer to your question depends upon the volume of the vehicle in question and the status of that manufacturer's fleet. In fact, the question really pertains to the few pounds required to cross over into a lower IWC. A manufacturer might be willing to spend $1.50/lb. to take out 10 pounds, but unwilling to spend $1.50/lb. to take out 150 pounds.

Discussion

Panelists estimate that for the current passenger car CAFE (27.5 mpg) and light truck CAFE (20.7 mpg), manufactures value a pound of weight saved at $0.75 and $1.00 respectively. For 2002, given current CAFE standards, the panel forecasts the manufacturers to value a pound of weight saved at $1.00 for both passenger cars and light trucks. For 2007, given CAFE scenarios of 30 and 35 mpg, the panel forecasts a pound saved to be valued at $1.59 and $3.00 respectively. For a 2007 light truck CAFE of 24 mpg, the panel expects a pound of weight saved to be valued at $1.75.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was first asked in this format in the 1996 Delphi VIII. For passenger cars, the Delphi IX panelists forecast lower values for a pound saved for the 30 mpg scenario ($0.75 less) and the 35 mpg scenario ($1.00 less). The Delphi IX panel estimated the value of a pound saved currently as $0.25 less than did the 1996 panel.

Strategic considerations

The value of a pound saved is dependent on many variables and is extremely difficult to estimate. Several of the panelists' comments suggest that due to current government regulations, the value of a pound saved varies greatly depending on a vehicle's position relative to its inertial weight class. Vehicles that exceed their inertial weight class of CAFE goals slightly are likely to place a high value on weight savings. Conversely, those programs that are within their weight class goals place little value on weight savings. Although this may be possible for some components such as hoods and other "hang on" parts, we suspect that the material selection decisions for many components are completed well before the final vehicle weight is known. Finally, a luxury car program, due to its higher margins may place a higher value on a pound saved than a compact car program.

The panel's forecast indicates that increased CAFE requirements will greatly increase the value of a pound of weight saved. However, unless the method to calculate CAFE is changed, it is likely that the actual value of a pound saved will continue to be highly dependent on the specific requirements of each program.

Potential increases in light truck CAFE may create many changes in the coming decade. The California Air Resource Board is considering a proposal to increase light truck CAFE to 27.5 mpg in the coming decade. A change of that significance would have far reaching effects on the selection of materials for light trucks and concomitantly impact the value that manufacturers place on a pound of weight saved.

MAT-19 **How much additional cost per vehicle in current dollars would a manufacturer be willing to add to a typical mid-size passenger car to improve fuel economy by one (1) mile per gallon? This cost may be added for a new device, alternate material, revised material, improved technology, etc. Assume CAFE requirements at 27.5 mpg in 2002 and 30 and 35 mpg in 2007.**

	Median Response				Interquartile Range			
Vehicle Type	**1997 Current Value CAFE= 27.5 mpg**	**2002 CAFE = 27.5 mpg**	**2007 CAFE = 30 mpg**	**2007 CAFE = 35 mpg**	**1997 Current Value CAFE= 27.5 mpg**	**2002 CAFE = 27.5 mpg**	**2007 CAFE = 30 mpg**	**2007 CAFE = 35 mpg**
Passenger car	$3.00	$10.00	$40.00	$62.50	$0/8.75	$1.00/18.75	$11.25/60.00	$25.00/115.00

Selected edited comments

- $0, unless that's the only way to meet CAFE
- A 1 mpg increase requires a 5% weight saving that is 150 lb.—manufacturers are paying 50 cents/lb. now.
- About one half of fuel cost saved will be added to the cost of vehicles. This is not technology related but purely related to the car pricing strategy.
- About one half the cost required to save the weight for meeting those fuel economy targets will be added to the vehicle price.
- Again, what is the projected penalty?
- Answers for CAFE of 27.5 reflects the fact that this is currently being achieved. Answers for the higher CAFE levels are based on needing to pay to achieve the CAFE—not to exceed it—and that no cost-neutral way to get to these CAFE levels without downsizing are yet available.
- Cars are becoming too costly. The consumer needs to be able to afford it.
- Consumers don't care about mileage; it all depends on the regulatory zeal of the government.
- Expectations are that suppliers will fund through ideas submission.
- If they can achieve current CAFE requirements they would spend nothing to improve. They will spend only what the law demands, e.g., if they must pay a penalty for failure to achieve, they would spend up to that amount to net out no dollar loss.
- It depends on where fleet average is relative to CAFE.
- Ongoing improvements in vehicle mass and fuel efficiency should enable manufacturers to meet the 35 mpg by 2007 without increasing costs.
- The key word is willing. However, they may be forced to add cost.
- The proper use of direct injection or diesel may answer the cost question very clearly.
- There are still opportunities to keep total vehicle cost in line by good material/manufacturing/design. At 35 mpg cost will be added to reach the fuel economy target.

- This is very complicated because of fleet averages, part commonality, etc.
- This question can not be accurately answered without understanding the pressure on the corporate fleet.
- Ultimately, the question is not how much would a manufacturer be willing to pay, but how much the car buyer might be willing to pay. Current experience suggests that consumers are not willing to pay anything to improve fuel economy. The way the question has been worded only perpetuates the fiction that, somehow, automakers will pay for improved fuel economy.
- With gasoline selling at about $1.20/gal and CAFE=27.5 mpg, it cost about $4,346 to go 100,000 miles, or approximately $.044/mile. If CAFE=28.5, 100,000 miles would cost $4,210. So $4,364 - $4,210 = $153.50 for 1 mpg.

Discussion

The panel estimates that currently manufacturers would be willing to pay an extra $3.00 to improve fuel economy by 1 mpg. Given a CAFE of 35 mpg for 2007, the panel forecast that the manufacturers would be willing to pay an additional $62.50 for an additional 1 mpg. The interquartile ranges for this question are exceptionally wide, indicating great uncertainty regarding this question.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-8

There is a statistically significant difference in responses between technology and materials panelists. Mean responses for the two panels are summarized in the following table.

Mean Value of One Mile Per Gallon - $					
2002 CAFE = 27.5 mpg		2007 CAFE = 30 mpg		2007 CAFE = 35 mpg	
TECH	MAT	TECH	MAT	TECH	MAT
$47	$17	$93	$46	$161	$82

Technology panelists forecast a much higher value placed on saving one mile per gallon than materials panelists for all scenarios. It should be noted, however, that the interquartile range is high for all parts of this question for the technology panel, indicating uncertainty or differences of opinion.

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII. The wide interquartile ranges for both the Delphi VIII and Delphi IX responses make comparison difficult.

Strategic considerations

The wide interquartile ranges in MAT-19 and MAT-20 suggest that these questions are exceptionally difficult to answer. There is most certainly no consensus among panelists regarding the value of a pound of weight saved, or how much additional cost per vehicle a manufacturer is willing to accept to increase gas mileage by 1 mpg. The comments for both questions are worth reading carefully and suggest that there are many factors that determine the value of weight savings and fuel economy gains. It may be a valuable exercise for manufacturers to develop better methods to analyze the costs and benefits associated with weight saving trade-offs.

MAT-20 Considering the following vehicle systems, please indicate any material cost saving ideas that merit consideration in the next decade.

RESPONSES

Body exterior:

- Adoption of aluminum for the body structure, which will give 50-55% weight reduction and hence enable very significant materials weight and cost reduction in the chassis, engine and powertrain systems.
- Avoid using steel and save the cost of e-coat continuous cast aluminum sheet.
- Black-unpainted bumpers
- Changes to glass—less weight, noise absorbing, UV absorbing
- Convert any aluminum panels to steel. Convert plastic panels to steel when volumes exceed 50,000. Covert all bumper systems to steel.
- Direct casting of strip for aluminum sheet
- Higher usage of HSLA steels and aluminum
- HSS outer panels with thinner gauges
- I'll go along with PNGV materials tech team and USAMP.
- Increased use of nonpainted plastics
- Lighter gauge can be expected by the adoption of stretch-draw technology, and resulting cost reduction can also be expected.
- Low-cost aluminum sheet; lightweight low-cost magnesium extrusions for bumper support
- Low temperature paint process would open the door to huge savings in body panel cost and weights.
- Lower coating weights for corrosion-resistant steels
- May need to revert back to thin steel because of recyclability, because of image and government regulations; reduced cost of material will result.
- Paint off-line and use more thermoplastics
- Plastic body panels allowing for ease of exterior styling changes
- Plastic panels and cross members
- Precoated metal substrate to prevent sacrifice of zinc precoats and enhance formability
- Preprimed and prepainted metal; preprimed body in white with adhesive bonding or weldable primers; preprimed closure panels with possible prepainted topcoat to match BIW
- RRIM replacing SMC and assembled steel components for style complex pickups' quarter panels; static dissipative plastic substrate that reduces the cost of painting; enhanced reinforcement that allows thinner gauge
- Structural polymeric body panels

- Systems integration of glazing materials and exterior trim
- Thermoplastic panels included—in color
- Use a holistically-developed model very early in the design process, iterating every part change back through the model for mass optimization. Don't aggregate the part designs into a holistic model at the end of the design process.
- Use of polyolefin-based thermoplastic materials for bumper covers, expanded use of thermoplastics for thermosets, laser treatment to increase rigidity of thinner gauge steel, less energy-consuming painting operation, large panel fabrication with help of laser joining technique
- Use of stainless body panels (allows thinner gages and improved corrosion protection)

Body interior:

- Aluminum and magnesium seat structures; reduce foam content in seats (thinner pads)
- Body component reductions through parts consolidation—steel and aluminum
- Commonization of 1 or 2 platforms for interior will decrease material costs.
- Consolidation of part systems, e.g., roof header that would reduce the total number of parts in the system; hydroformed steel tubing in some parts
- Continued complexity reduction through reducing the number of components and increasing size of preassemblies; increased use of inexpensive natural-occurring materials
- Embodying reinforced optional structures by "holistic design" and cost reduction and weight reduction by tailored blanks
- Increase use of plastics and lightweight sound-deadening pads
- Increased modularization
- Increased use of magnesium driven by plastics recycling issues
- Increased use of polypropylene plastic
- Integrated design and fabrication of instrument panels, in-mold printing technique for meter cluster, wider application of flexible printed circuit board for signal and power transmission, appropriately redesigned airbag system
- Integrated die cast magnesium instrument panels and new low-cost world magnesium supply to produce seats, supports, and door inners
- Integrated self supporting modules e.g., the integrated structural instrument panel
- Less leather, more cloth
- Magnesium cross beams, magnesium and aluminum seat structure
- Make all seat frames from steel.
- Molded-in color plastic parts from ABS to high crystalline polypropylene
- One-piece magnesium die castings integrating (A) IP structure, steering column bracket and passenger-side airbag and knee bolster and (B) steering-wheel ornamentation and airbag retainer

- Parts consolidation at door systems
- Plastic system design that consolidates function and reduces material and assembly costs, (e.g. the Dakota instrument panel structure) extending this same design efficiency from instrument panels to doors and seats
- Polypropylene for ABS in trim; molded-in color plastic components
- Polypropylene interior, magnesium and aluminum
- Reduce significantly the number of types and grades of polymer materials specified.
- Replace high hardness heat-treated alloy steel with high-strength low-alloy steel in seat-belt hardware.
- Select one type of plastic material for all trim applications.
- Use a single supply source for cockpit modules.
- Use of olefin-based materials in lieu of engineering thermoplastics; development of component systems incorporating features that allow for part reduction

Chassis:

- Adoption of semi-solid, near-net shape casting of components in aluminum; weight and cost would be reduced if body exterior and interior is down-weighted by using aluminum there.
- All aluminum structure to take advantage of the difference in density
- Aluminum suspension/chassis components–stiffer and lighter to achieve higher performance
- Cast aluminum and magnesium, hybrid /extended aluminum, hydroformed aluminum
- Converting aluminum wheels to steel will save $100 per car.
- Cost and weight reduction by use of hydroforming technology
- Electric motor for power steering system; drive by wire system for acceleration and braking
- Eliminate some of the goodies like smart suspension
- Extensive use of aluminum
- Foam-filled, energy absorbing rails and cross members
- Hydroforming—steel or aluminum plastic
- Increased use of carbon fiber composites.
- Increased use of engineered plastics
- Integration of suspension parts with permanent die casting and injection moldings
- Lighter vehicles will allow downsized chassis components
- Lighter weight and durable brake components that dramatically reduce today's +$75/vehicle warranty cost
- Look for opportunities to "clone" chassis components to reduce manufacturing cost (see AISI Light Truck Study).
- Optimized designs to use less material

- Space frame—metal and metal plastic hybrids
- Stainless steel frame (less cost than steel and aluminum)
- Ultrathin CAD/CAE designs in aluminum castings
- Use carbon composites for body in white.
- Use of higher specific/stiffness materials and more sophisticated design/forming (1997 Corvette for example)
- Use of stainless in structural components

Powertrain-engine:

- Aluminum blocks without cylinder liners
- Aluminum engine blocks, nylon intake manifolds
- Convert plastic fuel tanks to coated steel.
- Critical design of components
- Elimination of costly plastic/rubber carrier-type gaskets with more cost-effective sealing solutions at the tier 1 component manufacturer
- High-strength ultrathin wall, iron castings
- High temperature-resistant composites for valves; prepainted and metal-to-metal laminates for oil pans and valve covers; prepainted (adhesives) gasket stock.
- Hybrid (IC-Electric)
- Increased use of engineered plastics
- Increased use of magnesium and aluminum for casting applications
- Increased use of polymers for fuel rails and air intakes
- Integration of intake manifold and air managing system (air flow meter and surge tank), elimination or reduction of heat spot within cylinder through uniform heat flux to coolant
- Light weight iron, use of more plastics
- Lower overall weight results in reduced powertrain size and thus lower weight
- More accurate, lower cost manufacturing processes
- More cast aluminum applications, same cast-aluminum applications, additional application of plastics
- More use of worn-out-shape casting processes which can integrate more features; lower costs through precise improvements, higher material utilization
- Movement to heat-resistant materials (i.e., NASA-developed composites) could result in much lighter parts allowing entire engine redesigns for weight and size reductions.
- No cams, all aluminum engines
- Nodular iron crankshafts in place of steel
- Optimized designs to use less material

- Plastic ILO of aluminum intakes; linerless aluminum blocks (coatings)—319 secondary aluminum; ILO stamped steel oil pans/rockers covers
- Replacement of magnesium castings with aluminum
- Unified approach to valve cover design in magnesium, combining total recyclability

Powertrain-transmission:

- All aluminum housings and differential for light trucks
- Better surface treatments may enable the use of less expensive materials.
- Convert to variable transmission.
- Increase use of engineered plastics.
- Increased usage of sintercasts
- Increased use of magnesium and aluminum for casting applications
- Integration of case and structural covers will raise and lower cost, raise durability in materials for CVTs.
- Lesser engine torque fluctuation resulting in smaller and more efficient transmission
- Lighter vehicles achieve increased performance without transmission upgrades.
- Magnesium castings, higher strength gearing/shafts, magnesium/plastic converters
- Magnesium housings
- More accurate lower cost manufacturing processes
- Optimized designs to use less material
- Prepainted transmission pans; prepainted (adhesives) gasket stock
- Replacement of magnesium with aluminum castings and cast iron with aluminum where volume-for-volume replacement is possible
- New low-cost supplies of ultrathin wall magnesium die castings for transmission.

Discussion

The panelists' comments suggest that the automotive industry will increasingly rely on "holistic" design models to more effectively reduce costs.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

Material selection has historically focused on individual components. However, over the past decade, the industry increasingly has accepted a systems approach to the material selection process. Panelists' comments suggest that the coming decade will see a continuation of this trend.

The North American automotive industry faces the potential of significant change in the coming decade. Increased federal regulation of emissions and CAFE could have far reaching implications in the selection of materials. Electric vehicles, hybrid vehicles, and fuel cells may present viable alternatives to the current internal combustion engine in the coming decade. Potential changes of this magnitude present opportunity for new materials that are both lightweight and cost-effective. The implementation of such materials from the earliest design stages will be critical.

Interestingly, recent developmental work in electric/hybrid technology indicates that significant weight reduction may not be essential for increased fuel economy. Many of the recently introduced hybrid concept vehicles have relied on traditional materials to offset the increased cost of the hybrid powertrain. Although weight will continue to be an important concern, the cost savings offered by traditional materials may in fact be an integral part of future hybrid strategies.

Cost reduction will likely remain a critical material selection factor for the coming decade (see MAT-11). It is especially important to note the wide array of comments regarding cost reduction. Incumbent materials will likely face increased competition in the coming decade. Systems integrators will be challenged by materials parochialism and must work diligently to select the materials that best meet the requirements of the system.

The wide ranges of materials represented in the panelists' comments indicate the varied expectations and prejudices of the materials panel. This only reinforces the idea that materials competition will likely continue to increase.

MAT-21. It appears that weight reduction, government regulations and recyclability are significant issues confronting the auto industry. Please indicate how these issues can be successfully addressed within the current cost reduction environment.

Design

- Address weight reduction using approaches such as holistic designs using steel—ULSAB project.
- Better design using computers, finite element analysis, and a better understanding of materials can address all these and reduce cost.
- By proper design, painting and assembly techniques, and investment in new processes
- Cab-over design to maintain interior space while reducing overall strength.
- Consider redesigns where current materials are used to reduce weight through higher strength, assuming a design is used which eliminates stiffness.
- Design by analysis to optimize structures at lowest weight.
- Design for disassembly
- Design for disassembly of parts and modules containing significant plastics.
- Design for manufacturing (more cast aluminum/magnesium for example in chassis)
- Develop optimized designs using less current materials.
- More sophisticated frame design
- Start new vehicle designs with lightweight materials to achieve the benefits of a significant overall weight reduction.
- The integrated-structural-plastic instrument panel is an example that lowers weight, complies with impact requirements, and is highly recyclable; yet also lowers cost. This is done by optimizing design around the plastic materials.
- ULSAB has proven that mass reduction and cost reduction can be accomplished together. Further, steel has a proven recyclability track record, as recovering steel scrap from junked autos has been a for-profit business ever since the car was invented. Steel is also unsurpassed in enabling automakers to meet safety regulations.

Environmental

- Allowing incineration (technology exists) as option to recycling
- Better and more shredders, perhaps tax-supported
- Consumer recognition of the need for reducing CO_2 from vehicles is becoming clearer, and this is forcing vehicle manufacturers to respond quite faithfully.
- Develop recycling technologies for all new lightweight materials.
- Energy recovery from auto plastics waste

- For recycling—discourage difficult to recycle products by imposing a "disposal fee" based on content of those difficult-to-recycle materials.
- Improve air quality by getting older cars off-road with programs like "Cash for Clunkers."
- Make auto companies responsible for scrap cars, then rely on market forces.
- Manufacture major interior component systems out of blend-compatible thermoplastics for ease of recyclability at the end of vehicle life.
- Raise landfill costs to spur change.
- Recyclability—reduce the number of different kinds of plastics used; commonize where possible to facilitate tear down separation for recycling weight reduction. Utilize low specific gravity plastics (i.e., PP & PE) to displace heavier plastics (i.e., PC and ABS) in instrument panel, exterior and interior trim.
- Recycling can actually reduce costs of noncritical parts (wheel liners, reflective lenses) through replacement of virgin plastic with regrind.
- Reduce the mix of materials to ease end-of-life separation. However, as for all metal structures, separation of ferrous alloys from nonferrous lightweight metals is readily achieved.
- Weight reduction at minimal cost penalty will be achieved by a balanced use of high-strength steel, tailored blanks aluminum, plastics, and composites. Recycling is not the issue that it is thought to be by automotive media and automotive-environmental people because the impact of recycling improvements, even if dramatic is, in reality, almost too small to measure. In time, people will come to realize that large efforts that do not help or improve the situation are not productive.

Governmental Issues

- Elect more sensible government officials.
- Fuel economy (weight reduction) and safety regulations tend to be in conflict and need to be reconciled.
- Government regulations (2)
- Government regulations need to be harmonized globally.
- Increase influence in government affairs—up-front responsiveness to public needs.
- Only government regulations or "gas-guzzler" taxes will force increases in costs of vehicles. Otherwise, weight reduction and recyclability must be economical.
- Tax gasoline.

Material Issues

- Aluminum molding and welding leading to low-cost components and assemblies
- Develop technologies such as feedstock and manufacturing, to reduce the cost of lightweight materials.
- Elimination of significant plastics content in favor of metals in vehicle interiors

- Increase use of magnesium and aluminum in lieu of steel for castings, chassis, and body panels.
- Increased use of magnesium and aluminum interior structural parts
- New polymer families
- R&D needs to go beyond each material producer looking for new ways to use its product. The industry needs real materials breakthroughs that I suspect are there if sufficient effort is expended to find them. PNGV should be the catalyst.
- Replace mild steel with thinner, high-strength/low-alloy steel for weight savings, while maintaining recyclability.
- Select from cost effective materials (HSLA steels, aluminum, and some magnesium) and use designs suited to their respective manufacturing processes.
- Use lighter materials where steel has traditionally been used.
- Use more poly (plastic) product when weight savings can result. Disposal, however, can be an issue.
- Use naturally occurring and regenerable raw materials to avoid investment in synthesis equipment.
- Use of more aluminum—weight reduction and recyclability
- Use of more flexible materials such as high-strength plastics
- Use plastics/composites.
- Weight reduction can be helped by the use of stronger materials, which would allow them to be used in lighter gages, thereby reducing the overall weight.
- Weight reduction, through component consolidation into large castings

Other Issues

- Early introduction of even a small number of advanced technology vehicles justifies the higher cost and earns the respect due a pioneer.
- Education of OEM design engineers in the use of new materials and manufacturing methods
- Engineers/designers must understand the business core/issues support to ensure cost reduction, which will require further development projections and transfer of new technologies.
- It will become increasingly difficult, as the low-hanging fruit is gone. Automakers will continue to press suppliers and begin to work up the courage to confront the UAW. Beyond the issues you cite above–competition from transplants will increase significantly.
- Need relief in all areas!
- Optimization of full systems
- Overall vehicle size reduction is the only way to address all of the above-mentioned issues.
- Performance of CAE designs and CAE models of lightweight castings performance vs. in-vehicle performance and 10-year durability; to reduce mass, reduce costs using aluminum and magnesium

- Preprimed and prepainted products eliminate VOCs from the assembly plants and concentrate the issue in the coil coater's operation. The coil coater can effectively deal with the emissions and, in fact, is favored by government regulatory agencies for that reason.
- Realistically, customers know costs.
- Reduce vehicle size.
- Smaller cars with smaller engines
- System approaches may be the answer for ease of assembly.
- This will be driven by new competitors.
- Use smaller displacement engines.
- Vehicle downsizing addresses all three (weight reduction, government regulations, and recyclability) simultaneously.
- Very difficult since, traditionally, adding cost is required to address these issues.
- Weight reduction
- Weight reduction through component consolidation into large castings
- Weight reduction can be achieved together with cost reduction by structural optimization, optimal material selection with the introduction of tailored blanks, and innovation of production technology such as hydroforming.
- Weight reduction, recyclability, and all the required government regulations can be met with aluminum, provided a cost-efficient system is adopted for its use. The weight of the aluminum used must be minimized and full advantage taken of the secondary weight and cost savings that can result from a large primary weight savings in the body structure. However, this overall weight and cost saving can only be achieved with a total system approach; it can't be done piecemeal.
- With the fierce competition in very specialized market segments, manufacturers who can claim any advantages over others in these areas are getting more and more recognition.

System Management

- All of these issues can and will be addressed due to the "cost reduction environment" and in some cases lack of trust/commitment from OEM to suppliers—progress will be a small fraction of what would be possible (10-20 percent).
- An agreement among the OEMs to reduce weight and recycle would help. This is difficult to do because of the cost-competitiveness among the OEMs.
- Competent, open thinking about the function of each area of the vehicle without curtailment due to material bias, existing manufacturing investment, etc.
- Full use of all suppliers
- Increased supplier involvement in developing new system solutions
- OEMs must do a better job of informing legislators of the practicable realities of science vs. politics.
- Offset allowances for "blue sky" R & D investment by component/material suppliers

- Outsourcing of major subsystem components
- Partnerships with bulk material suppliers to ensure their involvement in the early development and design
- Supply chain management to include postconsumer-use points
- There is a need to focus not so much on lower cost materials but on total system costs–we have many opportunities for cost reduction.

Discussion

The range of responses is indicative of the severity of the challenge represented by weight reduction, government regulation, and recyclability within the current cost reduction environment. Panelists' comments focused on design strategies, systems management, environmental challenges, and material strategies.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

The panelists indicate that North American automotive industry participants are increasingly viewing the automobile as a complete system and not merely a compilation of individual parts. Panelists comments also indicate that material selection and the competition between materials is more intense than ever and is likely to get even more intense in the coming decade.

A continued emphasis on system design optimization will be an important element in addressing weight reduction, government regulation and recyclability. As first tier suppliers are increasingly relied upon for system integration, the coordination of systems may become even more critical. Companies that are able to manage the communication between system integrators may have a strategic advantage.

MAT-22. Please forecast the material content change in percentage for the typical North American-produced passenger car and light truck for 2002 and 2007, 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%).

Passenger Cars							
		Median Response			Interquartile Range		
MATERIALS	Est. Current Weight* (27.5 mpg)	2002 27.5 mpg	2007 30 mpg	2007 35 mpg	2002 27.5 mpg	2007 30 mpg	2007 35 mpg
STEEL							
Low-carbon steel	1409 lbs.	-5%	-10%	-15%	-5/-4%	-15/-7%	-20/-10%
HSS steel	287	5	9	10	4/8	7/10	10/20
Stainless steel	47	0	0	0	0/1	0/1	0/2
Other steels	39	0	0	0	0/0	-2/0	-2/0
TOTAL STEEL	1782	-3	-7	-10	-5/-2	-11/-4	-16/-7
CAST IRON	389	-10	-20	-30	-15/-6	-25/-10	-35/-16
PLASTICS							
Thermosets	n/a	3	5	8	2/5	4/7	5/10
Thermoplastics	n/a	5	10	14	5/8	8/12	10/16
TOTAL PLASTICS	245	5	10	19	5/9	8/12	10/20
ALUMINUM							
Castings	n/a	10	15	20	5/10	10/20	15/30
Forgings	n/a	5	10	15	3/5	8/10	10/19
Sheets	n/a	5	10	18	4/9	8/19	11/23
TOTAL ALUMINUM	195	10	19	28	5/11	12/25	16/60
RUBBER							
Tires (include spare)	n/a	0	-5	-10	-2/0	-5/0	-14/-6
All other rubber	n/a	0	0	0	0/0	0/0	0/1
TOTAL RUBBER	139	0	-4	-8	-1/0	-5/-2	-13/-5
GLASS	94	0	0	-5	0/0	-3/0	-10/-5
COPPER (including electrical)	45	-2	-5	-10	-4/0	-10/-4	-20/-5
ZINC							
Zinc coatings	17**	0	0	0	0/0	0/0	0/0
Zinc parts	16	-5	-10	-18	-8/-4	-19/-6	-30/-11
TOTAL ZINC	33	-5	-10	-16	-5/-2	-13/-5	-20/-7
POWDERED METALS	29	5	8	10	5/7	6/10	4/12
MAGNESIUM	6	50	75	150	25/73	30/175	45/225
CERAMICS	n/a	0	0	2	0/0	0/1	0/5

Light Trucks					
MATERIALS	Est. Current Weight* (20.7 mpg)	Median Response		Interquartile Range	
		2002 20.7 mpg	2007 24 mpg	2002 20.7 mpg	2007 24 mpg
STEEL					
Low-carbon steel	n/a	-4%	-9%	-5/2%	-11/-6%
HSS steel	n/a	5	10	3/9	5/10
Stainless steel	n/a	0	0	0/2	0/2
Other steels	n/a	0	0	0/0	0/0
TOTAL STEEL		-2	-5	-5/-1	-10/-5
CAST IRON	n/a	-8	-15	-15/-5	-25/-10
PLASTICS					
Thermosets	n/a	4	7	2/5	4/10
Thermoplastics	n/a	5	10	5/7	8/11
TOTAL PLASTICS		5	10	5/6	9/12
ALUMINUM					
Castings	n/a	8	15	5/10	10/24
Forgings	n/a	5	10	2/5	5/10
Sheets	n/a	4	10	2/5	5/15
TOTAL ALUMINUM	n/a	10	18	5/14	15/25
RUBBER					
Tires (include spare)	n/a	0	-5	-3/0	-5/0
All other rubber	n/a	0	0	0/0	0/1
TOTAL RUBBER		0	-3	-2/0	-5/0
GLASS	n/a	0	-1	0/0	-5/0
COPPER (including electrical)	n/a	-2	-8	-8/-1	-15/-4
ZINC					
Zinc coatings	n/a	0	0	0/0	0/0
Zinc parts	n/a	-5	-10	-8/-4	-20/-8
TOTAL ZINC		-5	-10	-6/-2	-15/-5
POWDERED METALS	n/a	5	9	4/6	6/10
MAGNESIUM	n/a	30	80	20/50	43/100
CERAMICS	n/a	0	0	0/2	0/4

*Source: *Ward's Automotive Yearbook* 1996 and OSAT estimates, except ** Wards Automotive Yearbook, 1993.
n/a–not available.

Selected edited comments

- Aluminum and magnesium casting applications will include cast iron and steel. Plastic will be included but there will be a change in the mix of plastics.
- Among steel, HSS and stainless steel will see increased usage because of stiffer HSS and the fact that stainless manifolds are a good way to save weight. Thermoplastics will somewhat replace thermosets and aluminum if high fuel economy improvement is mandated.

- Biggest and easiest change would be switching from cast iron to cast aluminum engines.
- Carbon steel loses out to thinner HSS for skin panels and to aluminum and composites A/C weight. Cost of alternative products to steel will keep its loss from disastrous levels (for steel suppliers). Aluminum still must overcome forming and joining issues in addition to cost.
- Ceramics will be used as reinforcement in either MMC or PMC.
- I believe magnesium will grow rapidly as the supply continues to develop and costs are controlled by long-term contracts. Most engines will have aluminum heads and blocks by 2007.
- I see an overall decrease in vehicle weight based on dramatically improved design (design optimization). A slight growth in steel percentage is possible.
- Increases in CAFE will lead to a substantial number of cars with all aluminum bodies and the use of lightweight materials (magnesium and plastics or composites) wherever feasible. Multiplex and fiber optics will reduce the use of copper. The use of more sheet aluminum will reduce the zinc needed for coatings and magnesium and plastics will replace many component applications of zinc.
- Stainless steels will be looked at for "nontraditional" structural applications where their higher strength will help reduce mass via a reduction in material thickness.
- Taillight assemblies will likely be replaced with low-weight alternative lighting systems.
- The Ducker study (funded by the Aluminum Association), published in 1996, gave the aluminum content for North American-produced vehicles in 1996 as: Extrusions; 25 lbs., Castings; 190 lbs., Forgings; 2 lbs., Sheet; 30 lbs., Total; 247 lbs. The annual increase over the last 5 years has been 6%.
- The work of the ULSAB consortium essentially means a significant reduction in the amount of steel required to satisfy all of the automotive requirements. It was understood at the beginning of the project that the reduction would occur. Because of the associated cost reductions, it is assumed that even under a no-change CAFE scenario, these changes would be adopted relatively quickly. It should be noted that, at .5 mpg per inertia weight class, the change from 30 to 35 would require a shift of 10 inertial weight classes—a very expensive and unlikely scenario. Other technologies will have to come into play to achieve this quantum improvement.
- The use of zinc coatings will go down as aluminum sheet goes up.

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.

For passenger cars, the panel was give one CAFE scenario for 2002 and two for 2007. The short-term forecast with a given CAFE of 27.5 mpg shows steady movement toward lightweight materials. The panel forecasts steel and cast iron to decrease by 3 percent and 10 percent respectively, by 2002. Aluminum and plastic are expected to increase by 10 percent and 5 percent respectively.

The two CAFE scenarios for 2007 present further evidence of mass reduction through material substitution. For the 30 mpg scenario, the panel forecasts steel and cast iron to decrease by 7 percent and 10 percent respectively. Aluminum and plastics are forecast to increase by 19 percent and 10 percent respectively. For a 35 mpg CAFE in 2007, steel and cast iron are forecast to decrease by 10 percent and 30 percent respectively, while aluminum and plastic are forecast to increase by 28 percent and 19 percent respectively.

For light trucks, the panel was given a CAFE of 20.7 mpg for 2002 and 24 mpg for 2007. For 2002, the panel forecast a weight reduction of 2 percent and 8 percent for steel and cast iron respectively, while aluminum and plastic are forecast to increase by 10 percent and 5 percent respectively. For 2007, the panel forecasts a reduction of 5 percent and 15 percent for steel and cast iron and an increase of 18 percent for aluminum and 10 percent for plastic.

Magnesium is forecast to see significant growth in both passenger cars and light trucks in the coming decade.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, they differ on their passenger car forecasts for magnesium for the year 2007 (35 mpg CAFÉ). The manufacturers forecast a much higher growth rate (283 percent) than do the suppliers (87 percent).

Comparison of forecast: TECH-37

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

Material Content Change - Percent						
	2002 CAFE – 27.5 mpg		2007 CAFE – 30mpg		2007 CAFE – 35 mpg	
Materials	**TECH**	**MAT**	**TECH**	**MAT**	**TECH**	**MAT**
Steel	–	–	-9	-12	-14	-21
Aluminum	–	–	–	–	26	51
Rubber	–	–	-1	-4.4	–	–
Zinc	–	–	-1.2	-15	-1.9	-22
Magnesium	29	56	47	99	70	184

In all cases the materials panel forecasts a greater change, whether the change is positive or negative. For zinc and magnesium the total quantity of material currently used in a vehicle is relatively small. If a change is thought of in terms of absolute weight, a small change in weight can cause a large percent change.

Trend from previous Delphi surveys

This question was changed in the 1996 Delphi VIII to ask for percentages instead of actual pounds. Therefore, comparison to Delphi forecasts prior to Delphi VIII are not possible. The Delphi IX panel is in general agreement with the Delphi VIII panel. However, the Delphi IX (2 percent growth for long-term 35 mpg scenario) panel forecasts much smaller growth for ceramics than did the previous panel (10 percent growth for the long-term 35 mpg scenario).

Strategic considerations

The automotive industry is expected to continue the trend to lightweight materials in the coming decade. Increased penetration of lightweight materials will come at the expense of traditional materials such as low-carbon steel, cast iron, cooper and zinc.

To achieve a passenger car CAFE of 35 mpg, by 2007 the panel forecasts a vehicle weight of 2835—a reduction of approximately 155 pounds. Whether or not that is enough mass reduction to reach a 35 mpg is questionable.

For the past two decades, it has been commonly agreed upon that the automotive industry would increasingly rely on lightweight materials to meet increased CAFE requirements. Recent powertrain advances have made the increased use of lightweight materials less certain. Gasoline/electric hybrid vehicles are becoming increasingly technologically feasible. Although the use of lightweight materials will be an integral part of any hybrid vehicle, it is possible that in an effort to maintain affordability, manufacturers may choose to forego the higher cost of some lightweight materials. At least initially, it is likely that to meet cost constraint, the initial hybrid vehicles will be comprised of a high-technology powertrain mated to a vehicle with rather traditional materials.

Usage of steel is expected to decrease by 1 - 2 percent per year in the coming decade. There are at least two drivers of this reduction: the direct substitution of lightweight materials for steel and a very proactive steel industry. U.S. Auto/Steel Partnership continues to be an example of proactive suppliers working with their customers to develop cost-effective, innovative designs.

Cast iron will likely continue to see substantial reductions in automotive applications in the coming decade. The panelists forecast continued substitution of alternative materials for cast iron in cylinder heads and blocks (MAT-27), camshafts, crankshafts, and connecting rods (MAT-30).

Aluminum will likely see continued growth in several automotive applications in the coming decade. Delphi IX panelists forecast strong growth in aluminum castings, forgings and sheet applications. Those applications expected to see increased aluminum usage include radiator and heater cores (MAT-35), cylinder head and blocks (MAT-27), unibody structures (MAT-36), body panels (MAT-38), and several chassis and brake applications (MAT-42, MAT-43).

The panelists believe that, in order to meet increasing CAFE standards, a slow movement toward lightweight materials is necessary. However, in order to meet substantially higher CAFE requirements, downsizing of vehicles will also be a needed element. The usage of lightweight materials presents an opportunity to reduce the overall mass of the vehicle, yet concerns for affordability are likely to slow such a movement.

MAT-23. Assuming the same market size (13,293,000 passenger cars and light trucks) as in the base year 1995, please consider the following list of plastic materials and forecast change in plastic usage for 2002 and 2007. <u>Please indicate plus or minus.</u>

Material	Median Response		Interquartile Range	
	2002	2007	2002	2007
ABS	-5	-10	-10/-3	-20/-5
Acetal	1	1	0/2	0/2
Acrylic	2	2	0/2	1/5
ABS/PC(pulse)	4	5	2/5	5/9
PC/PBT (Xenoy)	0	-2	-10/0	-20/0
PPO/nylon	3	4	0/5	0/10
PPO/styrene	0	0	0/1	0/1
Epoxy	0	0	0/0	0/0
Ionomer	1	1	0/1	0/2
Nylon	5	10	5/10	9/16
Phenolic	-2	-3	-4/0	-5/0
Polycarbonate	4	8	2/9	5/19
Polyester elastomer	2	5	1/5	1/10
Polyester thermoplastic	5	10	4/8	5/15
Polyester thermoset	2	4	0/5	0/8
Vinyl ester - TS	0	0	0/8	0/15
Polyethylene	5	10	4/10	6/13
Polypropylene	10	20	10/15	13/28
TPO	10	18	10/18	15/28
Polyurea	0	0	0/0	0/0
PVC	-5	-10	-11/-5	-20/-5
SMA	0	0	-2/0	-5/0
Urethane	-5	-10	-10/-1	-18/0
Total				

Selected edited comments

- As designers realize the value of high stiffness thermoplastics, such as SMA, in structural applications that can incorporate a great deal of parts consolidation, the usage of these types of materials will grow significantly.
- From the standpoint of concerns regarding toxics and recyclability, some thermosets and chlorine containing polymers will be replaced with polypropylene-based TPOs. I expect some side glasses of so called recreational vehicles to be replaced with plastics.

- I believe that as designers become more familiar and expert in designing integrated structures utilizing thermoplastics, the need for thermosets will decline since thermoplastics offer greater design functionality and freedom and do not have the post user-waste problems associated with thermosets. I also believe low-elongation materials like SMA will decline to essentially zero as designers realize they can achieve cost savings by using stronger, ductile, multiple functionality, higher cost materials than they can with cheaper "single functionality" materials. Cost per pound doesn't matter. Cost per functional value does, and how the available functionality is applied to creating a solution is the key.
- I expect nylon growth in intake manifolds, ABS to be replaced by PP and TPO to be material of choice for fascias and moldings.
- There may be polycarbonate glazing by 2007.
- Thermosets are booming currently, but unless incineration becomes politically viable (it is technically feasible), thermosets must lose ground to thermoplastics.
- This answer depends of the future cost of fuel economy, from CAFE and/or taxes at the pump. A significant jump in this cost is assumed for 2007, justifying wider use of heat stable plastics for body panels. The significant jump in polyethylene reflects a wholesale conversion from steel to blow-molded gas tanks. For TPO, significant momentum to replace RIM fascia was only in midstride in 1995 and use of TPO on the interiors (replacing ETPs) was just beginning.
- With wider and new applications of polymer-alloy technologies, PP-based thermoplastics and TPOs are finding more applications. Intake-manifold, fuel tanks are becoming standard use. Ease for recycling is more and more important.

Discussion

Panelists forecast substantial growth for polypropylene (20 percent), TPO (18 percent), nylon (10 percent), polyester thermoplastic (10 percent), and polyethylene (10 percent). The panel also forecasts a significant decrease in usage for ABS (10 percent), PVC (-10 percent), and urethane (-10 percent).

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The table shows those materials where there is a difference between the 1994 Delphi VII, the 1996 Delphi VIII and the 1998 Delphi IX.

Long-term Forecasts			
	Delphi VII	Delphi VIII	Delphi IX
ABS	n/a	0	-10
ABS/PC Pulse	n/a	10	5
PC/PBT	0	-10	-2
Nylon	5	6	10
Phenolic	0	0	-3
Polyester Thermoplastic	2	15	10
Polyester Thermoset	3	10	4
Polyethylene	8	5	10
PVC	-4	-5	-10
Urethane	n/a	-2	-10

Strategic considerations

Plastics offer the materials engineer the opportunity to chemically design a material with specific and unique characteristics. This versatility has lead to a wide variety of very effective resin compounds for a wide array of applications. However, the ability to design a resin for a specific application—possibly plastic's most valuable aspect—can present an environmental challenge with regard to the final disposition of vehicles. In an effort to decrease barriers to recycling, many manufacturers are developing strategies that markedly limit the number of different types of plastics in a vehicle. The ability to develop entire component systems using one family of plastics may represent the most environmentally acceptable applications for plastics in the future. However, it may also limit the versatility of materials engineers to design application-specific materials.

Polypropylene and TPO are forecast to see the largest percentage gains in the coming decade. Polypropylene—a likely candidate for widespread interior component material consolidation—will likely see increased usage for interiors and bumpers.

Given the continued activity in the development of plastics for new applications, it is apparent that the industry is committed to a long-term strategy that includes plastics. However, the recyclability of plastics will continue to present a challenge to the auto industry in the coming decade.

MAT-24. 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	50%	50/70%
Steering wheel components	34	25/50
IP components	30	21/30
Airbag canister	25	20/30
Electric car transaxle	25	13/40
Seat frames	25	20/29
Brackets	20	15/20
Brake pedal	15	8/19
Engine covers	15	10/20
Housing	10	9/18
Support braces/beams	10	10/24
Transmission cover	8	5/11
Wheels	8	5/10
Door hardware	5	2/10
Intake manifold	5	2/5
Oil filter adapter	5	3/18
Transmission cases	5	2/10
Oil pan	3	1/5
Door frame	2	0/4
Trim	0	0/4

Other components:

Transfer cases: 5%

Selected edited comments

- Cost considerations will drive the market.
- Higher stiffness than that of aluminum and its sound/vibration-deafening characteristic are the reasons for it to be employed for the above parts.
- Magnesium will appear on all of the listed components to some extent. The answers reflect the percentages that will have been in production sometime during the decade, not necessarily the total fraction of such parts that will be produced during the decade.
- Magnesium will have a significant usage growth. I also assume that magnesium price will stabilize, and be more competitive with aluminum.
- Parts and design consolidation trend will work both ways. A large increase of usage because of larger parts or very limited usage because of limited magnesium parts producers.

- The assumption is that added magnesium will be on-stream in addition to the Dead Sea work and Queensland range.
- There are certain problems with magnesium that must be resolved before we see any significant increases in its use: corrosion, high temp strength, cost compared to aluminum, creep, compatibility with other materials, coolant fuel, oils, etc.
- There is a need for better low-cost corrosion coatings for wheels. Market share depends on the ability of raw materials supply to increase in volume and decrease in cost as expected to ~ $1.25/lb. There is also a need for a much larger engineering die casting supply base integrated into first tier suppliers (who now are more polymer-based). The industry needs more data on component design for thin wall advantage and rules for diecasting. We also need better low-cost prototyping. Shortened length of new product development is an issue, as well.

Discussion

Panelists expect magnesium usage to increase significantly in interior components such as instrument support beams, steering-wheel components, seat frames, and airbag canisters. They also expect to see increased application of magnesium for noncritical structural components like brackets, covers, cases and housings. The wide interquartile ranges suggest significant uncertainty or differing strategies between manufacturers.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was changed for the 1996 Delphi VIII, so comparison with surveys prior to Delphi VIII is not possible. The 1998 Delphi IX panel is somewhat less optimistic with regard to magnesium than was the Delphi VIII panel. Of the 20 components listed, the Delphi IX panel forecast higher magnesium rates for 3 components than the previous panel. It is important to note that, with few exceptions, the current Delphi forecast is lower than that of Delphi VIII, but is within the similar range.

Strategic considerations

The panel's forecast suggests that magnesium will continue to be viewed as a viable alternative for aluminum, plastic and steel. Magnesium delivers good strength to weight performance and excellent dampening characteristics, yet there are concerns regarding its use. Unstable prices, limited industry experience, and an uncertain supply make a wide scale commitment to magnesium unlikely. Magnesium also presents galvanic corrosion issues that must be considered.

Any significant increase in fuel-economy standards will likely lead to a rapid increase in magnesium usage. However, cost, supply, manufacturing considerations, and other barriers may impede material substitution.

MAT-25. Please indicate significant new material applications/technologies that are likely to emerge within the next decade for each of the following vehicle systems.

RESPONSES

Body

Exterior:

- 100 percent galvanized (any OEM not using coated steel should be chastised).
- Aluminum (wrought) joining technology
- Aluminum and stainless body panels
- Aluminum panels
- Bake-hardenable or equivalent closer panel; increasing use of aluminum hoods/decks
- Bake-hardened steel sheet, tailored blank
- Continued growth of bake-hardenable steels and other postfabrication technologies
- Durable polypropylenes and TPOs, bake-oven, stable-plastic body panels, static dissipative plastics for enhanced electrostatic painting
- Greater use of aluminum, thermoplastics
- Growth of nonpainted plastics
- Higher strength aluminum panels
- Hydrophorbic glass coatings, theft-deterrent glazing systems
- Increased thermoplastic and thermoset body panels
- Low-cost, lightweight bumper supports in magnesium and aluminum
- Magnesium body panels
- More aluminum panels, some increase in plastic and/or composite exterior panels
- New lighting systems—NEON, LED
- New TPO developments that will allow the material to be used in vertical body panels are needed. This will open new design opportunities.
- Plastic additives to dramatically improve adhesion to low surface-energy plastics
- Powder coatings, two-coat pearl paints
- Preprimed steel and aluminum; dry-film-lube-coated sheet, prepainted or laminated aluminum trim
- Revert back to new higher strength steel which will be thinner, thus reducing weight
- Revisit the use of thermoplastic panels, especially on small cars. Use aluminum body panels on higher priced vehicles.
- Unpainted plastic body panels

Interior:

- All aluminum weld-bonded sheet body structures
- Durable polypropylenes and TPOs
- Fiber optics
- Greater use of aluminum and magnesium; introduction of polymer-matrix composite materials.
- High-volume stamped aluminum body structures, additional space frame or multiproduct aluminum body structures for lower volumes
- Integrated-magnesium instrument panels with electrical transmission
- Less leather, more cloth, but better cloth in terms of cleaning
- Longer, more modular plastic moldings
- Magnesium brackets, structures, steering wheels
- Magnesium cross-car beams and seat frames
- Not much change; except for an increase in the use of magnesium
- Occupant-friendly interior materials
- Plastic additives to dramatically improve adhesion to low surface-energy plastics
- Polypropylene will replace ABS and PC/ABS as the primary material for all interior applications based on performance and cost.
- Preprimed and prepainted steel and aluminum; dry film-lube-coated sheet; hydroformed tube for various components such as header rails and door intrusion seams; sound deadening (laminate) for wheel house, dash panel, etc.
- Sound deadening for quieter interior will be an issue that can be solved by metal-to-metal laminates on panels that separate the interior from the engine compartment, drive train, etc.
- Tailor welded blanks, sprayable insulators/deadeners
- Ultrahigh-strength steel sheet, tailored blank
- Use of magnesium displacing rigid plastics

Chassis

Brakes:

- 100,000 mile systems, electronically activated, eliminating the hydraulic system and its weight
- Additional consumers for ABS
- Aluminum calipers, possibly aluminum MMC caliper rotors
- Aluminum matrix composite disks
- Aluminum metal matrix brake rotors and drums
- Cast aluminum

- Lighter materials for brake rotors and calipers; aluminum, aluminum-metal matrix composites, titanium; ceramic corrosion protective coatings on cast iron brake rotors
- Low-cost aluminum MMC
- Metal-matrix composite discs and calipers on high-volume production cars
- Metal-to-metal laminated brake shoe assembly.
- MMC rotors
- Power-assisting system for emergency braking (especially for women and elders)
- Something better for friction material is likely.

Exhaust:

- All stainless steel construction for 150,000 miles
- De-NOx catalyst for both gasoline and diesel engines
- Low chromium stainless steel will remain the material of choice.
- More corrosion-resistant metals; life-of-car exhaust system is technically feasible
- New catalytic converter materials/processes
- Sensing for HC NOx O_2, higher temperature catalytic converters, higher cell density, more surface area, thermally managed systems
- Stainless exhaust will become standard equipment because of its corrosion resistance.
- Stainless-steel exhaust systems
- Thin-wall cast parts (stainless), hydroforming
- This last bastion of class a-b corrosion should change to better-coated steels and stainless steels.
- Titanium exhaust in limited application

Suspension:

- Aluminum brackets, air suspensions with load leveling
- Aluminum frames
- Cast aluminum
- Continuation and refinement of already existing technologies
- Fewer vehicles with automatic suspension control, because it's too expensive
- Formable tube, hydroforming (tube)
- High-strength thin-wall die casting
- Higher strength alloys; perhaps some composite suspension components etc.
- Hydroformed tubular components
- Integrated metallic/polymers components

- Lightweight-metal (aluminum) suspension components
- Lightweight steel designs will begin to emerge to compete with cast and forged aluminum providing performance improvement with little or no cost penalty.
- More aluminum
- More aluminum-intensive, but also magnesium and polymer composites on some limited applications—we also may see titanium springs on very limited basis
- Thin-wall cast parts (stainless)
- Titanium coil springs
- Use of semisolid forge aluminum components

Wheels

- Air pressure monitoring and self-adjusting wheel, tires, or systems to keep proper friction coefficient on the icy surface
- Composite wheels to have advantages of aluminum (weight, styling, and appearance), without the disadvantage of filiform corrosion.
- Cost and repair considerations will provide impetus to return to steel wheels.
- Fabricated and near net-shape cast aluminum wheels
- Forged vs. cast
- Higher aluminum alloys will begin to dominate the market.
- HSLA steel; aluminum will level off
- Lighter materials
- Lightweight steel wheels with stylish appearance
- Low-cost colored coated magnesium
- Magnesium
- Magnesium and composites emerge
- Magnesium wheels replace steel and aluminum
- More aluminum usage
- More aluminum wheels
- Polymer matrix composites possible—used on bicycles and exotic cars already

Powertrain

Engine

- 100 percent aluminum head and blocks, 100 percent intake manifolds - nylon
- All-aluminum engine block, ceramic metal pads, lightweight engine valves

- Aluminum blocks with integral aluminum composite liners instead of cast iron liners or aluminum 390 alloy
- Aluminum cylinder blocks and heads
- Aluminum engine housing
- Compact graphite block and heads—cylinder bore coatings; plastic oil pans—cast steel exhaust manifolds
- Complex-multipiece-plastic intake manifolds
- Continued growth of i.e. cast aluminum
- Electromagnetic-controlled throttling and high flexible valve timing and lift control will require lightweight but highly durable materials and systems.
- Engine: aluminum block, plastic components; transmission/final drive: aluminum and magnesium castings
- Greater use of aluminum
- High performance in automobile fluids sealing materials with 200M-250M life of seal performance
- Higher horsepower (performance) at same fuel economy
- Hydroform frames/aluminum blocks
- Increased plastic fuel rails and air intakes
- Magnesium block, metal matrix composite and titanium moving parts
- Magnesium cover and blocks, alternative power systems will drive new materials opportunities
- Magnesium covers
- Magnesium, polymers
- More aluminum blocks, heads; MML aluminum pistons
- More lost foam castings
- Powdered metal rods; ceramic/metal composite rods, pins, pistons
- Precoated sealants to steel for gaskets, prepaint and dry film lube for oil pans
- Spray-coated boards for aluminum blocks
- Transmission/final drive: magnesium case, ultrahigh-strength steel gears and shafts

Transmission:

- Aluminum-based metal matrix composites
- Composite driveshafts
- Composites/polymer components
- Continued growth of i.e. cast aluminum
- CVTs in cars

- Magnesium (assuming VW success in Germany)
- Magnesium covers
- Magnesium housings, composite internal
- Magnesium substituting for aluminum
- Magnesium–possibly
- Metal matrix composite drive shafts
- Precoated sealants to steel for gaskets, pre-paint and dry film lube for transmission pans
- Same type of materials
- Use of CVT may become popular with the need to increase fuel economy.
- Wear-resistant aluminum alloys, without anodizing for transmission valves
- Wider application of flexible lock-up operation of automatic transmission requires higher performance friction materials and fluid.

Discussion

The majority of responses pertain to material applications or technologies that reduce weight. Aluminum, high-strength steel, magnesium, and plastics are the most frequently mentioned materials.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

Many of the panelists' responses are essentially continuations or extensions of current developmental work. In the coming decade, the industry will likely see increased usage of aluminum, high-strength steel, magnesium, and plastics. Competition among these materials will be great. The development of economically viable applications will increasingly rely on process and technological innovation. The responses suggest a significant amount of effort on the part of suppliers to develop cost-competitive applications for a wide range of materials. It will be important to monitor developmental activity in all competing materials.

MAT-26. Please indicate significant new developments that are likely to emerge within the next decade for each of the following fluids:

RESPONSES

- I expect continued pressure to make cars "maintenance free" for 10 years, including fluid. The key exception is engine oil.

Brake Fluids

- Higher temperature performance, if fluid doesn't disappear.
- I do not think any fluid other than DOT-5 grade oil is required.
- Longer life (2)
- Synthetic (2)

Engine Oils

- Engine oils which retain longer fuel economy improvement capability and longer oil-drain intervals while keeping phosphorus level low to avoid catalyst poisoning
- Extended drain oils
- High-temperature stability, longer change intervals, increased synthetic use
- Increased usage of synthetic oils
- Less contaminants to pollution control devices, O_2 sensor, catalysts
- Longer life, lower friction
- Longer times between changes
- Low viscosity oils, fuel-economy improvements, longer oil-change intervals, higher-cost oil
- Lower viscosity oils

Power Steering Fluids

- "Lifetime" fluids
- No-change power steering fluid
- No specific fluid is required

Radiator Fluids

- "Lifetime" fluids
- 10-year life requirements
- Continue to extend life beyond 5 years to life of vehicle (10 years)
- Extended life packages, propylene-glycol formulations
- I don't think any new coolants are required.

- Life time coolants—organic acid technology
- Long-life fluids
- Longer life ethylene-glycol coolants, some polypropylene-glycol coolants
- Organic and environmentally friendly

Transmission Fluids

- "Lifetime" fluids
- Automatic transmission fluids which show higher shear stability and antishudder performance for flexible lock-up operation
- Higher temperature, longer life
- Long life, better wear protection
- Lower viscosity at low temperature
- More synthetic-based fluids
- No change for customer transmission fluid

Rear Axle Fluids

- Long-life/fuel-efficient fluids
- Lower viscosity fluids
- More synthetic-based fluids

Discussion

In the next decade, panelists expect longer life and extended periods between change for all listed fluids. They also forecast increased usage of synthetic fluids for several applications.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

Panelists forecast only incremental changes for automotive fluids in the coming decade. However, by 2007, each of the listed fluids is forecast to have significantly longer life. The panel indicates that considerable effort is currently being focused on the development of fluids that will be engineered to last a lifetime.

Environmental considerations will affect several listed fluids. Because of environmental concerns, polypropylene-glycol radiator fluid is expected to see increased usage as a replacement for the ethylene-glycol mixture. Although, the polypropylene mixture does meet manufacturer requirements, it does not have the heat control properties of the ethylene glycol mix. The polypropylene mixture also is more expensive. However, it is possible that the environmental advantages of the new fluid will eventually outweigh the cost and performance concerns, and it will gain wider acceptance.

Another environmental challenge will be the economical and safe recycling of automotive fluids. There are currently a number of automotive fluids that are recycled. It is likely that programs designed to reclaim these fluids will expand.

The panelists expect incremental improvements in motor oils, leading to better antioxidants, antiwear, reduced friction, and longer life. Panelists also expect increased use of synthetic motor oils, but it is likely the higher cost of synthetic oils will prevent widespread use.

MAT-27. What percentage of North American-produced passenger car and light truck engines in 2002 and 2007 will utilize cast iron or aluminum cylinder heads and blocks?

Passenger Cars Material	Est. 1996*	Median Response		Interquartile Range	
		2002	2007	2002	2007
Heads					
Cast iron	13.7%	10%	5%	8/10%	0/5%
Aluminum	86.3	90	95	90/92	95/100
Blocks					
Cast iron	83.5%	75%	50%	70/75%	40/60%
Aluminum	16.5	25	50	25/30	40/60

Light Truck Material	Est. 1996*	Median Response		Interquartile Range	
		2002	2007	2002	2007
Heads					
Cast iron	76.8%	60%	40%	50/61%	20/50%
Aluminum	23.2	40	60	40/50	50/80
Blocks					
Cast iron	97.4%	90%	75%	80/90%	65/83%
Aluminum	2.6	10	25	10/20	18/35

*Source: Ward's Automotive Reports, Feb. 3 & Feb. 24, 1997. Rates for 1996 are based on production in U.S., Canada and Mexico for the U.S. market

Other head materials

Composite: Passenger Car: 2002, 1%; 2007, 2%; Light Truck: 2002, 0%; 2007, 1%

Magnesium: Passenger Car: 2002, 3%; 2007, 5%; Light Truck: 2002, 0%; 2007, 3%

Magnesium: Passenger Car: 2002, 0%; 2007, 1%; Light Truck: 2002, 0%; 2007, 0%

Selected edited comments

- A change to aluminum cylinder heads will be accelerated in passenger cars, but not so for the blocks because of wear problems. Light trucks will follow the passenger car trend but diesel engines for trucks will still use cast iron head and blocks.
- Aluminum in these applications is the most effective mass reduction and will be driven by CAFE requirements.
- Cast aluminum is a cost-effective mass reduction application, and heads and blocks are key products.
- Diesels are becoming preferred to gasoline engines to meet more stringent fuel-economy standards, and this means relatively high cast iron share in light trucks.
- Magnesium may start making inroads in this area, late in the decade.

- There is some possibility for magnesium block (or other, if alternate powertrains are implemented).
- There will be some allowance for alternate block materials by 2007.

Discussion

Panelists forecast 95 percent of cylinder heads and 50 percent of engine blocks for passenger cars will be made from aluminum by 2007. Panelists forecast 60 percent of cylinder heads and 25 percent of engine blocks for light trucks will be made from aluminum by 2007.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-62a

There is a statistically significant difference in mean responses between technology and materials panelists for the cylinder blocks in passenger cars and cylinder heads in light trucks in the years shown in the following table.

Cylinder Block and Head Material – Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Passenger Car Blocks				
Cast iron	74	69	59	48
Aluminum	26	31	41	52
Light Truck Heads				
Cast iron	65	53	52	34
Aluminum	35	47	47	66

Technology panelists forecast a lower use of aluminum in passenger car cylinder blocks and light truck cylinder heads than materials panelists.

Trend from previous Delphi surveys

This question was changed to separate the forecast for passenger cars and light trucks for the 1994 Delphi VII. Therefore, direct comparisons with Delphi forecasts prior to Delphi VII are not possible. The Delphi IX forecast is similar to the two prior forecasts.

Strategic considerations

The substitution of aluminum for cast iron in cylinder blocks and heads offers substantial weight reduction opportunity at an acceptable cost penalty. The industry has developed a comfort level with aluminum engine heads and is rapidly gaining confidence with aluminum engine blocks. However, some questions may remain regarding noise suppression and durability—especially for light truck applications. Cast iron sleeves are currently used in all North American-produced aluminum engine blocks to address noise suppression and durability concerns. (MAT-28, MAT-29).

Light trucks are forecast to see steady growth in the use of aluminum for cylinder heads and engine blocks. The authors offer one caveat: there is a significant amount of discussion regarding large increases in light truck CAFE. If any such conversion does occur, the conversion to aluminum cylinder heads and blocks would likely be rapid. Through a cascading effect, the conversion to aluminum cylinder heads and blocks—especially in the case of major vehicle redesign—can allow for further weight reduction. 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 head and engine block, rather than a cast iron block, it is likely that many other components can be made lighter. These may include the engine cradle, front suspension, brakes, tires, and even frame components. As these additional components are made lighter, the fuel economy of the vehicle will increase. A total analysis of the vehicle is thus required to determine the total weight savings and systems level cost obtained by substituting aluminum for cast iron in cylinder heads and engine blocks.

MAT-28. What percentage of the aluminum blocks forecast in MAT-27, will be sleeved, unsleeved and coated, and unsleeved in 2007?

Aluminum Block Engines	Est. 1996*	Median Response	Interquartile Range
Sleeved	100%	80%	70/90%
Unsleeved and coated	0	10	4/25
Unsleeved aluminum 390 type alloy	0	0	0/8

* Source: OSAT estimates

Selected edited comments

- Electro- or plasma-coated blocks will be introduced mainly by European OEMs.

Discussion

Panelists forecast that 80 percent of aluminum cylinder blocks in 2007 will be sleeved.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

Long-term Forecast for Unsleeved and Coated Aluminum Cylinder Blocks					
	Delphi V 2000	Delphi VI 2000	Delphi VII 2003	Delphi VIII 2005	Delphi IX 2007
Unsleeved and coated	30%	20%	10%	20%	10%

The long-term forecast for the past five Delphi surveys has shown a reduced expectation by the later panels for sleeveless cylinder blocks.

Strategic considerations

Few questions better illustrate the difficulty of introducing new material technologies to the automotive industry. The ability to manufacture sleeveless aluminum cylinder blocks currently exists. Several offshore manufacturers currently do so. However, there does not appear to be a sufficient comfort level or weight reduction incentive among manufacturers to introduce sleeveless aluminum cylinder blocks in North America.

Manufacturers are comfortable with the current cast iron sleeved aluminum engine blocks. With an increasing emphasis on quality, reliability, and durability, manufacturers will be cautious in implementing any technology that may negatively impact these attributes. This is especially true for applications as critical as the powertrain.

MAT-29. What percentage of the sleeved aluminum blocks forecast in MAT-28 will use the following sleeve materials in 2007?

Sleeve Material	Est. 1996*	Median Response	Interquartile Range
Aluminum 390 alloy	0%	0%	0/10%
Cast iron	100	83	60/90
Ceramic	0	0	0/1
Material matrix composites	0	2	0/8

* Source: OSAT estimates

Selected edited comments

- Cast iron domination will continue with only experimental use of other materials.

Discussion

Panelists forecast cast iron (83 percent) to be the predominant sleeve material for aluminum blocks in the coming decade. All other listed materials are forecast to see only limited application.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII survey. A similar question was also asked in the 1989 Delphi V survey. The Delphi VIII and Delphi IX panels are much less aggressive in their forecast of alternative sleeve materials than was the Delphi V panel. The Delphi V panel forecast application rates for steel (10 percent), aluminum (5 percent) and ceramic (5 percent) for 2000. It appears that the industry has significantly reduced its expectations for these alternate materials.

Strategic considerations

In the coming decade, cast iron will continue to be the predominate material for aluminum cylinder block sleeves. Panelists show little or no expectation for the use of the other listed materials. Application of these alternate materials will be slow due to cost, quality, reliability, and durability issues.

MAT-30. **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 2002 and 2007. Please total each component to 100 percent. Leave blank any component with which you are not familiar.**

Component Material (Internal)	Median Response			Interquartile Range		
	Curr. Est.	2002	2007	Curr. Est.	2002	2007
Camshaft						
Cast iron	80%	60%	50%	79/86%	57/75%	38/56%
Composites (e.g., steel/powdered metal combination)	10	24	45	8/16	16/43	30/69
Steel	5	5	5	5/8	4/11	2/13
Crankshaft						
Cast iron	82%	75%	65%	80/85%	70/80%	60/70%
Steel	18	25	35	15/20	20/30	30/40
Connecting Rod						
Cast iron	30%	20%	15%	20/35%	8/28%	1/20%
Metal matrix composites	0	0	3	0/0	0/1	0/5
Powdered metals	25	40	55	20/40	30/61	45/73
Steel	43	35	28	30/50	20/47	8/39
Fuel Rails						
Aluminum	5%	3%	7%	0/10%	0/14%	0/20%
Steel	90	73	54	70/90	68/82	43/65
Plastic	5	20	35	0/10	10/29	20/48
Piston						
Aluminum	100%	98%	94%	100/100%	95/100%	89/95%
Hybrid (e.g., plastic skirt/ceramic crown)	0	0	1	-	0/0	0/2
Magnesium	0	0	0	0/0	0/2	0/8
Metal matrix composites	0	2	5	-	0/3	1/8
Valves						
Aluminum matrix composite	0%	0%	0%	0/0%	0/1%	0/8%
Steel	100	99	95	99/100	95/100	88/98
Titanium	0	1	5	0/0	0/2	2/5

Component Material (Engine Exterior)	Median Response			Interquartile Range		
	Curr. Est.	2002	2007	Curr. Est.	2002	2007
Air Cleaner Housing						
Aluminum	5%	5%	3%	5/9%	2/5%	0/5%
Plastic	73	83	90	70/85	75/94	82/99
Steel	20	12	0	3/25	0/22	0/10
Exhaust Manifold						
Cast iron	80%	70%	50%	89/90%	70/75%	40/60%
Stainless steel	15	30	40	10/20	20/30	30/60
Front Cover						
Aluminum	75%	80%	90%	75/80%	80/86%	85/100%
Cast iron	25	20	10	20/25	15/20	0/15
Intake Manifold						
Aluminum	75%	60%	50%	75/80%	57/70%	40/60%
Cast iron	10	0	0	5/10	0/3	0/0
Plastic	15	35	50	10/17	25/41	40/60
Oil Pan						
Aluminum	5%	15%	20%	3/13%	7/30%	8/36%
Magnesium	0	0	5	0/0	0/2	0/10
Plastic	0	5	15	0/5	5/10	10/20
Steel	90	80	60	88/95	50/85	40/70
Rocker Arm Cover						
Aluminum	50%	40%	30%	47/58%	31/47%	25/30%
Magnesium	5	10	15	3/10	6/22	10/24
Plastic	15	30	50	15/20	25/40	40/53
Steel	25	15	8	20/30	5/19	1/10

Other material components:

Connecting Rod:

Titanium: Current estimate, 0%; 2002, 1%; 2007, 2%

Exhaust Manifold:

Cast steel: Current estimate, 2%; 2002, 5%; 2007, 10%

Composite: Current estimate, 0%; 2002, 5%; 2007, 10%

Hi-Temp Plastic: Current estimate, 0%; 2002, 0%; 2007, 20%

Front Cover

Magnesium: Current estimate, 0%; 2002, 0%; 2007, 5%

Plastic: Current estimate, 20%; 2002, 26%; 2007, 26%

Intake Manifold:

Magnesium: Current estimate, 2%; 2002, 2%; 2007, 5%

Oil Pan:

Aluminum/magnesium: Current estimate, 10%; 2002, 15%, 2007, 20%

Aluminum/Magnesium: Current estimate, 5%; 2002, 6%, 2007, 5%

Cast AL: Current estimate, 50%; 2002, 54%; 2007, 40%

Piston:

Aluminum/ceramic coating: Current estimate, 0%; 2002, 1%, 2007, 3%

Valves:

Ceramic: Current estimate, 0%; 2002, 0%; 2007, 5%

Titanium Aluminide: Current estimate, 0%; 2002, 1%; 2007, 5%

Selected edited comments

- Ceramics and MMC might see some experimental level of application but I don't see wider use. Plastic usage will be somewhat limited because of recycling concerns and higher temperature requirements, except for the intake manifold where huge weight reductions are apparent.
- In general, the trend will be towards lightweight materials such as aluminum, magnesium, and plastics and away from steel and cast iron for covers and manifolds.
- Plastic and magnesium applications in the engine area will be somewhat restricted by the tendency of increasing temperature.
- The trend will be towards using light materials: aluminum, magnesium, and plastics.
- Use of plastics is expected to decline due to recycling issues. Magnesium and aluminum will be favored.

Discussion

The panel forecasts a continued trend toward lightweight materials for engine applications in the coming decade.

For internal engine components, the panel predicts increased penetration for composite camshafts, steel crankshafts, powdered metal connecting rods, and plastic fuel rails. Initial penetration for metal matrix composites is forecast for connecting rods and pistons.

For external engine components, the panel forecasts increased penetration for stainless-steel exhaust manifolds, aluminum front covers, plastic intake manifolds, rocker arm covers and air cleaner housings, and aluminum and plastic oil pans.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, the manufacturers (15 percent) current estimate for steel crankshafts is lower than the suppliers (36 percent).

Trend from previous Delphi surveys

A comparison of the last four Delphi surveys (see table) 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 often overcome, and the materials are accepted. However, there are instances where other materials arise that replace the earlier "best new candidate". The forecasts for Camshaft (lobes) best show this: For several years, forged steel was viewed as the material that would replace cast iron as the material of choice for camshaft lobes. However, the Delphi IX forecast indicates that powdered metal is rapidly becoming the preferred material for camshaft lobes.

Comparison of Delphi VI, Delphi VII, Delphi VIII and Delphi IX Forecasts Component Material: Selected Internal Engine Components							
	Short-term			Long-term			
Component Material (Internal)	**1998 Delphi VII**	**2000 Delphi VIII**	**2002 Delphi IX**	**2000 Delphi VI**	**2003 Delphi VII**	**2005 Delphi VIII**	**2007 Delphi IX**
Camshaft							
Cast iron	70%	55%	60%	50%	60%	48%	50%
Composites (e.g., steel/powdered metal combination)	10	17	24	40	15	25	45
Steel	20	30	5	10	20	25	5
Crankshaft							
Cast iron	80%	70%	75%	70%	80%	62%	65%
Steel	20	30	25	30	20	38	35
Connecting Rod							
Aluminum	0%	0%	n/a%	5%	0%	0%	n/a%
Cast iron	20	20	20	25	20	10	15
Metal matrix composites	0	0	0	4	5	5	3
Powdered metals	10	45	40	45	15	53	55
Steel	50	35	35	20	47	28	28
Piston							
Aluminum cast	90%	90%	98%	70%	73%	75%	94%
Aluminum reinforced	10	5	n/a	20	15	8	n/a
Hybrid (e.g., plastic skirt/ceramic crown)	0	0	0	5	0	0	1
Metal matrix composites	3	1	2	n/a	10	13	5
Valves							
Aluminum matrix composite	2%	0%	0%	n/a%	5%	0%	0%
Steel	98	100	99	90	95	90	95
Titanium	n/a	n/a	0	n/a	n/a	n/a	4

Comparison of Delphi VI, Delphi VII, Delphi VIII and Delphi IX Forecasts Component Material: Selected External Engine Components							
	Short-term			Long-term			
Component Material (Engine Exterior)	**1998 Delphi VII**	**2000 Delphi VIII**	**2002 Delphi IX**	**2000 Delphi VI**	**2003 Delphi VII**	**2005 Delphi VIII**	**2007 Delphi IX**
Air Cleaner Housing							
Aluminum	10%	5%	5%	n/a%	15%	0%	3%
Plastic	35	83	83	n/a	50	95	90
Steel	50	10	12	n/a	30	0	0
Exhaust Manifold							
Cast iron	80%	70%	70%	55%	70%	50%	50%
Stainless steel	20	30	30	35	25	50	40
Intake Manifold							
Aluminum	60%	60%	60%	60%	70%	50%	50%
Cast iron	20	10	0	10	10	0	0
Plastic	5	30	35	20	15	50	50
Oil Pan							
Aluminum	n/a%	n/a%	15%	n/a%	n/a%	n/a%	20%
Magnesium	n/a	n/a	0	n/a	n/a	n/a	5
Plastic	5	14	5	10	15	30	15
Steel	92	85	80	50	80	70	60
Rocker Arm Cover							
Aluminum	15%	45%	40%	20%	20%	30%	30%
Magnesium	5	10	10	10	5	15	15
Plastic	20	28	30	60	30	40	50
Steel	55	17	15	10	40	10	8

Strategic considerations

For several years, automotive industry has been (increasingly) substituting lightweight materials for cast iron and steel in engine applications. As components made from alternative materials approach manufacturing scale economies, these materials may rapidly become the industry standard. Also, for many of the listed components, North American manufacturers may be behind offshore companies in converting to lightweight materials for the listed engine components.

Internal engine components

Camshafts illustrate the ever-increasing competition between lightweight materials. For several years, it was thought that forged steel, would replace cast iron as the material of choice for camshaft lobes. Many companies invested heavily in technology to manufacture near net shape steel forged camshafts. However, the Delphi IX forecast indicates that powdered metal is rapidly becoming the preferred material for camshaft lobes. Crankshafts are expected to continue a steady shift from cast iron to forged steel. Powdered metal is also expected to become the dominant material for connecting rods by 2007.

Plastic fuel rails continue to see increased usage in North American vehicles. Plastic fuel rails offer opportunity for reduced weight and part consolidations.

External engine components

The panel forecasts aluminum and plastic to gain equal shares of the intake manifold market by 2007. Both materials have proven to be viable contenders. This may be a case where two materials become the accepted standard for a component. However, slight improvements in either material or process technology may make a significant difference for future material selection decisions and therefore should be closely monitored.

Plastics are expected to 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.

MAT-31. What percentage of spark-ignited engines in North American-produced passenger cars will use these ceramic engine components in 2002 and 2007?

	Median Response		Interquartile Range	
Ceramic Engine Components	**2002**	**2007**	**2002**	**2007**
Exhaust manifold/port liner	0%	5%	0/2%	1/9%
Piston upper ring land	0	0	0/1	0/5
Piston crown	0	3	0/3	0/9
Piston rings, coating	1	8	0/9	0/10
Seals	0	0	0/3	0/5
Turbocharger turbine/rotor (based on % of engines equipped with turbochargers)	3	10	1/10	3/25
Valvetrain components (includes valves, inserts, guide seats, tappets, cam, etc.)	3	5	0/5	3/10
Wrist pins	0	1	0/3	0/10

Selected edited comments

- I don't believe ceramic will be used anywhere where a chip could cause serious damage to the engine.
- To my knowledge, all programs in this area have been stopped.
- Use of a solid ceramic component is quite questionable because of its cost and potential for catastrophic failure, except in the areas of seals and turbine rotors. I rather expect coating applications for piston surfaces or valve surfaces as a heat insulation measure.

Discussion

Panelists forecast little penetration of ceramics for all applications by 2002 and limited growth through 2007.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-68

There is a statistically significant difference in mean responses between technology and materials panelists for the ceramic engine components in passenger cars in the years shown in the following table.

Ceramic Engine Components – Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Piston upper ring land	3.0	0.7	8.0	2.8
Seals	12.4	1.4	16.3	2.8

Technology panelists forecast a higher use of ceramic materials in passenger car engine piston upper ring lands and seals than materials panelists.

Trend from previous Delphi surveys

The application of ceramics for engine components in spark-ignited engines has been asked in different forms throughout the nine Delphi surveys. Although the questions have varied between surveys, there is a significant trend toward decreased optimism with regard to the potential of ceramics in engine components. The 1998 Delphi IX panel continues this trend and is, in fact, less optimistic than any previous panel.

Strategic considerations

Presently there is no significant use of ceramics in the listed spark-ignited components. While ceramics present some intriguing material characteristics, significant doubts remain. The panelists' forecast suggests that there is great doubt regarding the cost, manufacturability and durability of ceramics. A decade ago there was strong support for a ceramic-intensive engine. This enthusiasm has subsided, and it is likely that ceramics will gain only limited acceptance on a part- by-part basis in the coming decade.

MAT-32. Which powertrain components for North American-produced passenger cars and light trucks will be made from various forms of powdered metals in 1997, 2002, and 2007?

	Median Response			Interquartile Range		
Powdered Metal Components	**Curr. Est.**	**2002**	**2007**	**Curr. Est.**	**2002**	**2007**
Connecting rods	25%	40%	53%	20/29%	31/50%	45/79%
Transmission gears	5	13	23	5/5	8/15	13/25
Valvetrain components:						
Camshaft lobes	10%	20%	30%	5/10%	15/25%	20/45%
Rocker arms	1	5	9	0/2	3/5	5/10
Tappets/lifters	0	5	9	0/2	3/5	5/10
Valve guides	20	30	40	18/25	25/40	25/60
Valve seat inserts	25	50	75	20/30	45/60	60/80

Selected edited comments

None

Discussion

Panelists forecast strong growth in powdered metals for connecting rods, camshaft lobes, valve guides and valve seat inserts. Although several of the interquartile ranges are somewhat wide, it is likely that the industry will continue to rapidly expand powder-metal usage in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

A review of the forecasts from the three most recent Delphi surveys suggests significant uncertainty regarding the future application of powdered metals for the listed components. The forecast for several of the listed components indicates a fairly steady growth trend, yet the forecasts for valve inserts, transmission gears and valve guides show a significant amount of variation between forecasts. The table shows the long-term forecasts for the 1994 Delphi VII, 1996 Delphi VIII and the 1998 Delphi IX.

Long-Term Forecast for Selected Components			
Components	**2003 Delphi VII**	**2005 Delphi VIII**	**2007 Delphi IX**
Connecting rods	60%	55%	53%
Valve seat inserts	50	80	75
Valve guides	40	78	40
Tappets/lifters	0	20	9

Strategic considerations

Powdered metal continues to gain acceptance for many automotive engine applications. The ability to achieve near net shapes with powdered metals offers the opportunity for cost reduction. Powdered metals also offer the opportunity to design-in properties by controlling the alloys and densities of various mixtures—thereby allowing for a more application-specific material.

Powdered metals will likely continue to see significant growth in many engine applications. Because of the recent rapid implementation of powdered metals, and the vast array of mixtures and properties, it is essential to closely monitor the industry for further developments.

MAT-33. What percentage of the following North American-produced components will be made of aluminum, copper or plastic in 2002 and 2007? Please estimate for current vehicles.

Passenger Car	Median Response			Interquartile Range		
Material	**Curr. Est.**	**2002**	**2007**	**Curr. Est.**	**2002**	**2007**
Engine Oil Cooler						
Aluminum	50%	65%	81%	38/70%	55/83%	70/99%
Copper	50	30	15	25/53	18/40	0/30
Plastic	0	0	0	0/0	0/1	0/4
Heater Cores						
Aluminum	70%	80%	98%	50/83%	70/90%	80/100%
Copper	30	20	1	18/50	10/25	0/18
Plastic	0	0	0	0/0	0/0	0/0
Radiators						
Aluminum	70%	80%	95%	58/86%	70/90%	75/100%
Copper	28	20	0	5/40	3/30	0/15
Plastic	0	0	0	0/1	0/5	0/5
Transmission Oil Cooler						
Aluminum	50%	60%	70%	25/55%	40/75%	60/100%
Copper	50	40	30	45/75	20/60	0/40
Plastic	0	0	0	-	0/0	0/0

Light Trucks	Median Response			Interquartile Range		
Material	**Curr. Est.**	**2002**	**2007**	**Curr. Est.**	**2002**	**2007**
Engine Oil Cooler						
Aluminum	50%	60%	75%	28/60%	38/76%	54/99%
Copper	50	40	20	40/68	20/53	0/35
Plastic	0	0	0	0/0	0/1	0/4
Heater Cores						
Aluminum	50%	70%	83%	50/65%	60/80%	73/100%
Copper	50	28	13	25/50	20/40	0/20
Plastic	0	0	0	0/0	0/0	0/0
Radiators						
Aluminum	50%	66%	80%	30/80%	44/90%	60/98%
Copper	40	33	13	18/68	9/51	0/38
Plastic	0	0	0	0/3	0/5	0/4
Transmission Oil Cooler						
Aluminum	40%	55%	70%	20/50%	30/75%	50/100%
Copper	60	45	30	50/80	24/70	0/50
Plastic	0	0	0	-	0/0	0/0

Selected edited comments

- I believe aluminum has made its maximum penetration in the heat exchange market. Copper/brass will fight to regain some of this market by making stronger alloys. Plastics may be used for headers, but not the actual heat exchange part.
- Radiator end tanks will be plastic.

Discussion

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

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

While in general agreement with the 1996 Delphi VIII panel, the long-term forecast of the 1998 Delphi IX panel forecasts higher penetration rates for aluminum in all listed components. The table shows the 1996 Delphi VIII and 1998 Delphi IX long-term forecasts for aluminum in each of the listed components.

Forecast for Aluminum Usage in Listed Components, Long-term Forecast, Delphi VIII (2005) and Delphi IX (2007)

Material	Passenger Car		Light truck	
	Delphi VIII	Delphi IX	Delphi VIII	Delphi IX
Engine oil cooler	75%	81%	57%	75%
Heater cores	90	98	80	90
Radiators	90	95	70	90
Transmission oil cooler	40	70	50	40

Strategic considerations

Panelists expect the trend to replace copper with aluminum in all of the listed components to continue through the forecast period. Although the copper industry has had some success in developing cost and weight competitive components, much of the recent manufacturing investment has been in aluminum processes. This new investment will represent a significant barrier for future copper application.

The panel forecasts no usage of plastic for any of the listed components. However, there is interesting developmental work that may lead to initial application in the coming decade. It will be critical to monitor this work. It may be an early indicator of future change.

MAT-34. **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 2002 and 2007? Please estimate for current vehicles.**

Fuel Tank Material	Median Response		Interquartile Range	
	2002	2007	2002	2007
Steel	50%	30%	50/60%	24/40%
Plastic	50	70	40/50	60/76

Other materials:

Stainless: Current estimate; 5%, 2002; 10%, 2007; 10%

Selected edited comments

- Because underbody space is becoming a premium, plastic will continue to gain share regardless of price.
- By 2007, hydroformed aluminum tanks will be available.
- Change to plastics seems to be accelerating and trend will be boosted by the introduction of smaller and more fuel-efficient new models like Mercedes Benz A-Class. Space is becoming more and more critical.
- Cost and design flexibility of plastic tanks will allow trend to continue away from steel.
- It is unlikely that significant vapor-control improvement will offset increased requirements to allow for increased plastic usage.
- It seems that Toyota is the only major OEM not committed to the conversion to blow-molded HDPE fuel tanks.
- Mass reduction and improvements with emissions will allow plastics to become the preferred material.
- Mass reduction, packaging and cost will all favor plastic.
- Packaging is the current concern, but the decreasing cost of steel tanks and increasing costs of multilayered plastic tanks will return all but the most demanding packaging problems to steel.
- Recent global legislative actions limiting the use of certain corrosion-resisting coatings (e.g., terne plate and zinc dichromate) will push the balance toward plastic.
- The trend of plastic fuel tanks is getting more and more clear. Despite tighter vapor control requirement, a more simple and reliable antipermeation process will make this easier.
- Unless the vulnerable EVOH barrier layer actually fails in the field or fails SHED testing after exposure, plastic will continue to displace metal. EVOH is not an ideal barrier.

Discussion

The panel forecasts plastic to be the dominant material for fuel tanks by 2007.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX forecasts continue the trend set forth by previous panels for a steady shift from steel to plastic for gasoline fuel tanks.

Strategic considerations

Because plastic fuel tanks offer the opportunity for significant weight savings, corrosion protection, and unmatched design flexibility, they are likely to see continued growth in application for both passenger cars and light trucks. However, some concern over the potential of plastic tanks to meet possible evaporative emission requirements remains. The panelists forecast steel to continue as a viable alternative for gasoline fuel tanks in the coming decade.

Finally, the comment regarding hydroformed-aluminum fuel tanks warrants noting. Although aluminum does not appear to be a candidate for fuel tanks in the short-term, there is significant developmental activity in this area. These developments should be monitored for future breakthroughs that may make aluminum a competitive fuel-tank material.

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MAT-35. What percentage of North American-produced passenger cars and light trucks will use an integral frame or other design in 2002 and 2007?

		Median Response		Interquartile Range	
Frame Construction	**Est. 1996***	**2002**	**2007**	**2002**	**2007**
Passenger Cars					
Integral body/frame or unibody	91%	90%	90%	89/92%	81/92%
Separate body/frame	5	4	3	3/5	1/5
Space frame	4	5	8	5/8	6/10
Sport Utility Vehicle					
Integral body/frame or unibody	16%	20%	25%	17/25%	20/40%
Separate body/frame	84	80	75	74/82	60/80
Space frame	0	0	0	0/0	0/5
Pickup					
Integral body/frame or unibody	0%	0%	0%	0/0%	0/5%
Separate body/frame	100	100	100	100/100	90/100
Space frame	0	0	0	0/0	0/0

**Ward's Automotive Reports*, Jan. 20 & Feb. 3, 1997
Rates for 1996 are based on production in U.S., Canada, and Mexico for the U.S. market.

Selected edited comments

- Each category of vehicles will seek distinctions from others and this means more integral bodies for passenger cars and minivan and more separate body for sport utility vehicles. There is no reason for pickups to seek other body structures.
- The LTS project has demonstrated the ability of body integration of front and rear frames to be an effective means of improving structural performance and reducing mass and cost. It will be adopted on an increasing number of vehicles.
- Unibody is still the most effective structure.

Discussion

Panelists forecast little or no change in frame construction for passenger cars and pickup trucks and only a slight increase in unibody frame construction for sport utility vehicles in the coming decade.

Manufacturer/supplier comparison

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

Comparison of forecast: TECH-43

There is a statistically significant difference in mean responses between technology and materials panelists for pickup trucks in the years shown in the following table.

Pickup Frame Construction – Percent				
	2002		2007	
	TECH	MAT	TECH	MAT
Integral body/frame or unibody	3.2	0.4	7.1	2.9
Separate body/frame	96.3	99.1	–	–

Technology panelists forecast a higher use of integral body/frame for pickup trucks than panelists.

Trend from previous Delphi surveys

For passenger cars, this question has been unchanged since the 1994 Delphi VII. The Delphi IX panel is in close agreement with earlier panels. This question was further changed to include separate forecasts for sport utility vehicles and pickup trucks in the 1996 Delphi VIII. Therefore comparison with forecasts prior to Delphi VIII is not possible. The Delphi IX panel has a lower long-term forecast use of unibody sport utility vehicles (25 percent) than the Delphi VIII panel (30 percent).

Strategic considerations

In the coming decade, the integral (or unibody) frame construction will continue to be the dominant frame design for the North American passenger car industry. The panel also expects an increased number of sport utility vehicles to be built using unibody design.

Unibody construction is inherently a weight savings structure vis-à-vis the separate body/frame and space frame alternatives. As manufacturers continue to experience increased pressure to reduce weight, unibody construction will continue to offer the most viable design for passenger cars. It will also be increasingly viewed as an alternative for sport utility vehicles.

The sport utility market is in the midst of significant change. Many of the initial entries were engineered from existing pickup truck platforms. Increasingly, companies are developing compact and subcompact SUVs from unibody car platforms. In 1997, Mercedes Benz introduced the M-Class, a luxury SUV built using the separate body/frame design. In 1998, Lexus introduced a luxury SUV (not built in North America) that uses unibody construction. These two vehicles give some indication that there are likely to be many different strategies in the SUV market.

The panel's continued expectations for a slightly higher usage of space frames is very interesting. Space-frame construction is forecast to account for 8 percent of the passenger car market by 2007. Currently, General Motors' Saturn is the only high-volume vehicle manufactured in North America using the space frame. Saturn's independence is currently in doubt and any further assimilation into the parent company could temporarily signal the end of the high-volume space frame.

Although the Delphi IX panel's forecast is for a continued dominance of the unibody design for passenger cars, there remains the potential for hybrid frame designs in the coming decade.

Significant effort is being given to the development of lighter weight vehicles. This developmental effort may lead to new designs that quickly become viable alternatives.

MAT-36. 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 2002 and 2007.

Frame Materials	Est. 1996*	Median Response		Interquartile Range	
		2002	2007	2002	2007
Integral Body/Frame or Unibody					
Steel	100%	99%	95%	95/100%	90/97%
Aluminum	0	1	5	0/5	2/10
Plastics	0	0	0	0/0	0/1
Space Frame					
Steel	100%	97%	90%	90/100%	70/96%
Aluminum	0	2	10	0/10	3/23
Plastics	0	0	0	0/0	0/1

*Source: OSAT estimates

Selected edited comments

- Aluminum space frames could be experimentally introduced before 2002 and, if field acceptance is as expected, its share will increase.
- New space frame vehicles will be aluminum but most vehicles will not be space frames.
- Tailor-welded blanks may expand to tailor-welded extrusion, which may expand the use of multimetals for body/frame parts.
- The dominant challenge is cost-to-manufacturer, which will be mitigated by requirements for higher fuel economy and high-speed production techniques.
- The space frame vehicle is neither cost- nor mass-effective. I don't expect to see it used except in rare niches.

Discussion

Steel is forecast to remain the dominant material for frame/structural members in the coming decade. However, panelists expect aluminum to be used for limited unibody (5 percent) and space frame (10 percent) applications by 2007.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

Steel will likely continue to be the predominant material for all types of frame construction in the coming decade. Although steel suffers from a weight disadvantage vis-à-vis aluminum, it provides a significant cost advantage. Steel also benefits from having been the material of choice for nearly a century. The combination of a cost advantage and a high comfort level places steel in a very strong position.

Several manufacturers are working intensely to develop aluminum frame technology. However, significant cost, bonding, and manufacturing challenges remain. Currently the Plymouth Prowler is the only aluminum-intensive vehicle manufactured in North America. Two other aluminum intensive vehicle are sold in North America: the Honda NSX and the Audi A8. However, these vehicles are produced elsewhere. Interestingly, each of the three vehicles is built using a different frame design. The Prowler has a predominantly aluminum body on an aluminum frame, the NSX is an aluminum integral frame construction with aluminum panels, and the A8 has an extruded aluminum space frame with aluminum panels. The General Motors EV-1 also uses an aluminum frame. The lessons learned from these programs and other developmental work will be instrumental in developing confidence with aluminum frame structures.

An important driver in the development of aluminum-framed vehicles has been the proactive work of aluminum suppliers—suppliers who have played a key role in each of the aforementioned programs. Their contributions have ranged from the development of materials, to the design and manufacture of the vehicle.

The panel foresees no usage of composite frame designs in the coming decade. Although the USCAR Automotive Composites Consortium continues to make progress on precompetitive issues pertaining to composite frames, many major hurdles remain. Safety may present a significant barrier for composite frame usage, although there is considerable disagreement on this point. Unlike steel and aluminum, finite element models are not 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 frame/structural applications.

MAT-37. What are the most significant challenges for the increased usage of structural composites? Please consider all aspects of the vehicle/component life cycle. *(Emboldened headings represent authors groupings of common ideas.)*

RESPONSES

Cost Concerns

- Cost (10)
- COST! COST! COST! System manufacturing and materials
- Cost, including the cost of carbon fibers which will be needed in order to maximize weight savings
- Labor costs
- Low-cost carbon fibers
- Low cost of manufacturer—design freedom
- Material cost (2)
- Material cost and fabrication cost: material cost will decline steadily but fabrication cost reduction will be quite difficult.
- Materials cost and limited supply base
- Overall cost reduction
- Piece price–it is high due to both high material cost and slow manufacturing time
- Price/cost ratio and level
- Recyclability (13)
- Recyclability: Reclamation of each component of the materials is a tough problem to be solved.
- The dominant challenge is cost-to-manufacturer, which will be mitigated by requirements for higher fuel economy and high-speed production techniques.
- Willingness of OEMs to phase out/scrap existing metal stamping facilities

Manufacturing Challenges

- Attachment techniques
- Automated lay-up of orientated fibers
- Component-forming restrictions
- Designers unfamiliarity to use
- Fastening systems
- High-volume manufacturing capability—both to fabricate components and to assemble vehicle structures
- Manufacturing cost and variability

- Manufacturing cycle time
- Manufacturing impact via new capital and learning curve in plants
- Manufacturing speed, productivity, cost
- Reliable joining design and technology: adhesive bonding and mechanical fastening are not yet fully explored and need to be refined
- Repair/replacement
- The development of a space frame design

Material Properties and Performance

- Characterizing fatigue/life
- Crash and crash properties
- Demonstrate competitive life-cycle assessment parameters
- Durability (2)
- Energy absorption
- Fatigue resistance
- Field repair after collision
- Long-term durability and reliability
- Repairability (3)
- Uniformity
- Unknown effect of environment on strength properties or durability

Other Challenges

- Availability
- Inspection
- Lack of knowledge
- Limited design experience for composite structures
- Long product--application times for structural parts since customers don't see changes; must improve structural stiffness or provide significant cost savings to make inroads
- New lightweight steel materials as a competitor
- OEM's reluctance to pressure labor savings-based cost reduction
- One challenge is production technology that allows low cost solutions—essentially net shape preform; this is not a viable answer today, and based on work underway, it may not be viable for a long time to come.
- Raw-material suppliers must join forces to improve the system, not just their raw material.
- Structural design

- Supply infrastructure
- The typical polyester used in SMC or BMC is low-cost, but the production process doesn't allow effective use of the material. I believe the use of these materials will decline as design engineering learns more about how to utilize all the functional attributes of alternatives and create systems that can compete with steel cost effectively.

Discussion

The panel views cost, recyclability, crashworthiness/safety, and manufacturability as the most significant challenges for the increased usage of composites in structural applications.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was first asked in the 1996 Delphi VIII survey. The Delphi IX panel is in general agreement with the Delphi VIII panel.

Strategic considerations

The use of composites for structural applications presents many potential advantages, and at least currently, even more challenges. Composites offer the opportunity to significantly reduce weight, while increasing design flexibility and eliminating corrosion. However, the panel indicates that there is a long list of barriers to the implementation of structural composites. Cost, recyclability, crashworthiness/safety, bonding/joining, and manufacturability all appear to be very significant barriers. It is important to note that breakthroughs in one or two of these areas will not necessarily guarantee the increased application of composites for structural applications

The USCAR Automotive Composites Consortium continues to examine manufacturing techniques that may increase the likelihood of future composite usage for major structural applications. Increasingly, there are examples of composites being used in weight-bearing structural applications such as instrument panel and radiator supports. It is now dependent upon the automotive engineering and manufacturing community to develop information resources that contain pertinent information on these early adaptations of structural composites.

The automotive industry has developed a century of experience with steel structural components. This long history with steel presents at least two significant barriers for expanded application of structural composites. First, industry has developed manufacturing strategies that are based on steel; any shift to composites would require a significant new tooling investment. Second, many individuals that control the material selection process have reached a high level of comfort with steel. They understand the characteristics of steel and are highly skilled in the design and engineering of steel structural components. These people may perceive using composites for a structural application as unfamiliar and too risky. It is possible that a new paradigm in automotive manufacturing and engineering may be necessary to enable the shift toward composite structures.

MAT-38. **Consider the following list of North American-produced automotive <u>body components</u>. Please indicate the percentage of each likely to be made from the listed materials currently and in 2007. It is not necessary to enter a response for every component, just those with which you are familiar. Where you answer, <u>please be sure that your estimates add up to 100 percent.</u> Please use zeros where applicable.**

Passenger Car Body Components - Currently												
	Median Response						Interquartile Range					
Material	**Fender**	**Door**	**Quarter panel**	**Decklid**	**Hood**	**Roof**	**Fender**	**Door**	**Quarter panel**	**Decklid**	**Hood**	**Roof**
Steel	91%	94%	95%	92%	91%	99%	90/95%	90/95%	95/98%	87/94%	88/94%	98/100%
HSS	2	2	0	1	0	0	0/5	0/6	0/0	0/2	0/1	0/0
Aluminum	0	0	0	3	5	0	0/0	0/0	0/0	2/5	3/5	0/0
Plastic												
Thermoplastic	3%	2%	2%	0%	0%	0%	2/5%	1/4%	0/5%	0/1%	0/1%	0/0%
Thermosets	1	1	0	2	2	0	0/2	0/2	0/2	1/5	1/4	0/1

Passenger Car Body Components - 2007												
	Median Response						Interquartile Range					
Material	**Fender**	**Door**	**Quarter panel**	**Decklid**	**Hood**	**Roof**	**Fender**	**Door**	**Quarter panel**	**Decklid**	**Hood**	**Roof**
Steel	75%	75%	82%	75%	70%	86%	70/80%	70/83%	80/87%	70/80%	60/80%	80/95%
HSS	10	10	5	5	5	5	3/10	5/15	1/10	0/9	0/10	0/10
Aluminum	5	5	2	10	15	2	2/10	0/10	0/5	10/20	10/20	0/8
Plastic												
Thermoplastic	5%	5%	5%	1%	0%	0%	5/10%	4/10%	3/5%	0/6%	0/5%	0/1%
Thermosets	1	0	0	2	4	0	0/4	0/2	0/2	0/5	0/6	0/2

Light Truck Body Components – Currently												
	Median Response						Interquartile Range					
Material	**Fender**	**Door**	**Hood**	**Roof**	**Truckbed liftgate**	**Rear hatch**	**Fender**	**Door**	**Hood**	**Roof**	**Truckbed/ liftgate**	**Rear hatch**
Steel	100%	100%	95%	100%	100%	98%	100/100%	100/100%	91/99%	100/100%	95/100%	95/100%
HSS	0	0	0	0	0	0	0/0	0/1	0/0	0/0	0/0	0/0
Aluminum	0	0	2	0	0	0	0/0	0/0	0/5	0/0	0/0	0/0
Plastic												
Thermoplastic	0%	0%	0%	0%	0%	0%	-	-	0/0%	-	0/0%	0/0%
Thermosets	0	0	0	0	0	0	0/0	-	0/0	-	0/0	0/2

Light Truck Body Components – 2007												
	Median Response						Interquartile Range					
Material	**Fender**	**Door**	**Hood**	**Roof**	**Truckbed liftgate**	**Rear hatch**	**Fender**	**Door**	**Hood**	**Roof**	**Truckbed/ liftgate**	**Rear hatch**
Steel	90%	86%	75%	97%	80%	80%	80/93%	80/90%	63/85%	90/100%	75/94%	68/91%
HSS	5	5	4	0	0	0	0/10	1/11	0/5	0/2	0/5	0/4
Aluminum	4	2	11	0	0	5	0/10	0/10	10/23	0/5	0/5	0/6
Plastic												
Thermoplastic	0%	0%	0%	0%	0%	0%	0/2%	0/0%	0/0%	0/0%	0/5%	0/5%
Thermosets	0	0	0	0	5	5	0/1	0/1	0/5	0/0	0/10	0/10

Other light truck material:

Light truck body components (Rear quarter panels) 2007: Thermoplastic, 0%; Thermosets, 25%

Light truck body components (Rear quarter panels) currently: Thermoplastic, 0%; Thermosets, 6%

Selected edited comments

- Bake-hardenable or dent resistant steel is not a true high-strength low-alloy steel.
- Failure to adequately define HSS suggests that the totals for steel should be combined, i.e., steel = steel + HSS. 2007 figures will depend on what CAFE is.
- High fuel-economy models will use aluminum frame structure and aluminum add-on panels. I count bake-hardening grade as HSS.
- Light truck components could change quickly if CAFE laws change to match cars.
- Model differentiation on a common platform will drive the economic value of composites.
- Response presumes +35 mpg CAFE by 2007, paint-bake oven and economical RRIM thermoset plastic, extensive use of plastic in the pickup tailgate (>50%), and 200,000 plastic composite truck beds. Lightweight plastics, because of their decompounding effect on system components weight (and thus cost) are ideal for rear hatch structures.
- The above percentages are based on the midluxury car segment.
- The biggest winner for the body panel will be HSS because of safety concerns and weight reduction.
- Thermosets (FRP) will continue to suffer from recyclability problems.

Discussion

Panelists forecast the continuing dominance of steel for all listed exterior body panels. For passenger cars, high-strength steel is forecast to see growth in all of the listed applications. Aluminum is forecast to see limited growth in fender, door, decklid, and hood applications. Thermoplastics are expected to see limited application in fenders and doors.

For light trucks, high-strength steel is forecast to see growth in fender, door and hood applications. Aluminum is also expected to see very limited application in fenders, doors, hoods, and rear hatches for light trucks. Thermosets are forecast to see limited application on truck bed/liftgates and rear hatches.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was significantly changed for Delphi IX and therefore comparison with previous surveys is not possible.

Strategic considerations

During the next decade, steel usage for exterior body panels is forecast to decline only slightly. The panelists' forecast indicates that steel will likely remain the material of choice for all listed applications. Manufacturers and suppliers have worked diligently to develop competitive manufacturing processes for alternative materials, with varied success.

Aluminum has experienced growth in horizontal panels, especially hood applications. In recent years, several high volume programs have committed to aluminum hoods. These programs have given aluminum a proven track record and may lead to further application of aluminum for horizontal applications in the future. The panel expects limited potential for vertical body panels, although there may be potential for higher than forecasted application. Several low volume programs currently use aluminum for vertical panels. These programs have begun to establish a comfort level with aluminum.

Reinforced thermoplastics have gained acceptance for vertical body panels, although they are used on relatively few programs. Thermoplastics do present several advantages and may see increased application in the coming decade. Thermoplastics are perceived as more recyclable than thermosets and therefore more environmentally friendly. The panel forecasts little growth for thermosets in the coming decade. However, it is likely SMC will continue to be viewed as an acceptable alternative, especially if there are any increases in CAFE.

MAT-39. 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

STAGES OF VEHICLE LIFE CYCLE

Material for Body Panels	Mean Response					
	Raw Material Cost	Design	Component Processing	Assembly	Field Use	Vehicle Disposal
Aluminum	4.2	3.0	3.3	3.3	2.9	1.8
Thermoplastics	3.2	2.1	2.7	2.7	2.5	3.3
Thermosets	3.1	2.4	3.1	3.0	2.7	4.2
Steel	1.4	2.4	1.9	2.1	2.6	1.5

Selected edited comments

- Aluminum costs are coming down fast. Costs that were once 2 to 3 times the price of steel have been reduced to 1.5 to 1.75 times steel's price. Assembly of thermoplastic and aluminum assemblies will save costs (compared to steel) and offset material costs.
- An infrastructure exists for 100 percent recycling capability for steel; this will prove to be a key advantage.
- Design—mass saving of aluminum outweighs its disadvantages; component processing—"A" for class finish remains a problem for plastics; assembly—the need for "E" coat is a key disadvantage for steel
- Given steel's superiority in nearly every category, it is hard to imagine why such significant amounts of money are being spent on the use of the other materials. The UltraLight Steel Auto Body (ULSAB) project currently being carried out by the world's leading steel producers will provide still more innovative steel-based solutions to problems of the auto industry and, perhaps, reduce the necessity to spend so much on finding alternative solutions.
- Look for the price of aluminum to drop as volumes go up. Also, look for more efficient processing assembly. Look for plastic being replaced with metals (such as aluminum and magnesium and their composites) due to plastics' recycling difficulties.
- Material advantage depends on production volume and vehicle concept, but generally speaking, with increasing needs of low cost and lighter weight, each of the above materials will find their usage in various vehicles. There will be no single material domination.
- Once energy recovery from plastic waste becomes acceptable, then steel and aluminum will lose the current temporary advantage at the vehicle's end of life.
- Polymer-based systems, particularly glass reinforced composites, facilitate modular assembly and lower vehicle cost. Reinvestment economics will limit aluminum use.
- Raw material costs in terms of $1/part, <u>not</u> $/pound. Thermosets are both RRIM (≈ $1.25/lb., sp. gr. 1.25) and e.g. SMC ($.85/lb. and sp. gr. 1.70). "Assembly" includes complex shapes and parts consolidated. "Field use" includes both durability and fuel economy.

- Steel is still the material of choice and the standard of the industry.
- Steel remains the material of choice because of cost, availability, ease of manufacture, alternate joining methods, durability and recyclability. Aluminum is disadvantaged with regard to cost, formability. and joining.
- Steel still dominates the share for panels because of its versatile processability and recyclability. New technology is expected to improve its strength-to-weight ratio further, enabling the use of a thinner gauge panel with the same strength.
- Steel still holds many advantages over other materials in these applications.
- Steel will be around for the foreseeable future due to its availability, cost, and ease of fabrication.
- Steel will only slowly get displaced in many applications unless there are extreme mass reduction requirements. Aluminum will see lower applications in cast, extruded and forged applications and limited use in sheet form. Thermoplastic will continue to find applications. Disposal will make wide use of thermosets risky.
- Steel will still be the material of choice with increased usage of stainless and other alloyed grades. This will force a new standard in design/manufacturing.
- The answer depends on vehicle sales volume.
- The cost category remains misstated. It is the assembled cost that is important, not $/lb. For true life cycle assessment, the value of fuel economy must be included. The special accommodation of plastic body panels through the paint processes remains as their major challenge. For SMC, it is porosity. For thermoplastics, and to a lessor extent for RRIM, it is dimensional change. The value of aluminum sheet, especially with new technology that efficiently separates wrought aluminum from cast aluminum, is greatest at disposal. There is no difference in disposal costs of painted plastics among ETP, SMC, or RRIM. But considering the perspective of life cycle, disposal issues are minor.
- The rating above presumes full exploitation of polymeric material attributes by competent product designers capable of valid plastic structure design and not constrained by existing production and assembly plant capital requirements.
- The raw-material cost for steel is stable.
- Thermoplastics and thermosets can be molded to unusual contours to take advantage of space available under the hood and body; e.g., many fuel tanks are formed to fit irregular contours under body. Disadvantages include speed of molding (slow, relative to stamping) and joining alternatives. Paint finish is also a concern and thermosets are not easily recyclable.
- Ultimately, thermoplastics seem like the best technical solution, but economics will slow the conversion. Steel is the only material with a serious corrosion problem, but this is a big drawback.
- With the need for advance styling, steel will become displaced due to the inability to maintain process capability and dimensional stability of body panels. Assembly plants and interfacing component design engineers will become weary of the "floating" dimension of steel body panels and trying to match other components.

Discussion

Panelists rate steel as having an advantage over the other listed components in the raw material cost, component processing, assembly, and vehicle disposal stages of the vehicle life cycle. The panel rates thermoplastics as slightly more advantageous than the other listed materials in the design stage and thermoplastics, thermosets and steel as equally advantageous in the field use stage.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

Steel continues to be the material of choice for many body-panel applications. Yet, aluminum and thermosets continue to see increased application rates. In four of the six life-cycle stages steel is seen as more advantageous than the other listed materials. In the other two stages, steel is seen as nearly equal to the more competitive material. It is likely that steel will remain the dominant material for body panels in the coming decade. However, one caveat is offered. This question assumes current CAFE standards. If CAFE were to increase, it is likely that these ratings would change drastically.

Raw-material cost: Steel continues to be rated as extremely advantageous vis-a-vis the other materials for the raw-materials cost stage. Conversely, aluminum is rated as highly disadvantaged due to its high, and often volatile, cost. Any lasting reduction in the price of aluminum would likely lead too significant application rates for aluminum. Raw material costs for thermoplastics and thermosets are viewed as neither an advantage nor a disadvantage.

Design: The panel rates thermoplastics as slightly more advantageous for design than thermosets and steel. Plastics offer designers versatility that is difficult to match. It is likely that steel is viewed as design-competitive, not necessarily because of its versatility, but instead because of the more than 100 years of experience with the material for automotive body panels. Many current material engineers began their schooling with steel and focused little on other materials. Although this comfort level currently may represent an advantage for steel, designers and engineers are rapidly gaining increased familiarity with competing materials. Any such advantage for steel will likely quickly disappear.

Assembly: Steel is viewed as significantly more advantageous in the assembly stage compared to the other listed materials. The automotive industry has developed a century of steel-forming knowledge. For this reason, combined with a significant investment in tooling, steel presents a formidable competitor for the other competing materials. Plastics suffer from a cycle-time disadvantage that may limit usage for some high-volume programs, and aluminum forming and assembly is still very much a new technology for the industry.

Field use: The four materials are viewed as relatively equal for field use. Steel suffers from corrosion and higher weight vis-à-vis the other materials, but is extremely reliable for crash predictability. Plastics present significant durability and weight advantages, yet may suffer due to the lack of predictability during a crash. Aluminum saves weight, but presents galvanic corrosion and dent resistance challenges and may present challenges for aftermarket repair—at least initially.

Vehicle disposal: According to the panel, steel and aluminum have a significant advantage over plastics at the vehicle disposal stage. Both steel and aluminum have economically successful recycling infrastructures. Thermoplastics and thermosets currently lack economically viable recycling infrastructures.

MAT-40. **Consider the following list of North American-produced automotive bumper components. Please indicate the percentage of each likely to be made from the listed materials currently and in 2007. It is not necessary to enter a response for every component, just those with which you are familiar. Where you answer, please be sure that your estimates add up to 100 percent. Please use zeros where applicable.**

Passenger Car Bumper Components - Currently						
	Median Response			Interquartile Range		
Material	**Fascia/ bumper**	**Support**	**Energy absorption**	**Fascia/ bumper**	**Support**	**Energy absorption**
Steel	0%	63%	13%	0/0%	60/70%	0/61%
HSS	0	25	0	0/0	16/29	0/16
Aluminum	0	5	0	-	1/5	0/0
Plastic						
Thermoplastic	80%	5%	30%	75/85%	5/10%	20/76%
Thermosets	20	0	10	15/25	0/4	0/21

Passenger Car Bumper Components – 2007						
	Median Response			Interquartile Range		
Material	**Fascia/ bumper**	**Support**	**Energy absorption**	**Fascia/ bumper**	**Support**	**Energy absorption**
Steel	0%	20%	3%	0/0%	10/45%	0/36%
HSS	0	40	5	0/0	20/50	0/19
Aluminum	0	10	0	-	1/20	0/9
Plastic						
Thermoplastic	85%	10%	50%	80/90%	5/20%	23/74%
Thermosets	10	0	8	10/20	0/3	0/28

Light Truck Bumper Components – Currently						
	Median Response			Interquartile Range		
Material	Fascia/ bumper	Support	Energy absorption	Fascia/ bumper	Support	Energy absorption
Steel	70%	80%	73%	60/77%	70/90%	50/83%
HSS	0	10	0	0/5	5/20	0/15
Aluminum	0	0	0	0/0	0/0	-
Plastic						
Thermoplastic	22%	0%	15%	20/25%	0/2%	4/31%
Thermosets	0	0	0	0/5	0/0	0/9

Light Truck Bumper Components - 2007						
	Median Response			Interquartile Range		
Material	Fascia/ bumper	Support	Energy absorption	Fascia/ bumper	Support	Energy absorption
Steel	50%	58%	48%	28/50%	40/68%	18/50%
HSS	0	25	8	0/13	20/30	0/25
Aluminum	0	5	0	-	0/18	0/1
Plastic						
Thermoplastic	50%	1%	20%	30/55%	0/9%	7/30%
Thermosets	0	0	8	0/5	0/1	0/20

Selected edited comments

- Bumper systems of compact SUVs are more like that of passenger cars, and that means more TPOs for fascias and energy absorbers.
- I do not believe that polyolefin-based bumper fascia will increase its share compared to that of thermosets (polyurethane) because of its easy recycling capability. Rather, I believe it will increase its share because of cost advantage.
- Look for big changes in truck-bumper design and materials to make trucks less aggressive.
- Plastic (TPO) bumpers will continue to dominate future trends due to cost advantage, design flexibility and damage resistance.
- Polyolefin-based bumper fascia will increase its share because of its easy recycling capability compared to that of thermosets (polyurethane).
- The need for lighter weight will continue the drive to plastics, including for pickup rear bumper/fascia.
- The strength of steel (and formability) will keep it in good standing. Corrosion resistance and lightweight favor plastic composites. The backside corrosion of steel bumper/fascia backing will be addressed with prepainted steel that is resistant to attack by plating chemicals for bright chrome bumpers.

- The styling whims are difficult to call for light trucks. This last bastion for lightweight bumpers could easily shift away if trucks become even more car-like.

Discussion

The panel forecasts thermoplastics to continue to be the dominant material for passenger car bumper/fascia in the coming decade. High-strength steel, aluminum, and thermoplastic are forecast to see increased application for passenger car bumper supports by 2007.

For light trucks, the panel forecasts steel to see reduced application and thermoplastics to see increased usage for fascia/bumpers. High-strength steel and aluminum are forecast to see increased application for light truck bumper supports by 2007.

The wide interquartile ranges for passenger car and light truck bumper energy-absorption material indicates great uncertainty among panelists regarding this material.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was significantly changed for Delphi IX and therefore comparison with previous surveys is not possible.

Strategic considerations

Thermoplastic is forecast to increasingly become the material of choice for bumper/fascia. Thermoplastic gains are expected to be at the expense of thermosets for passenger cars, and steel for trucks. It is possible that much of the forecast increase in thermoplastic bumper fascias for light trucks may be due to the expected increase in the number of small sport utility vehicle programs. Many of these vehicles are built from passenger car platforms, and therefore are more likely to use passenger car bumper systems.

The forecast indicates several materials are viewed as probable candidates for bumper support application in the coming decade. It is likely that significant effort will be focused on the development of bumper supports made from high-strength steel, aluminum and thermoplastic. These efforts should be closely monitored.

MAT-41. **For the following North American-produced passenger car and light truck components, please indicate what percentage is likely to be made from the listed materials currently and by 2007. Please total each component to 100 percent. Leave blank any component with which you are not familiar.**

	Median Response		Interquartile Range	
Component Material	**Current Est.**	**2007**	**Current Est.**	**2007**
Seat Frame				
Aluminum	3%	10%	2/5%	8/20%
Polymer composite	0	1	0/0	0/8
Magnesium	1	5	1/1	3/20
High strength steel (HSS)	8	15	5/10	5/24
Steel	90	60	83/90	42/68
Seat cover				
Knitted and cut	75%	75%	68/80%	68/87%
Leather	10	12	10/20	10/23
PVC	10	1	3/18	0/13
Urethane	0	0	-	0/0
Seat cushion				
Horse hair	0%	0%	0/0%	0/0%
Polyester	0	5	0/0	0/10
Urethane	100	93	99/100	87/97
Woven/suspension	0	2	-	1/3
Carpet Fiber				
Nylon	70%	50%	70/70%	43/58%
Polyester	10	15	8/15	10/20
Polypropylene	20	30	20/23	25/43
Carpet backing				
Polypropylene	97%	100%	90/100%	95/100%
Instrument panel skin				
TPO	5%	31%	3/5%	19/38%
Urethane	5	5	2/5	5/6
PVC	81	50	70/91	30/70
PVC/ABS	9	3	0/24	0/16
Instrument panel cross beam				
Aluminum	2%	5%	1/2%	5/10%
Polymer composite	0	5	0/3	0/10
Magnesium	4	20	2/5	10/36
High strength steel (HSS)	0	5	0/2	1/14
Steel	90	58	84/95	31/69

	Median Response		Interquartile Range	
Component Material	**Current Est.**	**2007**	**Current Est.**	**2007**
Instrument panel retainer				
ABS	10%	0%	0/25%	0/25%
Polycarbonate (PC)	20	5	18/32	0/20
PC/ABS alloy	23	30	20/40	25/65
Polypropylene	6	15	5/7	14/24
SMA	5	5	0/50	0/50
Styrene	0	0	-	-
Urethane	0	0	0/1	0/0
Door trim panels				
ABS	45%	20%	40/49%	19/26%
Polypropylene (PP)	35	65	35/40	50/75
Wood/fiber	13	8	10/19	2/10
Urethane	3	2	1/6	0/9
Interior trim panels (Garnish - A-pillar, C-pillar, etc.)				
Polypropylene (PP)	50%	75%	50/54%	70/78%
ABS	44	20	40/47	13/22
Polycarbonate (PC)	1	0	0/3	-
PC/ABS alloy	2	4	1/5	1/5
Urethane	0	0	0/0	0/0
Headliner				
Fiberglass	45%	25%	40/50%	10/25%
Thermoplastic	5	10	0/10	5/25
Urethane	35	50	30/40	49/65
Fabric	10	5	5/10	5/5
Airbag doors				
Polyester	30%	5%	18/30%	0/16%
Polycarbonate/ABS	0	0	0/10	0/6
PVC	10	0	5/20	0/8
TPO	50	75	40/60	60/85
Urethane	10	10	5/11	4/13

Other component materials

Seat cover:

TPO: Current estimate, 0%; 2007, 16%

Seat cushion:

Rubberized hair: Current estimate, 2%; 2007, 0%

Carpet backing:

Polyethylene: Current estimate, 10%; 2007, 5%

Instrument panel skin:

No skin, painted PC, PC/ABS: Current estimate, 13%; 2007, 35%

Instrument panel cross beam:

Blow-molded PP: Current estimate, 5%; 2007, 25%

Instrument panel retainer:

SMA PPO: Current estimate, 37%; 2007, 20%

Door trim panels:

SMC, Azdel, composites: Current estimate, 10%; 2007, 15%

Interior trim panels:

Thermoplastic Foam PP: Current estimate, 0%; 2007, 20%

Thermoplastic: Current estimate, 0%; 2007, 20%

Selected edited comments

- Cloth may replace leather and vinyl interior components because it is more comfortable in cold and hot weather, less expensive, and easier to repair.
- Door trim panels: Polypropylene (PP)—limited only by need to have up-level vehicles with "covered" panels. PP hard to adhere to; if a good adhesive is found, PP penetration could increase to 70 percent by 2007.
- For headliners, many materials are combined in a laminate, e.g. nylon fabric, polyethylene adhesive film, chopped glass over a foam core (polyurethane or PET, etc.) stiffened with a resin (phenolic or MDI, etc.) adhesive film, etc.
- Hard instrument panel is not listed; perhaps instrument panel retainer is meant to include this.
- Polypropylene-based alloy (TPO) will increase its application significantly from the standpoints of material unification in addition to cost savings.
- TPO will be a dominant material for headliners, airbag doors, and other interior parts, because of its wider design capability of properties and better cost advantage.

Discussion

The panel forecasts decreased application of steel and increased application of lightweight alternatives for seat frames and instrument panel cross beams. They also forecast increased effort to develop the listed plastic components from similar plastics families.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, the manufacturers (96 percent) forecast higher penetration for urethane seat cushions than do the suppliers (87 percent).

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

Plastic has created many opportunities to reduce weight, improve safety, and simplify component design and assembly for interior components. The need to increase commonality of materials for recycling purposes has led to increased interest in designing groups of components with similar materials. Weight reduction will also continue to drive interior component material selection. Steel is forecast to decline in usage at the expense of lighter-weight materials.

Seat frames: The panel expects the usage of steel for seat frames to decline in the coming decade. Aluminum, high-strength steel and magnesium are expected to see increased usage for seat frame structures. Weight reduction will likely force this change. There are several vehicle programs that currently use these materials. Lessons learned from these programs will likely be an important piece of information for the seat-frame, material-selection process on future vehicle programs.

Seat cushion: Urethane is forecast to continue as the dominant material for seat cushions in the coming decade. The panel forecasts polyester to gain initial penetration by 2007, however. Although urethane is a thermoset, and thus potentially more difficult to recycle, urethane used for seat cushions can be recovered, and the reclaimed material can be reprocessed for application in other parts.

Woven/suspension seat cushions are forecasted to see very limited initial production within the coming decade. Suspension seats have been commonplace among manufacturer concept vehicles for several years. However, many challenges remain before such seats are considered viable for production.

Carpet fiber: Polyester (+5 percent) and polypropylene (+10 percent) are forecast to increase penetration for carpet fiber in the coming decade. However, nylon is expected to continue to be the most commonly used carpet fiber material.

Carpet backing: The only material that is expected to be used for this application is polypropylene. Polypropylene is a low-cost, highly recyclable material that meets all carpet backing material requirements.

Instrument panel skin: TPO is forecast to be used increasingly for instrument panel skins. Because of its better long-term ultraviolet protection, and no plasticizers, TPO offers the opportunity to improve skin durability. TPO also presents the opportunity to more closely match interior components made from polypropylene for greater recycling compatibility. Although PVC is considered the low-cost material for instrument skins, environmental concerns will likely lead material engineers to increasingly select TPO.

Instrument panel cross beams: The panel forecasts a drastic reduction in steel for instrument panel cross beams. In an effort to reduce weight, aluminum, polymer composites, magnesium, and high-strength steel are all forecast to see increased application.

Instrument panel retainer: The panel forecasts PC/ABS alloy and polypropylene to increasingly be used for instrument panel retainers. The wide interquartile ranges suggest uncertainty, or differing strategies, regarding material selection for instrument panel retainers. Polypropylene may be viewed as a strong contender because of its lower cost and ability to be molded in color. In addition, polypropylene offers the opportunity for weight reduction and increased compatibility with other polypropylene interior components for easier recycling.

Door trim panels: The forecast indicates increased usage of polypropylene for door-trim panels in the coming decade. Weight and cost reduction will likely drive this change. However, because of difficulties associated with adherence of carpet or cloth to polypropylene, the material may have limitations for luxury market vehicles.

Interior trim panels: The interior trim panel material selection forecasts are similar to those of door trim panels. All simple applications are likely to be polypropylene, but many components that need to be covered with carpeting or cloth may use ABS. Importantly, polypropylene has proven to be capable of meeting pending head impact regulations.

Headliner: Urethane is forecast to increase penetration in the coming decade. System sourcing will likely favor urethane.

Airbag doors: TPO is forecast to increase penetration in the coming decade. The ability to meet material performance requirements at a low cost, while maintaining recyclability, position TPO as the likely material of choice for airbag doors.

MAT-42. **Consider the following list of North American-produced automotive chassis components. Please indicate the percentage of each likely to be made from the listed materials currently and in 2007. Leave blank any components with which you are not familiar. Where you answer, please ensure that your estimates add to 100%. Please use zeros where applicable.**

PASSENGER CARS - Chassis Components – Current Estimate								
Chassis Components	Median Response				Interquartile Range			
	Steel	HSS	Aluminum	Plastic	Steel	HSS	Aluminum	Plastic
Control arms	85%	0%	10%	0%	75/98%	0/3%	2/20%	-
McPherson strut								-
Front springs	100%	0%	0%	0%	100/100%	-%	0/0%	-%
Rear springs	100	0	0	0	95/100	0/0	-	0/4
Stabilizer bars	100	0	0	0	100/100	0/0	-	-
Steering knuckle assembly								
Spindle	100%	0%	0%	0%	98/100%	-%	0/2%	-%
Knuckle	98	0	2	0	80/100	-	0/20	0/0
Steering linkage								
Idler arm	100%	0%	0%	0%	100/100%	0/0%	-%	-%
Pitman arm	100	0	0	0	100/100	0/0	-	-
Tie rod	100	0	0	0	100/100	0/0	0/0	0/0
Wheels	50	0	45	0	40/64	0/0	35/54	0/0

LIGHT TRUCKS - Chassis Components – Current Estimate								
Chassis Components	Median Response				Interquartile Range			
	Steel	HSS	Aluminum	Plastic	Steel	HSS	Aluminum	Plastic
Control arms	100%	0%	0%	0%	95/100%	0/0%	0/3%	-%
Drive shaft	94	0	7	0	83/100	0/0	0/10	0/0
Rear axle assembly								
Gears	100%	0%	0%	0%	-%	-%	-%	-%
Differential carrier	100	0	0	0	96/100	0/0	0/2	-
Torque tubes	100	0	0	0	100/100	-	0/0	-
Axle shaft	100	0	0	0	-	-	-	-
Springs	100	0	0	0	100/100	0/0	-	0/0
Spring covers	100	0	0	0	91/100	-	-	0/9
Stabilizer bars	100	0	0	0	-	-	-	-
Steering knuckle assembly								
Spindle	100%	0%	0%	0%	-%	-%	-%	-%
Knuckle	100	0	0	0	100/100	-	0/0	-
Steering linkage								
Idler arm	100%	0%	0%	0%	-%	-%	-%	-%
Pitman arm	100	0	0	0	-	-	-	-
Tie rod	100	0	0	0	-	-	-	-
Wheels	75	0	25	0	60/80	0/0	15/35	-

PASSENGER CARS - Chassis Components – 2007								
Chassis Components	Median Response				Interquartile Range			
	Steel	HSS	Aluminum	Plastic	Steel	HSS	Aluminum	Plastic
Control arms	70%	0%	21%	0%	58/80%	0/10%	15/33%	0/1%
McPherson strut								
Front springs	100%	0%	0%	0%	95/100%	0/0%	-%	0/0%
Rear springs	95	0	0	1	90/100	0/0	-	0/9
Stabilizer bars	100	0	0	0	100/100	0/0	-	0/0
Steering knuckle assembly								
Spindle	98%	0%	0%	0%	80/100%	0/0%	0/20%	-%
Knuckle	70	0	30	0	58/83	0/0	13/38	0/0
Steering linkage								
Idler arm	100%	0%	0%	0%	93/100%	-%	0/4%	0/0%
Pitman arm	100	0	0	0	93/100	0/0	0/0	0/0
Tie rod	100	0	0	0	75/100	0/0	0/3	0/0
Wheels	34	0	60	0	27/36	0/10	50/60	0/2

LIGHT TRUCKS - Chassis Components – 2007								
Chassis Components	Median Response				Interquartile Range			
	Steel	HSS	Aluminum	Plastic	Steel	HSS	Aluminum	Plastic
Control arms	80%	0%	10%	0%	63/89%	0/9%	3/24%	-%
Drive shaft	85	0	15	0	65/100	-	0/35	0/5
Rear axle assembly								
Gears	100%	0%	0%	0%	100/100%	-%	-%	-%
Differential carrier	90	0	5	0	83/100	0/0	0/10	-
Torque tubes	100	0	0	0	81/100	-	0/2	0/0
Axle shaft	100	0	0	0	100/100	-	0/0	-
Springs	100%	0%	0%	0%	90/100%	-%	-%	0/10%
Spring covers	85	0	0	15	70/100	-	-	0/30
Stabilizer bars	0	0	0	0	-	-	-	-
Steering knuckle assembly								
Spindle	100%	0%	0%	0%	94/100%	-%	0/6%	-%
Knuckle	93	0	5	0	80/99	-	0/10	0/0
Steering linkage								
Idler arm	100%	0%	0%	0%	100/100%	-%	0/0%	0/0%
Pitman arm	100	0	0	0	100/100	-	0/0	0/0
Tie rod	100	0	0	0	100/100	-	0/0	0/0
Wheels	50	0	45	0	38/73	0/11	20/51	0/0

Selected edited comments

- A steel industry study of wheels showed that, in 1995, 42 percent of steel wheels were made of high-strength grades. Those grades have been growing 4 to 5 percent per year and should continue.
- Perhaps "mag wheels" will actually be made from magnesium if cost comes down and availability goes up.

- The need to reduce weight both in cars and light trucks will lead to use of lightweight materials, and the differences in material selection between the two vehicle types will lessen.
- Thin wall-cast stainless should gain a 10 percent share of chassis components by 2007.

Discussion

The panel forecasts little change in material for most of the listed components. Control arms and steering knuckles are expected to see increased penetration of aluminum. The panel also forecasts increased application of aluminum for light truck drive shafts and differential carriers. The interquartile ranges for passenger cars in 2007 suggest some uncertainty regarding future material selection for several chassis components. However, steel remains the likely material of choice according to the panel.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, the manufacturers (32 percent) forecast higher penetration for aluminum control arms in passenger cars than do the suppliers (16 percent).

Trend from previous Delphi surveys

This question was significantly changed for Delphi IX and therefore comparison with previous surveys is not possible.

Strategic considerations

Vehicle manufacturers face a continuing challenge to reduce weight, while maintaining affordability. Steel, although adding weight to a vehicle has proven to be a very cost-effective material for chassis components. Aluminum is likely to see increased application for several of the listed components, yet cost will probably remain an issue.

Aluminum will increasingly be used for wheels. Aluminum offers a balance of affordability, function, and styling. However, recent advances in plastic wheel coatings afforded steel the ability to meet styling requirements and may make styled steel wheels more competitive.

We find it somewhat surprising that the panel did not forecast any application of high-strength steel for the listed components. The industry appears to be relying on steel (and to a lesser degree aluminum) for future vehicle programs. Most manufacturers and suppliers have significant work underway with regard to alternative chassis component materials. Currently cost appears to be the most critical barrier to the implementation of these materials. Any increase in CAFE requirements would likely lead to a much more rapid increase in the penetration rates of the listed lightweight materials.

MAT-43. **What percentage of North American-produced passenger cars and light trucks will use materials other than conventional glass for windshields, side windows or rear windows in 2002 and 2007?**

2002	Median Response			Interquartile Range		
Alternative Material for Glass	**Windshield**	**Side Window**	**Rear Window**	**Windshield**	**Side Window**	**Rear Window**
Polycarbonate	0%	1%	0%	-%	0/10%	0/2%
Polycarbonate-glass laminates	0	0	0	-	0/3	0/2
Special coatings and/or interlayers to:						
Reduce solar load	25%	20%	25%	10/50%	3/36%	3/50%
Provide defrosting capability	10	0	1	1/15	0/0	0/40
Provide abrasion resistance for plastics (e.g., diamond film glazes)	0	3	0	-	0/9	0/8

2007	Median Response			Interquartile Range		
Alternative Material for Glass	**Windshield**	**Side Window**	**Rear Window**	**Windshield**	**Side Window**	**Rear Window**
Polycarbonate	0%	4%	2%	0/1%	1/10%	0/9%
Polycarbonate-glass laminates	0	2	3	0/0	0/6	0/4
Special coatings and/or interlayers to:						
Reduce solar load	50%	50%	50%	25/94%	18/90%	7/94%
Provide defrosting capability	15	1	5	5/35	0/9	1/65
Provide abrasion resistance for plastics (e.g., diamond film glazes)	0	5	0	0/3	0/43	0/28

Selected edited comments

- I do not see glass being replaced with plastics, due to cost.
- Plastic windows are applicable only to side windows because of safety concerns and the high cost of abrasive coatings. Coatings for side windows and windshield to reduce solar load, especially ultraviolet protection, will become popular.
- PUB may be a better choice than polycarbonate.
- Solar glass and possibly new solar developments will be required in the marketplace. Also, system benefits for HVAC and increased plastic-interior-part durability will help push solar glass. Cost is the key negative.

Discussion

The panel forecast little or no application of polycarbonate as an alternative window material by 2002. They forecast only small penetration rates for polycarbonate in side or rear window applications by 2007. They expect no use of polycarbonate for windshields in the coming decade. Special coatings and interlayers are expected to see increased usage through the forecast period.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

Current styling themes promote large glass surfaces. As more glass is used, it becomes an increasingly attractive alternative for replacement by lightweight alternatives such as polycarbonate. According to the panel, glass will continue to be the material of choice for all listed applications. Polycarbonate will likely see initial usage in side and rear windows. Although polycarbonate offers an opportunity to reduce weight, it suffers from a lower resistance to scratching, less sound dampening, and is less forgiving at impact than glass laminates.

As the automobile greenhouse continues to grow, material engineers will be increasingly challenged to develop strategies that protect the occupants and the vehicle interior from ultra-violet rays. In response to these challenges, the panel expects special coatings and interlayers to see increased application in the coming decade. Many of these interlayers and coatings are either currently, or will soon be, offered on higher-priced luxury vehicles.

MAT-44. **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 2002 and 2007. Please total each component to 100 percent. Leave blank any components with which you are not familiar.**

	Median Response			Interquartile Range		
Component Material	**Current Est.**	**2002**	**2007**	**Current Est.**	**2002**	**2007**
Drum						
Aluminum	0%	1%	5%	-%	0/5%	0/16%
Cast iron	100	95	90	100/100	90/99	75/95
MMC	0	0	2	0/0	0/5	0/20
Drum Brake Backing						
Aluminum	0%	8%	10%	0/0%	1/10%	6/20%
Aluminum Matrix Composites	0	0	0	-	-	0/0
Plastic	0	0	0	0/0	0/2	0/9
Steel	100	89	80	95/100	58/94	31/84
Rotors						
Aluminum	0%	5%	15%	0/1%	2/5%	6/19%
Cast iron	100	95	85	100/100	95/99	83/96
Caliper Housings						
Aluminum	5%	13%	45%	0/10%	9/26%	19/50%
Nodular iron	95	88	55	90/100	74/91	50/81
Plastic	0	0	0	-	-	-
Calipers						
Aluminum	0%	0%	2%	0/0%	0/13%	0/23%
Aluminum Matrix Composites	0	0	2	-	0/5	0/13
Nodular Iron	100	95	85	100/100	80/100	60/98
Pistons						
Aluminum	0%	4%	8%	0/4%	0/14%	0/20%
Aluminum Matrix Composites	0	0	0	-	0/0	0/5
Metal Matrix Composites	0	0	0	-	0/2	0/1
Plastic	0	0	3	0/1	0/16	0/44
Steel	100	87	70	80/100	53/99	25/90

Other responses:

Drum:

MMC on EV1: Current estimate, 1%; 2002, 1%; 2007, 5%

Drum brake:

Steel metal to metal laminate: Current estimate, 40%; 2002, 55%; 2007, 80%

Steel: Current estimate, 0%; 2002, 5%; 2007, 10%

Rotors:

Aluminum matrix composites: Current estimate, 0%; 2002, 5%; 2007, 0%

Aluminum/ceramic: Current estimate, 0%; 2002, 0%; 2007, 15%

MMC: Current estimate, 0%; 2002, 1%; 2007, 3%

Calipers:

Al-MMC on AL with steel insert: Current estimate, 1%; 2002, 1%; 2007, 2%

Aluminum/ceramic: Current estimate, 0%; 2002, 0%; 2007, 5%

Pistons:

MMC: Current estimate, 0%, 2002; 2%, 2007; 10%

Phenolic, MMC: Current estimate, 15%; 2002, 35%; 2007, 70%

Phenolics: Current estimate, 10%; 2002, 15%; 2007, 15%

Selected edited comments

- Aluminum MMC will be used for rotor and caliper housings for their weight saving capability and higher stiffness.
- Aluminum rotors will be widely used in the EVs to save weight. Stainless steel rotors, which are standard material in motorcycles, will also be used for weight reduction.
- Brakes are too much of a safety item to mix different metals and experiment with new materials.
- Fuel economy inducement for lighter weight materials, plus the need to lower the current $85/car warranty cost on an average vehicle, will stimulate redesign around new materials.
- Interest in economical solutions to mitigate the persistent problems of warranty cost and customer dissatisfaction remains high. Thus OEM and Tier 1 suppliers of brake components are receptive to new approaches, the latter especially if warranty is transferred to them.

Discussion

Panelists forecast that aluminum usage will increase significantly for caliper housings. The panel forecasts a less significant increase in aluminum for the other listed brake components. The wide interquartile ranges for the 2007 forecast of drum brake backings, caliper housings, calipers, and pistons suggest significant uncertainty with regard to future material applications for the listed materials, or differing strategies among the manufacturers.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was significantly changed for Delphi IX and therefore comparison with previous surveys is not possible.

Strategic considerations

The application of aluminum or other alternative lightweight materials for the listed components would drastically reduce overall vehicle weight. These lightweight materials will also add cost. However, at the systems level the higher material cost may be offset by other factors such as component consolidation or increased performance.

In each of the listed components, aluminum is forecast to see increased application. The components listed in MAT-42 and MAT-44 present significant opportunity for weight reduction. In the event that CAFE requirements are increased, it is highly likely that these components would rapidly move toward higher penetration rates for the lightweight materials.

MAT-45. Approximately 40 percent* of 1996 North American-produced passenger cars and 71 percent of light trucks had styled wheels. What percentage of styled wheels will be made from each of the following materials in 2002 and 2007?

		Median Response		Interquartile Range	
Styled Wheel Materials	**Est. 1996***	**2002**	**2007**	**2002**	**2007**
Passenger Car					
Aluminum	94.9%	95%	92%	90/96%	83/97%
Hybrid (steel and plastic)	0	0	0	0/0	0/2
Magnesium	0	0	0	0/0	0/5
Plastics	0	0	0	0/0	0/5
Steel	5.1	4	2	0/5	0/5
Light Truck					
Aluminum	72.4%	76%	85%	75/84%	75/90%
Hybrid (steel and plastic)	0	0	0	0/0	0/0
Magnesium	0	0	0	0/0	0/0
Plastics	0	0	0	0/0	0/0
Steel	27.6	20	14	15/25	10/20

* Source: Ward's Automotive Reports, Feb. 17, and Mar. 3, 1997.
Rates for 1996 are based on production in U.S., Canada, and Mexico for the U.S. market.

Selected edited comments

- Consumer studies have indicated that customers are generally unaware of what wheels are made of. Further, they are very particular about how they look, hence the trend to styled wheels. The added cost represented by cast aluminum wheels is yet another factor in sticker cost creep. A more durable steel wheel, with appropriately styled high quality wheel covers will help hold down costs while providing consumers with the look they want.
- High costs will drive wheels back to steel.
- Magnesium wheels are already proven by the application of magnesium in Japan; this will be the same in the United States. Wheels are a good application for big weight reduction.
- Uretch, formerly Motorwheel/Goodyear, produces a polycast-styled wheel—urethane molded on a steel or aluminum rim then painted to simulate cast aluminum.

Discussion

Panelists forecast aluminum wheels to account for 92 percent of styled wheels for passenger cars and 85 percent of styled wheels for light trucks by 2007. Steel will account for the remainder of the styled wheels. Magnesium and plastic are not expected to see any application in the coming decade, yet the interquartile ranges for both materials suggest some potential for initial application.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with previous Delphi panels.

Strategic considerations

Styled wheels continue to be a high-demand option for both passenger cars and light trucks in the coming decade. The materials panel expects aluminum to be increasingly the dominant material for styled wheels. Aluminum wheels, while suffering from a cost disadvantage compared to styled steel wheels, offer styling and appearance attributes. Aluminum wheels also present weight savings potential while meeting durability and safety requirements.

The comment regarding the styled steel wheel with a urethane-molded cover merits special mention. This application technology presents an interesting option for designers and should be closely watched. The wheel is currently offered on at least one luxury car. This application will provide an interesting test to gauge consumer acceptance and durability of the product.

The panel forecasts little or no usage of plastic or magnesium for original equipment styled wheels in the coming decade. Although both materials present opportunity for weight reduction, acceptance will be slow due to cost and safety concerns. Barring unforeseen advances, neither material will gain significant penetration in the coming decade.

MAT-46. What percentage of North American-produced passenger cars and light trucks utilize the following bonding/joining technologies in body assembly currently and will in 2007?

	Median Response		Interquartile Range	
Bonding/Joining Technologies	**Currently**	**2007**	**Currently**	**2007**
Acrylics				
Body panels	0%	6%	0/4%	5/20%
Body reinforcement	0	3	0/7	0/13
Glass	0	0	0/3	0/4
Hem flanges	18	28	9/25	19/39
Ornamentation	28	38	0/63	0/63
Structural	5	11	3/10	4/15
Epoxies				
Body panels	20%	25%	2/44%	10/51%
Body reinforcements	53	65	29/100	28/100
Hem flanges	78	73	63/93	50/80
Structural	45	45	4/88	16/85
Foam Tape				
Exterior trim	90%	95%	63/95%	90/98%
Interior trim	18	50	5/-	10/-
Urethanes				
Body panels	23%	20%	3/55%	4/36%
Hems	1	1	0/5	0/8
Stationary glass	100	100	95/100	95/100
Structural	7	10	2/13	5/18

Selected edited comments

- Epoxies are for body panels and body reinforcements where high temperature and rigidity are needed. Acrylics/foams are for both inner and outer ornamentation, including tail lamps. Urethanes are primarily for glasses.

Discussion

Panelists forecast a slight increase in the listed bonding/joining technologies for body component bonding in the coming decade.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

The 1998 Delphi IX forecast differs in several areas from previous forecasts. Only a long-term forecast was asked for Delphi IX, so comparisons can only be made to previous long-term forecasts. The Delphi IX panel forecasts higher application of acrylic for hem-flanges, and a lower forecasted use of acrylics for ornamentation than the 1996 Delphi VIII panel. The Delphi IX forecasts higher penetration rates for all listed epoxy applications and interior applications of foam tape.

Comparison of Delphi VII and Delphi VIII Forecasts			
	Median Response		
Bonding/Joining Technologies	2003 Delphi VII	2005 Delphi VIII	2007 Delphi IX
Acrylics			
Body panels	5%	6%	6%
Body reinforcement	0	5	3
Glass	10	0	0
Hem flanges	5	15	28
Ornamentation	10	55	38
Structural	0	10	11
Epoxies			
Body panels	15%	30%	25%
Body reinforcements	15	40	65
Hem flanges	50	70	73
Structural	20	25	45
Foam Tape			
Exterior trim	50%	95%	95%
Interior trim	40	30	50
Urethanes			
Body panels	20%	15%	20%
Hems	n/a	n/a	1
Stationary glass	n/a	n/a	100
Structural	20	15	10

Strategic considerations

It appears that manufacturers will not significantly increase usage of many bonding and joining techniques in the coming decade, although growth in some key areas is forecast. Of the listed materials, only epoxies are forecasted to see even moderately increased penetration for the listed components. The usage of adhesives to join body panels during assembly may be limited, depending on the role nonmetallic recycling has in the material-selection process. 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—thus, better enabling recyclability.

Epoxy adhesives are expected to be the most common material for hem-flange and body-reinforcement bonding applications. Epoxy adhesives deliver excellent mechanical strength properties, especially at current paint oven temperatures.

The panel forecasts urethane adhesives to be the sole material for stationary glass applications. This is largely due to urethanes' ease of processing and ability to successfully adhere to federal safety standards while meeting cost constraints.

Acrylic adhesives and foam tape are expected to be used for ornamentation and exterior applications, respectively. These materials have proven to be the lowest cost while still meeting the requirements.

MAT-47. What percentage of North American-passenger car and light truck manufacturing facilities will use the following paint systems in 2002 and 2007?

	Est.	Median Response		Interquartile Range	
Paint Systems	**1994***	**2002**	**2007**	**2002**	**2007**
UNDERCOAT					
Electrocoat					
Current technology	100%	95%	40%	80/95%	0/75%
Lead-free	0	8	70	5/20	25/100
Primer surfacer					
None	15%	10%	10%	9/10%	3/13%
Solvent-borne	80	75	50	69/79	48/69
Powder	5	8	15	5/13	10/28
Waterborne	0	10	15	5/11	10/30
TOPCOAT (Base coat/clear coat)					
Base coat					
Solvent- borne	90%	75%	50%	70/78%	50/50%
Waterborne	10	25	50	20/30	44/50
Clear coat					
Conventional solvent melamine	35%	25%	15%	20/28%	5/20%
Solvent-borne etch resistance	65	75	80	70/77	70/81
Powder	0	0	5	0/4	0/10
Water-borne	0	0	0	0/0	0/4

* Source: Automotive Manufacturer estimate

Other response:

2007: 1% molded in color

Selected edited comments

- Air pollution requirements continue to push waterborne base coats.
- Lead seems destined for elimination, solvents for reduction.
- Prepaint and preprimed steel and aluminum in coil will make an impact on paint operations, especially in new plants. There will be little to no impact on existing facilities. The big reason is paint quality improvement and concentration of VOC in the coil-coater paint facility.
- Recent efforts to upgrade powder-coating technologies may result in the powder top coat/powder-clear-coat system.
- The Europeans have moved the date of their proposed ban on lead to January 1, 2003.
- The lead-free question is totally in the hands of the Europeans—if their proposal to ban Pb by January 2002 is approved, all electrocoat will be lead-free in 2002 and 2007. Otherwise, there will probably be some split between lead-free and the current electrocoat, because of the higher costs of the Pb-free system

- Use of preprimed products for selected vehicles will gain attention as EPA pressures increase. A coil-coated product (steel or aluminum) would contain VOCs in one location (the coil coater) instead of many assembly plants.
- Waterborne will steadily increase its share in every category. Lead-free electrocoat will be mandated before 2007.

Discussion

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

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

Paint Systems	Short-term			Long-term		
	1998 Delphi VII	2000 Delphi VIII	2002 Delphi IX	2003 Delphi VII	2005 Delphi VIII	2007 Delphi IX
UNDERCOAT						
Electrocoat						
Current technology	90%	90%	95%	70%	50%	40%
Lead-free	10	10	8	30	50	70
Primer surfacer						
None	40%	10%	10%	30%	5%	10%
Solvent-borne	40	60	75	30	50	50
Powder	5	20	8	10	30	15
Waterborne	10	8	10	25	10	15
TOPCOAT						
Base coat/clear coat						
Base coat						
Solvent- borne	n/a	n/a	75%	n/a	n/a	50%
Water-borne	20%	30%	25	40%	60%	50
Clear coat						
Conventional solvent melamine	60%	20%	25%	25%	10%	15%
Solvent-borne etch resistance	30	70	75	30	65	80
Powder	0	0	0	8	5	5
Waterborne	0	0	0	10	10	0

In general the 1998 Delphi panel forecasts a slower transition to the more environmentally friendly paint technologies than did the 1994 Delphi VII or 1996 Delphi VIII panels. The table shows the short- and long-term forecast from the three Delphi surveys.

Strategic considerations

Airborne chemicals or volatile organic compounds have been a significant byproduct of traditional automotive paint systems. In the past 20 years, the industry has significantly reduced paint shop emissions of VOC. However, further reduction will be required.

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 stricter government regulation.

The conversion of a paint shop is an expensive activity. A new paint shop can cost several hundred million dollars and considerable downtime. The conversion of facilities must be coordinated with the major model changes at each facility. Therefore the conversion of all facilities will likely take many years. The combination of cost and coordination with vehicle programs may be a reason the Delphi IX forecast is somewhat more conservative than previous forecasts. The conversion to more environmentally-acceptable paint systems must not have a negative effect on consumer satisfaction.

Solvent-borne paint systems will decrease markedly as waterborne and powdered paint systems are implemented. Conversion to lead-free electrocoats will likely require government regulation, since they are more costly when compared to current technology.

The USCAR Low Emission Paint Consortium (LEPC) continues to research environmentally-sound paint systems. The LEPC is currently concentrating much of its effort on the development of powdered paint systems. This "prove-out" facility will likely be a major step in defining future powdered paint systems, and the activity should be closely monitored by all automotive industry participants.

MAT-48. What are your expectations of oven temperature currently and for 2007 for the following paint systems.

Oven Temperature				
	Median Response		Interquartile Range	
Paint Systems	Current Estimate	2007	Current Estimate	2007
Electrocoat	360°F	350°F	350/360°F	310/353°F
Topcoat	275	263	275/280	250/274

Selected edited comments

- Effects of lead-free electrocoat on the baking temperature is not clear, but I assume no big changes.
- I am assuming paint systems stay in the assembly plant and are not replaced by precoated product.
- I presume on-line painted materials, not off-line painted articles such as fascia. Some two package, low-bake systems will likely be used in the future, as will powder primer and powder clear coating. But solvent and water-based coatings will continue to dominate.
- I see no drastic changes in E-coat temperature.
- In 2007, bake temperature can be lowered for electrocoat but sealers and bake-hardening steel require higher bakes. Lower bake temperature for topcoats will cost more in $/gallon so lower temps are unlikely.
- It's interesting to note the infusion of both bake-hardened steel and aluminum into body construction.
- The reduction of oven temperature will result from increased cost pressure. Once the oven temperatures are reduced, new materials (such as plastics) will begin to replace steel and other metals for panels. This will reduce oven temperatures further, because of molded-in color and the lack of the need for paint altogether (for low-line cars).
- Topcoat temperatures will rise only if powder clearcoats become common.

Discussion

The panel forecasts paint oven temperatures for electrocoat and topcoat applications will decrease 10 degrees and 12 degrees (F) respectively by 2007.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was changed significantly for the 1996 Delphi VIII. Therefore, comparison with surveys prior to Delphi VIII are not possible. The 1998 Delphi IX panel is in agreement with the

Delphi VIII panel. Their current estimate and long-term forecasts are identical. However, the Delphi IX panel current estimate (275^{O}F) and their long-term forecast (260^{O}F) are significantly higher than the Delphi VIII current estimate (260^{O}F) and long-term forecast (250^{O}F).

Strategic considerations

A slight decrease in oven temperatures in the next decade would be an important part of a continuing energy-conservation strategy, and would marginally reduce costs. However, it is expected that increased volatile organic-compound emission standards will increase the use of powdered and waterborne coatings. Such a move may, in fact, force the need to increase oven temperatures.

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

MAT-49. Please indicate how materials will influence the improvement of future customer satisfaction over the next 10 years for body and chassis.

RESPONSES

BODY: EXTERIOR

Quality/reliability/durability:

- A compromise to permit compliance with government regulations may cause future customer satisfaction to be eroded rather than enhanced.
- A negative influence will probably prevail until large quantities of aluminum are introduced, which corrode less.
- Better corrosion resistance and plastics will make durability an issue over metals because of increased durability.
- Better fit-up and durability will result from current initiatives.
- Corrosion-resistant steels and acid-tolerant clear coat will greatly improve customer satisfaction.
- Dent-resistant steels will be less prone to damage from parking lots, belt buckles, etc.
- Each attribute will improve, especially durability.
- Fit, dirt resistance will improve.
- Higher strength panels of aluminum will improve already good dent resistance.
- I expect better weatherability, chipping and scratch-resistant paints.
- Improved chip resistance will eliminate corrosion as an issue at any level.
- Improved corrosion resistance (3)
- Improved cosmetic durability from the adoption of aluminum
- Improved dent-/scratch-resistance
- Mar- and abrasion-resistant TPO will become commonly used, as will damage-resistant body panels.
- More durable finishes and paints
- More scratch and dent resistance and extended corrosion resistance
- North American automakers have one very high standard for steel and a less critical standard for other materials. The lower quality appearance of the competing materials does not go unnoticed by the consumer.
- Probably not much change within 10 years, but I believe significant changes will be under way in terms of utilizing alternative materials for bodies that will be starting production in 10 years. The result of these programs will be improvement in all these dimensions. (The 10-year estimate could be low or high in certain overseas opportunities.)
- Recycled materials will meet function in the same fashion as virgin materials.

- Repairability (cost)
- The inherent corrosion resistance of aluminum improves durability.
- The surface must be more glossy and less susceptible to dings and dents.

Appearance:

- A reduction of corrosion will improve customer satisfaction.
- Aluminum panels maintain good appearance.
- Appearance can be maintained at current levels.
- Body color will be even better.
- Coatings—new colors, iridescence. LEDs may offer new rear lamp displays
- Etch-resistant clear coats that will make vehicles look better longer
- High-gloss paints, three-coat pearl appearance, but not at the expense of manufacturing
- Highly efficient reinforcements will become available to stiffen plastics without detracting from surface quality.
- Improved light stability of plastics will allow increased use of unpainted parts.
- Improved paint systems will help long-term appearance.
- Lightweight materials may slightly degrade surface appearance.
- Long-life high glossy finishes
- Maintain gloss
- More flexible design and lower tooling cost will be possible with the use of plastic for exterior body panels.
- More styled wheels
- Much wider application of clear coat and thicker coating layer will assure improved appearance.
- No color fade, better paint chip resistance and resistance to acid rain will all be sought.
- North American automakers have one very high standard for steel and a less critical standard for other materials. The lower quality appearance of the competing materials does not go unnoticed by the consumer.
- Preprimed and prepainted steel and aluminum have smoother (no orange peel or cratering) finishes. Adhesive bonding will eliminate spot weld craters.
- Recycled materials will meet function in the same fashion as virgin materials
- The evolution of paint systems to "hide" finishing shortcomings of new candidate materials

Safety

- Better frame design and materials
- Compliance with frontal- and side-impact regulations does not require new materials (for body exterior). Wide-angle outer mirror will improve visibility.

- Continued use of metal panels will avoid risks from the shattering of composite panels.
- Exterior crush of "systems" will improve energy absorption.
- Improved crashworthiness through FEA modeling and subsequent material characterizations
- Increased crashworthiness
- Materials won't be used if safety is compromised.
- More rigorous safety requirements will favor steel.
- Plastic materials will help meet the new FMVSS regulations and improve the cost-effectiveness of new designs.
- Recycled materials will meet function in the same fashion as virgin materials.
- There is no question that consumers equate steel with safe vehicles, and also with personal safety.
- Water-repellent glass coatings, multifunctional glazing for safety and security

Other (please specify)
- Lighter swing panels offer much improved customer satisfaction.
- Multifunctional antenna systems to improve cost and performance, reduce warranty
- Must reduce the cost of repair.
- Reduced weight of lift gates, etc., will be appreciated by both designers and customers.

BODY: INTERIOR

Quality/reliability/durability:
- A trend toward one material for plastic-trim components will help in recycling.
- Great improvement will be due to increased use and application of plastics in integrated structural modules such as the integrated structural instrument panels.
- High durability/rigidity from well-designed aluminum body structures
- High-strength steels with defined and consistent properties and advanced welding (especially laser)
- I don't think any significant changes of materials are likely; therefore, quality/reliability/durability will be the main area of focus.
- Improve weatherability (resist fading, cracking, etc.)
- Improved UV protection due to the use of solar glass
- Improved UV resistance
- Improved wear resistance and solar protection

- It will have a negative influence until the effect of 10-year consumer experiences is tabulated. However, integrated-cost magnesium and plastic components should lead to improved quality and a reduced number of parts.
- Mar- and abrasion-resistant TPO will be widely used as the dominant first surface material in interiors.
- Recycled materials will meet function in same fashion as virgin materials.

Fit and finish:

- Ability to maintain close tolerances will help.
- Better dimensional stability/control
- Better fit and finish will result in a more uniform look and will improve squeak between parts.
- Big Three will meet Japanese levels of fit and finish.
- Combat squeak and rattle through materials development and design.
- Far fewer squeaks and rattles will result when one-piece castings replace multiple part assembly.
- Fit and finish will be improved due to net-shape, fabricated-alternative, material-based designs that eliminate hundreds of pieces and assembly operations.
- Improved CLTE will increase fit.
- Improved FE modeling of part forming/die design and stamping to give improved fit and finish
- Increased use of plastics will allow designers to consolidate more parts thus improving fit.
- Magnesium and plastic-integrated structure can allow for reconfiguration of seating patterns.
- Must fit better with all pieces
- Near net shape manufactured metals, including die cast aluminum and magnesium, thixocast aluminum, and metal injection molding
- Parts consolidation will certainly improve fit and finish.
- Plastic cross-car beams will aid fit and finish.
- Plastics will be used in large consolidated structures for instrument panels, doors, and seats. This consolidation will significantly improve fit.
- Recycled materials will meet function in the same fashion as virgin materials.
- Tighter gaps and component consolidation.

Ergonomics:

- Adoption of adhesive bonding will improve NVH characteristics and reduce squeaks and rattles.
- Design through part consolidation made possible with new plastic materials will assist ergonomic designs.

- Improved satisfaction would be expected, due to the fact that some alternative materials such as thermoplastics may be fabricated net shapes, thus making improved ergonomics cost-effective.
- Lightweight seat structures may allow for reconfiguration of seating load-carrying patterns.
- More comfortable seats (especially foam technology and design)
- Plastic cross-car beams allowing cockpit build
- Recycled materials will meet function in same fashion as virgin materials.
- Softer feel of materials or material coatings over internal hardware
- Softer touch buttons and dials
- We need to develop materials for better egress and ingress.

Safety:

- Have we maxed out? Will we expect more individual accountability?
- High-strength steels with defined and consistent properties will be important; advanced welding; especially laser will increase safety. Energy absorbing foam for seats, headliners, and pillars are expected.
- If we have to move away from zinc plate and dichromate to paint on hardened steel hardware parts, there should be fewer incidences of hydrogen embrittlement failures.
- Improved protection through structural design and airbag/other technologies (2)
- Increased use of plastics in occupant safety areas such as instrument panels will improve safety since they can eliminate hard points caused by too-stiff traditional materials, and the "bracketology" that goes with traditional materials-based designs.
- Magnesium IPs has improved properties vs. steel cross-car beams.
- More passive safety
- More than adequate crash energy absorption
- More use of energy absorbing materials
- Passenger protection
- Recycled materials will meet function in same fashion as virgin materials, i.e., no difference in materials
- Safety cannot be compromised.
- Smart airbag system both for frontal and side impact will have optimized bag volume and speed of deployment. Together with the use of softer surfaces, these changes will reduce unexpected injuries.
- Use of foams to improve occupant protection

Other (please specify):

- Reduced weight will improve vehicle handling and driveability.

CHASSIS

Quality/reliability/durability:

- Better strength-to-weight ratio
- Designs will continue to improve once we learn how to design with lightweight materials.
- Develop coatings for brake rotors to prevent grinding noise; improved corrosion coatings to improve cosmetic appearance
- Each attribute will improve.
- Improved coating to protect against corrosion; materials will be developed to give longer life at a lower cost
- Improved corrosion resistance in electrical systems will improve vehicle reliability.
- Improved hybrid designs using steel, plastics, and bonding technology will impact the design solution.
- Moving from cast iron to aluminum for many components will reduce unsightly red rust.
- Protection must last 10 years to justify cost increases.
- Quality is reliability and durability—therefore they must continue to improve to effect quality.
- Recycled materials will meet function in same fashion as virgin materials.

Noise/vibration/harshness:

- Better structure leads to improved NVH. Look for a 20Hz car standard.
- Improved busing materials will maintain NVH performance longer.
- Improved hybrid designs using steel, plastics, and bonding technology will impact the design solution.
- Improved rotor and friction materials to reduce brake noise and roughness
- Increased use of plastics will help damp out noise and vibration.
- Laminated metal, polyvinyl or metal-to-metal, will increase sound deadening capability.
- Laminated side glass will reduce interior noise levels by 5 dB.
- More sound absorption materials (i.e., foam) will be incorporated into chassis/frame.
- Need to work to reduce wind noise.
- Noise and vibration must continue to improve; though harshness might be compromised.
- NVH will improve due to lighter weight and reduced noise of nonferrous metals.
- Use of noise dampening foams in pillars to reduce noise
- Vehicles will become very quiet.

Performance:

- Decreased mass, better handling, more efficient engines at no loss in horsepower
- Handling will definitely improve with the use of lightweight materials.
- Lighter weight—if consumer willing to pay
- Materials will have a low influence on performance.
- Reduced weight will help to improve performance as well as mileage.
- Tailor-welded blanks will decrease weight and therefore improve performance.
- We will see strong gains in handling due to material advances.

Safety:

- More sophisticated frame design/materials
- Safety can not be compromised.

Discussion

The panel presents a diverse list of ways materials will influence customer satisfaction in the coming decade. Corrosion protection and increased durability of paint are the most frequently noted advances for body exteriors. Panelists also expect improved fade resistance and better fit and finish for interior components.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was first asked in the present form in the 1994 Delphi VII. The Delphi IX panel is in general agreement with the previous two forecasts.

Strategic considerations

Panelists forecast continued material developments to improve quality, reliability, durability, and other performance requirements. In many instances, the technologies are available to address many of the mentioned challenges. However, cost prevents many of these technologies from being implemented. Numerous ideas are presented by the panelists, and we urge the reader to closely review the responses for new and innovative strategies

Panelists' responses indicate that improvements in paints will be critical to the development of better chip and mar protection. Paint and clear coat serve as the first line of defense for any successful corrosion protection strategy. The ability to better prevent damage to the paint will be an important element to improved appearance and subsequent corrosion protection.

Environmental regulation is leading the industry to radically change the method in which vehicles are painted (MAT-47). The conversion to powder and waterborne paints will have created a new set of issues and challenges. The USCAR Low Emissions Paint Consortium is working to overcome these challenges. Early results suggest that powdered paints will likely be more durable, and will therefore provide better chip and mar resistance.

MAT-50. 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

Potential Recycling Barriers	Mean Rating						
	Plastics/Polymers			Non-Ferrous metals			Ferrous metals
	Unreinforced Thermoplastics	Reinforced Thermoplastics	Thermosets	Aluminum	Copper	Zinc	
Alloy content/contamination	2.5	2.0	2.8	2.6	3.2	3.1	4.0
Automated processing/separation of materials, e.g., density gradient	2.0	2.0	2.2	3.3	3.2	3.1	4.2
Dismantling/disassembly	2.2	2.2	2.3	3.2	3.3	3.3	4.3
Ease of materials separation	1.7	1.6	1.9	3.0	3.1	2.9	4.2
Economics of reclamation/ recycling process	1.5	1.4	1.3	3.3	3.2	3.0	4.0
Energy required for recovery	3.1	3.0	2.8	3.5	3.3	3.3	3.7
Energy required to process raw material	3.1	3.1	3.0	2.4	3.2	3.3	3.6
Environmentally safe disposal	3.2	3.1	3.0	4.3	3.8	3.4	4.5
Industrial environment/ health issues	3.6	3.6	3.3	4.1	3.8	3.4	4.5
Labeling/identification	2.1	2.2	2.4	3.7	3.8	3.6	4.5
Lack of design for disassembly	2.5	2.5	2.5	3.5	3.5	3.4	4.2
Lack of labor skills for parts disassembly	3.7	3.7	3.6	4.1	4.1	4.0	4.4
Landfill availability and cost	2.8	2.6	2.5	4.3	4.1	3.9	4.4
Limited markets/uses for recommended parts and materials	2.3	2.1	2.0	4.3	4.0	3.9	4.7
Recycling infrastructure/logistics	1.5	1.6	1.5	3.5	3.6	3.5	4.3
Scrap value	1.7	1.7	1.4	3.6	3.0	3.0	3.7

Selected edited comments

- "Automated processing/separation of materials, e.g., density gradient" should include magnetic separation, as this is now commonly used and much more effective than the density technique. Plastics are not being recycled at the end of vehicle life in North America. Plastics will not likely be cost-feasible in the next 20 years unless federally subsidized. Disassembly will likely only occur in the U.S. if mandated, if government subsidized, or if stiff penalties drive the business cost. Disassembly in Europe is occurring due to government subsidies and as a way to get jobs for the Eastern Block country workforce.

- "Economics of reclamation/recycling process": This is a high barrier for glass recycling.
- Energy recovery remains an economically viable disposition of plastics. There is 50 percent *more* landfill space available now vs. the mid 1980s.
- Plastics face very high barriers because price of the recovered or reclaimed materials cannot compete with original materials (virgin material) so they have to be sent back to OEMs to be reused or recycled as an energy source.
- Recycling must be economical to have staying power. Infrastructure is key. As they find additional ways to make money, more products will be recycled. The OEMs' job is to provide pull by showing where recycled materials can be used with no engineering risk and at a cost savings.
- Recycling steel from scrapped autos has been a for-profit business since the invention of the automobile. Contrary to claims by the aluminum industry, increasing the aluminum content of cars will not increase their recycling rate (over 97 percent in 1996). Any recycling plan that relies on disassembly will not be cost-effective. Cars have to be recycled the same way they are built—on a mass basis. A shredder can recycle an automotive hulk in about 30 seconds. It takes human beings about 30 minutes to remove most of the nonferrous components from a hulk.
- Structural aluminum castings are different from cast aluminum and aluminum sheets.

Discussion

Panelists see no significant barriers to recycling ferrous and nonferrous metals. However, with regard to plastics, the panelists view economics, ease of material separation, infrastructure, and value of reclaimed material as significant challenges.

Manufacturer/supplier comparison

The manufacturers and suppliers are in general agreement. However, there are five areas where their answers are statistically different. Table 1 shows those areas and materials where the manufacturer and suppliers have statistically different answers.

Recycling Barriers: Supplier and Manufacturer Comparison: Selected Categories		
	Manufacturers	**Suppliers**
Lack of design for disassembly—copper	4.0	3.0
Landfill availability and cost—reinforced thermoplastics	1.9	3.2
Landfill availability and cost—reinforced thermosets	1.8	3.0
Landfill availability and cost—aluminum	3.8	4.6
Recycling infrastructure/logistics—unreinforced thermoplastics	1.2	1.8

Trend from previous Delphi surveys

The 1998 Delphi IX panel is in general agreement with the 1996 Delphi VIII panel. However, there are several areas where their responses differ. For those barriers and materials where they disagree, the Delphi IX panel consistently views the challenge as more severe. The table shows those areas where the two panels' responses differ.

Potential Recycling Barriers	Mean Rating						
	Plastics/Polymers			Nonferrous metals			Ferrous Metals
	Unreinforced Thermoplastics	Reinforced Thermoplastics	Thermosets	Aluminum	Copper	Zinc	
Alloy content/contamination	-	-	-	-	3.7/3.2	3.7/3.1	-
Automated processing/ separation of materials, e.g., density gradient	2.5/2.0	2.5/2.0	2.9/2.2	-	-	-	4.7/4.2
Dismantling/disassembly	-	-	-	-	2.7/3.3	2.8/3.3	-
Ease of materials separation	-	-	-	-	-	-	4.7/4.2
Energy required for recovery	-	-	-	-	-	3.8/3.3	4.2/3.7
Limited markets/uses for recommended parts and materials	-	-	-	-	4.7/4.0	4.5/3.9	-
Recycling infrastructure/logistics	-	-	-	-	-	4.0/3.5	-
Scrap value	-	-	-	-	3.7/3.0	3.5/3.0	-

Strategic considerations

Over the past decade, the automotive industry has become increasingly aware of the environmental impact associated with the final disposition of automobiles. Presently 75 percent of each vehicle is recycled. This is accomplished by the removal of resalable fluids, parts, and metals. The remaining 25 percent, comprised mostly of automotive shredder residue, goes to landfills. This increased awareness has come at a time when plastics usage in automobiles—an important component of automotive shredder residue—has increased significantly.

The use of lightweight, but economically difficult to recycle, plastics presents an interesting life-cycle case study. Plastics offer an opportunity for weight reduction and concomitant reduction in energy used during the operational life of the vehicle. Yet, the disposition of plastics at the end of the vehicle's operational life presents environmental concerns that may partially offset the benefits of the reduced energy consumption. It is likely that industry will continue to develop more complete and complex life cycle analysis strategies to resolve these issues. It is also likely that no important automotive materials will be eliminated solely by life-cycle concerns.

Recycling is an issue that has received considerable attention—especially in Europe. North American manufacturers and suppliers will continue to actively develop strategies that address the environmental and economic challenges presented by the final disposition of the vehicle.

MAT-51. With reference to the three most significant barriers indicated in your response to MAT-50, please indicate your recommendations on how these issues can be rectified.

RESPONSES

- Barrier: All the barriers are substantially outside the automotive industry's sphere of influence.
  Recommend: We must react quickly when issues are resolved or change.
- Barrier: Alloy content/contamination
  Recommend: (1) All aluminum alloys should have an alloy identification on the part, especially castings and forgings. (2) Effective disassembly design and alloy bar coding.
- Barrier: Auto reuse/specification of recycled plastics
  Recommend: Must simplify specification process and insist that molders use recycled content.
- Barrier: Automated separation
  Recommend: Hard to do for plastics that look the same and have very similar densities.
- Barrier: Bonding to recyclable plastics
  Recommend: Commonality of plastic formulations with end-use tracking.
- Barrier: Disassembly of component parts
  Recommend: (1) Establishment of training and an aftermarket network. (2) Design for disassembly through reduced material mix, threaded fastening, common fastener. (3) Design for disassembly and labeling/coding (this will not be easy).
- Barrier: Economic
  Recommend: Create an infrastructure to support/promote recycling.
- Barrier: Economic separation of thermoplastic
  Recommend: (1) R&D, material selection based on separation (2) Have a very limited SAE-approved list for thermoplastic selection.
- Barrier: Economics of plastic recycling, disassembly, lack of infrastructure
  Recommend: Recognize and credit the value of energy recovery *and* the total life-cycle benefit of plastics over metals in saving energy.
- Barrier: Economics of plastics recycling
  Recommend: Give same value to postindustrial and postconsumer waste.
- Barrier: Economics of reclamation
  Recommend: Develop steady materials stream to encourage and justify investment in recycling operations.
- Barrier: Economics of recovery/recycling
  Recommend: Automakers have to develop a better understanding of the recycling industry and its economic base. Generally speaking, composites cost money to recycle, and metals generate money when they are recycled. In part, this is because of the embodied energy content. The higher the energy input to produce the material in the first place, the higher its reclamation value. As a rule of thumb, therefore, it is usually cheaper to make metal by recycling (using the embodied energy content) and it is usually cheaper to make a polymer from virgin feedstock. Adding infrastructure and labor cost to recover a material with marginal market value will not resolve the problem. The answer is to use less of the material, not more.

- Barrier: Economies of recycling process, especially the process of collecting not-so-valuable parts or materials
  Recommend: Some measures to force the vehicle owner to bring the car to either a dealer or a specified recycle depot to save the money the owner paid at the time of the purchase of the car.
- Barrier: Energy required for recovery
  Recommend: Work on method of extracting zinc from galvanized steel to improve scrap value. Energy required with today's capability to do this is prohibitive.
- Barrier: Environmentally safe disposal
  Recommend: Must develop properties to enable maximum recyclability, especially polymers.
- Barrier: A key barrier is material sorting and especially alloy sorting for aluminum alloy
  Recommend: Development on an industrial scale of the methods that have already been proven at the lab level for aluminum-alloy sorting.
- Barrier: Labeling of the materials used in the parts, including ingredients
  Recommend: Plastic parts now have a system to indicate the type of polymers used but not the case for polymer alloys, which require other treating for recycling. Aluminum and magnesium parts need some information on the content of other elements to be identified correctly.
- Barrier: Labeling/ID
  Recommend: Label all polymer composites; alloy stamp all aluminum components.
- Barrier: Landfill availability and cost
  Recommend: The forecast in the United States is good. Solutions are needed for Europe.
- Barrier: Limited markets for the recycled materials
  Recommend: Generally speaking, cost for recycled materials (specifically in the case of plastics) far exceeds the price of virgin materials. So only OEMs are currently the users of those materials. To solve this problem, there needs to be some kind of subsidizing system for other users to cover excess cost for materials.
- Barrier: Limited markets/uses
  Recommend: None, until the economics of recycling make sense, it shouldn't be mandated.
- Barrier: Low cost of recycled thermoplastics
  Recommend: Legislative actions—more demand use for recycled plastic
- Barrier: Market value for the scrap, regardless of the material in question is the most important issue. Contamination controls quality, and market value is a combination of quality and application opportunities.
  Recommend: Product design significantly impacts the contamination and separation issues and therefore, the designer needs to know going into a program what the reuse issues are. Market opportunity is the result of many factors outside the automotive designer's hands, but if the designer helps ensure the cleanest, least contaminated reuse product possible through competent design and material selection for the whole integrated system (rather than part by part) the market opportunity will be greater and value higher.
- Barrier: Ownership of valuable materials at the end of the vehicle's life
  Recommend: We need some form of government registration system that will require that the value of materials goes back to the auto industry.
- Barrier: Plastics material separation
  Recommend: Content labeling of all parts

- Barrier: Recycling infrastructure for plastics
  Recommend: Consider energy recovery as a viable recycling option.
- Barrier: Recycling infrastructures for thermoplastic
  Recommend: Continuing to work the issue with various collaborators to try to find what works
- Barrier: Relates to the disposal issue for polymers
  Recommend: Must find a solution to the lack of recyclability of many polymers so that landfill would not be an issue.
- Barrier: Scrap value
  Recommend: The best solution for recycling economics is a strong demand for recycled material and cost/benefit over virgin material.
- Barrier: Scrap value for plastics
  Recommend: Work to drive cost of recovery down.
- Barrier: Separation—contamination
  Recommend: Prove that energy recovery from mixed plastics is environmentally safe and economically sustainable.
- Barrier: The generation of ASR
  Recommend: We need to reduce this—preferably by reducing the numbers and type of plastic material and using materials that can genuinely be recycled.
- Barrier: Thermoset material reuse—not much market for reused thermoset materials other than as fillers
  Recommend: Develop lower cost methods for remanufacturing monomers or prepolymers from cross linked thermoset product.
- Barrier: Thermoset scrap value, also zinc
  Recommend: Eliminate use of thermoset and zinc
- Barrier: Too many dissimilar materials
  Recommend: Set standards for general material types to avoid cross contamination.
- Barrier: Value of reclaimed material
  Recommend: Support for OEM to purchase reclaimed material back at true economies
- Barrier: Value/cost of glass.
  Recommend: Burial
- Barrier: Value/cost of recovered thermostat materials
  Recommend: Incineration or burial are the most sensible disposal strategies for polyester and epoxies; urethanes are likely recyclable.

Discussion

The panelists' comments suggest significant concern over the economic viability of automotive recycling, and more specifically the development of an economically viable recovery and reuse techniques for plastics.

Manufacturer/supplier comparison

This comparison is not made for open-ended questions.

Trend from previous Delphi surveys

This question was not asked in any previous Delphi surveys.

Strategic considerations

This question is intended to provide insight into the barriers identified in MAT-50 as most significant. Overwhelmingly, the panelists focused on the economic viability of recycling plastics. Few panelists disagree that increased recyclability is an important goal. However, they also suggest this goal will be difficult to achieve. The economic hurdles will continue to make increased recyclability a long-term challenge.

MAT-52. Please indicate your view of the degree of challenge each of the following methods presents to effective recycling/disposition.

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

Method	Mean Response
Thermoplastics	
Closed loop recycling	2.0
Heat recovery	3.8
Open loop recovery	3.1
Thermosets	
Closed loop recycling	1.3
Heat recovery	3.1
Open loop recovery	2.0
Ferrous	
Closed loop recycling	3.7
Open loop recovery	4.7
Nonferrous	
Closed loop recycling	3.3
Open loop recovery	4.4

Selected edited comments

- Assumed definitions: Closed-loop recycling means a bumper is recycled into a bumper. Open-loop recovery is a bumper recycled into another application—perhaps nonautomotive.
- Economically unrecyclable plastics are actually cost-effective plastics for OEMs and therefore are expanding in usage. OEMs must define their preferable type of plastics from the standpoint of ease of recycling.
- Economics are the drivers today, not environmental issues.
- I believe in the next few years the industry will move from concentrating on recycling to focusing on life-cycle analysis. When the life-cycle analysis says a type (or form) of recycling makes sense, it will be done. Otherwise requirements that sound good today, but don't pass life-cycle analysis will not be executed.
- In part, the answer depends upon the definition of open loop and closed loop. Does a hood have to become another hood; can it be made into any other exposed component; or can it be made into any other automotive component and still be classified as closed loop?
- Open-loop recovery is quite desirable but quite difficult to effectively promulgate because of the lack of content description system for the materials used.

- Postconsumer plastic reuse requires collection, separation, cleaning, and reforming. Accommodating thermoset paint on thermoplastic parts is not without challenge, as is accommodating varying amounts and types of fillers in the same thermoplastic polymer matrix. Economical glycolysis/pyrolysis of thermosets remains a challenge.
- Recycling technologies exist at OEMs with some cost penalty, and closed loop or heat recovery are the methods to be applied with relative ease. However open-loop recovery has to overcome many obstacles before it can be effectively executed.
- Suppliers may be more likely to impose options 2 - 5 on their own as requirements they will pass through.
- The drive to fuel economy dominates recycling plastics as a polymer. Cost dominates plastic choice, not the economics of recycling–look what happened to the market for recycled PET once the price of virgin dropped below $.65/lb. The difficulty of recycling painted TPO fascia and claddings has not hindered TPO use in these applications.
- The response for thermoplastics varies depending on 1) ease of disassembly and 2) if the component is painted.
- Unfortunately, as stated earlier, the opportunity for cost effective recycling is significantly determined by the product design program and is not in the hands of the material supplier. Done properly, recycle and reuse can be very effective, even profitable, but must be in partnership with the vehicle designer.

Discussion

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

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was first asked in the 1994 Delphi VII. The table shows those methods where there has been substantial change in responses between the Delphi VII, the 1996 Delphi VIII and the 1998 Delphi IX surveys.

Method	Delphi VII	Delphi VIII	Delphi IX
Thermoplastics: Closed-loop recycling	2.4	2.4	2.0
Thermoplastics: Heat recovery	3.3	3.3	3.8
Thermosets: Closed-loop recycling	1.9	1.6	1.3
Thermosets: Open-loop recovery	2.9	2.2	2.0
Nonferrous: Open-loop recovery	N/A	3.9	4.4

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; however, the majority of plastics used in automobiles are landfilled in the form of automotive shredder residue (ASR). According to the panel, the degree of severity for the recycling of plastics depends on the method, material, and ultimate usage of the material. Thermosets continue to be viewed as difficult to recycle—either via a closed loop or open loop method. Thermoplastics are viewed as a somewhat less severe challenge, yet still present significant barriers to the implementation of viable recycling programs.

Many of the challenges preventing implementation of plastic recycling are not technical, but instead economic-based. Plastics recycling will not become viable until there is an economic, or regulatory, incentive to develop an infrastructure. Until that happens, many plastics will be viewed as unrecyclable.

Heat recovery for plastics is both technically feasible and potentially economically viable. However, the "not-in-my-backyard" syndrome makes implementation of such strategies a compelling political challenge.

The panel does not view the recycling of ferrous or nonferrous metal as a significant challenge. Currently there is an economically viable recycling infrastructure for metals. For several years, approximately 100 percent of ferrous metals used in an automobile have been reclaimed. Until recently, class "A" steel surfaces contained no recycled steel; much of the steel recycled from automobiles was used in open-loop recycling (i.e., reuse for lesser applications).

MAT-53. Relative to plastics usage in the next decade, how likely are North American light vehicle manufacturers to undertake each of the following actions?

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

Action	Mean Rating
Pass through recycling requirements to suppliers	2.5
Restrict the amount of plastics in the vehicle	3.8
Restrict the amount of economically unrecyclable plastics in the vehicle	2.8
Restrict the number of types of plastics in the vehicle	2.7
Substitute lightweight metals for plastics	3.3

Selected edited comments

- Any cost that can be passed on to the supplier by the assemblers is being done today. Recycling will not be an exception if there is no financial incentive for them to recycle on their own. The only drivers for restricting plastic in vehicles are cost, productivity, safety, and performance. If they need to reduce weight to meet CAFE for a line of vehicles, cost becomes less important. Lightweight metals can present EPA concerns (e.g., castings) but are worth looking into if there is an economic or weight/strength advantage.
- If "heat recovery" (incineration) becomes politically viable, proven technologies should make recyclability a small issue.
- The number of plastic types used will be restricted allowing the continued use and growth of plastic application. There will be competition in certain applications for plastics from light metals. Designing for recycling and use of recycled plastics will be passed through to suppliers as we continue to outsource manufacture and design.
- The value of painted TPO recyclate is low, but its use is not likely to be restricted because of value in low initial cost and fuel economy. Restriction on types of plastics will be an artifact of economics (volume purchasing power) rather than due to recycling issues.

Discussion

Panelists forecast that in the coming decade manufacturers will likely pass through plastic recycling requirements to suppliers, restrict the number or types of plastics, and restrict the amount of economically unrecyclable plastics in the vehicle.

Manufacturer/supplier comparison

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

Trend from previous Delphi surveys

This question was first asked in this form in the 1994 Delphi VII survey. The 1998 Delphi IX panel generally views the implementation of the listed actions as less likely. The table compares the results from Delphi IX with the two previous forecasts.

	Mean Rating		
Action	Delphi VII	Delphi VIII	Delphi IX
Pass through recycling requirements to suppliers	2.1	2.4	2.5
Restrict the amount of plastics in the vehicle	3.6	3.8	3.8
Restrict the amount of economically unrecyclable plastics in the vehicle	2.1	2.4	2.8
Restrict the number of types of plastics in the vehicle	2.4	2.2	2.7
Substitute lightweight metals for plastics	4.3	3.3	3.3

Strategic considerations

The final disposition of plastics continues to present a significant 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. Restricting the number of families of plastic will diminish alloy contamination and foster complete subassembly recycling. Potential applications of this strategy include bumper systems and instrument panels. Manufacturers and suppliers will need to work closely together to develop the most effective processes and material specifications for future plastics 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 full responsibility. Others believe that the material supplier should take responsibility. It is likely that given their brand identity, manufacturers will be given initial responsibility. It is also likely that manufacturers will require their suppliers to share in the recycling process.

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.

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

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).

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

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KEY WORD INDEX

Key Words	Question Number		
	Materials	Technology	Marketing
ABS(brakes)	9,20,21,23,41	—	25
ABS(plastic)	23,41	—	—
AC compressor	—	78	—
Accessory drive	—	6,11	—
Acetal	23	—	—
Acrylic	23,46	—	—
Active engine mounts	—	56	—
Actuators	—	34,48,72,77	—
Advanced features	—	—	43
Aerodynamics	—	6,11	48a
Affordability	10-12,22,31,33,40,42, 44	16, 17	10,12,14,23,40b,46
Age of vehicles	15	—	2
Air pump	—	78	—
Airbags	9	48	23,25,48b
Alcohol	5	13	—
Alternative energy sources	—	13,16	—
Aluminum	5-7,9,12-16,20,22,24, 25,27,30,33, 34, 36, 38-42,44,45,47,49-51	37, 38, 62a,b	47,48a
Anti-theft	8	16, 75	6,46
Balance shaft	—	55	—
Battery	6,7	35	48b
Body beaming frequency	—	32b	—
Body torsional frequency	—	32b	—
Bonding/joining	37,46	—	—
Brakes	25,27,44	46,78	25,29,42
Brakes, anti-lock	—	46	—
Buying process	—	—	17,18
CAFE (Corporate average fuel economy)	1,5,8,9,11,12,17-20, 22,23,27,38,39,42,44, 53	2,5,7,8,9,16,41	1,6,10,11,14,41
Cam	—	54,55	—
Car attributes	—	—	8,10,27
Cast iron	20,22,25,27-30,44,49	37, 62	—
Catalytic converter	25	64	—
Compact Disc player	—	75	—
Cellular phone	—	75	—
Ceramics	7,12,14,22,30,31	37, 68	—
Chassis	6,7,15,20-22,25,42,49	—	41
Coil-on-plug	—	61	—
Collision warning	—	50	43

Key Words	Question Number		
	Materials	Technology	Marketing
Combustion engine	5-7,17,20	13,15	45
Comfort	7,12,14,27,28,36-39	12	8,9,10,23,46,48b
Competition, elements of	—	22	—
Component production	—	26	5
Components	6,7,12-15,18,20,21,24, 25,27,30,38,40-42,44	25,26,27	1,29,40a,41,42
Computer	6,12,14,21	—	18,19,26b,28,46,48b
Congress	1,2,8	—	3a,6
Consortia	—	—	—
Consumer purchase decisions	—	—	8,9,10,15,17,24,25
Convenience	5	12	8,9,17,18,20,22,46
Copper	22,33,50	—	—
Corrosion	11,12,14-16,20,24,25, 34,37,39,40,49	—	25,35,48a
Cost	1,2,4,6-19,21-27,29, 31-53	12	1,5,8,9,11,12,14,15,24, 29,40a,40b,45
Cost/benefit	—	8,41	6
Crashworthiness	7-9,37,49	16	6,45
Cruise control	—	50, 75	43,46
Cycles	—	—	13,14,34
Cylinder blocks	25,27,28	62a,b	—
Cylinder heads	22,27	62a	—
Cylinder heads & blocks material	—	62a,b	—
Cylinders	27	—	41
Cylinders, no. of	—	51	—
Cylinders, sleeved	27,28	62b	—
Dealership	—	—	8,9,15,17,18,19,20,21, 22,23,31
Decontenting	—	19,21	—
Design issues	14	—	—
Design specifications	—	20,21,36a	—
Development cycle time	—	29,30	—
Diagnostic	—	75	22
Diesel	3,5,19,25,27	6,13	40a,41
Digital audio tape	—	75	—
Direct injection	5,19	5,59	—
Distribution system	—	22,81	4,18,20,21,40a,40b
Downsizing	9,19,21,22	6,7	3b
Drive-by-wire	—	75	—
Drivetrain configuration	—	71	—

Key Words	Question Number		
	Materials	Technology	Marketing
Durability	6,7,9,12-14,20,21, 27-29,31,37,39,41,43, 45,49	81	2,10,12,23,48a
Economic trends	—	—	1
Education	6,12,14,21	—	1
Efficiency	6,7,9,14,49,20	6	26a,40a,48a
Efficiency, noise	—	32a	—
Efficiency, packaging	—	32a	—
Electric	—	13,75,77,78	2
Electric vehicles	1,4,6,10	—	7
Electrochromatic glass	—	56	—
Electronic	12,15	11,72,73,75,79	23,48a,48b
Electrorheological fluids	—	56	—
Emissions	1,4,8,9,11,12,14,20,21, 34,47,49	12,13,16,65,66	6,10,41,45,48a
Energy	1,5-10,14,17, 20,21,25, 37,39,40,48-51	13	1,3a,10
Engine	1,5-7,9,10,12-14, 17, 20-22,24-28,30-33,35, 49	6, 51-70	6,29,36,40b,41,45,48b
Engineering	12-14,17,20,24,37, 50	23,24	20,28,30
Environment	9,10,12,16,17,21,37	13,22	1,3a,3b,5,23,40b,45
Epoxy	23,46	—	—
Ergonomics	49	22	48a,48b
Exhaust manifold	25,30,31	68	—
Exports	—	—	37,38,39,40a,40b
Exterior components	—	38	—
Fiber optic	22,25	74	—
Financing	—	—	12,13,14,16,18,20,21, 23
Fore-aft	—	—	—
Four-wheel drive	—	71	10,41
Frame	27,35-38,49	43	10
Frame construction	35,36	—	10
Frame materials	36	—	—
Fuel economy	1,2,4,5,7-9,12,14, 17-27,36-39,44,52,53	3,5,6,8,9,10,11,12,16, 22	3a,4,6,8,9,10,23,26a, 26b,45,48a
Fuel price	1,2,17	1a,3	3a,3b
Fuel rails	20,25,30	67	—
Fuel taxes	1,2,9	1a,b	3b
Gas guzzler	—	4,8	—
Gasoline	1,2,3,5,11,19,21,25,27, 34	1a,13	2,3a,3b,10,40a
Gasoline tank/fuel tank	39	39	—

Key Words	Question Number		
	Materials	Technology	Marketing
Glass	7,22,25,3941,43,46,49, 50,51	—	48a,48b
Global warming	2,9	1a,2,17	—
Hydrocarbon (HC) trap	—	65	—
HSLA steel (HSS)	7,14,20,21,22,25,38, 40,41,42	—	—
Human resources	—	82,83	—
Hybrid	1,4-7,10,20,22,30,35, 45,49	13	2,7,10,48a,48b
Ignition systems	—	61	—
Image, corporate	—	22	—
Industry structure	—	—	4
Infrastructure	1,6,7,10,12,14,37,39, 50-52	1b	3a,3b,40a,43,44,45
Injection	5,19,20,49	—	—
Intake manifold	20,23-25,30	67	—
Internet	—	82,83	17,19,21
Ionomer	23	—	23
ITS Intelligent transportation systems (IVHS)	9	50	43,44
Keyless entry	—	75	46
Lead-acid	6	—	—
Lean burn	—	63	—
Lean NOx trap	—	65	—
Legislation	4,5,8,9,10,14	16,17,42	6
Lift control	1,25	—	—
Lightweight materials	6,7,9,12,14,17,21,22, 30,42,44,49	—	48a
Loans	—	—	12,13,14,16
Magnesium	6,7,9,12,14,15,20,21, 22,24,25,27,30,39,41, 42,45	—	—
Maintenance	1,26	—	2,3a,19,22,24,36
Manufacturing	6,7,9,11-14,18-21,24, 30,33,36-38,47,49	—	1,4,5,7,12,14,38,39, 40b,45,48a
Market segments	21	—	7,44,46
Market share	5,14,17,24	—	2,6,14,22,31,32,33,45
Marketing divisions	—	—	4
Materials	6,7,9,11,14,18,19,25, 27,29,32-34,43,49,50	12,42	40b,45,48a,48b
Materials change	12	37	—
Math base	—	33a	—
Message system	—	50	43
Metal matrix composite (MMC)	22,25,30,44	—	—

Key Words	Question Number		
	Materials	Technology	Marketing
Metal substrate	—	64	—
Miller cycle	—	56	—
Motors, electric	—	77,78	—
Multiplexed	—	73,74	—
Nameplate offerings	—	—	4,7
Natural gas	1,5	13	—
Navigation	—	50	43,44,46,48b
Nodular iron	20,44	—	—
Noise cancellation	—	79	—
NOx catalyst	5,25	63	—
Nylon	23,25,41	—	—
Occupant restraint	8,9	16	6
Oil pan	20,24,25,30	67	—
Outsourcing	21	—	—
Owner loyalty	6	—	—
Ownership	51	—	13,15,18,19,24,26a,35, 36,45
Paint	9,13-16,20,39,46-49,52	—	48a
Particulate controls	—	65	—
Parts	7,10,12-16,18-20,23, 25,27,36,37,39,41,49, 50-52	25,26	8,29,40a
PC/PBT	23	—	—
Performance	4-7,9,11,12,14-18,20, 21,25,26,35,37,41,44, 48,49,53	22	5,6,25,26,41,42,45,46, 47
Phenolic	23,41,44	—	—
Piston	30,31,44	67,68	—
Platforms	20,35,40	18,19	4,7,10,28,29,40b,48a
PNGV (Partnership for a New Generation Vehicle)	7,8,14,17,20,21	9,10,11,12	3a
Polycarbonate	23,41,43	—	—
Plastic/composite	7,12,21	37,38,39,67	—
Polyester elastomer	23	—	—
Polyester thermoplastic	23	—	—
Polyester thermoset	23	—	—
Polyethylene	23,41	—	—
Polymer based	—	37,67	—
Polypropylene	20,23,25,26,41	—	—
Polyurea	23	—	—
Powdered metal	22,25,30,32	37,55	—
Powertrain material applications	—	—	29,39,41
PPO/nylon	23	—	—
PPO/styrene	23	—	—

Key Words	Question Number		
	Materials	Technology	Marketing
Prices	1,7,16,24	—	1,2,3a,3b,10,11,12,13, 14,17,21,23,40b,42,43, 44,45
Product design	12,14,51,52	23,24	3a.6
Product differentiation	—	—	7,23,26a,26b,29
Product liability	8,11	16	6
Production, volumes	12	—	—
Production development	7,37	—	—
Production process	5	12	—
Propane	—	13	—
Prototypes	—	19,33b	28
Push rod	—	54,55	—
PVC	14,24,41	—	—
QRD	—	22	—
Quality	3,9,10,11,12,18,21,28, 29,45,49	—	2,4,5,8,23,24,26a,26b, 35,37,40b,46
Recyclability	6,7,9-12,14,20,21,23, 37-39,41,46,50-53	42	2,6,45
Redesign	6,7,14,21,27,44	57	28,30,37,48a
Reformulated gasoline	1,3	—	—
Regionalization	—	16,17	6
Regulation	3,4,6-12,14,17,18,20, 21,41,47,49	16,17,42	1,6,10,11,12,14,40b
Repair	1,2,6,12,14,16,25,37, 39,41,49	—	3a,18,19,22,23,40b,44, 48a
Retail prices	—	—	11,14
Retail sales	—	—	17
Ride and handling	—	22	10,26a
Roller lifters	—	55	—
Rolling/resistance	—	6,11	—
Rubber	22,41	—	—
Safety	6-13,17,21,36-38,41, 43-46,49,53	22	6,23,25,
Sales	4,6,12,13,15,17	—	2,5,7,8,10,13,17,18,19, 23,30,31,32,33,34,36, 38,39
Sales personnel	—	—	18
Sales procedures	—	—	18
Seals	31	68	—
Selling	19	—	4,5,7,17,18,20,23,24, 28,36,38
Sensors	—	72a,b	42
Service	11-15	—	17,18,19,20,22,23,24, 25,
Sequential shift	—	70	—
Sharing	6,7,	18	7,29

Key Words	Question Number		
	Materials	Technology	Marketing
Skills	50,23,41,	—	18
Spark plugs	—	61	—
Springs	25,42	44	—
Stainless Steel	7,14,20,22,25,30,44	—	—
Standardization	12	34	29
Standards	1,3,4,6,8-10,12,14,18, 22,24,27,39,46,48,51	16	5,10,23,24,40b,45
Start-up catalyst	—	64	—
Steel	6,7,12-16,18,20-25,29, 30,34,36-42,44,45, 47-52	37,38,39	25,47
Steering	20,24-26,42	78	46
Stirling	—	15	—
Strategic planning	—	—	1
Stratified charge	—	56	—
Styling	6,11,12,14,20,25,39, 40,42,44,45	—	8,9,23,28,30,48a,48b
Sub-assemblies	—	25,26,27	—
Supercharged/ Supercharger	—	6	—
Suppliers	7,10-14,18,19,21,22, 24,25,36	—	1,2,3a,3b,4,5,6,7,8,9, 10,11,12,13,14,15,16, 17,18,19,20,21,22,24, 25,26a,26b,27,28,29, 30,31,32,33,34,35,36, 37,38,39,40a,40b,41, 42,43,44,45,46,47,48a
Suspension	20,25,27,41,42	44	7,41
Systems engineering	—	35	—
Taxes	1,2,11,12,17,21,23	1a	3a,3b,40b
Technology leadership	—	31	—
Thermoplastic	6,14,20-23,25,38-41, 49-52	—	—
Thermoset	22,23,25,38-41,50,52	—	—
Tires	7,10,22,25,27,30	6,11,47	47,48a
Titanium	6,7,9,25	—	—
Toll collection	—	50	43
Tooling	6,12,14,37,39,49	28	—
Torque converter	—	70	—
TPO	23,25,40,41,49,52,53	—	—
Traction control	—	46	42,44
Trade	—	—	1,5,12,17,39,40a,40b
Transaction prices	—	—	12
Transmission	—	6,69	—
Transverse	7,9,15,20,24-26,32,33	—	—

Key Words	Question Number		
	Materials	Technology	Marketing
Trends	40	—	1,2,4,6,10,13,20,22, 26a,35,36,47,
Truck attributes	—	—	9,10,27
Turbine	7,12,31	15,68	—
Turbocharger	31	6,60	41
Two-stroke engine	—	56	—
Urethane	23,41,42,45,46,51	—	—
Value of 1 mpg improvement	—	8	—
Value of pound saved	—	41	—
Valve covers	—	67	—
Valves per cylinder	—	53	—
Valvetrain	31,32	54,68	—
Vehicle attributes	—	—	10,41,42,44,45,46,47, 48a,48b
Vehicle demand	—	—	2
Vehicle features	—	—	43,47
Vehicle integrity	8	16	6
Vehicle production	5	—	5
Vehicle servicing	—	—	23
Vehicle use	—	—	2
Virtual college	—	83	—
Voice activated	—	75	48b
Voltage, system	—	76	—
Water pump	—	78	—
Weight reduction/weight	6,7,9,12,14,17,18,20, 21,27,28,30,38,41,44, 45,50	6,7,11,40,41	—
Wheels	6,7,20,24,25,42,45,49	—	47,48a
Wrist pins	31	68	—
Zinc	20,22,34,49,50,51	—	—