Automotive Plastics Chain:
Some Issues and Challenges

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Automotive Plastics Recycling Project

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Preface

The Office for the Study of Automotive Transportation (OSAT), in cooperation with researchers from other units of the University of Michigan, is undertaking a multiyear program of research titled "Effective Resource Management and the Automobile of the Future." The first project focused on recycling automotive plastics and provides an independent evaluation and review of the issues and challenges that recycling pose for this class of materials.

The Automotive Recycling Project benefited from the financial support of numerous sponsors: The American Plastics Council; The Geon Company; Hoechst Celanese; Miles, Inc.; OSAT's Affiliate Program; Owens-Corning Fiberglas; and The University's Office of the Vice President for Research. In addition, representatives of each of the Big Three automakers graciously served on the Project's advisory board, as did Suzanne M. Cole.

The project reports provide an overview and analysis of the resource conservation problems and opportunities involved in the use of plastics, and describes the factors that are likely to influence the future of automotive plastics. We develop information on the economic, infrastructure, and policy aspects of these issues, identifying the barriers to and facilitators of automotive plastics use that is less constrained by resource conservation and recycling concerns. At the same time, the Vehicle Recycling Partnership, a precompetitive joint research activity of the Big Three, is devoting its resources to the technical issues raised by recycling automotive plastics.

The Recycling Automotive Plastics project yielded six reports:

Life Cycle Assessment: Issues for the Automotive Plastics Industry (UMTRI Report #90-40-1), by Brett C. Smith and Michael S. Flynn, an overview of the LCA approach and its implications for automotive plastics (15 pages). This paper includes, as an appendix, the EPA design manual by Greg Keoleian and Dan Menerey, *Life Cycle Design Manual: Environmental Requirements and the Product System;*

Economic Issues in the Reuse of Automotive Plastics (UMTRI Report #90-40-2), by Daniel Kaplan, a general consideration of the economic barriers and issues posed by recycling automotive plastics (42 pages);

Recycling the Automobile: A Legislative and Regulatory Preview (UMTRI Report #90-40-3), by Suzanne M. Cole, Chair, Society of Plastic Engineers, International Recycling Division, describes the likely developments on the federal regulatory and legislative front that will influence the future of automotive plastics use and disposition (26 pages);

Postconsumer Disposition of the Automobile (UMTRI Report #90-40-4), by T. David Gillespie, Daniel Kaplan, and Michael S. Flynn, a review of the issues and challenges over the different disposal stages posed by postconsumer automotive plastics (54 pages);

Material Selection Processes in the Automotive Industry (UMTRI Report #90-40-5), by David J. Andrea and Wesley R. Brown, an overview of the factors and issues in vehicle manufacturers' material selection decisions (34 pages);

Automotive Plastics Chain: Some Issues and Challenges (UMTRI Report #90-40-6), by Michael S. Flynn and Brett C. Smith, a report of the OSAT survey of the automotive plastics industry (27 pages), plus appendix on types of automotive plastics.

These reports are all available from:

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The Recycling Automotive Plastics project provides an overview and analysis of the resource conservation problems and opportunities involved in the automotive use of plastics and composites, and describes the factors that are likely to influence their future. The project produced a series of six reports targeted to different aspects of the recycling challenges posed by automotive plastics. Combined with the technically oriented reports of the Vehicle Recycling Partnership, these reports should serve two purposes. First, they can serve as a broad introduction to the diverse and numerous dimensions of the recycling challenge for automotive managers whose areas of responsibility only indirectly or peripherally touch on recycling. Second, they can provide specialists with a broad panoply of contextual information, anchoring their detailed knowledge within the broad framework of recycling issues.

Automotive plastics posses numerous advantages for the automotive manufacturer and consumer. They contribute to lower vehicle weight, important for fuel conservation and emission reduction, while permitting the additional weight of new safety equipment. Plastics and composites are corrosion resistant, so their use can prolong vehicle life, and they are an important element in the paints used to protect other materials. They offer the designer greater flexibility, reducing the constraints that other materials often impose on shapes and packaging. If the difficulties of recycling automotive plastics present a potential barrier to their use, their advantages suggest that the barrier should be overcome, rather than deterring their continued automotive applications.

However, automotive plastics are visible and easily tied to the vehicle manufacturers. Hence, they may become targets for public opinion and government action out of proportion to their real role in solid waste disposal issues and potential for economic recycling.

I. The first report (<u>Life Cycle Assessment: Issues for the Automotive Plastics Industry</u>, UMTRI Report #90-40-1, by Brett C. Smith and Michael S. Flynn) provides an overview of the developing Life Cycle Assessment (LCA) approach and its implications for automotive plastics. An element of the emerging "design for the environment" method, LCA calls for an inventory, impact assessment, and improvement analysis targeted to the environmental consequences of a product across its production, use, and retirement. While environmental costs are typically unavailable, LCA supports the inclusion and consideration of any such costs that can be estimated, particularly for some of the environmental factors often ignored in traditional product decisions.

A fully developed LCA for vehicles or even components presents numerous significant analytic challenges to the industry, and may never become practical. First, a full LCA would be extremely costly, and the human and financial resources it would consume may be simply unavailable. Second, the handling of the data in an LCA can critically determine its outcome. The data for factors in an LCA are often lacking, typically measured in different metrics, subject to variable weightings, and frequently aggregated in different, noncomparable ways. Third, LCAs are difficult to evaluate and compare because they often reflect differing assumptions, varying boundaries, and there are no commonly accepted standards for their execution. Finally, the comparison of environmental costs with more traditional cost factors is at best difficult and speculative.

Nevertheless, LCA offers industry a sensitizing tool, useful for ensuring consideration of some environmental effects, and consistent with an industrial ecology approach to resource conservation. Moreover, the LCA approach resonates with some other developments in the automotive industry. Thus the industry is moving to more system-based material decisions, while its accounting system is evolving to a form that would more readily provide input for an LCA. The growing emphasis on cost reduction and waste elimination is also philosophically consistent with LCA goals. The industry has gained experience in other analytic techniques, such as quality function deployment, that have value even if only partially executed.

The automotive industry must shift from a reactive to a proactive approach in the management of its environmental effects. The ability to move quickly and surely to develop environmentally acceptable products and processes will be critical to future success. Establishing environmental credibility will increasingly afford the manufacturers an opportunity to create a positive image and thus a competitive edge in the marketplace. LCA might become an important tool in the development of an environmentally friendly product. However, cost pressures in today's competitive environment will likely make the industry approach environmental issues in a cautious manner.

II. The second report (Economic Issues in the Reuse of Automotive Plastics, UMTRI Report #90-40-2, by Daniel Kaplan) presents a general consideration of the economic barriers and issues posed by recycling automotive plastics. The United States currently recycles roughly 75% of the automobile, although plastics constitute roughly one-third by weight of the landfilled residue. An important question facing the automotive plastics industry is whether a combination of economic and technical developments might occur that would permit plastics to repeat the recycling success story of automotive steel.

Recycling automotive plastics faces two major economic barriers. First, the labor cost to recover the materials in usable form is quite high, making it unlikely that recycled stock can compete with the price of virgin stock. The second is that recyclers cannot rely on a consistent and stable flow of plastic scrap, as retired automobiles vary greatly in the level and type of plastic content. This makes it difficult, if not impossible, to establish end markets. Other economic barriers to successful recycling include the costs of transportation and recovery.

There are nonrecycling options for automotive plastics disposal. The landfill option still exists, although current trends suggest that it may soon become expensive enough to promote the use of other options, such as pyrolisis. Incineration permits energy recovery, but faces some of the same undesirable side-effects as landfills.

Pressure for recycling may raise the likelihood of policy interventions, as the government tries to avert the negative consequences of automotive plastics content, such as landfilling, while preserving its benefits, such as reduced fuel consumption and vehicle emissions. Government efforts will likely focus on attempts to capture the environmental externalities in the price of materials. However, recycling may have an economic down side: at least some automotive plastics, if fully recycled, could damage the viability of both recyclers and resin producers by creating an oversupply of material.

The numerous policy tools that might be invoked by government have a predictably wide range of consequences, and these must be incorporated into a cost-benefit analysis before appropriate selections can be implemented. In any case, the industry must be prepared to respond to a wide range of possible policy developments that will shape the economic viability of recycling.

III. The third report (Recycling the Automobile: A Legislative and Regulatory Preview, UMTRI Report #90-40-3, by Suzanne M. Cole) describes the likely developments on the federal regulatory and legislative front that will influence the future of automotive plastics use and disposition. Public policy often tries to incorporate social and environmental costs in the price of goods so that markets can achieve efficient use of energy and resources. The U.S. government has typically relied on regulatory actions to achieve this aim, but may now be moving more in the direction of market-based incentives. Moreover, many key legislators are persuaded that the model of extended producer responsibility, popular in Europe, offers a mechanism for encouraging producers to heed environmental costs in the design of their products. Legislation requiring producers to "take back" their products at the end of the life cycle make them ultimately responsible for its final disposition.

The new administration appears to be committed to a course of emphasizing environmental goals within a framework that permits rational trade-offs with the need for economic growth and development. Increased government R&D spending, much of it in cooperation with private industry, provides a foundation for the search for technical solutions to environmental problems. The Clean Car program is a major example of how this approach may affect the automotive industry.

EPA appears to lack the anti-business rhetoric that many feared, and is shifting to more of a pollution prevention approach rather than a pollution clean-up response. In addition, the director now has a credible staff in place. In spite of the fears of many, Nafta is unlikely to have major adverse environmental consequences for the United States, and may actually improve Mexico's capability to enforce its fairly stringent regulatory regime.

The give and take of politics will certainly determine exactly how the balance of environmental and economic considerations will be achieved in numerous specific decisions, from take back through recycled content legislation to the permit processes governing both new and old facilities.

IV. The fourth report (Postconsumer Disposition of the Automobile, UMTRI Report #90-40-4, by T. David Gillespie, Daniel Kaplan, and Michael S. Flynn) reviews the issues and challenges that postconsumer automotive plastics pose over the different disposal stages. The United States currently has an economically viable vehicle recycling industry, composed of dismantlers, shredders, and resin producers. Increased automotive plastics content and requirements for its recycling present enormous challenges to this industry. Developing appropriate markets for recycled stock is a critical challenge. Mandated, rather than market-led, recycling could threaten the very existence of this recycling industry and doom recycling efforts.

Shrinking landfill capacity and rising prices threaten the recycling industry, which must dispose of superfluous material. Increased nonrecyclable plastic content threatens profits, as it often replaces material that can be sold and increases the volume of residual material for landfilling. For plastics to be profitable, the labor costs associated with recovery must be lowered and/or the price of recovered materials rise. Development of automated sorting, chemical and physical technologies for reduction, and pyrolisis all offer some hope, but the public opinion environment and automotive industry demands may force the pace of recycling beyond the infrastructure's capacity.

There are steps the industry can take to facilitate higher recycling rates for automotive plastics. First, plastic components and parts can be designed for easy disassembly and dismantling. Second, plastics can be clearly and consistently labeled, to avoid contamination in the recycle stock. Third, designers can try to limit the numbers and types of incompatible plastics in the vehicle and within any part or component. Fourth, further development of incineration and energy recycling could well support resource conservation, and ultimately higher reuse of nonplastic automotive materials. Fifth, techniques for recycling commingled plastics merit support.

V. The fifth paper (Material Selection Processes in the Automotive Industry, UMTRI Report #90-40-5), by David J. Andrea and Wesley R. Brown) discusses the factors and issues in vehicle manufacturers' material selection decisions. Material selection in the automobile industry is an artful balance between market, societal, and corporate demands, and is made during a complex and lengthy product development process.

Actual selection of a particular material for a specific application is primarily driven by the trade-off between the material's cost (purchase price and processing costs) and its performance attributes (such as strength and durability, surface finish properties, and flexibility.) This paper describes some thirty criteria used in material selection today. How critical any one attribute is depends upon the desired performance objective. The interrelationships among objectives, such as fuel economy, recyclability, and economics, are sufficiently tight that the materials engineer must always simultaneously balance different needs, and try to optimize decisions at the level of the entire system.

The vehicle manufacturers' materials engineer and component-release engineer play the pivotal role in screening, developing, validating, and promoting new materials, although initial consideration of possible material changes may be sparked by numerous players. These selection decisions are made within a material selection process that will continue to evolve. This evolution will largely reflect changes in the vehicle and component development processes to make them more responsive—in terms of accuracy, time, and cost—to market and regulatory demands. The balancing of market, societal, and corporate demands will continue to determine specific automotive material usage in the future.

VI. The sixth paper (Automotive Plastics Chain: Some Issues and Challenges, UMTRI Report #90-40-6), by Michael S. Flynn and Brett C. Smith) is a report of the OSAT survey of the automotive plastics industry (vehicle manufacturers, molders, and resin producers). This survey collected the industry's views on recycling, often contrasted with more general automotive industry views reflected in our Delphi series. This report covers four general topics: recycling and disposition challenges; regulatory challenges and responses; recycling in material selection decisions; and the future of automotive plastics.

The industry in general views a variety of economic, technical, and infrastructural recycling concerns as more important in the case of plastics than of metals. The automotive plastics industry, while perhaps viewing these concerns somewhat differently, sees a complex set of recycling challenges, varying over both the automotive plastics production chain and the stages of recycling/disposition. The manufacturers see these challenges as more severe than do molders or resin producers, and the industry generally views market development and disassembly as more critical stages. The automotive plastics industry generally favors more emphasis on open-loop recycling and the development of the disassembly infrastructure, while evidencing little support for disposal in landfills.

Government CAFE regulations are important drivers for automotive plastics use. However, government is also moderately committed to recycling. The various levels of government are somewhat likely to establish differing regulations to encourage recycling, but are less likely to impose outright bans on any current plastics/composites. Among the range of governmental incentives for recycling, tax incentives are generally seen as useful, but more restrictive and limited actions are seen as not particularly useful. The automakers are unlikely to restrict the total amount of plastics in the vehicle, although they will probably limit the use of unrecyclable plastics and restrict the number of types of plastics in the vehicle. They are also likely to pass through any recycling requirements to their suppliers, the molders and resin producers.

The recyclability of automotive plastics is not yet a major factor in automotive materials-selection decisions, ranking far below the traditional factors. Recyclability is viewed as, at most, of moderate importance to the customer and the industry. Moreover, there are concerns about the cost of recycling automotive plastics, and very real apprehension that there is little market for them, once recycled. These considerations are likely to drive up the cost of plastics, should they be recycled, and thus further discourage their use.

Our results present a somewhat mixed picture as to the future role of automotive plastics in the North American industry, although in general a promising one. There are clear drivers for their use, including their advantages for design flexibility, and these are likely to be buttressed by more stringent fuel-economy regulations in the future. However, there are concerns about their ultimate disposition when the vehicle is retired. These concerns reflect a different environmental priority, one that the automotive industry does not yet view as a customer demand, nor as a "heavyweight" materials-selection factor.

Our survey suggests that the automotive plastics industry and its vehicle producing customers are aware of and concerned about the environmental challenges that lie ahead. Moreover, they are seeking solutions to these challenges that are environmentally sound and responsive to the demands of vehicle purchasers and users. To be sure, their views are often influenced by their own position in the plastics value chain, and they reveal some tendency to prefer solutions that impose responsibility on other stages in that chain. However, they reject solutions that might relieve their own burden, but are environmentally problematic, such as landfilling.

These papers suggest that the automotive industry's adoption of plastics and composites is moving forward. The pace of adoption is responsible, and the industry treats the environmental effects of its material decisions neither lightly, nor as someone else's problem. However, that pace is cautious, reflecting many uncertainties. These include concerns that the industry may be disproportionately blamed by the public for problems in recycling disposed materials, and apprehensions that the industry may be disproportionately targeted by government to resolve such problems. Since plastics and composites confer a wide variety of benefits, including environmental advantages, the industry may be erring on the side of too much, rather than too little, caution.

Automotive Plastics Chain: Some Issues and Challenges[1]

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INTRODUCTION

Recycling is a key element of the developing resource-conservation strategies of the automotive industry, which includes the vehicle assemblers and their suppliers of parts, components, and raw materials. The recycling and ultimate disposal of any material poses its own specific challenges, and that is as true of plastics and composites as it is of others. It is therefore not surprising that the increased use of plastics by the auto industry raises particular technical, economic, infrastructural, and policy issues. Drawing on two industry surveys, this report reviews some of these issues in the context of industry competition and compares the views and concerns of the broader industry with those of the automotive plastics suppliers. The primary focus of this report is:

- The industry's views on recycling challenges
- Likely regulatory initiatives at the national, state, and local level
- Factors in the materials selection decision
- The industry's probable responses to these developments and to competitive considerations that will shape the future of automotive plastics.

BACKGROUND

Discarded automobiles constituted a major solid-waste-disposal problem in the 1960s, a problem substantially alleviated by economic and technical developments in the 1970s.[2] However, the decade of the 1970s also saw the emergence of its own environmental challenge—one of resource conservation—as the first oil shock led to concerns over apparently declining fuel stocks and dependence on potentially unstable sources of supply. In response, the Energy Policy and Conservation Act mandated Corporate Average Fuel Economy (CAFE) standards, requiring manufacturers to achieve

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[1] Based in part on a presentation by these authors and David J. Andrea to the SAE Annual Meeting, March 3, 1993.

[2] See Kaplan, (University of Michigan Transportation Research Institute report no. 93-40-2, 1993), 1-3, for a discussion of these developments.

substantial improvements in fuel economy for new vehicles. The second oil shock amplified and accentuated these conservation and dependency concerns.

CAFE led to the dominance of front-wheel-drive configurations, more efficient structures, reductions in the physical size of vehicles (downsizing), and lower vehicle weight. The automakers pursued many routes to lighten vehicle weight, including substituting lightweight steel and using thinner castings where feasible. Replacing heavier materials, such as iron and steel, with lighter weight materials, such as aluminum and plastics, rapidly became an important means of weight reduction.[3] The average 1992 North American-produced passenger car weighs 3,136 pounds, some 12 percent less than the 1978 vehicle. Its iron and steel content are, respectively, 16 percent and 20 percent lower by weight, while its 243 pounds of plastics/composites is about 35 percent higher.[4]

Plastics offer the automakers many other advantages as well. Use of plastics often permits higher levels of component integration, replacing many metal pieces with one plastic piece. Plastics support design flexibility, allowing shapes that simply cannot be achieved in metal. Plastics are dent resistant, an important attribute for many applications traditionally reserved for metal: quarter panels, door panels, and major body panels like roofs and hoods. Plastics are also corrosion resistant, an increasingly important customer demand. Finally, plastics may offer some tooling advantages that will make them particularly suitable for low volume niches, and will support the decreased design time and shorter model life for the typical passenger car that many analysts are predicting.

However, the rate of plastics substitution for iron and steel has been slower than many expected in the mid-1980s. To be sure, there are numerous reasons for this, but the automakers' concerns about plastic recyclability is an important one.[5] The substitution of plastics for steel increased fuel efficiency, but it also threatened resource recovery and reuse at the vehicle's retirement. Further attempts to improve fuel efficiency through reliance on plastics would risk conflict with the Environmental Protection Agency's current target of 25 percent reduction in solid waste through source reduction and recycling.

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[3] Office for the Study of Automotive Transportation, Delphi V: Forecast and Analysis of the U.S. Automotive Industry through the Year 2000, Volume 3 Technology, 1989.

[4] *Wards Automotive Yearbook, 1992*, Ward's Communication 1992

[5] Hervey and Smith; and Kaplan, op. cit., 6-9.

The 1990s may again see a sharp increase in automotive plastics applications, reflecting new regulatory enthusiasm for fuel conservation, whether tied to consumer preferences or not. Further, the vehicles of the early and mid-1980s, with their substantial plastic content, will reach retirement. Thus automotive plastics recycling issues will not fade away, and are likely to become more urgent in the near future. These recycling issues will be resolved in the broader context of automotive competition.

Three main challenges confront any automaker or supplier in North America today. The first is the changed bases of competition in the industry today, with the emergence of a new mix of competitors and a more sophisticated and complex customer. The second is the limited supply of resources—both financial and human—available to the industry. Finally, there is expanding demand for changes in technology and materials. Although this report focuses on aspects of this third challenge, it is important to recognize that it will develop in the context of the other two. Future materials choices will be made in light of their implications for these other major challenges.

Material substitution raises its own serious direct issues and challenges for the automobile industry and the vehicle disposal industry—scrappers, dismantlers, shredders, recyclers, and land fills. First, separating and recovering different materials involves numerous technical and economic challenges. The broad array of these challenges is discussed in other papers prepared for this project.[6]

Second, an array of environmental concern pressures the industry to move from traditional disposal to higher value reuse.[7] These pressures may well target the automobile because of its visibility. Vehicles are at once visible, ubiquitous, and large, and thus public awareness of them is high. Therefore, the industry must proactively address issues of resource conservation and recycling, lest public perceptions of the automobile as an environmental problem continue to exceed the reality. Moreover, we think customers are increasingly concerned about environmental issues, and that these issues may become more important drivers of automotive competition throughout the decade. The corporate image of good citizenship will be an important competitive asset, but good citizenship will be defined more broadly than it has been in the past. High levels of support for the United Way will be less important than the image of a socially and environmentally responsible,

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[6] See Gillespie, Kaplan, and Flynn (University of Michigan Transportation Research Institute report no. 93-40-4, 1993)and Kaplan, op. cit.

[7] James F. Kinstle, Recycling of Organic Polymeric Materials," Chapter in The Impacts of Substitution on the Recyclability of Automobiles, New York: The American Society of Mechanical Engineers, 1984.

contributing member of the community. The Council on Economic Priorities 1994 edition of *Shopping for a Better World* will include coverage of the U.S. operations of the major automakers, and such information may increasingly influence at least some consumers.

Third, competitive dynamics influence materials selection because of materials' implications for customer value across a range of vehicle attributes, such as styling, safety, longevity, and maintenance.[8] Finally, materials usage and disposal inherently involve decisions in both the private business and public policy sectors. Private decisions should reflect consideration of the entire vehicle life cycle, spanning design, development, manufacture, use, and retirement.[9] To the extent this occurs, and recycling infrastructures and secondary markets develop, regulations will likely be less constraining.

These recycling and disposal issues are very real concerns and constraints in the materials selection process. The future of automotive materials remains turbulent and unclear, reflecting the uncertainty and lack of consensus in the private sector, and the apprehension that regulatory initiatives will force substantial changes in the current mix.

RESEARCH PROJECT

The Office for the Study of Automotive Transportation (OSAT), in cooperation with researchers from other units of the University of Michigan, is undertaking a multiyear program of research on automotive materials. The first project focuses on recycling automotive plastics, and this report presents the results of a survey specifically undertaken for the project. These data provide the views of the automotive plastics community, in some cases amplifying and specifying the views of the general automotive industry, as revealed in other surveys, and in other cases challenging those views. An important question for the automotive plastics industry is whether the image held by the industry in general is a function of misperceptions, possibly resulting from poor communication. If so, the automotive plastics industry faces an important challenge in communicating more effectively and accurately the value of plastics for automotive applications.[10]

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[8] See Andrea and Brown, (University of Michigan Transportation Research Institute report no. 93-40-5, 1993), for a discussion of the material selection decision.

[9] David W. Conn, "Consumer Product Life Extension in the Context of Materials and Energy Flows" Chapter 7 in Resource Conservation: Social and Economic Dimensions of Recycling, David W. Rierce and Inga Waller, eds., 1977, 127-143

[10] Our survey required us to identify plastic resin producers and molders. We have appended the list we were able to identify, including information on the type of plastic and its automotive applications where possible. This list can be found in Appendix I.

Our plastics survey includes a random sample of plastics resin suppliers (30), and smaller, targeted samples of molders (14) and manufacturers (6), thus providing information across the automotive plastics chain. We queried these respondents about many of the issues that arose in our earlier Delphi research and report these results here.

Second, we draw on our latest Delphi survey of expert opinion in the North American automotive industry to summarize some of the views and concerns of the general industry on issues in plastic usage.[11] The Delphi method collects information iteratively from carefully selected expert panels, as data collected in the first round of surveys are anonymously reported to respondents, who then provide a second round of responses. One of the strengths of the Delphi method is that it taps the responses of key executives who are often in positions to take decisions that influence the future, and thus Delphi studies can provide unusual insight into that forecast future.

Delphi VI is based on the responses of 227 participants on three panels—marketing, technology and materials—and includes two survey rounds. Respondents are from vehicle manufacturers (34 percent), from component suppliers (56 percent), and the remaining 10 percent are drawn from specialists, consultants, and academics.

RECYCLING/DISPOSITION CHALLENGES

The past few years have seen increased concern about the recyclability of plastics. Auto manufacturers must address recycling as plastic content increases, threatening the recyclability of the total vehicle. The total vehicle may become less recyclable because its recovery value falls as plastics replace steel and iron.[12] Some 12 million vehicles were disposed of in the United States in 1988, averaging about 600 pounds of fluff, material ultimately disposed of in landfills. Most plastics/composites are in the fluff, and they total over 200 pounds.[13] Moreover, shrinking landfill capacity and tightened landfill regulation are increasing the price, and perhaps eventually foreclosing the option of disposal.

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[11] Office for the Study of Automotive Transportation, Delphi VI: Forecast and Analysis of the U.S. Automotive Industry through the Year 2000. Volume 3 Materials. 1992

[12] See M.M. Nir, J. Miltz, and A. Ram, "Update on Plastics and the Environment: Progress and Trends," *Plastics Engineering*, March 1993, 77, for a recent review of this recycling issue.

[13] Helmut Hock and M. Allen Maten, Jr., "A Preliminary Study of the Recovery and Recycling of Automotive Plastics," *Automobile Life Cycle Tools and Recycling Technology*, (Warrendale, PA: Society of Automotive Engineers, Inc., 1993), 59.

More of our Delphi panelists expressed concern about materials recyclability for plastics/polymers (90+ percent) than for either nonferrous (about 58 percent) or ferrous metals (51 percent). When we examine the reasons for concern, we find that virtually all the concerns for metals involve identification and/or separation of materials and the costs of recycling. Yet these categories cover just 35 percent of the concerns expressed for plastics/polymers. Limited reuse for plastics/polymers constitute another 25 percent of the panelists' concerns; safe disposal, limited infrastructure, and health issues each account for 10 percent or more. The greater range of recycling concerns for plastics/polymers than for either type of metal suggests the uncertainty that exists in this area. There are many unknowns, and the industry has only recently begun to address them.

We also asked our Delphi panelists to rate directly the importance of 13 recycling issues for different materials on a scale of one to five with one representing "extremely important" and five representing "not important." Table 1 presents these data, averaging the responses of our technology and materials panelists. Although respondents rated all of these concerns more important for plastics/polymers than for the metals, we present only the seven issues rated 'very important' for plastics.

Table 1 Importance of recycling issues, by material (1=extremely important, 5=not important)

	Material		
Issue	*Plastics/ Polymers*	*Nonferrous Metals*	*Ferrous Metals*
Lack of infrastructure	1.9	3.2	3.4
Process economics	2.1	2.8	3.0
Labeling/identification	2.2	3.7	3.5
Separation	2.2	2.8	3.5
Safe disposal	2.2	3.2	3.6
Limited reuse	2.3	3.4	3.6
Dismantling	2.3	3.0	3.2

Panelists believe that plastics do suffer clear disadvantages, and these seven issues are all rated substantially more important for plastics than for metals, with differences ranging from 0.6 to 1.5 scale points. In fact, the first round results of our Delphi VII indicate that the relative importance of all of these issues for plastics/polymers compared with ferrous metals has increased, with the sole exception of safe disposal.[14] This suggests that plastics use in the automotive industry continues to face very real barriers in the industry's concerns about its ability to recycle or dispose of it.

These barriers to the use of automotive plastics are technical, economic, and infrastructural in nature. In fact, the comments of the respondents suggest that these barriers are often present in combination. Hence, technology to separate materials may exist, but it is often uneconomical, especially in view of the dearth of markets for the recovered materials. Such a situation reflects the systemic nature of the barriers to recycling plastics, and the multiple potential barriers to recycling solutions they present. Perhaps a less costly separation technique will emerge, or a new market may develop that increases the value of the recovered materials, thus facilitating the development of the appropriate infrastructure.

However, simultaneous progress across all types of barriers is probably necessary for an effective system-wide solution, since any one type of barrier may effectively block the recycling effort. These barriers present the further problem that there are so many possible solutions that efforts may be scattered over a number of approaches, and none may be sufficiently effective to drive the resolution of the others.

The recycling/disposition of automotive plastics/composites raises a complex set of issues that are distributed over the stages of value added in the production process; these effect the resin suppliers, molders, and vehicle manufacturers. Moreover, the recycling process itself involves numerous stages. The severity of the challenges facing the automotive industry probably varies over both the production and the disposition process.

We explored this possibility in our plastics survey, asking our respondents to rate the severity of challenges to effective recycling/disposition on a scale anchored by one (extremely severe) and five (not at all severe). Table 2 displays these results.

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[14] Office for the Study of Automotive Transportation, Delphi VII: Forecast and Analysis of the U.S. Automotive Industry through the Year 2000, Volume 3 Materials, 1994 forthcoming, winter 1994. Delphi results referenced in this paper are drawn from the Materials panel and are first round results.

Table 2 Severity of challenge, by production and recycling stages (1=extremely severe, 5=not at all severe)

	Production Stage			
Disposition Stage	*Over All*	*Manu-facturers*	*Molders*	*Resin Producers*
Collection				
Creating collection sites/infrastructure	2.8	2.2	3.3	2.8
Logistics for collection of scrapped vehicles	2.7	2.2	3.0	3.9
Labor costs for collection	2.6	1.7	3.3	2.9
Disassembly/separation				
Creating parts disassembly sites/infrastructure	2.1	1.5	2.3	2.6
Labor costs for parts disassembly	2.1	1.5	2.6	2.3
Lack of labor skills for parts disassembly	3.4	3.3	3.7	3.2
Identification of parts/materials	2.4	2.0	2.5	2.6
Automated processing/separation of materials (e.g., density gradient)	2.5	2.2	2.6	1.9
Reuse				
Loading/unloading recovered parts/materials for distribution	3.2	3.0	3.3	3.2
Transportation for recovered parts and materials	3.6	3.7	3.4	3.6
Development of markets/uses for recovered parts and materials	1.9	1.5	1.9	2.3
Scrap				
Landfill availability and cost	2.5	2.2	2.1	2.9

If we consider the severity of challenge across the total industry, three challenges dominate: the development of markets and uses for recovered parts and materials (1.9), creating the infrastructure and sites for parts disassembly (2.1), and labor costs for disassembly (2.1). Our Delphi comparisons of plastics and ferrous metals suggest similar results, although our Delphi panelists perhaps rate process economics (+0.9) as less differentiated than problems with the current infrastructure (+1.4) and limited reuse (+1.3). Perhaps the most important difference between plastics/composites and ferrous metals in the recycling context lies in the relatively undeveloped markets for recycled plastics/polymers. The lack of clear evidence that there are markets for recycled plastics raises serious issues as to their future use, and certainly poses a fundamental challenge to the economic viability of recycling them.[15]

[15] See Kaplan, op. cit., 12, for the separation and market challenges that subverted the automotive recycling efforts of one major automotive supplier.

The clearest difference between our Delphi panelists and plastics survey respondents as to the severity of different plastic recycling challenges is that the plastics survey respondents are even more concerned about the limited reuse and lack of markets for automotive plastics. However, while they report that about 25 percent of their major automotive plastic can be composed of recycled materials today, they expect this recycled content may grow to as much as 52 percent in future-generation materials. Moreover, the major barriers to recycling today's materials lies in economics (43 percent) and infrastructural problems (35 percent), rather than in inadequate recycling technology or likely changes in plastics materials over time (11 percent each).[16]

Two challenges to effective recycling/disposition fall into the less severe range: transportation for recovered goods (3.6) and labor skill for disassembly (3.4). The rest of the challenges are all in the moderately severe range, suggesting, as do our Delphi data, the breadth of the recycling issues facing the industry. Both identification and automated processing/separation pose important technical challenges, and again probably represent a disadvantage when compared to metals. However, our plastics survey respondents report that about 44 percent of current automotive plastic parts are identifiable for separation purposes.

On average, the manufacturers (2.2) rate these dozen challenges as more severe than do the molders (2.8) or resin producers (2.8). However, inspection reveals that this is primarily due to differences in rating challenges at the collection stage and two steps of the disassembly stage: creating the infrastructure and labor costs. It is not surprising that the manufacturers are more concerned about labor costs in view of the generally higher costs they incur than either the molders or resin producers.

These data suggest that the challenges in recycling automotive plastics indeed vary over both the production chain and the stages of recycling/disposition. The manufacturers are more concerned than the plastic suppliers about collection and labor cost issues, while overall industry concerns about market development and separation issues are higher than those for collection.

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[16] On the other hand, our *Delphi VII* first round respondents are even more concerned about landfill availability and cost (2.1) than the respondents to our Plastics Survey (2.5) This may reflect differences in sample composition, or changes over the past year.

What are the appropriate approaches for effective recycling/disposition of automotive plastics? Our plastics survey respondents rated the emphasis that should be placed on a number of approaches, ranging from one (hardly any emphasis) to five (extreme emphasis). Table 3 presents these results.

Table 3 Emphasis on approaches to effective recycling/disposition (1=hardly any; 5=extreme)

	Production Stage			
Disposition stages	*Over All*	*Manu-facturers*	*Molders*	*Resin Producers*
Disassembly/separation				
Expand current shredders/junkyards	3.2	3.3	3.1	3.2
Build new, dedicated disassembly facilities	3.5	3.2	3.7	3.5
locally sited disassembly facilities	3.3	3.7	3.8	2.4
regionally sited disassembly facilities	3.7	3.7	4.1	3.4
nationally sited disassembly facilities	2.3	1.5	2.7	2.8
Pyrolysis	3.4	3.5	3.6	3.2
Heat recovery	3.5	3.7	3.6	3.3
Reuse				
Closed loop (same product) recycling	3.1	3.2	3.2	2.8
Open loop (less demanding products) recycling	4.0	4.2	3.8	4.0
Scrap				
Landfill expansion	2.2	2.0	2.3	2.3

The industry feels that strong emphasis (4.0) should be placed on open-loop recycling, the reuse of materials in less demanding (typically lower value) products. There is a clear preference for this strategy over closed-loop, or same-product, recycling (3.1). The reasons for this include the lower purity and consistency often required for lower value applications. For the automotive industry, there is also a clear need to develop markets for the substantial quantities of material that cannot be absorbed by new automotive demand at likely levels of recycled content.

Dedicated disassembly facilities, heat recovery, and pyrolysis receive recommendations for moderate emphasis. There is some preference for emphasis upon regionally (3.7) rather than locally (3.3) or nationally sited (2.3) disassembly facilities. These respondents recommend placing more emphasis on regionally sited disassembly facilities than on expanding junkyard and shredder capacity (3.2). The resin producers especially prefer regional (3.4) over local (2.4) disassembly facilities.

It merits comment that the respondents place little emphasis (2.2) on landfill expansion, even though they rate its availability and cost as a moderately severe challenge in table 2, above. We suspect that this reflects the industry's recognition that disposing of scrapped plastics in landfills is simply not an environmentally sound mainline response to recycling/disposition issues.

Summary The industry in general views a variety of economic, technical, and infrastructural recycling concerns as more important in the case of plastics than of metals. The automotive plastics industry, while perhaps viewing these concerns somewhat differently, sees a complex set of recycling challenges, varying over both the automotive plastics production chain and the stages of recycling/disposition. The manufacturers see these challenges as more severe than do molders or resin producers, and the industry generally views market development and disassembly as more critical stages. The industry generally favors more emphasis on open-loop recycling and the development of the disassembly infrastructure, while evidencing little support for disposal in landfills.

REGULATORY CHALLENGES AND RESPONSES

The North American industry expects to face these recycling challenges in an atmosphere of heightened regulation by government at all levels. All three Delphi panels expect to see more restrictive regulatory standards and legislative activity in areas that directly affect materials selection policies and actions, such as fuel economy and emissions, as displayed in table 4.

Our Delphi panelists expect much more stringent standards for fuel economy, forecasting a 7 percent increase in CAFE-mandated, fuel-economy performance by 1995 to 30 m.p.g., a 16 percent increase by 2000 to 33 m.p.g., and a total of 29 percent by 2005 to 36 m.p.g., compared with today's level of 27.5 m.p.g.

Table 4 Delphi panelists expecting more restrictive government actions (Percentage)

Regulatory domains	Panel: *Technology*	*Materials*	*Marketing*
Fuel economy			
Passenger Car	90%	100%	88%
Light Truck	89	100	92
Emissions			
Passenger Car	65	75	91
Light truck	81	91	100
Crashworthiness			
Passenger Car	55	69	75
Light truck	77	81	85
Interior safety			
Passenger Car	58	84	77
Light truck	78	91	83

More restrictive vehicle-fuel-economy and emission levels standards are drivers for expanded reliance on lighter-weight materials such as plastics. How far the industry will need to go in downsizing and reducing the weight of the car of tomorrow is an open question, but some of the regulatory bills now being considered by the U.S. Congress have the industry concerned that draconian standards may develop—if not today, then tomorrow.[17] In any case, change presents opportunity, and there are reasons to be hopeful that fuel economy will become a driver to overcoming some of the barriers to wider applications of plastics in automobiles.

While weight reduction is only one of many possible methods to achieve increased fuel economy, it is the one that is particularly likely to involve changes in the vehicles' material mix and increased reliance on plastics. Our technology panel estimated the comparative contribution of various sources of fuel economy improvement, and identified weight reduction as the largest single source for both 1995 and 2000. However, even in the regulatory arena there are countervailing pressures, as more restrictive safety standards may represent at least temporary barriers, until such time as better information on the crush behavior and field history of plastics is available. Automotive plastics, then, raise complex and challenging issues in the regulatory arena, just as they do in the environmental.

[17] See S. Cole, (University of Michigan Transportation Research Institute report no. 93-40-3, 1993).

If plastics/composites represent a major avenue of weight reduction to meet likely increases in enforced fuel economy—thus serving an environmentally desirable end—they simultaneously raise a different environmental challenge, one of effective recycling and ultimate disposal. What kind of regulatory environment is liable to develop as the industry shifts to plastics?

Eighty percent of the Delphi technology panel expect that there will be some form of state or federal regulatory activity within the coming decade to enforce the recyclability of automotive materials in the United States. These technical specialists may not be experts on forecasting regulatory activity, but their beliefs will influence their materials selection decisions. While opinions differ as to what form such regulation will take, specific legislation regarding the recycling of plastics is the fourth most often mentioned initiative, trailing only more general actions, such as how recyclability will be assessed. The materials panel rated the likelihood of eight different legislative and regulatory initiatives, and rated the enforced recyclability of plastics/polymers as the most likely. The North American industry clearly expects the coming decade to witness the application of regulatory and legislative constraints on automotive materials selection, and plastics are seen as a likely target for such efforts.

There are especially critical regulatory initiatives that government might pursue. We asked our plastics survey respondents to estimate the likelihood of each action, and which level of government is more likely to pursue it. Table 5 displays their responses: one equals virtually certain and five means extremely unlikely.

Table 5 Likelihood of regulatory initiatives, by level of government (1=virtually certain; 5=extremely unlikely)

	Government Level		
Initiatives	*Federal*	*State*	*Local*
Landfill limits on material types	2.7	2.0	2.0
Ban on some current automotive plastics	3.1	3.6	3.9
Required minimum recycled content	2.4	3.4	4.3
End of product life cycle recyclability requirement for manufacturers	2.4	4.0	4.7

Two actions would enforce material bans. The first potential step is limiting landfill disposal of particular types of material, as has been done in both Quebec and Germany.

Our respondents think this is quite likely at both state and local levels, reporting a two on a five point scale. Moreover, the prospect of such limitation at the state or local level exceeds the likelihood that the federal government (2.7) will impose such limits. While this is sensible in terms of our regulatory and legal framework, it does mean that there can be variation in the limits for different materials across jurisdictions. That can create problems for makers of "national" products, like automobiles, as the rules governing product disposition can vary widely across localities.

However, there is substantially less expectation (3+) that any level of government will enforce outright bans on any currently used automotive plastics. Nevertheless, it bears mention that such a possibility exists at the federal level, where respondents rate the likelihood at 3.1, just about the midpoint of the scale. If we convert this likelihood scale to a probability scale, the mid-point is the "50-50" position.

Two other actions would directly require some level of recycling, either by requiring a minimum of recycled content in new products or by requiring the manufacturer to take back a product at the end of its life cycle, effectively putting the recycling burden on the manufacturer. Our respondents see some possibility (2.4) of minimum content regulations and "take back" requirements at the federal level, but less chance that state (>3.0) or local (>4.0) government will pursue this strategy. "Take back" requirements are already developing in Europe, although there is debate as to whether they are likely in North America. Our Delphi technology panelists were concerned about the possibility, while our materials panelists viewed it as unlikely. Our more recent plastics survey respondents share the concerns of the Delphi technology panel.

We suspect that life-cycle management of automotive products will develop, whether driven by customer demand, regulatory initiatives, or business opportunity. The automotive industry (including manufacturers and their suppliers) will need to expand its view of the automotive product life cycle beyond the point of sale or warranty expiration, up to and including the ultimate recycling or disposal of the vehicle's material. This may well represent one of the major challenges that the industry will face in the current decade.

How do these plastics survey respondents think the manufacturers are likely to respond, assuming that the regulatory scenarios develop in the ways they anticipate? Table 6 presents our plastics survey respondents' replies, where one is labeled "extremely likely" and five denotes "not at all likely."

Table 6 Likely automaker actions in response to government initiatives (1=extremely likely; 5=not at all likely)

	Production Stage			
Actions	*Over All*	*Manu-facturers*	*Molders*	*Resin Producers*
Restrict the amount of plastics in the vehicle	3.8	3.5	4.0	3.9
Restrict the amount of unrecyclable plastics in the vehicle	1.9	1.6	2.0	2.1
Restrict the number of types of plastics in the vehicle	2.2	1.7	2.5	2.4
Substitute light weight metals for trim plastics	3.4	3.5	3.1	3.5
Substitute light weight metals for structural plastics	3.1	2.7	3.3	3.2
Pass-through recycling requirements to suppliers	2.0	2.3	1.8	1.7

Our respondents do not believe that the automakers are likely to restrict the amount of plastics in the vehicle, although they are quite likely to limit unrecyclable plastics and even restrict the number of different types of plastics/composites that will be used in the vehicle. Both Delphi and plastics survey respondents expect a substantial increase in the total amount of plastics/composites in the vehicle, and our plastics survey respondents do not think that the total amount of plastics will be restricted. If some unrecyclable types are restricted, then recyclable plastics should not only increase absolutely, but they should also gain "share."

The manufacturers rate the likelihood of all three restrictive actions higher than do the suppliers, especially in regard to restricting the number of types of plastics in the vehicle. Restricting the number of different plastics has the potential for creating winners and losers, and may shift the selection grounds from suitability for a particular application to suitability across a range of applications. The higher likelihood assigned by the manufacturers suggests that this is a development that plastic molders and resin producers may wish to monitor more closely in the future.

Respondents do not think it especially likely that the automakers will substitute lightweight metals for either trim or structural plastics.[18] However, it is interesting to note the difference in our manufacturer respondents estimates of this possibility: they are slightly to the "likely" side of the midpoint for structural, and on the "unlikely" side for trim. Whatever recycling requirements do develop, all three types of respondents believe that the manufacturers are quite likely to pass them through to their suppliers along the value chain. Suppliers (1.8, 1.7) see this as somewhat more likely than do manufacturers (2.3).

What actions might the government usefully take to require or encourage recycling? plastics survey respondents rated the usefulness of a variety of government actions on a scale ranging from one—labeled "extremely useful"—to five— described as "not at all useful." These actions have all been serious topics or proposals in the industrial, governmental, or environmental communities. Table 7 displays these results across all respondents and separately for each type of respondent.

Table 7 Utility of government recycling requirements/incentives (1=extremely useful; 5=not at all useful)

	Production Stage			
Type of Action	*Over All*	*Manu-facturers*	*Molders*	*Resin Producers*
Infrastructure				
Tax credits for disassemblers	2.1	2.2	2.2	1.9
Location incentives for disassembly facilities	2.4	2.8	2.5	1.8
Disposition certificates, including final disposal	2.7	2.7	2.5	2.9
'Take back' regulations making manufacturer responsible for final product disposition	3.1	3.7	2.9	2.8
Technology				
R&D tax incentives	1.7	1.7	1.6	1.7
Technology transfer credits to ensure universal availability of recycling technology	2.1	1.8	2.3	2.1
Use of Federal Laboratories for R&D	2.4	1.7	2.9	2.8
Financial				
Consumer deposit on cars	3.4	3.0	3.8	3.5
Incentives/credits based on recycled content	2.8	2.5	3.4	2.5
Petroleum/natural gas tax increases	3.1	2.8	3.2	3.3

[18] Our *Delphi VII* first round respondents think this is even less likely to occur, rating these possibilities respectively 0.9 and 0.7 scale points less likely than do our Plastics Survey respondents.

Tax credits and incentives to support R&D (1.7), ensure transfer of recycling technology (2.1), and to encourage disassemblers (2.1) are viewed as the most effective actions. However, direct incentives for recycled content are not seen as particularly useful, perhaps reflecting the industry's resistance to the more constraining nature of such an incentive, and consistent with the strong preference for open-loop over closed-loop recycling expressed in table 3, above. Nor is the industry enthusiastic about the utility of consumer deposits on cars, "take back" regulations, and fuel taxes to spur recycling.[19]

The more interesting data in this table are possibly the differences among our three types of respondents, reflecting in most instances their different positions in the automotive plastics value chain. Resin producers (1.8) are more positive about location incentives for disassemblers, probably because of the transportation implications of the siting of these facilities. Manufacturers (3.7) are more negative to "take back" regulations, undoubtedly reflecting the fact that they would be the most likely targets of such regulation, as has been proposed in Germany.[20] Molders (3.4) are negative towards incentives for recycled content, perhaps because of the technical and cost implications for their operations. The manufacturers are quite positive (1.7) towards the use of federal labs for R&D, perhaps because their own higher levels and broader scope of R&D make these labs seem more promising partners than they might seem to the often smaller molders (2.9) and resin producers (2.8).

Summary Government CAFE regulations are important drivers for automotive plastics use. However, government is also moderately committed to recycling. The various levels of government are somewhat likely to establish differing regulations to encourage recycling, but are less likely to impose outright bans on any current plastics/composites. Among the range of governmental incentives for recycling, tax incentives are generally seen as useful, but more restrictive and limited actions are seen as not particularly useful. The automakers are unlikely to restrict the total amount of plastics in the vehicle, although they will probably limit unrecyclable plastics and restrict the variety of types of plastics in the vehicle. They are also likely to pass through any recycling requirements to their suppliers, the molders and resin producers.

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[19] Our *Delphi VII* round one Material panelists are even less enthusiastic, especially in the technology arena, where they respectively rate the three actions at 2.6, 2.6, and 2.8.

[20] See S. Cole, op. cit., for an extensive discussion of how this approach is being implemented in Germany.

RECYCLING IN MATERIALS SELECTION DECISIONS[21]

The automotive manufacturers base their materials selection decisions on many criteria, including a number of attributes and characteristics of competing materials. Where does recycling fit in the hierarchy of decision factors?

Consumer preference is ultimately the major competitive concern for any vehicle manufacturer. The manufacturers' beliefs about the bases of consumer preference act as a major constraint upon all their decisions. To the extent that the perceived bases of consumer preference relate to materials use, these become constraints upon the materials selection decision. If consumers are concerned about recycling plastics, then the industry will respond to this concern.

Our Delphi VI Marketing panel provides interesting, albeit indirect, data on these preferences. We asked our panelists to indicate the five most important product attributes that will differentiate passenger vehicles over the next ten years. The question was open-ended, permitting the experts to simply provide their own list of attributes. While a total of 13 attributes received more than one mention, table 8 displays the seven responses relevant to this report as a percentage of all responses. It is important to bear in mind that 20 percent is the theoretical maximum for any one response, since each panelist is asked to list five responses.

Table 8 Most important product-differentiation attributes (percent of all responses and percent of possible)

Attribute	*Percent*	*Percent of Possible*	*Rank*
Styling	16%	80%	1
Powertrain performance and fuel efficiency	14	70	2
Owner-dealer relations	14	70	2
Advanced product features	13	65	4
Safety	10	50	5
Price	9	45	6
Environmental responsiveness	3	15	13

[21] See Andrea and Brown, op. cit., for a discussion of the material selection decision process.

Somewhat surprisingly, only four attributes—styling, powertrain performance, owner-dealer relationships, and advanced product features—were identified by the majority of our marketing panel. For our purposes, the most important aspect of these data is that the marketing panel sees environmental responsiveness as a relatively unimportant attribute for product differentiation, since it receives but 15 percent of possible mentions, and ranks last among these thirteen attributes.

However, it is important to note that these responses do not necessarily mean that environmental responsiveness is unimportant in an absolute sense. Our respondents may view environmental issues as regulatory driven and involving a public good. Thus, like emissions controls, environmental responsiveness may be quite important and quite constraining, but not an important product differentiator at the point of sale. After all, there is ample evidence that consumers are actually less willing to pay for environmental goods than they say they are.[22]

We asked our plastics survey respondents to rate more directly the value of eight different vehicle attributes to the car-buying public, where one equals "extremely valuable" and five equals "not at all valuable". Table 9 displays these results over the value chain.

Table 9 Estimated value of vehicle features to consumers (1=extremely valuable; 5=not at all valuable; overall rank displayed in parentheses)

	Production Stage			
Features	*Over All*	*Manu-facturers*	*Molders*	*Resin Producers*
Safety (1)	1.4	1.0	1.6	1.7
Low initial price/maintenance costs (2)	1.5	1.0	1.9	1.5
Electronic/technical advances (3)	1.8	1.7	1.9	1.9
Fuel economy (3)	1.8	1.5	1.9	2.0
Styling (5)	1.9	1.7	2.0	2.0
Performance improvements (6)	2.1	2.0	2.2	2.0
Emissions reductions (7)	2.5	2.5	2.3	2.8
Recyclability (8)	3.2	3.0	3.1	3.4

[22] See Kaplan, op. cit., 11.

There are few differences across the production chain, although the average of all these features yields somewhat different attributed customer value, with the automakers rating them at 1.8, the molders at 2.0, and the resin producers at 2.2. Most of these differences result from the automakers' greater attributed value for safety and price than the molders' and resin producers', and the resin producers' lower attributed value for emissions reduction and recyclability than the automakers' and the molders'. The most striking result is the neutral rating—and eighth ranking—assigned recyclability by each group of respondents. Emissions reduction, another environmental concern, is also rated relatively low, and ranks seventh for each group. While fuel economy has clear resource conservation implications, we suspect that its higher rating—third—reflects its importance as a traditional factor in vehicle operating costs rather than its relationship to environmental goals.

While the wording and specific focus of the Delphi and plastics survey questions differ, some overall comparisons are useful. First, our plastics survey respondents assign a quite different rank-order to these attributes/features than do our Delphi marketing panelists. Thus safety and price rank first and second across the value chain in our plastics survey, but fifth and sixth in our Delphi. It is difficult to imagine that rankings of "product differentiation attributes" and "customer feature preference" would differ so much simply due to wording of the question, since we assume that there is a close connection between customer value and product differentiation. Moreover, these ranking differences probably do not simply reflect differences in question type (open versus closed formats).

Second, both Delphi and plastics survey respondents agree in the low ranking assigned to environmental concerns. The automotive industry does not believe that its customers currently place much importance on these issues, compared with the more traditional attributes/features customers consider when making a vehicle purchase.

However, customer expectations can change rapidly, usually due to some change in the automotive environment. Thus customers evidenced sharp increases in their concern for fuel economy at the time of the first oil shock, although that concern quickly abated as the supply of oil returned to normal levels. Similarly, customers moved quality higher on their purchase decision priority list in the early 1980s, as competition made quality a product differentiator.

We think that customer concerns for recyclability will likely grow over the balance of the decade, and that more consumers will want vehicles that are more recyclable and expressive of their own environmental values. However, these environmental attributes will operate at the margin of the purchase decision, and probably will not outweigh the more traditional factors, such as price and quality, for the vast majority of consumers.

Finally, we asked our plastics survey respondents to indicate their view of the direct importance of a number of these attributes and characteristics in the materials selection process itself, using a scale where one equals "extremely important" and five equals "not at all important." Table 10 displays these results averaged across the entire sample. There were no major differences among our manufacturer, molder, and resin producers for these ratings.

Table 10 Material attributes importance in automakers' selection decision (1=extremely; 5=not at all)

Material Attributes	**Importance**
Economics	
Purchase price	1.2
Processing cost	1.4
Market issues	
Design/styling potential	1.8
Formability	2.2
Customer Concerns	
Corrosion resistance	2.0
Perceived safety	2.0
Vehicle customer preference	2.6
Conservation	
Recyclability	3.3
Weight	2.0
Ease of final disposition	3.4

The materials-selection process is indeed a complex one, with eight of these ten factors crossing the midpoint of the scale to fall on the "important" side. Unfortunately—from a resource conservation view—the two factors that are clearly viewed as less important are recyclability (3.3) and ease of final disposition (3.4). Economics remains the basic driver of the materials selection process, with price (1.2) and processing cost (1.4) both rounding to "extremely important." Styling potential (1.8) is another important attribute, with direct connection to consumer appeal and major implications for materials-selection decisions.

Summary These results suggest that the recyclability of automotive plastics is not yet a major factor in automotive materials-selection decisions, ranking far below the traditional factors. Recyclability is viewed as, at best, of moderate importance to the customer and the industry. Moreover, data discussed earlier in this report suggest that there are concerns about the cost of recycling automotive plastics, and very real apprehension that there is little market for them, once recycled. These considerations are likely to drive up the cost of plastics, should they be recycled, and thus further discourage their use.

FUTURE OF AUTOMOTIVE PLASTICS

What does the future hold for automotive plastics? Our Delphi panelists see substantially increased usage by the year 2000, assuming a CAFE standard of 35 m.p.g. The technology panel provides the more conservative forecast, estimating that plastics/composites will increase to 290 pounds, some 19 percent higher than the 243 pounds found in the 1992 vehicle. Our materials panel forecasts even more gain in plastics usage, expecting to find 330 pounds on the typical car by the year 2000.

These differences are not simply artifacts of different expectations for total vehicle weight. The technology panel forecasts that plastics will constitute about 10.5 percent of total vehicle weight, compared with somewhat under 8 percent in the 1992 vehicle. The materials panelists expect the plastics/composite "share" of total vehicle weight to rise to 12 percent. The expertise base of the materials panel suggests that their forecasts in this area may be more accurate. However, it merits comment that the manufacturers and suppliers in the materials panel have somewhat discrepant views, with the automaker panelists seeing a somewhat higher plastics usage than the suppliers. This may reflect their differing positions in the automotive plastics chain, perhaps related to different levels or types of information. Of course, the materials panel includes suppliers of many materials, and their somewhat lower estimates may simply reflect the diverse competitive orientations and beliefs of such a mixed group.

Driven by customer demand and lower levels of public concern about fuel economy, average vehicle weight increased about 8 percent from 1990 to 1992. Steel increased nearly 11 percent by weight, while plastics/composites increased somewhat under 10 percent. Nevertheless, our Delphi forecasts do suggest that this development will reverse itself, and the year 2000, with a CAFE standard of 35 m.p.g., will see average vehicle weight fall about 12 percent compared with 1990 levels. Steel and iron content will fall 18 percent and 31 percent respectively, while plastics and aluminum each enjoy an increase of about 35 percent. In fact, our Delphi panelists see plastics/composites and iron at virtually the same weight in the typical 2000 passenger car, each accounting for just over 11 percent of total weight. Our plastics survey respondents estimate that plastics will constitute just under 13 percent, by weight, of the average automobile by the year 2000, assuming that the total weight will fall some 10 percent.

Estimates of the portion of today's vehicle that is recycled is about 75 percent, by weight, and our plastics survey respondents expect this to increase to about 85 percent by the year 2000. They estimate the percentage of automotive plastics, by weight, that is currently recycled at just under 9 percent, and expect that to more than triple—to just over 28 percent—by 2000. However, there is extreme variation in their responses, and molders report much higher current and future recycling estimates (18 percent and 45 percent respectively) than do the manufacturers (3 percent, 21 percent) or resin producers (5 percent, 19 percent). Note that the manufacturers and resin producers, more conservative in terms of today's estimates, see higher rates of increases in recycling by the year 2000.

If fuel economy standards will be more stringent and weight reduction is the primary route to fuel-economy gains, what is the value of weight savings to a vehicle manufacturer? Our technology and materials Delphi panelists both expect that a pound of weight saved will be worth $3.00 by 2000, up substantially from their somewhat differing views of its value today, with the technology panelists reporting $1.00 and materials panelists valuing it at $2.00. Weight reduction is valuable today, and will be even more valuable as the regulatory demand for fuel economy increases in the future.

Will more stringent regulation add cost to plastics/composites, thus offsetting their current advantage in weight saving? Probably not, as resin producers anticipate cost increases on the order of 16 percent, molders 22 percent, and manufacturers 15 percent due to increased regulatory constraints. In view of the current prices of these materials, the anticipated increase in the value of weight saved, discussed above, should offset these modest rises in materials costs.[23]

To be sure, CAFE is a major constraint on materials selection, but the automakers will select the package of total materials that simultaneously meet CAFE-driven, weight-reduction goals and fulfill other, competitive constraints, including product design, quality, and conservation goals.

Will these other factors constrain or enlarge the use of automotive plastics? We asked our plastics survey respondents to forecast whether the use of automotive plastics would increase (one) or decrease (five) over the next five years as a function of its implications for design options, product quality, and concerns about disposition/recycling. Table 11 presents these results, again averaged over all respondents because of the similarity of their ratings.

Table 11 Factors affecting the future use of automotive plastics (1=increase; 5=decrease)

Factors	Change
Future changes in design/styling	1.9
Concern for actual vehicle quality	2.2
Concern for customer perceived vehicle quality	2.3
Concern for material disposition/recycling	2.8

These respondents suggest a bright future for automotive plastics, as three of these factors will increase its usage, and the fourth (concern for disposition/recycling) is essentially neutral. The formability and packaging attributes of plastics are an important advantage to automakers, and the real and perceived quality potential is also substantial. We suspect that the experience of Saturn has somewhat muted industry concerns that consumers are likely to view plastics as inherently lower quality than metals, and equate plastic with cheap. Moreover, these respondents do not view recycling concerns as barriers to increased automotive plastics, at least over the five-year term.

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23 Jeff R. Dieffenbach, Anthony E. Mascarin, and Michael M. Fisher, "Cost Simulation of the Automobile Recycling Infrastructure: The Impact of Plastics Recovery," *Automobile Life Cycle Tools and Recycling Technology* (Warrendale, PA: SAE, Inc., 1993), 45-52.

A critical issue facing the industry is who will take the lead in recycling automotive plastics. We asked respondents to our plastics survey a number of questions regarding leadership developments. First, our plastics survey respondents report a moderate level of government commitment to recycling/disposition regulations, although both manufacturers and molders report moderate to strong commitment. The manufacturers feel this will be stronger at the federal level, next strongest at the state level, and less strong at the local level. Our respondents overwhelmingly feel (65 percent) that the federal level will have the greatest overall governmental effect on the direction and development of plastics recycling activity. However, we note that state and local governments can have important indirect effects (through regulations governing the siting and contents of landfills, for example).

Moreover, a strong plurality of respondents (47 percent) is persuaded that government action is likely to exceed consumer support for recycling. That may be critical, because it risks putting the industry in conflict with its customer base, as appears to have happened with CAFE. Legislating what people as voters want, while protecting them as consumers from the direct economic consequences of such actions, often leaves voters/consumers happy with government. Of course, it also often makes them unhappy with the manufacturer, who must pass on the costs of programs required to meet such regulatory goals.

Who *should* take the lead in developing an effective resource management program for automotive plastics, including recycling and disposition? The plastics survey respondents overwhelmingly prefer (73 percent) that leadership come from an industry consortium; 12 percent preferring leadership from the resin suppliers, and another 12 percent prefer leadership from the assemblers. Only one respondent felt that the government should take the lead. That poses an immediate challenge to the industry, because the government will surely step in if the industry fails to develop and exert leadership on these critical issues. Fortunately, both the manufacturers and the automotive plastics suppliers have established organizations to work towards recycling and resource conservation.

Summary These data present a somewhat mixed picture as to the future role of automotive plastics in the North American industry, although in general a promising one. There are clear drivers for its use, including its advantages for design flexibility, and these are likely to be buttressed by more stringent fuel-economy regulations in the future. However, there are concerns about its ultimate disposition when the vehicle is retired, and these concerns reflect a different environmental priority, although one that the automotive industry does not yet view as a customer demand, nor as a "heavyweight" materials-selection factor.

CONCLUSION

All materials have advantages and disadvantages, whether from an environmental, manufacturing, or product point of view. It is important that materials-selection decisions reflect a true systems view, incorporating all these various dimensions. These decisions should include product, process, and environmental considerations, covering the relevant factors as completely as possible. Perhaps most importantly, decision-makers must avoid considering only one desired and targeted outcome, broadening their perspectives to encompass a wide range of goals, and recognizing that rarely do all considerations point to the same decision.

The data reported here present a somewhat mixed picture as to the future role of automotive plastics in the North American industry, although in general a promising one. There are clear drivers for its use, including its advantages for design flexibility, and these are likely to be buttressed by more stringent fuel economy regulations in the future. However, there are concerns about its ultimate disposition when the vehicle reaches the retirement stage of its life cycle, and these concerns reflect a different environmental priority. However, the automotive industry does not yet view recycling as a customer demand, and that prevents it from being a “heavy-weight” factor in materials selection decisions.

Materials will change to meet the competitive demands of a differentiated, quality-aware, and environmentally concerned market, while allowing low-cost production. The advantages that plastics offer may provide sufficient demand for automotive plastics so that the resulting supply of scrapped plastics will force resolution of many of the recycling issues. After all, the junkyards of the 1960s themselves contributed to the solution of the problem of proliferating steel hulks, simply by providing a large supply of potential material.

Our survey suggests that the automotive plastics industry and its vehicle producing customers are aware of and concerned about the environmental challenges that lie ahead. Moreover, they are seeking solutions to these challenges that are environmentally sound while responsive to the demands of vehicle purchasers and users. To be sure, their views are often influenced by their own position in the plastics value chain, and they reveal some tendency to prefer solutions that impose responsibility on other stages in that chain. However, they also reject solutions that might relieve their own burden, but are environmentally problematic, such as landfilling.

In summary, the automotive industry faces a complex set of drivers, some of which are likely to increase the automotive use of plastics, and some of which may work against their expanded use. Among the major barriers to plastic use at this time, specific concerns about recycling loom relatively large. If these issues are not resolved, then automotive applications of plastics may well continue to face an uncertain future.

APPENDIX I

The Automotive Plastic Industry, Type of Plastic, and Automotive Applications

Thermoplastic	Specialty grades	Automotive Applications	Producers
Acetal polymers [polyoxymethylene] [POM]	Improved processing grades Low wear/low friction grades Glass-filled grades Mineral coupled grades UV-stabilized grades Elastomer-modified grades	electrical switches, body hardware, seat belt components, fuel system components, gears, window lift mechanisms, handles, and cranks	Dupont; Hoechst Celanese Akzo Engineering; LNP Thermofil; BASF; Texapol ICI Advanced Materials
Acrylic plastics		tail lights side markers escutcheons pillar posts instrument covers nameplates trim dials	Rohm and Haas Co. Continental Polymers Cyro; Du Pont; Plaskolite
Polyaryletherketones	natural grades glass-reinforced grades carbon fiber-reinforced grades mineral-filled grades	bearing races friction bearings piston components	Amoco; Alpha Precision Plastics BASF; International Polymer Corp. DuPont; RTP Co. ICI; W.S. Shambam & Co.
Nylons [polyamides]	mineral reinforced grades glass-fiber reinforced grades et cetera	speedometer and windshield wiper gears wire harness clips and fasteners connectors emission cannisters fluid reservoirs dipsticks engine fans and shrouds air cleaner housings fuel system components cowl vents painted exterior body parts lamp assemblies mirror housings wheel hubs door and window hardware	Allied-Signal; Adell; Ashley; Du Pont; Belding; Custom Resins; EMS; Hoechst Celanese; Huls America; ICI Americas; Monsanto;Nylon Corp.; Schulman; Texapol; Wellman; Akzo Engineering; BASF; Cast Nylons; ICI Advanced Materials; Mobay; Polymer; Radilon; Thermofil
*Poly(amide-imide) [PAIS]		transmission thrust washers& seal rings ball and other bearings joints power assisted devices	Amoco Rhone-Poulenc
Polyarylate		headlight housings brake-light reflectors exterior mirror housings exterior window trim, brackets exterior door handles, fasteners	Amoco; Bamberger Polymers DuPont; Canada Colors & Chemicals Hoechst Celanese; Ashland Chemical Polymer Corp.
*Polybenzimidazole		seals mechanical components thermal insulators electrical connectors, valve seats	Hoechst Celanese
Polycarbonate [PC]		tail and side marker lights headlamps and supports blends in instrument panels & bumpers	GE Plastics; ICI Advanced Materials 3M; Mobay; Dow Plastics; Thermofil Akzo Engineering
*Liquid crystal polymers [LCPS]		electrical components	Amoco
Poly(butylene terephthalate) [PBT]		under the hood applications distributer caps connectors other electrical parts door and window hardware large parts such as grille opening panels blends used in bumpers	GE Hoechst Celanese Mobay BASF
*Poly(cyclohexylenedimethylene terephthalate) [PCT]	Filled PCT compounds (w/glass&mineral fillers) Copolyesters melt blends(w/copolyester& other polymers)	under the hood components alternator armatures pressure sensors	Eastman GE

Thermoplastic	*Specialty grades*	*Automotive Applications*	*Producers*
Poly(ethylene terephthalate) [PET] (Engineering grades only)	glass-fiber and fillers	structural parts -luggage racks -grille opening retainer panels functional housings -windshield wiper motor housings -" "blade supports -end bells many electrical/electronic applications -sensors -lamp sockets -relays -switches -solenoids	
Polyetherimide	unreinforced glass-fiber reinforced(10-40%) carbon fiber reinforced	under the hood temperature sensors fuel system components lamp sockets metallized reflectors high-strength transmission components	GE only
High density Polyethylene [PE]		mud flaps fuel tanks and drums	Phillipps 66 Co.; Adell Plastics Allchem Industries; Allied Signal American Polymers; Ampacet Corp. Plastic Warehousing; Bamberger Polymers; Bolcof Plastic Materials; Bruck Plastics; Chevron; Comalloy International; Commercial Plastics& Supply; DEN Enterprise; DLM Am. Plastic; Cadillac Plastic & Chemical; Deer Polymer Corp.;Delta Polymers; DuPont; Enimont America; Enterplast Inc.; Essex Int'l Exxon Chemical;Federal Plastics; Ferro Corp.; Fiber Materials; L Fine Co.;Fleet Plastics Corp.; Herman A. Gelman Corp.; Gen'l Plastics&Chem.; Ashland Chemical; Gulf Plastics; H. Heller&Co.; Hoechst Celanese; M Holland Corp.;Howard Ind.; ICI; Insulating Specialties; International Polymers; Lovco Plastics; MA Industries; Macdil Enterprises; DWMalette&Ass.;Marco Polo Int'l; Marval Ind.; Mitsui Plastics; MobilPolymers;ModernDispersions MonmouthPlastics;Muelhstein&Co; NetworkPoly.; NovaCorpofAlberta; NovacorChemicals;Oxychem; HSattler Plastics;A Schulman Inc; Scrap Source;Shuman Plastics; SolfexPolymer;StandardPolymers; Penn Fibre&Specialty; Plastic Components of Mass; PlasticsMaterialsUnlimited; PlasticsService;Polydex; Polymer Composites; Polymerland Service Centers; PressureChemical;PrimeAlliance; QuantumChem.; Rototron; Santech;ThorEnterp.;TrademarkPlastics Triad Plastics; Union Carbide; United Composites; UnitedFoamPlast; VinmarImpex;WashPennPlastic George Woloch Co.; World Plastic Extruders
*Ionomers	unreinforced glass-fiber reinforced	alloys for air dams & other exterior trim parts bumper pads and bumper guards	Du Pont; Exxon; Schulman
Polyimide, thermoplastic		non-lubricating seals	DuPont, Rogers, Monsanto, Ethyl, Ciba-Geigy, GE AmericanCyanamid;

Thermoplastic	Specialty grades	Automotive Applications	Producers
Polyimide, thermoplastic (cont)			AlliedSignal; CommercialPlastics&Supply DLMAmericanPlastics; GLAChemicalCorp.; InsulatingSpecialtiesCorp. WS Shambam&Co; Westinghouse Electric Corp.
Poly(phenylene oxide), modified	non-glass filled foamable grades etc.	major internal parts -instrument panels -seat backs, etc exterior parts -rear spoilers -wheel covers -mirror housings electrical applications -connectors, fuse blocks, etc	GE Plastics;Akzo Engineering; ICI Advanced Materials;Thermofil
Poly(phenylene sulfide)		engine sensors halogen lamp sockets	Mobay; Akzo Engineering GE; ICI Advanced Materials Hoechst Celanese; Thermofil Phillips
Polypropylene		interior trim and panels exterior components batteries under the hood and dash applications	Himont USA; Soltex; Adell; Akzo Engineering; M.A. Industries; Polycom Huntsman; Schulman; Thermofil; Aristech; Fina; GenCorp; Monmouth;Phillipps; Quantum;Rexene; ShellEastman; Exxon; ICI Advanced Materials; Amoco
PP homopolymer		under the hood and dash	Eastman; Adell Plastics; American Polymers; Amoco Ampacet; Aristech; Auburn Plastic Engineering; Azdel Bamberger Polymers; Beta Polymers; Bolcof Plastic Materials Bruck Plastics; Canada Colors&Chemicals; Colonial Rubberworks Comalloy International; Custom Compounding; Custom Plastics DEN Enterprises; DLM American Plastics; Deer Polymer Corp.; Enterplast;Epsilon Products; Exxon; Federal Plastics; Ferro Corp. FerroIndustrialProducts,Ltd.; FiberMaterialsCorp;FinaOil&Chemical LFineCompany;FleetPlasticsCorp; HAGelmanCo;GeneralPlastics&Chem. Genesis Polymers;BFGoodrich; GulfColour;H.Heller&Co; HimontUSA M.HollandCo.;Howard Industries; HuntsmanChemical;ICI Adv. Materials Insulating Specialties; International Polymers;Lovco Plastics; Macdil Ent.; Major Prime Plastics; DWMallette&Associates; Marco Polo Int'l;Marval Industries; MitechCorp;Modern Dispersions; Monmouth;HMuelstein&Co; Network Polymers; Nova Corpof Alberta PennFibre&SpecialtyCo.;Phillips66; Plastic Compounders of Mass. Plastic Materials Co.; The Plastics House; Plastics Materials Unlimited PlasticsServiceInc;Polifil;Polydex; PolymerComposites; PolymerlandServiceCenters Pressure Chemical Co.; Prime Alliance Inc; Quantum Chemical Corp

Thermoplastic	Specialty grades	Automotive Applications	Producers
Polypropylene (cont)			Rexene; Rhe-Tech;Santech; H.Sattler Plastics; Scrap Source; Shell Chem.;Shuman Plastics; Soltex Polymer;Standard Polymers; Thor Enterprises;Trademark Plastics; Triad Plastics; UBE Industries; Ultra-Plax Corp;United Composites Inc; Vinmar ImpexInc;Vinyl PlasticsInc; GeorgeWoloch Co.;World Plastic Extruders Inc.; Washington Penn Plastic Co.;
Polypropylene, cont. *PP Impact copolymers*		interior trim battery cases fender liners trunk liners	Rexene Products; Adell Plastics; American Polymers;Ampacet Corp.; Aristech Chemical;Bamberger Polymers; Beta Polymers; Bolcof Plastic Materials; Bruck Plastics; Canada
Colors&Chemicals;			Colonial Rubberworks;Comalloy Int'l; Custom Plastics;DEN Enterprises; DLM American Plastics; Deer Polymer Eastman Chemical Products; Enterplast;Epsilon Products; Exxon Chemical; Federal Plastics;Ferro Corp; Ferro Industrial Products; Fleet Plastics;HAGelman Co.; General Plastics&Chemical; Ashland Chemical; Genesis Polymers; H.Heller&Co.;Himont USA; MHolland Co.; Howard Industries;Huntsman Chemical Insulating Specialties; International Polymers;Lovco Plastics; MAIndustries;Major Prime Plastics; DWMallette&Associates; Marco Polo Int'l; Marval Industries; Modern Dispersions;Monmouth Plastics; HMuelstein&Co; Network Polymers; Nova Corp of Alberta; Plastic Compounders of Mass.; Plastic Materials;Plastics House; PlasticsMaterialsUnlimited; PlasticsService;Polifil;Polydex; PolymerlandServiceCenters; Prime Alliance Inc; Quantum Chemical Corp; Rexene Corp;Rhe-Tech; Santech;HSattlerPlastics; Shell Chemical;Shuman Plastics; Standard Polymers;Thor Enterprises; Trademark Plastics;Triad Plastics; United Composites;Vinmar Impex; Vinyl Plastics; Washington Penn Plastic George Woloch Co.
ABS		instrument panels consoles, mirror housings interior trim, knobs, light bezels radiator grilles, decorative trim headlight housings, grilles	GE Plastics; Akzo Engineering Monsanto; ICI Advanced Materials Dow; Thermofil
Acrylic-styrene-acrylonitrile		exterior mirror housings grills bumper covers	BASF GE Monsanto Dow
Styrene-acrylonitrile [SAN]	UV-stabilized grades for. . . glass-reinforced grades for. . .	lenses instrument panels	Monsanto; Akzo Engineering; Thermofil; BASF ICI Advanced Materials
Styrene-maleic anhydride		instrument panels headliners floor and roof consoles glove box doors and trim parts instrument panels(40% of all in market) various trim parts heating duct louvers	ARCO Chemical; Comalloy International; DLM American Plastics; Ashland Chemical; Hoechst Celanese; Monsanto; Polymer Composites;

Thermoplastic	*Specialty grades*	*Automotive Applications*	*Producers*
Styrene-maleic anhydride (cont)		speaker grilles radio parts and fascia door inserts seat buckle components	Prime Alliance;
Polyarylsulfone		automotive fuses	Firestone; Amoco Performance Products; Loranger Mfg Corp.; Phillips; Mercury Tool&Mfg; Osley&Whitney; Parkway Products RTP Company; WS Shambam&Co
Polysulfone		automotive fuses and switch housings	Amoco; BASF; Akzo; Ferro; ICI; RTP; Thermofil
Thermoplastic elastomers [TPEs]			
Elastomeric alloy TPEs		window seals hose coverings gaskets seals convoluted boots deck lid seals	Monsanto; North Coast Compounders Novatec; Polysar
Engineering TPEs		fascia bumper covers cladding	Bamberger Polymers; Canada Colors&Chemicals; Comalloy Int'l;DLM American Plastics; Dexter Plastics; Discas; DuPont; GE Plastics;GLS Plastics; Polymerland Service Centers; Rhone-Poulenc; Schulman; Ashland; Genesis Polymers; BF Goodrich; H. Heller&Co; Howard Industries; Lucky America; Mobay; Modern Dispersions; Monsanto; Nova Corp.
Olefinic TPEs *Polyurethane TPEs*		bumper fascias grilles, rub strips air dams fender extensions filler and corner panels housings fascia gaskets	DuPont; Exxon; MA Polymers; Monsanto; Montedison; Polysar; Schulman; Teknor Apex; Union Carbide; Morton; Goodrich; Polyurethane Specialties; BASF;Dainippon; Dow Plastics; Mobay; Ohio Rubber
Thermoplastic elastomers, cont. *Styrenic TPEs*		under the hood applications heating and air conditioning ducts gaskets grommets	Shell; Atochem; Discas Inc; Firestone; Fleet Plastics Corp; J-Von; Furane Products Co.; GLS Plastics; H.Heller&Co.; Concept Polymer Technologies; Howard Industries;GLS; Lucky America;Teknor Apex; Ferro Corp; Fina Oil&Chem; Modern Dispersions
Chlorinated PVC		interior parts	BF Goodrich only
*Dispersion PVC			Occidental Chemical
**Alloys and Blends*		interior and exterior components including: instrument panels, body panels, cowl vents, bumpers	Monsanto, GE, Amoco, Dow, HoechstCelanese, Mobay

Thermosets	Specialty grades	Automotive Applications	Producers
Phenolic		automatic transmission reactors water pumps intake manifolds thrust washers brake pistons engine blocks and heads	Rogers Corp; ICI Fiberite Occidental; Plastics Engineering Resinoid;Valite
	Molding Compounds, phenol-formaldahyde		
	Woodflour-filled		Occidental; Plaslok;Plastics Engineering Valite Div.
	Woodflour and mineral-filled		Occidental; Plaslok; Plastics Engineering Valite Div.
	High strength glass fiber re-enforced		ICI Fiberite; Occidental;Plastics Engineering Resinoid; Rogers Corp.; Valite Div.
	Impact modified		
	cotton-filled		ICI Fiberite; Occidental; Plaslok; Plastics Engineering; Resinoid; Valite Div.
	cellulose-filled		ICI Fiberite; Occidental; Plaslok; Plastics Engineering; Resinoid; Rogers Corp.; Valite Div.
	fabric and rag-filled		ICI Fiberite; Occidental; Plaslok; Rogers Corp;
	Heat-resistant		
	mineral-or mineral and glass-filled		ICI Fiberite; Occidental; Plaslok; Plastics Engineering; Resinoid; Rogers Corp.; Valite Div.
	Casting resins		
	Unfilled		Ametek, Haveg; Monsanto; Reichhold; Schenectady Chem.; Union Carbide
	Mineral-filled		Monsanto; Reichold; Schenectady Chem.
Polyester, thermoset	SMC	hoods and deck lids front end panels	Not divided by type of compound: BP Chemicals; Premix; Aristech; Ashland
		headlamp housings	Haysite; ICI Fiberite; Polyply; Freeman
		rear wheel opening covers	Aristech; Occidental; American Cyanamid
	TMC	body parts	
	Cast		
	Rigid		Aristech Chemical; AZS; Cargill; Freeman;ICI Americas; Owens-Corning; Reichhold Shell;
	Flexible		Aristech Chemical; Cargill; Freeman; ICI Americas; Owens-Corning; Reichhold; Shell
	Glass fiber-reinforced		
	Preformed, chopped roving		Eagle-Picher, Glastic; Haysite; Ind. Dielectrics; Jet Moulding; Plumb; Premix; Reichhold;Rostone
	Premix, chopped glass		Am. Cyanamid; Applied Components; Eagle-Picher, Glastic; Haysite; Ind. Dielectrics; Jet Moulding; Plumb; Premix; Reichhold;Rostone

Thermosets	Specialty grades	Automotive Applications	Producers
Polyester(cont)			
	woven cloth		Eagle-Picher, Glastic; Haysite; Plumb; Premix; Reichhold; Rostone
	SMC		Applied Components; Budd; Eagle-Picher; Haysite; ICI Fiberite; Ind. Dielectrics; Jet Moulding; Plastics Mfg.; Premix; Rostone
	SMC low-shrink		Applied Components; Budd; Eagle Picher; Haysite; Ind. Dielectrics; Jet Moulding;Premix; Rostone;
	BMC, TMC		BP Chemicals; Eagle-Picher; Epic Resins;Glastic; Haysite; ICI Fiberite; Dielectrics Jet Moulding; Plumb; Premix; Rostone
	EMI shielding(conductive) SMC, TMC		Applied Components; Ind. Dielectrics; Premix
	BMC		Applied Components; Ind. Dielectrics;Premix
Polyurethanes(PUR)	fiber-reinforced composites	bumper beams floor pans pick up truck boxes exterior body panels	ICI; Dow Plastics; Goodrich; Mobay
	foams	seating armrests steering wheels	
	RIM Bayer Process ="Thermopressing"	body covers	Bayer, etc.
	Casting resins Liquid		Conap; Devcon; Dow Plastics; Emerson & Cumming; Hexcel Hysol; Mobay; Polyuretane Corp. Polyurethane Specialties; Thermoset Plastics; Union Carbide
	Unsaturate		Dow Plastics; Emerson & Cumming;Hexcel; Hysol; Polyurethane Corp of Am. Polyurethane Specialties
	50-65% mineral-filled potting and casting compounds		Conap; Thermoset Plastics
Epoxy		container coatings, electrodeposition primers	Ciba-Geigy Corp., Anhydrides&Chemicals Inc, Dow Chemical, Emerson& Cumming, HB Fuller Co. PD George Co., Huls America Inc., Permagile Industries Plaskon Electronic Materials, Reichold Chemicals, Rhone-Poulenc, Rogers Corp., Sartomer Co., H. Sattler Plastics Co., Schering Berlin Polymers, Shell Chemical Co., StanChem Inc., Westinghouse Electric
	Bisphenol molding compounds glass fiber-reinforced		Hysol; ICI Fiberite; M&T; Plaskon
	mineral-filled		Hysol; ICI Fiberite; M&T; Plaskon
	Low density glass sphere-filled		Hysol; ICI Fiberite;

Thermosets	*Specialty grades*	*Automotive Applications*	*Producers*
	Novolak molding compounds		
Epoxy (cont)			
	mineral and glass-filled, encapsulation		Cosmic Plastics; Hysol; ICI Fiberite Ind. Dielectrics; M&T; Plaskon Rogers
	mineral and glass-filled, high temperature		Cosmic Plastics; ICI Fiberite; Ind. Dielectrics; Plaskon; Rogers
	glass-filled, high strength		ICI Fiberite; Ind. Dielectrics
	Casting resins and compounds		
	unfilled		Ciba-Geigy; Conap; Dow Plastics; Devcon; Emerson & Cumming; Epic Resin; Hysol; Isochem; Shell; Thermoset Plastics
	silica-filled		Conap; Devcon; Emerson & Cuming; Epic Resins;Hysol; Isochem; Thermoset Plastics
	Aluminum-filled		Conap; Devcon; Emerson & Cuming; Epic Resins; Isochem; Thermoset Plastics;
	Flexibilized		Conap; Devcon; Dow Plastics; Emerson & Cuming; Epic Resins; Isochem; Thermoset Plastics
	Cycloaliphatic		Ciba-Geigy; Union Carbide