

Postconsumer Disposition of the Automobile

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Office for the Study of Automotive Transportation
University of Michigan Transportation Research Institute

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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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TABLE OF CONTENTS

INTRODUCTION.....	1
OVERVIEW OF PLASTICS DISPOSITION.....	2
Dismantlers.....	4
Shredders.....	6
Resin Producers.....	8
CHALLENGES TO THE RECYCLING INFRASTRUCTURE.....	12
Landfill Issues.....	12
Material Content.....	16
Material Recovery.....	19
Public Opinion and Environmental Regulation.....	26
Recycling Industry Structure.....	29
Automotive Industry Expectations.....	32
STEPS TO EFFECTIVE RECYCLING.....	38
Design and Disassembly.....	39
Labeling.....	40
Part Composition and Contamination.....	41
Incineration and Energy Recycling.....	45
Commingled Plastics Recycling.....	49
SUMMARY.....	54

**Executive Summary:
Recycling Automotive Plastics**

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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 possess 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 (Life Cycle Assessment: Issues for the Automotive Plastics Industry, 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 pyrolysis. 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 pyrolysis 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.

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INTRODUCTION

Postconsumer disposition of automobiles once again poses a major challenge to the automotive industry, and this round of concerns focuses not on rusting hulks blighting the landscape—as was the case in the early 1960s—but on some of the vehicle's constituent materials, perhaps most notably its plastic content. It may be useful to consider some of the characteristics of a car without plastics, so that we may recall their contribution and value to today's vehicle, transportation system, and society.¹ Today's cars would probably be less safe, as the lighter weight of plastics is certainly compensated by the safety equipment that plastics make possible, the seat belt and air bag. The metal that would replace plastics would be bare and unprotected by plastic-based paints and coatings, and therefore would quickly corrode. The heavier cars would create two other environmental problems, as fuel consumption and emission levels would both be higher. The vehicle design and the electrical system would be severely restricted, since the flexible hoses and insulation of today would be absent. The price of the vehicle would be higher, since at least some plastic substitutes would be higher cost. The contribution of plastics to the modern vehicle are indeed important, and vehicles that relied on substantially lower plastic content would carry numerous penalties.

Nevertheless, concerns about their disposition threaten automotive plastics. If the combined development of technical and business innovations solved the disposal challenges of the 1960s, the industry cannot rely on such fortuitous circumstances today.² To be sure, such circumstances may develop, but the industry must be prepared to meet the challenge of recycling plastics if they do not.

¹ Gunter Walter, "Activities for Recycling and Disposal of Used Vehicles," *Plastics in Automotive Engineering: Applications and Recycling*, VDI-Verlag GmbH, Dusseldorf, 1991.

² See Daniel Kaplan, "Economic Issues in the Reuse of Automotive Plastics," (University of Michigan Transportation Research Institute report no. 93-40-2, 1993), for a more detailed discussion of the developments of these technologies and the increased recycling of automotive steel.

The challenges of environmentally sound disposition, with its heavy emphasis on recycling as a primary strategy for resource conservation, require a systems response, incorporating changes and adaptations throughout the many complex stages of automotive production. Thus product design only for use and/or consumption is rapidly becoming obsolete. Increasing environmental concerns worldwide, together with the development and acceptance of the principles of Design for the Environment (DFE), are forcing this development. The Life Cycle Analysis (LCA) method for evaluating the full consequences of a design (including its environmental, economic, and social effects) provides support for broadened design criteria.³ Automobiles are a highly visible product, raising concerns about solid waste for some, while others recognize that they are perhaps the most recycled consumer durable product in the world. While no U.S. regulations currently require manufacturers to pay attention to the final disposition of a product, postconsumer disposition has become a much more important design consideration than in the past.

LCA extends the stages of the traditional product life cycle beyond its traditional limits, both before the design or engineering stage and after the product use stage. It also highlights the importance of the postconsumer disposition—or death—of the product. Just as the product life cycle includes a number of distinguishable stages, so too does the disposition of the product, and these disposition stages also raise their own particular and distinct concerns and problems.

OVERVIEW OF PLASTICS DISPOSITION

This paper provides an overview of three critical stages in the disposition of automotive plastics, reviewing the challenges and issues they raise for the successful recycling of these materials. The three stages are the initial dismantling, the shredding of the hulk, and the reuse of plastics by resin makers. If resin makers are the start of the automotive plastic chain, they are also often, but not always, the end of that chain when material is successfully recycled.

³ Gregory Keoleian, and Dan Menerey, "Life Cycle Design Manual: Environmental Requirements and the Product System." The United States Environmental Protection Agency, 1993.

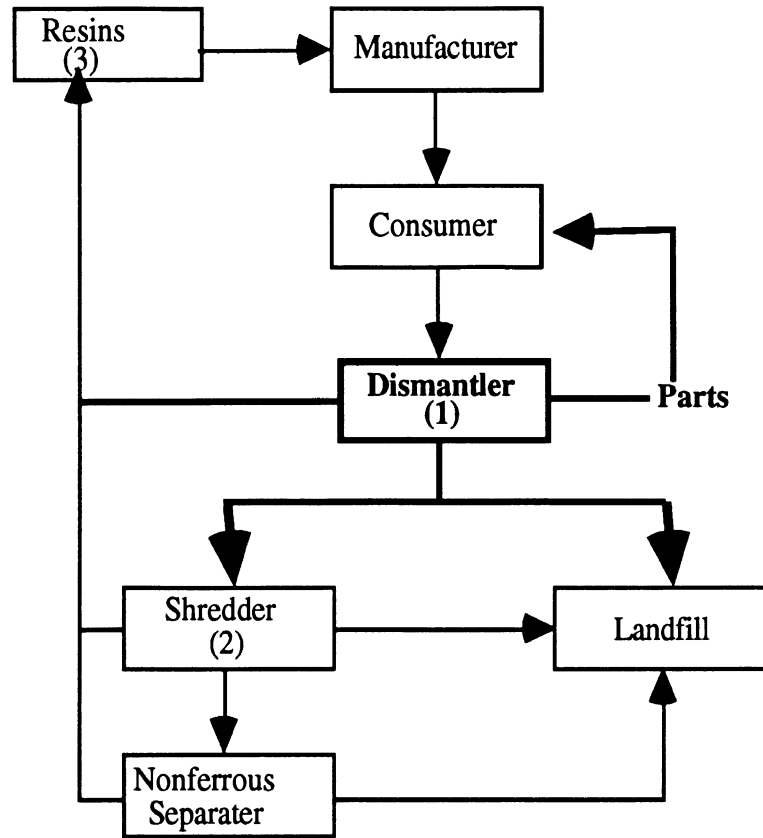


Figure 1 Simplified Overview of Postconsumer Disposition of the Automobile

Virtually all automobiles pass through a uniform, recycle-intensive process of final disposition, illustrated in figure 1. As many as 12 million vehicles are retired in the United States each year, and of those 90 percent start the disposition process at one of an estimated 12,000 dismantlers.⁴ Dismantlers, often the familiar local junkyard, comprise the first stage of a large infrastructure for vehicle disposal. They recover some parts and components for reuse in the automotive aftermarket, eventually discard a portion of the automobile, typically in a landfill, but send most of it on to the second stage, the shredders.

The shredders constitute the second stage, buying the vehicle hulk from the dismantlers and processing it for salable material. They put the vehicle hulk through a shredding machine, usually consisting of a set of large spinning rotors, cutting the hulk apart into small pieces. Cranes with magnetic heads typically separate the ferrous metal

⁴ 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.

from the nonferrous material. The ferrous metal is then sold to recyclers—such as steel minimills—who melt the scrap and refine the metal for resale, and thus reuse in various products.

There are two streams of nonferrous materials emerging from the shredders, often called automotive shredder residue (ASR), or fluff. The lighter ASR stream or fraction—consisting mostly of foam, glass, dust, and plastic—is put into a landfill. The heavier ASR fraction—containing nonferrous metals—is sold to the nonferrous separators, the third stage of the automotive recycling infrastructure. These operations use chemical, gravity, hand sorting, or other separation techniques to recover aluminum, zinc, and other recyclable metals for resale in scrap markets. Residue from the nonferrous separators is also landfilled.

The demand for various products from each of these three stages—dismantling, shredding, and separation—drives this recycle-intensive infrastructure for the final disposition of automobiles. Automotive plastics can theoretically enter the postconsumer recycling stream at any of the stages, although the value of recovered material depends on its composition, purity, and the method of recovery. For example, dismantlers more often rely on disassembling large components or masses of plastic, while shredders or separators would have to recover plastics from the current fluff, a difficult challenge indeed. In either case, the resin producers of today (or some new resin processing industry akin to the steel industry's minimills) are likely candidates for processing and marketing recycled plastics. A new resin processing industry might itself develop segments, with one type of company possibly targeting material recovery from light ASR, while a different type might target heavy ASR from shredders, or, later in the process, separator residue.

Dismantlers The demand for used automotive parts motivates dismantlers to do exactly what their name implies—they dismantle the vehicle. Dismantling results in three possible final dispositions for the various components in the retired vehicle.

First, *parts* that are readily usable and in relatively constant demand are removed, reconditioned, and stored for subsequent sale. These typically include engines, windows, stereos, hubcaps, starters, brake components, and other parts, depending on their marketability in the geographical region.⁵

⁵ Gerry Kobe "Recyclability," *Automotive Industries*, September, 1990, 40-41.

Second, unlike parts recovered for reuse, other parts may be removed for material recovery, and many dismantlers strip out certain parts to sell to recyclers. They break down or separate these parts by material type, and then sell them to companies for use in the manufacture of new parts. These parts typically include batteries, catalytic converters, and chrome parts, all containing valuable metals.

Third, some parts, such as automotive batteries, are recovered for both part and material salvage. A vehicle owner might well purchase a used battery from a junkyard—or dismantler—to save money. This would be recovery of a part for reuse in its original function. However, if the battery remains unsold, the dismantler will eventually sell the part to a lead smelter or a battery manufacturing company, who will salvage the lead and reuse it, often for production of new batteries. This is an example of parts recovery for its material value. Whether the battery is sold for use or for its lead content to be used in new batteries, it is recycled in a direct or “closed-loop” fashion.⁶

After the marketable parts are removed, the vehicles are usually stored in an area where they are readily accessible. The customer or the in-house mechanic will strip out specific parts (on an as needed basis) that do not have sufficient demand to warrant immediate removal, but might be profitable for resale. These typically include such parts as doors, hoods, fenders, transmissions, axles, suspensions, as well as interior parts such as seats or steering wheels.

Once the profit potential for parts reuse or materials resale has been exhausted, dismantlers prepare the vehicle for sale to the shredder—the next disposition stage. This preparation typically includes removing tires, exhaust systems, fuel tanks, radiators, air conditioners, and air bags, and may require the removal of metals that are toxic and/or potentially damaging to the shredding machinery—cadmium bolts, for example, are both. They also remove fluids such as antifreeze, oil, and brake fluid—items that shredders will not accept because they may potentially damage equipment or contaminate the material content.⁷ When the vehicle hulk is sold to the shredder, the dismantler must dispose of the remaining material, typically by paying a “tipping” fee to have any unwanted materials put into landfills.

⁶ “Closed-loop” recycling is the reuse of material in its original product. This typically results in higher value reuse than “open-loop” recycling, where the material is used for a different—and usually lower value—product.

⁷ Gerry Kobe, *op. cit.*

As with all businesses the dismantlers must live by the laws of economics. That is, they will only dismantle vehicles if they think they can realize a profit. The profits from the sale of the parts, materials, and the hulk must exceed the cost of the dismantling operation plus the cost of landfilling the nonsalable parts and materials, as illustrated in figure 2. Current and recent profit margins from dismantling have been large enough to create demand for all expired vehicles because of the value of the parts and materials.

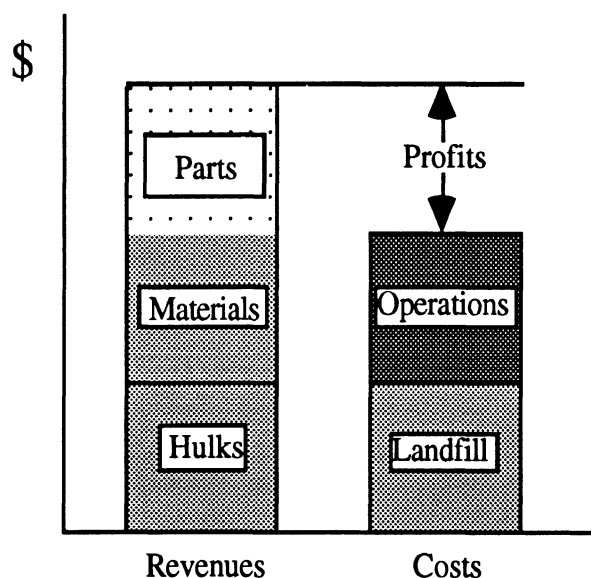


Figure 2 Economics of Dismantling

Vehicle dismantlers have traditionally concentrated almost all their efforts on the recovery of used parts rather than of valuable materials. If the recovery of valuable materials can generate profits, why do dismantlers not pursue it? Except for a few material-rich parts—batteries, catalytic converters, etc.—the profits from the sale of used parts, retailed at approximately half the price of new parts, are much higher than the profits from the sale of materials. Therefore, dismantlers prefer to devote their time and resources to parts recovery. They then sell the valuable materials to the shredders, along with the rest of the stripped vehicle, for the scrap price, even though many of the materials left in the vehicle may be worth more than the scrap price. This transfer of valuable material to the next stage of disposal, the shredders, also helps to assure that the dismantlers have a market for the unused portion of the automobile, the hulk.

Shredders Before the early 1970s postconsumer automobiles were stored in ugly and hazardous roadside graveyards. Many felt that government regulation was the only way

to prevent the problem from worsening.⁸ However, postconsumer automobiles now constitute the single largest source of recycled steel and iron in the country. This transformation occurred because a sharp increase in the cost of steel created a demand for large amounts of scrapped steel, in turn sparking the development of the electric arc furnace for resmelting postconsumer steel and the rise of minimills. At about the same time, another invention, shredders, came on the scene. These machines allow a company to reduce automobile hulks to a manageable size, permitting the economical separation and recovery of valuable materials. The abandoned cars were collected and recycled, and the problem of auto graveyards quickly solved.

The shredders, named for their expensive, high-speed machinery, are typically the second stage in the disposition of discarded automobiles, as illustrated in figure 1 above. Shredders are extremely large (30-45 tons) machines with fast spinning (usually around 600 rpm) rotating wheels with hammer-like protrusions that literally hammer a vehicle hulk into small fist-sized pieces. There are currently about 200 shredders in the country.

Vehicle hulks from the dismantlers, together with other postconsumer durables with a substantial amount of ferrous metal, constitute the shredders' raw material. Once shredded, scrap can be easily separated into a ferrous (magnetic metals) stream and a nonferrous (nonmagnetic materials) stream, the ASR. The ferrous metals are separated with magnets and sold for recycling, while the nonferrous ASR stream is split again into a light fraction or stream and a heavy stream. The light stream (consisting of foam, glass, dust, and plastics) is usually landfilled, while the heavy stream is processed for valuable nonferrous metals, or is sold to nonferrous processors. Density gradients, fluids, electricity, or other processes are used to separate out the nonferrous metals.

The shredder, too, must pay for the disposal of the light stream of ASR and either the shredder or the nonferrous separator pays to landfill the remaining materials from the heavy stream of ASR. In some instances, the ASR light fraction is incinerated, and this too typically involves a fee for the disposer.

Shredders are profitable operations as long as the revenues from the sale of salvaged materials exceed the operational costs of separating and marketing those materials plus the price of landfilling or incinerating the ASR. However, the mass of valuable materials

⁸ "The Automobile Cycle: An Environmental and Resource Reclamation Problem," U.S. EPA 1972.

in the hulk has generally been decreasing, while the cost of either landfilling or incinerating the ASR has been increasing. This is even more of a problem for shredders than for dismantlers, because shredders rarely have the attractive opportunity of salvaging and selling used parts. Eventually, these trends will cause loss of profit for the shredding industry, or be pushed back onto the dismantlers. In either case, if the industry becomes unprofitable, the disposal of automobiles may once again become a problem similar in magnitude to that faced before the development of the shredder and other technologies.

Resin Producers The use of plastics in automobiles involves three different groups of companies. In terms of the automotive industry, the second-tier, material-supplier companies create resins, and sell them to the first-tier molders for the manufacture of parts and components for sale to the automakers. Many resin makers are part of large, high-profile chemical or petroleum companies, including Union Carbide, Dow, Exxon, Chevron, Mobil, DuPont, B.F. Goodrich, Goodyear, General Electric, Amoco, and Shell. In 1992, resin companies supplied over two billion pounds of resins to the automobile industry; automotive uses accounted for over 23 percent of the total markets for ABS, nylons and polyacetals. These resin producers are, and likely will remain, the primary users of any recycled automotive plastics material.

Like the automakers, resin makers tend to be large companies, often affiliated with well-known corporations, and are therefore also subject to public scrutiny. Because their corporate parents make a variety of visible products, a public backlash against them on environmental issues could translate into a boycott—an unlikely problem for molders. It is clearly easier for people to refuse to purchase a GE radio or Shell gasoline than it would be for them to determine which partsmakers do not recycle and to refuse to buy vehicles that contain their parts.

Resin makers have another strike against them on environmental issues, simply because their products are seen as environmentally harmful. An article in *Industry Week* stressed this point: "Perhaps no sector is more closely associated with environmental issues than the chemical industry."⁹ A 1990 poll taken by the Council for Solid Waste Solutions concluded that 51 percent of Americans considered plastics "unfavorable"; 31

⁹ "The Environment: Industry's Talent for Solutions," *Industry Week*, January 4, 1993, 25.

percent called plastics the "most threatening" material in the environment. By contrast, only 4 percent considered automotive emissions "most threatening."¹⁰

Many resin makers have recognized that recycling programs must address a combination of business, politics, and public perception issues. "If we don't come up with solutions," said Jim McLellan of Amoco Chemical in 1989, "we'll have taxes, bans, and restrictions on products we market."¹¹ "Just the idea that plastics can be recycled can take the pressure off," said another industry source that year.¹² To some extent, the effect of public pressure on downstream companies serves to make recycling good business for resin companies. Bill Snodgrass of Dow Chemicals said a major reason for Dow's recycling project was that companies using resins wanted to be able to say they use recycled materials.¹³ Several well known companies involved in resin production created partnerships or independent operations in the late 1980s to meet these needs, as displayed in table 1.

Table 1: Resin company recycling operations¹⁴

Companies	Plastics Recycled	Capacity	Start-Up
Mobil Chemical/Genpak	Polystyrene Foam	3 mil lb	1989
Dow Chemical/Domtar	HDPE, PET	75 mil lb	1991
DuPont/Waste Mgmt.	HDPE, PET	40 mil lb	1990
Amoco Foam Products	Polystyrene Foam	1 mil lb	1989

These facilities recycled the types of scrap most widely available—the milk bottles and packages that families collect for curbside recycling programs in cities and towns across the country. Nationwide, over 4,400 community recycling programs helped gather more than 912 million pounds of postconsumer plastics in 1991; PET and HDPE each account for nearly one third of the plastics currently recovered.¹⁵ The existence of so much recovered plastics has provided major resin companies with a means for entering into recycling, in the United States and abroad. In 1990, BASF, Bayer, and Hoechst, three of the world's largest chemical companies, formed a joint venture to promote the

¹⁰ "Recycling, Source Reduction, and Opportunities for Biodegradables," *Plastics Engineering*, March 1993, 81.

¹¹ "A new wave of Plastics Recycling," *Chemical Week*, May 10, 1989, 9.

¹² *Ibid.* note 12, 9.

¹³ *Ibid.*

¹⁴ *Chemical Week*, op. cit.

¹⁵ "Plastics Recycling Hitting its Stride," *Environment Today*, December 1992, 3.

recycling of plastic waste.¹⁶ Occidental Chemical has invested in partnerships with independent recyclers. Union Carbide started a 55-million-pound-per-year, multi-plastics recycling plant in Piscataway, NJ in 1992. Phillips 66 and Partek Corporation have created a joint venture to recycle HDPE; their plant currently has a capacity of 18 million pounds annually and could expand to 40 million pounds. Quantum Chemical Corporation has a 32-million-pound-per-year plant in Heath, Ohio. Although these efforts have focused on materials that offer a steady supply stream, they all have run into the problem of contamination due to inefficient separation. Even one-tenth of one percent PET in a batch of recycled PVC can destroy value, but the labor costs required to separate different types of plastic are prohibitive.

Frank Aronhalt, director of environmental affairs and polymer recycling for DuPont, says that polymer suppliers are increasingly taking on the responsibility for recycling polymer products: "As a supplier, we have the best capability to develop the polymer chemistry processes for recycling reused plastic parts."¹⁷ DuPont is also working with APC, GM, Ford, Chrysler, and the Institute of Scrap Materials Recovery to sponsor ten automotive recycling projects for 1993. DuPont's plastics recycling efforts were, until recently, administered by the Plastics Recycling Alliance (PRA), a wholly-owned subsidiary of DuPont, formed with Waste Management, Inc. PRA proved to be unprofitable, even though most of its recycled plastic was purchased by DuPont.¹⁸

The recession, low virgin resin prices, and a lack of end markets for recycled plastic have taken a toll on some recycling programs. The DuPont/Waste Management partnership was dissolved, and the National Polystyrene Recycling Corporation (which was to recycle McDonalds' now abandoned clamshells) closed a plant in North Carolina. Amoco closed its Brooklyn, New York polystyrene recycling plant, saying that the small scale of the operation made it unprofitable.¹⁹ According to the Environmental Defense Fund, these failures demonstrate that successful recycling requires the creation of strong end markets, as well as strong collection programs.²⁰ Despite these difficulties, companies serving the \$85 billion, global, resin-sales industry have continued research

¹⁶ "The Future of Plastics: Flexible, but Unfriendly," *The Economist*, July 21, 1990, 72.

¹⁷ "Automotive Plastic Recycling R&D Shifts into High Gear," *R&D Magazine*, March 1993, 32.

¹⁸ "Waging War on Waste," *Distribution*, April 1992, 38. The article estimates that the price of oil would have to almost double for the resulting cost disadvantage of virgin resin to make recycling a viable long-term investment.

¹⁹ "Amoco Closes its Brooklyn PS Recycling Plant," *Recycling Times*, July 30, 1991, 3.

²⁰ *Plastics Engineering*, March 1993, 82.

into recycling; American resin companies expect to spend over \$1.2 billion on recycling technology by the end of 1995.²¹

Resin companies may hope that pressure for automotive plastics recycling will "fade away" given the extra challenges that it presents. Unlike curbside-collection materials such as HDPE and PET, postconsumer automotive plastics are not currently collected and separated for recycling on a large scale, and their removal from scrapped cars poses some unique problems. General Electric's partnership with Luria Brothers, of Cleveland, Ohio, demonstrates the difficulty of creating a profitable automotive plastics recycling program with recently scrapped cars, which were not designed for disassembly. Luria Brothers, a scrap metal dealer, was to recover body panels, bumper fascias, and other exterior parts made from GE PC/polyester blends from scrapped cars. These parts would be removed from cars prior to shredding, and sent to GE to be converted into a polymer with ABS-type building material, and other nonengineering applications and end uses. The recovered material was expected to have high thermomechanical properties relative to those of ABS, enabling GE to sell it at a premium above ABS.

The partnership was disbanded when it became clear that the procedure was a money loser. The two major enemies of successful plastics recycling were responsible for the failure of this pilot program: first, the irregular amounts and types of scrap supply made it impossible to meet the demands of end markets; and second, the cost of labor to separate postconsumer plastics was prohibitive. GE explained that they did not secure an adequate supply of uncontaminated plastic parts on a constant and reproducible basis, and they paid too much for laborers to separate plastic components by hand from scrapped cars.²² Despite the failure of efforts like this, political and public pressure for recycling will probably persist, and the resin makers will play a key role as consumers of recycled plastics and perhaps as recyclers, themselves.

Finally, there is no clear consensus among resin makers as to the potential for plastics recycling to become a profitable, and therefore viable, business. Franz Froelicher, vice president for environmental issues at DeWitt and Company says: "Recycling probably will never be market-driven on a national basis." However, Scott D. Noesen, Dow Plastics' project manager for environmental performance says: "We would

²¹ Ibid., note 17, 3; see also: "Industry Overview," *Modern Plastics*, December 1992, 19.

²² R. H. Burnett and G. A. Baum, "Engineering Thermoplastics," *Plastics Recycling: Products and Processes*, R. G. Ehrig, ed., (New York: Hanser Publishers 1992), 157.

not be in this business if we did not believe it would be economically driven."²³ Nevertheless, all of the largest resin producers, including Phillips 66, Exxon, Occidental Chemical, Quantum Chemical, Solvay Polymers, Chevron Chemical, Union Carbide, Dow Chemical, and Hoechst Celanese, have recycling programs. These and other resin companies may be betting that, because political pressures and public perceptions can affect their business, whatever losses they incur from recycling will be smaller than the damage caused by ignoring recycling altogether.

CHALLENGES TO THE RECYCLING INFRASTRUCTURE

Thirty years ago, the automotive disposal infrastructure was less recycle intensive. The technology of large shredding machines did not exist, and this technology was critical to the expansion of minimills to recycle automotive as well as other scrap steel. Instead, dismantlers either kept the vehicle hulks on their own premises, or landfilled them, leading to the unsightly automobile graveyards that dotted our rural landscapes. The steel in each hulk did not have high enough material resale value for profitable recovery, even though steel retains its attributes after several cycles of reuse. However, the value of scrap steel increased dramatically with the invention of shredding and minimill technology. Shredding machines allowed shredders to recover and separate steel in large quantities. Minimills—taking advantage of electric furnaces to competitively process scrap steel—created the demand for large quantities of scrap steel. These changes led to the increased material value of scrap steel and revolutionized the automobile disposal infrastructure, shifting it from a more landfill-intensive to a more recycle-intensive process.

However, the recent balance of recycling and landfilling may again be altered by increasing landfill costs, the changing material composition of the vehicle, the challenges to efficient material recovery, and heightened environmental awareness and regulations. Because of this changing situation, landfilling is becoming a less attractive, and potentially unavailable option.

Landfill Issues Rising landfill costs pose a major challenge. Since the industry cannot control costs of landfilling and demand for used automobile parts, it must reduce the amount of landfilled materials as a major means to cut costs.

²³ "Recycling in fits and starts: harsh economic realities force consolidation," *Chemical Week*, October 28, 1992, 46.

There are approximately 6000 solid waste landfills operating in the United States. According to the EPA, this figure will likely decrease to about 3000 operating landfills in the year 1995. While the number of operating landfills is not directly related to landfill capacity, it is important, since it can have a large effect on transportation costs. Landfill permits and regulations are becoming progressively more stringent, and it is difficult to establish new landfills.

Shrinking landfill capacity puts direct pressure on landfill prices. Although landfill capacity estimates exist, the data is often inconsistent. Nevertheless, it is clear that landfill capacity is a problem. As shown in table 2, 28 states will exhaust their current capacity within the next 10 years. These states will need to expand that capacity or find some sort of alternative to landfilling. Only five states reported increases in landfill capacity from 1986 to 1991 (Colorado, Oklahoma, Ohio, Pennsylvania, and Massachusetts) while eight states reported losses (Arkansas, Georgia, Mississippi, Nebraska, North Carolina, Rhode Island, Vermont, and Wisconsin). The EPA also estimates that waste generation in the United States has more than doubled since 1960, and will continue to grow throughout the remainder of the century.²⁴

Table 2 Change in landfill capacity timelines between 1986 and 1991²⁵

Estimated Years Until Landfill Exhaustion	Number of States (1986)	Number of States (1991)
< 5 years	8	10
5 - 10 years	17	18
> 10 years	25	22

In view of the diminishing capacity of landfills, it is not surprising that the tipping fees they charge are rising. Between 1988 and 1990, these fees increased over 18 percent nationwide, and reached a national average of \$28 per ton. Both the level and rate of increase vary across different regions. Thus the increase in the West was 32 percent, while average fees in the Northeast passed \$64 per ton and ranged as high as \$120.

²⁴ Edward Repa and Susan Sheets, "Landfill Capacity in North America," *Waste Age*, May 1992.

²⁵ Ibid.

Without any acceleration in the loss of landfill capacity, national tipping fees could readily pass \$70 per ton by 2001, just eight years into the future.²⁶

Ultimately, increased landfill costs will affect dismantlers in two different ways. First, higher landfill prices mean higher direct costs—tipping fees—to the dismantler for the disposal of the vehicle elements (tires, etc.) that shredders refuse to accept. Second, higher landfill prices decrease dismantler revenues from the sale of the scrap hulk to shredders. Shredders, too, must landfill residuals from their material recovery operations, and for many shredders, landfilling of the ASR can be as much as 50 percent of their total costs.²⁷ Thus they will pay less for vehicle hulks when landfill costs go up. In either case, the dismantler—or shredder—profit in figure 1 is lessened. To be sure, the degree to which the shredders push these higher disposal costs onto the dismantlers depends on the elasticity of demand and supply. If demand for vehicle hulks from dismantlers is relatively low, the shredders may push those costs onto the dismantler. If demand is relatively high, they will have to take the added costs upon themselves.

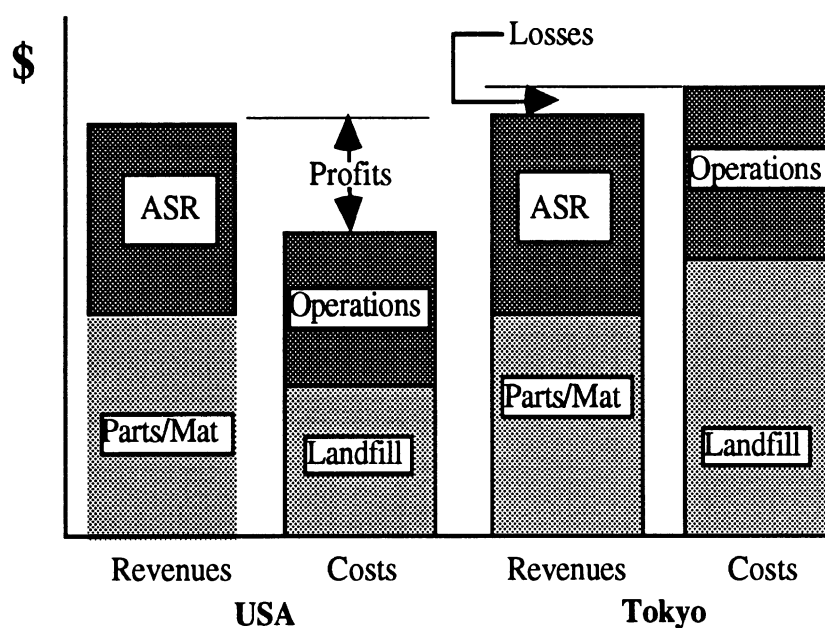


Figure 3 Economics of U.S. and Japanese Dismantling/Shredding operations

²⁶ Susan Sheets and Edward Repa, "1990 Landfill Tipping Fee Survey," National Solid Waste Management Association, 1991.

²⁷ B. J. Jody and E. J. Daniels, "Automobile Shredder Residue: Treatment Options," *Hazardous Waste and Hazardous Materials* 8, no. 3, Mary Ann Leibert, Inc., 1991.

The current situation in Tokyo, where landfill tipping fees have already begun to affect the automobile disposal industry, may be instructive. Japan's infrastructure for the disposal of automobiles is virtually identical to the U.S. infrastructure. Dismantlers disassemble the vehicle for parts and then sell the remaining vehicle hulk to shredders, who process out ferrous metals, landfill the light ASR stream, and sell the heavy ASR stream to be processed for nonferrous materials.

In Tokyo, however, the shredders and dismantlers are incurring landfill costs anywhere from \$100/ton to as high as \$160/ton, drastically threatening the survival of the disposal industry, as illustrated in figure 3. Moreover, the rate of increase in tipping fees has been quite high: 1990 fees were five times those of 1976, and twice as much as in 1988, as displayed in figure 4.²⁸ This rate of increase is far in excess of the 9 percent used to calculate our estimate of U.S. tipping fees in the year 2001.

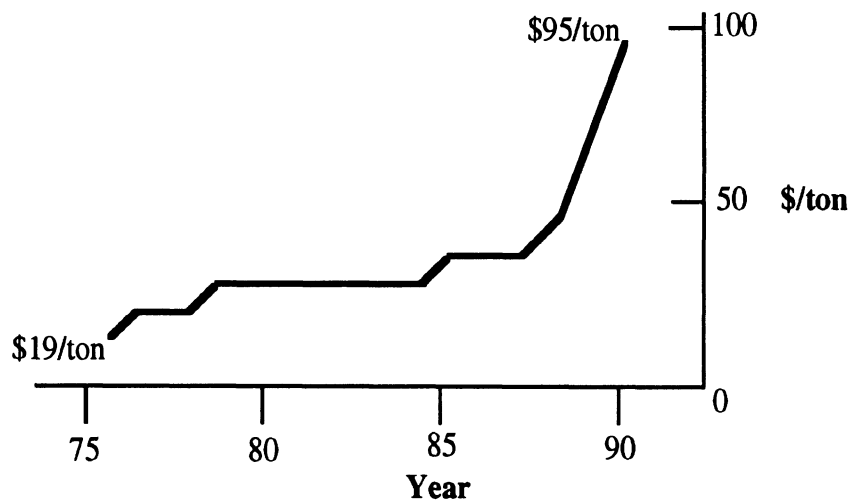


Figure 4 Landfill costs in Japan²⁹

Moreover, the number of scrapped automobiles per year are rising in Japan, causing a substantial rise in the weight of landfilled materials from ASR, detailed in figure 5. There were approximately 4.6 million cars scrapped in Japan in 1989, a bit over a third of the U.S. total.

²⁸ Kaoru Asakawa, "Automotive Recycling in Japan," *Emerging Technologies in Plastics Recycling*, American Chemical Society, 1992.

²⁹ Ibid.

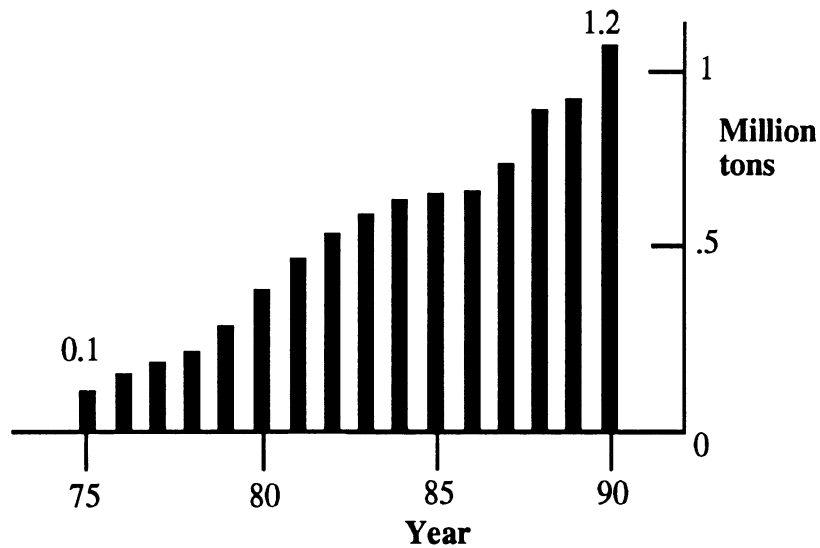


Figure 5 Automotive Shredder Residue in Japan³⁰

Because of the increasing landfill costs and volumes, and decreasing revenues from the sale of materials, shredders in Tokyo are decreasing the price they will pay dismantlers for each vehicle hulk. This transfer of costs makes it impossible for many dismantlers in Japan to operate profitably. Once again, as they were prior to 1970, discarded vehicle hulks littering the sides of roads and empty fields are becoming a problem in many areas of Japan, and Tokyo specifically.

Unfortunately, the United States appears to be moving in a similar direction. Increasing costs of construction, the political struggle necessary to establish sites, and public pressure against landfills are more and more constraining landfill capacity. This makes the search for viable disposal options to landfilling all the more urgent.

Material Content As salable materials decrease, and the associated proportion of nonsalable materials in the automobile increases, the profitability of shredders and dismantlers decreases. Table 3 displays the material content by weight of 1980 and 1990 new passenger cars. Not only has total vehicle weight reduced, but salable metals as a proportion of that reduced weight have also decreased. For example, in 1980 the typical car contained almost a ton of salable steel; by 1990, it had fallen to just over three-

³⁰ Ibid.

quarters of a ton, as steel content has dropped from 59 percent to 54 percent of reduced vehicle weight. Iron content has decreased some 90 pounds as well.³¹

Table 3 Materials content and share, by weight, in new domestic passenger cars³²

Material	1980		1990	
	Weight (lb)	Share (%)	Weight (lb)	Share (%)
Steel	1993.5	59.3	1564.0	54.0
Iron	484.0	14.4	398.0	13.7
Plastics/Composites	195.0	5.8	222.0	7.7
Aluminum	130.0	3.9	158.5	5.5
Rubber	131.0	3.9	128.0	4.4
Glass	83.5	2.5	82.5	2.8
Copper	35.0	1.0	46.0	1.6
Zinc Die Castings	20.0	0.6	19.0	0.7
Powder Metal Parts	17.0	0.5	23.0	0.8
Fluids	178.0	5.3	167.0	5.8
Other	96.0	2.9	88.0	3.0
Total	3363.0		2896.0	

Moreover, the weight of materials in each vehicle that dismantlers must landfill has increased.³³ Thus the plastics/composites content has increased some 14 percent by weight in a 1990 vehicle, to about 220 pounds, and plastics share increased by 1.9 percent, as illustrated in table 4. Plastics and powdered metals are the *only* nonrecycled materials with increased use in manufacturing automobiles over the last ten years. And most plastics are eventually landfilled. Dismantlers must find ways to avoid the increased costs, decreased revenues, and consequent reduction in profits arising from these changes.

³¹ M. S. Flynn, D. J. Andrea, D. E. Cole, R. L. Doyle, and S.P. McAlinden, "Automotive Plastics Recycling," paper presented to Fisita 92, London, June, 1992.

³² *Ward's Automotive Yearbook 1992*, Ward's Communications, 1992, 36.

³³ Martin Forman, "Reclamation of Automotive Plastics Prior to Shredding," *Plastics Recycling as a Future Business Opportunity*, (Lancaster, PA: Technomic Publishing Co., Inc., 1991), 28-34.

Table 4 Change in new domestic passenger cars' materials usage, by weight and share

Material	Weight change (lb, 1980-90)	Share change (% , 1980-90)
Metals	- 471	- 3.6
Plastics	27	1.9
Other (Fluff)	18	- 1.8

Approximately 25 percent by weight of each disposed vehicle is currently landfilled.³⁴ In order to reduce the quantity of these materials, ways must be found to recover profitably as much material content as possible from expired vehicles. Most of these materials, such as glass, fluids, paper, and fibers, are at best extremely difficult to recover and have a very low resale value. However, plastics, which represent approximately 30 to 40 percent of landfilled automobile materials, have the potential to be profitable if suitable recovery methods can be developed.³⁵

Plastics offer many advantages over other materials: enhanced design flexibility, reduced weight, lower manufacturing costs, and quieter operation, to name a few.³⁶ These are all reasons for increasing the use of plastics in automobiles. However, plastics also raise a number of concerns, including ease of recovery and recyclability. Resolving these concerns will probably require efforts by both automobile designers and the automobile disposal infrastructure to recycle more plastics from each disposed vehicle.³⁷

For example, in 1990 Chevrolet manufactured the APV sport-utility vehicle with a revolutionary design: major body panel parts made of plastics. Yet, despite its practicality, the consumers' perception of its "environmental unfriendliness" may have played a role in its lower than anticipated sales. However, GM's Saturns, with high plastic content, have suffered no such problem. In any case, the APV panels are made of complex composites that are almost impossible to separate for material recovery, and they replace metals that have value to the disposal industry. Because of this, many

³⁴ Ibid.

³⁵ Michael C. Montpetit, "Recyclable Instrument Panel Systems: A Step Closer to the Green Car," *Automobile Life Cycle Tools and Recycling Technology*, (Warrendale, PA: SAE, Inc., 1993), 60-61.

³⁶ Plastics reduce automobile weight, and a weight reduction of only 25% is estimated to reduce emissions of CO₂ from automobiles by 101 million tons per year. *Lightweight Materials for Transportation*, Office of Transportation, Materials, Energy Efficiency, and Renewable Energy, U. S. Department of Energy. (Washington DC: 1993), 14-15.

³⁷ See Andrea and Brown, op. cit.

dismantlers are threatening to refuse to accept the vehicle for disposal.³⁸ While cost seems to have been the main factor in GM's decision to switch to steel panels in 1996, recycling concerns may well have played some role in the decision.

Material Recovery From an economic viewpoint, dismantlers may not be attracted to plastic materials recovery, but may prefer to pass this burden along the disposition chain to the shredders. But shredders, too, face already substantial landfill costs, and shifting the landfilling problem along the chain will only buy the dismantlers minimal time, since it does nothing to remove the costs of landfilling from the disposition system. It is imperative that the dismantlers respond to the challenges posed by the recovery of plastic materials and parts, both because of the profit potential, and because current technology may be more effectively applied at the dismantling stage than at the shredding and separation stages. Some plastic parts have already proven profitable as used replacement parts. But, if landfill prices rise to a point where the recovery and sale of used parts do not bring in enough revenue to maintain profitability, plastics recovery as a material may be necessary to preserve the recycling industry.

The profitability of plastics recovery *as a material* is a function of labor costs and the price of recyclable plastic materials. The recovery of plastic as a material faces an overall obstacle in the simple lack of demand for the recovered material. Moreover, the costs of recovery are sufficiently high to restrict the development of potential markets. A major cost factor in plastics recovery is the labor required to remove plastic parts and components from the vehicle, partly reflecting the difficulty of such removal. Until labor costs can be brought down or landfill costs skyrocket, dismantlers are unlikely to remove much of the vehicle's plastic content, as illustrated in figure 6.

³⁸ Jack Keebler, "Engineers Focus on Plastics for Recycling," *Automotive News*, March 4, 1991.

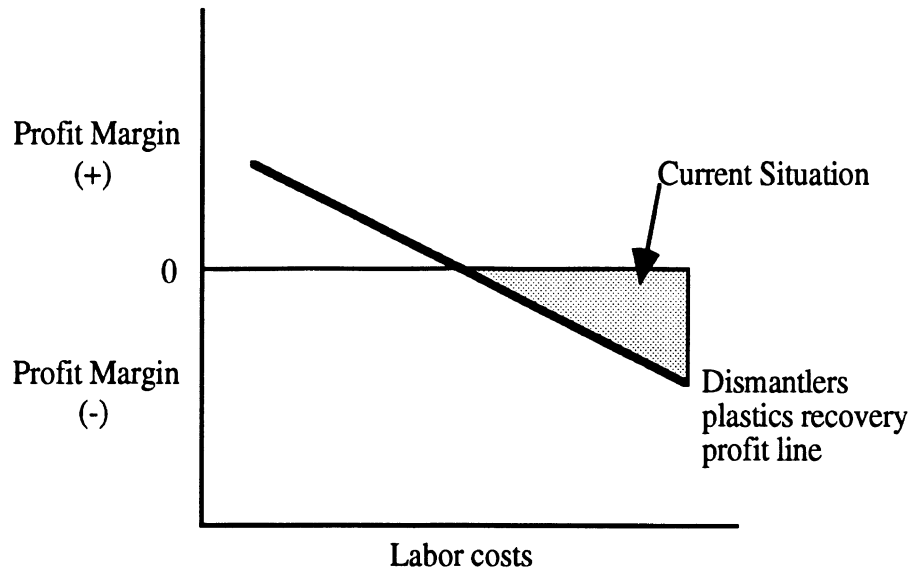


Figure 6 Labor costs vs. plastics recovery profit margin for dismantlers

Making plastics recovery profitable requires overcoming numerous challenges. A recent paper estimates recovery times for plastic parts in automobiles.³⁹ The radiator overflow reservoir provides a good example of the challenges of plastic materials recovery for lower value, nonengineering plastics. The authors estimate that only 40 percent of all reservoirs are currently recovered by dismantlers, because demand for this part is so low. However, there may be profits in the sale of the material to HDPE bottle recyclers. The average reservoir contains 1.2 pounds of polyethylene and polypropylene. The estimated time to recover and decontaminate a radiator overflow reservoir is 48 seconds, and transportation costs vary, but are typically less than five cents per pound. The prices of recycled industrial polyethylene and polypropylene varies from four to 12 cents per pound.⁴⁰ Assuming labor costs of \$4.35 (minimum wage), dismantler profit ranges from -1.3 to +13.1 cents per reservoir.

This example shows that the sale of plastics as recyclable materials from expired automobiles *may* be profitable. The profitability is dependent on many criteria: parts that contain a substantial amount of material, are easily dismantled, of consistent and uncontaminated composition, and contain few subcomponents.⁴¹ Unfortunately, the

³⁹ Hock and Maten, op. cit.

⁴⁰ *Waste Age's Recycling Times*, May 7, 1991, 5.

⁴¹ Jeff R. Dieffenbach, Anthony E. Mascarini, 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.

overflow reservoir is a “best case” low value material scenario, and even then represents a gamble for the dismantler. Most of the plastics in an automobile require too much time to recover or have too low a value for profitable recycling. Only technical changes in the material, the design of the vehicle, and/or the recovery processes themselves will permit the plastics recovery option to meet the necessary criteria and become economically feasible.

The automated sorting of postconsumer plastics might well lower the labor costs required for recovery. An efficient sorting machine would also reduce contamination of recovered plastics, thus increasing their value. Eastman Chemical, through a joint project with Waste Management, Inc., is applying for a patent on an automated sorting system that uses electronic detectors to identify different types of plastic by scanning molecular imprints left by manufacturers.⁴² A similar technology might have direct application to automotive plastics. A machine capable of dismantling a car, for example, or a chemical process that isolates the various components of post-shredder fluff, could enable the recovery of high-value uncontaminated plastics with low separation costs.

However, automotive plastics, reflecting their versatility and advantages, are widely distributed throughout the automobile, as displayed in table 5. This pervasive distribution partially explains the high labor costs associated with their recovery, and suggests that strategies for recovery that permit the separation of plastics en masse from the hulk may be the most promising. Even a vehicle specifically designed for disassembly and plastics recovery would require extensive labor or machine effort to accomplish major recovery.

Table 5 Percentage of total plastic applications, 1990 model year automobiles

Application	Percentage of total
Interior	21%
Large functional	18
Upholstery	13
Bumper systems	10
Electrical	9
Small mechanical	8
Exterior trim	7
Body Panels	6
Other	8
Total plastic applications	100

⁴² "The Environment: Industry's Talent for Solutions," *Industry Week*, January 4, 1993, 25.

Two main categories of plastics are widely used in automobiles, thermoplastics and thermosetting plastics (often called thermosets). Thermoplastics are impervious to most corrosives and can be recycled many times with minimum loss of quality. They are used for such parts as gear-type pumps, emission-control systems, exhaust systems, fuel tanks, valves, fittings, couplings, and interior applications. Generally stronger than thermoplastics, thermosets are used for wiring devices, electrical switch gear, connectors, power brake parts, transmission parts, knobs, end panels, and other high-wear or high-temperature components. Until recently, thermosets were thought to be largely unrecyclable.

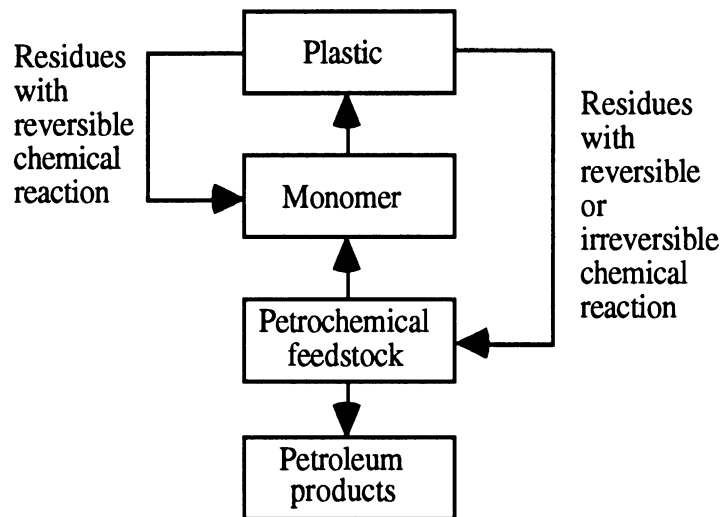


Figure 7 Residuals from the chemical depolymerization of plastic⁴³

Many plastics are in fact mixtures of different chemicals, and effective recycling may require separating the recovered automotive plastic part or component into its constituent chemicals. Often called tertiary recycling, chemical processes such as hydrolysis, glycolysis, and pyrolysis can be used to reduce postconsumer plastics to their original materials. Such chemical processing yields two main types of usable residues—monomers and petrochemicals, as shown in figure 7. Since all plastics are produced from monomers created from natural gas or crude oil (petroleums), reducing polymers (plastics) to their original monomers creates a feedstock that can be used to produce the same polymer, with properties identical to virgin polymers. The petroleum residues may

⁴³ J. Randall, M. Mexzaro, A. Adams, and J. Lohr, "Chemical Recycling," *Modern Plastics Buyers' Guide and Encyclopedia* (New York: McGraw Hill, Inc. 1993), 54-58.

be refined and used as an energy source. Chemical recycling also provides a solution to the concern that those recovered from a 10-year-old car may be rendered virtually worthless in the market due to rapid changes in plastics.

However, until the plastics in ASR can be economically separated into similar chemical types, processes that reduce plastics to monomers are not feasible. Until that time, the conversion of plastics to petrochemicals will continue to provide the best avenue to increased recycling of ASR.

Methanolysis, glycolysis, and hydrolysis are chemical processes that depolymerize plastics into monomers. Many plastics producers already use these processes for recycling their own clean, separated in-house scrap into monomers, and then again into plastics. Reducing polymers into monomers for reformation of the polymer works well with plastics such as polyesters (PET), polyamides, or polyurethanes/polyurethane foam (PU/PUF). But this process will only work efficiently if the plastics to be recycled are virtually all thermoplastics with reversible chemical reactions.

Reduction of postconsumer thermoplastics to monomers through physical processes also is possible. Thermoplastics consist of many small molecules covalently bonded together into long molecular chains called polymers. The covalent bonds connecting the long chains are stronger than the bonds of each small molecule, giving rigidity to the material. Once heated or pressurized, the stronger covalent bonds weaken and half covalent bonds form, allowing the material to be shaped and formed. Heat or pressure activate the smaller molecules, causing the double covalent bonds to break up and be replaced with an available free electron (a half covalent bond), potentially ready for covalent bonding with other small molecules, as displayed in figure 8.

When the material cools again the half covalent bonds join, rigidity returns, and it retains its new shape. The free electrons bond together upon cooling, causing rigidity when the long chains reform. Consequently, thermoplastics may be recycled many times over with minimal loss of quality.

However, although theoretically easily recyclable, thermoplastics recycling is not always easy in practice. The smaller molecules may be formed with many different atoms in order to create material with different characteristics. Different atoms may also be used when forming the long molecule chains. Therefore, recycling thermoplastics

requires the separation of materials into similar polymer groupings to achieve near-original quality, or, in some cases, to be recycled at all.⁴⁴

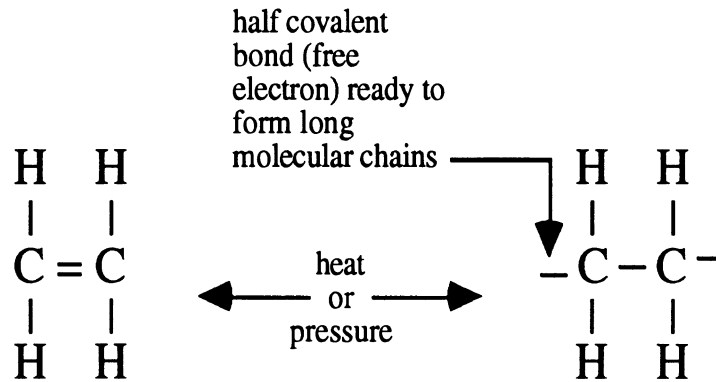


Figure 8 Example of a thermoplastic molecule (polyethylene)

Many other plastics used in automobiles are created using irreversible chemical reactions, including all thermosetting plastics and even some thermoplastics, such as high density polyethylene, polypropylene, or polyvinyl chloride. Thermosets are formed by creating a network of primary covalent bonded molecules, cross-linked by using heat, pressure, or chemical reactions. Unlike thermoplastics, thermosets may not be reformed because of their cross-links, as illustrated in figure 9. These plastics must be reduced to their even more basic components of petrochemicals.

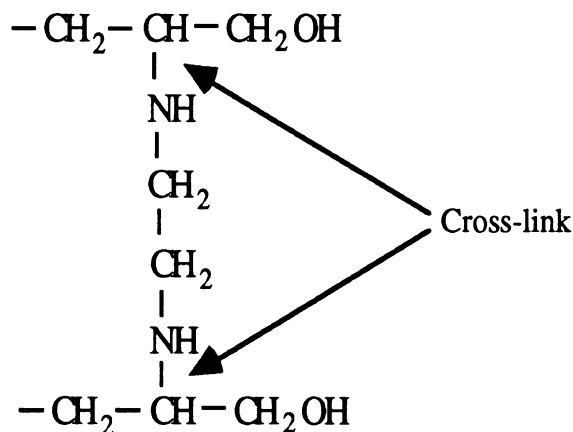


Figure 9 Thermoset: cross-links between two epoxy molecules

⁴⁴ William F. Smith, *Principles of Materials Science and Engineering*, New York, McGraw Hill, Inc., 1990, 321-399.

Thermosets may be melted into a softened form, but the covalent-bonding cross-links prevent them from being melted into the free-flowing state that existed before creation of the cross-links. Unlike thermoplastics, the repeating molecules in thermosets do not necessarily reduce to their exact state before bonding. The cross-links are more difficult to dissolve, and different cross-links may stay intact, creating different molecules in the melted mixture. However, Miles has begun compression molding of heated thermosets with some success.

Since thermoset plastics may not be reformed, other disposal or recycle techniques have been used to avoid landfilling them. Often the thermoset pieces were pulverized into granules, and then inserted as a filler in concrete, asphalt, or other construction composites. However, major breakthroughs have recently occurred with a process called pyrolysis, and these may enhance the recyclability of thermosets.

Pyrolysis is a chemical process that depolymerizes plastic into petrochemicals through heat. Pyrolysis differs from incineration at very high temperatures because it occurs in an oxygen-free environment. The absence of oxygen prevents the production of oxygenated residues, so most residues remain liquid rather than gas, and are thus more easily contained and transported. Pyrolysis also allows contaminants to be separated after depolymerization, thus saving the costs of cleaning.

When pyrolysis is performed on thermoset plastics, two usable residues occur, char and oil. Char (a mixture of calcium carbonate, glass fibers and other filler) can be reused as filler to sheet molding compound (SMC), another plastic with numerous automotive applications. The oil can be used for its energy content. Once initiated, the pyrolysis of thermosets can potentially fuel itself, if the flue gasses emitted during decomposition of the plastics are recirculated. There has been a consortium for the exploration of pyrolysis since 1990. While results have been encouraging, it is still not economically feasible, although plans to build a pyrolysis unit are underway. If pyrolysis proves effective, thermosets may be added to the list of recoverable materials from an expired automobile.

The major barrier to chemical processing is that the ASR's chemical composition is too complex for existing technology: plastics must be separated from the ASR before chemical processing, and that, as we have seen, is a costly operation. Nevertheless, chemical processing merits further research and development. If costs of separating plastic from ASR decrease or if new technology permits direct chemical processing of

ASR, then its benefits are indeed attractive. It eliminates the now necessary step of cleaning the plastics, and it increases the value and market potential of commingled plastics. Because of its technical and process demands, chemical recycling almost certainly will be located at the resin makers or molders rather than at dismantlers or shredders.

Public Opinion and Environmental Regulation Public opinion in support of the postconsumer recycling of materials can be a source of both direct and indirect pressure on the industry. The direct pressure springs from consumer concerns and resulting market behavior that rewards companies that consumers think are environmentally responsible, and punishes those seen as irresponsible. The indirect—but often stronger—pressure comes through the legislative and regulatory actions of government as it responds to consumers in their role of voters.

Suppliers of plastic materials and components to the automobile industry face more or less the same waste-disposal pressures as the rest of the plastics industry. The negative perception of plastics as an environmentally troublesome material creates pressure on resin makers to take a serious look at recycling. Indeed, the main impetus behind most recycling programs is public opinion, often influenced by environmental groups and sometimes misguided. Unfortunately, accommodating demands for "greener" products does not always defuse further pressure from environmentalists, nor even serve the environmental goals originally intended. For example, the movement to biodegradable plastics has been largely ineffective for reducing solid wastes, since research indicates that even organic materials do not biodegrade in most landfills.

Several of the major issues that define the importance of recycling for resin companies came together in the case of the McDonalds' "clamshell." The story of this polystyrene sandwich packaging is now widely cited both as a triumph of public environmental concern and as a fiasco for the environment, sometimes in the same breath. Public pressure led McDonalds' to begin a recycling program for the clamshell, and for a while people disposed of these packages in separate bins. But the company found that people still viewed the polystyrene package as environmentally unfriendly, and the company complained that the resin producers involved in the National Polystyrene Recycling Corporation were unable to commit themselves to recycling all of

the packages collected.⁴⁵ They cut their losses and averted further public objection by abandoning the clamshell in favor of a wrapper made from paper and polyethylene.

The authors of a 1991 Environmental Action Coalition book on plastics recycling acknowledge that the new wrappers are neither recyclable nor compostable, while the polystyrene had the benefit of being made without CFCs as a blowing agent. Nevertheless, they still count the decision as a sort of victory for consumer power and citizen pressure—however wrongly informed. More pertinent, and sobering, for resin manufacturers is the suggestion that "Logically, since McDonalds' and partners represented the best hope of a nationwide PS foam recycling infrastructure, perhaps the question of banning all polystyrene foam in the retail marketplace ought to be seriously examined."⁴⁶ Public opinion sometimes behaves like a juggernaut, whose direction cannot be finely adjusted by companies or even by the very advocacy groups that helped to set it in motion. In order to keep out of its path, resin companies will probably need to preempt any danger of being branded polluters by making progress in recycling as early as possible.

The lack of public controversy surrounding demolition rubble provides an instructive example. This material is estimated to take up 20 percent of America's landfill space, yet raises little public outcry.⁴⁷ However, demolition rubble is not very visible to the general public, and construction companies are numerous, small, diverse, and unfamiliar to most people. Automobiles and the automotive industry (and many resin makers) are, of course, the opposite. There is no confusion about where to turn when automobile waste becomes an issue, and the Big Three have already begun to anticipate legislation calling for a reduction in the industry's solid waste. Because most of the car is steel, which is already recycled, the brunt of these regulations will fall on the remaining materials with some potential for recycling, primarily the plastics.

Legislative and regulatory proposals in Germany is already forcing more materials recycling. While this approach is controversial, the German government has proposed that manufacturers set a goal to recycle 80 percent of their products by 1995. The German government feels that recycling laws aimed at the manufacturer force designers to rethink the way they design their products, so that the economical disassembly and

⁴⁵ Nancy Wolf and Ellen Feldman, *Plastics: America's Packaging Dilemma*, Environmental Action Coalition, 1991, xii.

⁴⁶ *Ibid.*

⁴⁷ "Waste and the Environment," *The Economist*, May 29, 1993, 4.

separation of materials, as well as the use of recyclable materials, will become mandatory design considerations. BMW is one of the leading German companies in recycling efforts. BMW is already addressing the difficulties of dismantling automobiles for optimal recycling—and trying to make recycling a marketing advantage.

Some legislators in the United States support Germany's recycling approach. For example, Senator Max Baucus (Democrat, MT) is particularly supportive of the German approach.⁴⁸ He is currently chairman of the Senate Environment and Public Works Committee, and strongly believes that companies that take the lead in recycling will gain future competitive advantage:

The aggressive German recycling law is driving the development of new environmental technology. BMW is taking advantage. When the law takes effect, BMW will have an edge. And when other countries enact similar recycling laws, BMW will have an international edge.⁴⁹

Senator Frank Lautenberg introduced a bill calling for a "comprehensive study which would set design standards to eliminate hazardous and non-recyclable materials in automobiles."⁵⁰ It seems clear that industries will either move towards design for disassembly and recycling by their own accord, or the government will force the issue.

However, if the U.S. government does pursue "product take-back" strategies, as in Germany, there are a number of issues that must be considered. First, Germany lacks the developed infrastructure for disposal that exists in the United States.⁵¹ If similar laws were passed in the United States, the manufacturers might recycle automobiles in-house as will manufacturers in Germany, severely damaging the existing infrastructure. The costs of recycling might also be higher because the manufacturers pay higher labor rates, would incur start-up costs, etc. Second, the manufacturers might face a competitive disadvantage against import manufacturers not subject to such laws in their home markets. Third, these higher costs would be pushed onto the consumer in the form of higher product prices. One hundred percent recycling may not be the optimal solution for the automobile, but current trends suggest it is increasingly likely.

⁴⁸ Ferdinand Protzman, "Germany's Push to Expand The Scope of Recycling," *The New York Times*, Sunday July 4, 1993, F8.

⁴⁹ Suzanne M. Cole, "Recycling the Automobile: a Legislative and Regulatory Preview," (University of Michigan Transportation Research Institute report no. 93-40-3, 1993).

⁵⁰ Ibid.

⁵¹ Ferdinand Protzman, op. cit.

Finally, the current situation in Europe shows the danger of collecting materials without first developing markets for them.⁵² Germany has been so aggressive in mandating the collection of plastic waste, it has created an imbalance in Europe's recycling efforts. They collected so much plastic that they have had to offer it to recycling companies in other countries at zero cost; they have even paid foreign companies to take it, threatening the business of the scrap sellers in those countries. This situation has led a French polymer producer to criticize Germany's recycling agency for failing to develop markets to accept the tremendous amount of waste collected under their new "green dot" program.⁵³ For an example closer to home, resin makers can remind legislators of the consequences of New Jersey's law mandating recycling of newsprint, which quickly drove the price of postconsumer newspapers from \$20 per ton to zero.⁵⁴

Recycling Industry Structure The infrastructure for the final disposition of the automobile may undergo dramatic change. For better or worse, change will happen—unfortunately this change may not be within the current recycling industry's control. Government policy, disposal economics, technology, and the automobile designers will have the largest role in shaping this change. If automobiles are designed to facilitate the existing disposal infrastructure, current dismantler, shredder, and separator operations may greatly benefit. If the design of automobiles does not change to permit more recyclable plastics and economical disassembly, labor and landfill costs may pose a threat to the very existence of these operations. If designs change to facilitate in-house recycling at the manufacturers, the current infrastructure is again at risk. The Vehicle Recycling Partnership, a consortium of the Big Three and a number of suppliers, is addressing these kinds of issues.

Development of chemical recycling technologies may increase the role of plastics recyclers and/or resin producers without substantially affecting the current structure of the automotive metals recycling infrastructure; in fact, chemical recycling may increase its potential profitability as ASR disposal costs reduce. However, the volume of recycling being carried out by resin companies has been large enough in some markets to severely disrupt the business of smaller recycling companies.

⁵² See Kaplan, (University of Michigan Transportation Research Institute report no. 93-40-2, 1993), for a discussion of the importance of the market for effective recycling.

⁵³ "German Efforts Seen as a Threat," *Chemical Week*, February 17, 1993, 20.

⁵⁴ "Recycling Becomes a Big Business," *Fortune*, August 13, 1990, 81.

The large and established market for postconsumer HDPE, although a plastic with few automotive uses, may be instructive. Many of these smaller companies are complaining that the big resin makers have "muscle in," stealing their customers and driving down prices by increasing supply. In some cases, resin makers have offered recycled resin buyers attractive deals, including volume discounts and long-term payment agreements that cannot be matched by smaller companies.⁵⁵ While resin companies sometimes pursue partnerships with smaller recycling companies, they often retain most of the control over the recycling operations. In many cases, the resin company simply buys recycled material from the smaller company, relabels it, and resells it; in others, such as Oxychem's partnership with EnviroPlastics Corp., the larger company provides venture capital, use of laboratory facilities, and backup for marketing negotiations.⁵⁶ However, virtually all of these arrangements have something in common—they are not profitable for the resin companies.

Analysts have offered a variety of possible explanations for the involvement of resin makers in the unprofitable recycling market, beyond their public image and political concerns. In the market for HDPE, recycling is especially important because domestic markets are only growing at 5-6 percent per year, and recycled HDPE displaces virgin resin. One independent recycler claims that the resin companies' involvement in recycling is like the "fox wanting to guard the hen house." One Wall Street analyst compares their actions to auto makers buying out makers of energy-efficient cars, or oil companies purchasing solar-energy patents: "Resin companies want to control recycling to destroy the independents in case some day there's money to be made in it."⁵⁷

An industry representative suggested that resin companies must be involved in recycling, to avoid becoming obsolete in the way that large integrated steel mills became comparatively obsolete in the 1970s and 1980s as minimills emerged. The minimills captured markets from steelmakers by setting up small operations near end markets and using scrap steel instead of ore, cutting several steps from the production process, and lowering production and transportation costs. Terrance Mohoruk warned resin makers that the same fate could await them:

⁵⁵ "Recycling Update: High Noon in High-Density PE," *Plastics Technology*, July, 1993, 96.

⁵⁶ *Ibid.*, 99.

⁵⁷ *Ibid.*, 102.

Look what happened in the steel industry. The steel guys allowed ISRI (Institute of Scrap Recycling Industries) members to grow, and now they're huge. A third of all metal is recycled today. Are we going to tolerate an independent group handling one-third of all polymers?⁵⁸

Others suggest that resin companies are selling recycled stock at a loss in order to buy market share: as recycle reduces virgin HDPE volume, a resin producer may elect to sell recycled stock to protect volume and share. One resin-company recycling official sees money-losing recycling efforts as the early stage of a marketing strategy "being played out by some resin companies that think HDPE recycling will fade away once it is recognized as a money loser."⁵⁹

To develop a stable market, resin producers may need to make contracts with molders, automakers, dismantlers, and shredders to guarantee a sufficient supply of scrap. A new set of relationships between these tiers of suppliers and recyclers may have to emerge to support wider recycling.

Entry into established commodity trading systems may also help to rationalize the scrap market. Efforts are currently underway to make recycled plastics a commodity bought and sold through the Chicago Board of Trade, which was originally formed to help American farmers overcome similar marketing difficulties.⁶⁰ In the meantime, efforts to make the variety of plastic scrap manageable include a two-year, \$325,000 EPA-funded project headed by the Rutgers University Center for Plastics Recycling Research, which has set the goal of creating a database in which millions of combinations of resin types, additives, and end uses for durables can be stored and accessed by recycling centers.⁶¹

The public sector may also be able to play a part in making recycling work. If private market forces cannot create a dependable supply to serve users of postconsumer plastic, resin makers may want to seek government intervention. Fostering plastics recycling serves public objectives by drawing out the useful lives of landfills and averting fears of a solid waste crisis, so government may consider encouraging recycling. For example,

⁵⁸ Ibid., 101.

⁵⁹ Bruce Kuiken, V.P.-Resource Recovery, Quantum Chemical; Ibid., 102.

⁶⁰ David Dougherty, of Washington state's Cleand Washington Center, is negotiating with the CBOT currently. He says that the entry of plastic scrap into the CBOT will standardize material specifications, lead to more competitive pricing, and allow for real price discovery. ("Two States of Market Development," *Waste Age*, December, 1992, 83).

⁶¹ "Plastics Automation," *Waste Age*, May 1993, 61.

resin makers may find that brokers will not ensure a sufficient supply of scrap unless the brokers know that they can sell an occasional oversupply. To prevent excessive losses from storage costs and degradation, the government might agree to purchase the excess, and store it, incinerate it, or try to find other buyers. Governments may not make a profit from this excess, but purchasing it may well be cost-effective if it supports successful recycling.

In any case, the development of an effective plastics recycling infrastructure poses little threat to the current metals recycling infrastructure; whether it offers that recycling industry new business opportunities is less certain, although it could play a major role in its continuing viability. The nascent plastics recycling industry faces much more uncertainty, both in regard to its long-term viability and exactly what its structure will be. Chemical recycling may favor the large resin producers as the key automotive plastic recyclers of the future.

Automotive Industry Expectations What do the automobile and plastic industries think about the likelihood of government policy on recycling, and the importance of recycling? Two OSAT surveys explored the views and concerns of the automotive industry and the automotive plastics industry.⁶²

Our plastics survey respondents think it quite likely that state and local governments will limit landfilling of some materials, although banning any current automotive plastics is at most a 50-50 likelihood. However, the federal government is somewhat more likely than not to establish requirements for minimum recycled content and impose product take-back requirements for manufacturers.

The Delphi VI survey respondents rated the importance of material attributes in the automakers' selection decision. Recyclability was rated second to the lowest in importance, while ease of final disposition was rated least important among the ten identified attributes.

On the other hand, the industry is not ignoring the recycling challenge, and appears to be realistic about its options. Thus, our plastics survey respondents indicate that the automakers will likely restrict the amount of unrecyclable plastics in the vehicle, as well

⁶² Michael S. Flynn and Brett C. Smith, "Automotive Plastics Chain: Some Issues and Challenges," (University of Michigan Transportation Research Institute report no. 93-40-6, 1993).

as restrict the number of types of plastics. Moreover, they suggest that landfill expansion should receive by far the least emphasis of ten approaches to effective recycling/disposition. Finally, our plastics respondents believe that any product take-back rules imposed on the manufacturers will be passed through to their suppliers, suggesting that any such disposition strategies will affect the entire automotive plastics chain.⁶³

It is not surprising that the auto companies would like their supplier companies to be held responsible for reducing the solid waste generated by scrapped automobiles. Many recycling specialists at the automakers simply see this as the most effective approach, given that the automakers lack the expertise to develop efficient plastics recycling procedures. Moreover, the Big Three assemble parts ordered from hundreds of suppliers, and feel they should not be held responsible for the products of all of these individual companies.

While the Big Three may use this argument to object to proposed legislation making them responsible for scrapped cars, they probably cannot avoid being the focal point for public pressure on the issue of automotive waste. Making the parts suppliers responsible means, effectively, defusing the issue, since suppliers are smaller, more diverse, and less familiar to people—in short, a much more elusive target. In fact, the auto companies will be held responsible for the environmental image of their product, and in recognition of this, they are promoting projects that advance automotive plastics recycling. Auto companies may be worried that lawmakers will want them to follow the examples set by BMW and by Opel. These companies plan to use some 22 million pounds per year of recycled plastics in its new cars by the end of 1993.⁶⁴ However, these targets reflect a major reliance on in-plant scrap, and little postconsumer scrap. United States laws prohibit labeling in-plant scrap as recycled.

Because of the momentum behind the demand for recycling, the automakers, resin producers, and molders all have an interest in expanding the recycling of plastic resins; none of these groups can wash their hands of the issue. The Big Three will have to answer for the environmental character of their products, and blaming their suppliers will not mollify skeptical legislators and environmentalists. Resin makers already have faced pressure to increase their recycling, and the increasing concern over automotive plastics

⁶³ Ibid.

⁶⁴ "Plastics in new Opels Will be 'Easily' Recyclable," *Plastics World*, April 1992, 12.

is just another manifestation of public concern over plastics as solid waste. Parts makers will have to satisfy the needs of these suppliers and customers by helping them achieve recycling goals. The development of technology that allows the cost-effective use of recycled resins for automotive components helps everyone in this chain, and each player has some stake in its development. The tricky part in organizing a serious recycling effort will be discovering the amount each group is willing to pay, and determining how best to match the resources of each set of companies to develop these new technologies.

Another reason for the cooperation of these three groups is the special nature of recycling as a manufacturing and marketing challenge. Designing, making, and marketing a product that will be called 25 percent recycled content or will be singled out as in some way advancing recycling is not the same as making any other type of product. The ability of the end user to make that claim, which may be necessary to satisfy legislated requirements or to meet consumer demand for recycled products, depends on a steady supply of a particular type of postconsumer scrap processed in a particular way. The supply of scrap, in turn, depends on what people discard, and upon the extent and type of collection, separation, and processing in their community. What people discard depends on how manufacturers made their bottles a month ago, or their cars seven to ten years ago. Deviations in one or more links of this chain can effectively break it.

Closed-loop recycling (that is, reuse of recovered materials for their original use) is politically the most attractive type of recycling. Open-loop techniques also divert waste from landfills. Plastics companies should inventory the products that they and their suppliers could make and are making, and consider the possibility of substituting postconsumer for new plastic in each of these applications. Where automotive supplier companies have relationships with other users of plastics (who may have potential uses for recycled plastic obtained from scrapped cars) the auto suppliers could try to promote these end uses

The proper role of various types of companies in the development of new products and markets is the subject of a book by Harvard Business School Professor E. Raymond Corey.⁶⁵ Corey addresses the needs of the supplier company interested in finding uses for new materials in reference to its "fabricator-customer group." The fabricators have the potential to use the supplier's material to make products serving a new market, but

⁶⁵ E. Raymond Corey, *The Development of Markets for New Materials: A Study of Building New End-Product Markets for Aluminum, Fibrous Glass, and the Plastics*, Harvard Business School, 1956.

organizing the proper group is a complicated issue for the supplier. Fabricator-customers are bound to ask whether a big investment will be required. Will sales of the new product simply substitute for sales of an existing product? Will the new product confer a competitive advantage/increase market share/provide entry into a new market?

Corey makes the point that simply choosing the fabricator-customer group may not be the best policy for a supplier. A better strategy may be to develop the technology to reach an identified potential market, and then wait for fabricators to approach them. This puts suppliers in a better position, with something of value to bargain with, less search cost, and more competition between fabricators. Corey argues that suppliers should be the technology leaders, because they are more likely to develop markets accessible to a variety of fabricators. If individual fabricators take the lead, he says, they are likely to develop markets accessible only to a few fabricators, and a strong, growing market will not develop. Joint technical development projects between suppliers and fabricators are recommended wherever they promise to lower the cost for each participant and create synergies. These arrangements may be hard to set up, however, because the supplier will want to invite other fabricators to produce new products that emerge from the research, while the fabricators will want the sole right to benefit from their research.

Applied to the automotive plastics chain, Corey's reasoning suggests that the resin companies may be the appropriate entities to become technical leaders in developing uses and markets for recycled plastic. Depending on the uses that they find, the fabricator-customer group may consist of companies that are already buying their resins to make automotive parts, or to make other products, or companies that do not currently buy from them.

The main difference from the general framework Corey discusses is the fact that resin companies often do not supply the material—scrap plastic, in this case. Nevertheless, the resin companies are uniquely suited to playing this role, and the solutions they offer will probably involve new forms and combinations of scrap plastic, created to meet market demands. Another difference is that the resin companies can turn to the automakers for assistance in their research, for the reasons discussed above. They may also be able to turn to the public sector, which has an interest in promoting recycling.

The automotive industry, as well as for other industries using large amounts of plastics in their products, may respond to such difficulties by looking for alternate

materials to replace plastics. Aluminum, for example, parallels plastic in offering auto makers weight reduction and faster machining than iron or steel. Unlike plastics, aluminum is not considered a solid waste problem: recycling aluminum is cheaper than making it from bauxite ore, and supplies for recycling are widely available because of aluminum-beverage-can-deposit legislation, although the alloys in drink containers differ from automotive alloys.⁶⁶ *Ward's 1993 Automotive Yearbook* reports that aluminum had a "banner year," and is expected to increase its presence in automobiles in the future. Among the parts increasingly being made of aluminum are body panels, which means plastic will compete directly with aluminum to replace steel in this application.⁶⁷

Increasing pressure on auto companies to reduce the solid waste generated by their products could shift the balance in favor of other lightweight materials and cost resin makers a major part of their customer base. The threat of materials substitution is another reason for the involvement of resin companies in recycling efforts, particularly for materials used by large, visible companies like the Big Three. The more vulnerable their customers are to public pressure and government regulation, the more resin companies may worry that their product will lose out to a "greener" material.

The criteria for materials selection are extremely numerous and complex, suggesting that recyclability is not important enough in itself to sway a materials decision. In fact, the three most important criteria categories for an automobile manufacturer are function (strength, texture, noise, etc.), weight/density, and costs (tooling costs, development lead time, etc.).⁶⁸ Recyclability is not a major criterion to a competitively oriented manufacturer because it usually does not directly affect cost or material performance. Nor, realistically, should it be the dominant criterion, but must be balanced against others, such as safety and life-cycle economic efficiency.

Steel, aluminum, and magnesium are all examples of recoverable and recyclable material substitutes for automotive plastics. However, weight consideration is very important to an automobile manufacturer because of the Corporate Average Fuel Economy (CAFE) standard. Meeting this standard is important to the individual manufacturers because failure to do so incurs fines and risks negative public reaction.

⁶⁶ "Recycling, Source Reduction, and Opportunities for Biodegradables," *Plastics Engineering*, March 1993, 81.

⁶⁷ 1993 *Ward's Automotive Yearbook*, 27.

⁶⁸ David Andrea and Wesley Brown, "Material Selection Processes in the Automotive Industry," (University of Michigan Transportation Research Institute report no. 93-40-5, 1993).

Plastics are often the lightest material choice, and thus important to meeting CAFE standards, especially since it is clear that the market prefers that manufacturers produce lighter, rather than downsized, vehicles.

Currently CAFE standards are at 27.5 mpg for passenger cars, and 20.2 mpg for light trucks. It is difficult to believe that the industry will substitute significant amounts of heavier materials for plastics, since market demand has jeopardized the meeting of CAFE standards for the past few years, as displayed in table 6. The off-setting credits for exceeding CAFE in earlier years are rapidly exhausting,

Table 6 CAFE standards, domestic and import industry fuel economy, mpg⁶⁹

Model Year	Passenger Cars			Light-Trucks ⁷⁰		
	Domestic Actual	Imports Actual	CAFE Standard	Domestic Actual	Imports Actual	CAFE Standard
1979	19.3	26.1	19.0	17.2	23.2	16.5
1980	22.6	29.6	20.0			
1981	24.2	31.5	22.0	17.85	26.3	15.85
1982	25.0	31.1	24.0			
1983	24.4	32.4	26.0	19.6	27.1	18.5
1984	25.5	32.0	27.0	19.3	26.7	19.4
1985	26.3	31.5	27.5	19.75	26.0	19.3
1986	26.9	31.6	26.0	19.75	26.7	20.0
1987	27.0	31.2	26.0	19.9	26.4	20.25
1988	27.4	31.5	26.0	20.6	24.6	20.25
1989	27.2	30.8	26.5	20.4	23.5	20.25
1990	26.9	29.8	27.5	20.2	23.0	19.75
1991	27.3	30.0	27.5	20.9	23.0	19.9
1992	27.0	29.0	27.5	20.4	22.4	20.2

However, substitution among plastic materials is likely, as automakers require that more easily recyclable thermosetting plastics replace those less readily recycled. This substitution will increase automotive plastics recycling, at least when dismantling or

⁶⁹ Sources: *Ward's Automotive Yearbook, 1993*, and *MVMA Motor Vehicle Facts and Figures '92, 1992*.

⁷⁰ Average of both 2-wheel drive and 4-wheel drive light-trucks CAFE standards and industry averages are shown, although many years separate CAFE standards and industry averages exist for both types of vehicles.

automated separation from ASR becomes economically possible. Auto manufacturers are also starting to simplify the numbers of plastics types used in manufacturing, making separation and recycling easier and less costly, as ASR plastics become more uniform.⁷¹

STEPS TO EFFECTIVE RECYCLING

There are numerous possible developments that might alleviate the threats to the viability of the current vehicle-disposal infrastructure. If the easiest solutions might be decreased local government threats and restraints and expanded landfill capacity, these are not likely. The most prominent options the industries could explore include design for easy dismantling, technology for separation of uniform plastics in ASR, incineration and energy recycling with antipollution technologies, depolymerization of plastics in ASR by chemical processing, commingled plastics recycling, and alternative materials. It may be that the further development of one of these technologies, or some combination thereof, would allow the existing industry to proceed profitably with the disposing and recycling of automobiles.

Both the automotive plastics industry and the disposition infrastructure are addressing these issues. However, just as effective recycling requires the simultaneous improvement of all elements of the recycling system, progress toward the recycling goal requires movement along all of these steps. Moreover, these steps all target future vehicles, and, unfortunately, almost half of the postconsumer automobiles entering the disposition stream in 1992 were built before 1980. The average age of vehicles on the road is about eight years (the oldest since 1950), and that means it will be some time before the majority of scrapped vehicles reflect any material, design, or use changes that enhance the recyclability of new automobiles.

Multiple steps are required to increase the likelihood of the recycling option. Each of these steps constitutes challenges for one or more stages of the automotive plastics value chain and the postconsumer vehicle disposition stages. These steps include 1) increased ease of dismantling, largely through design for disassembly; 2) clear and consistent labeling; 3) attention to the plastic composition of parts, the consistency of the recycle stock, and reduced contamination; 4) incineration and energy recovery; and 5) improved techniques for the recycling of commingled plastics.

⁷¹ Survey, 15-16.

Design and Disassembly Automobile manufacturers today are already attempting to meet these challenges by stressing the use of recyclable materials and design for disassembly. Design for disassembly and recyclability might boost recyclers' profit margins substantially as newer cars enter the recycling stream. Automobile parts with recyclable plastics, designed for disassembly, would lower costs for dismantlers. The dismantler could more easily and economically remove plastic and hazardous material parts from scrapped vehicles, and then separate them into compatible polymer groupings for sale to recyclers. This should reduce the amount of ASR for disposal by the shredder, thus reducing costs at this stage as well, since plastics make up on average 34 percent by weight of shredder ASR.⁷²

The dismantling of plastic parts in postconsumer automobiles is extremely difficult for a number of reasons. Design for recyclability is only one of many design criteria, and these other criteria may create problems for recyclers. For example, the adhesives used for fastening parts to each other or to the vehicle can be a driver of decreased manufacturing costs and improved reliability in vehicle use, but a substantial barrier to dismantling and/or parts recovery. Ford Motor Company introduced a new process of encapsulating windows in the 1992 Econoline Club Wagon. Ford used a frame and seal made of reaction injection molded (RIM) polyurethane, coupled with an adherent to secure the glass to the frame. While the plastic is potentially recyclable, the adherent has a unique property of bonding "firmly to the glass" while "the other end bonds completely with the isocyanate components of the polyurethane systems when the materials react with each other during the RIM process."⁷³ These materials are reacting chemically, and bonding together, and thus the polyurethane component cannot be removed in the normal dismantling operation.

On the other hand, many companies are trying to reduce the costs of manufacture, and these efforts sometimes also alleviate dismantling hardships. DuPont Automotive Products developed a software system that enables engineers to better accommodate snap-fit designs into production, allowing for more precise connection points and more efficient assembly.⁷⁴ Snap-fit designs also allow the dismantler to remove parts without having to dissolve adhesives or cope with corroded fasteners. Himont's new design for

⁷² *Automotive Industries*, September 1992, 46.

⁷³ Roger Rowand, "New method gives windows better fit," *Plastic News*, May 13, 1991.

⁷⁴ "New Software Offers Precise Snap Fit Design," *Technology*, November 1991.

instrument panels (traditionally one of the hardest components to recycle) provides a good example of snap fits. When plastic components are composed of numerous, small, integrated parts, dismantling is more difficult. Himont's design also reduces the number of integrated parts and decreases design, manufacturing, and recovery time.⁷⁵

Accessibility can be a major inhibitor to the recovery of plastic parts and materials. GM has replaced the metal valve roller-lifter guide with a plastic one on its 3300 and 3800 V-6 engines.⁷⁶ The new part will cost less, allow for easier assembly, and reduce weight, thus helping GM meet CAFE standards. However, it is located deep within the engine block. A dismantler would have to disassemble practically the entire engine block to recover this plastic part. When the accessibility of plastic parts is limited to this extent, dismantling may not be a feasible option. Rather, dismantlers might send the part along to the shredder in the hulk, and it would probably end up in the landfilled ASR. To be sure, such a small part might well wind up in a landfill regardless of its location.

The development of new designs for the car's plastic components by itself could enhance the recycling of automotive plastic. For example, plastics suppliers may be able to match their resources to the manufacturers' to assist them in simplifying the materials content of plastic components. The most efficient dismantling process would permit an unskilled worker to pop all of the recoverable plastic components off of the scrapped car with a crowbar, toss them into a few separate boxes, and pour the contents of each box into a shredder to yield pure, usable scrap. This requires separate components that are made entirely of single, reusable materials and are unspoiled by contaminants such as paints and adhesives. Steps in this direction have already been taken by companies such as BMW, which devised a dashboard for which the skin, foam filling, and supports are composed entirely of one material. Further progress will probably require collaboration between parts makers and resin makers, to bring the structure and composition of parts in line with recycling needs.

Labeling A major challenge to dismantlers in recovering plastics from postconsumer automobiles is the recognition of the different types of plastic in use today. More than

⁷⁵ Lindsay Brooke, "Take it Apart," *Automotive Industries*, June 1991. Michael C. Montpetit, "Recyclable Instrument Panel Systems: A Step Closer to the Green Car," *Automobile Life Cycle Tools and Recycling Technology* (Warrendale, PA: SAE, Inc., 1993), 60-61.

⁷⁶ Jack Keebler, "GM Swaps Metal Engine Guides for Plastic to Cut Costs, Weight," *Automotive News*, June 21, 1993, 45.

100 different kinds of plastics are used in the manufacture of automobiles.⁷⁷ Some are processed in unique ways, such that mixing them prevents recycling them. The dismantlers must separate the recovered plastics into the different types because plastic recyclers and processors want only homogeneous materials.

Many different plastics have the same texture and appearance, making visual identification unreliable. Recently, automobile makers have recognized this problem and have taken steps to label plastic parts. Although there has been some labeling in the past, it was infrequent, random, and often erroneous.⁷⁸ Recent efforts show improvement.

Ford Motor Company established an in-house system of labeling and has been using it since October, 1990. The Society of Automotive Engineers also developed a labeling standard that will be adopted by all automobile manufactures in the United States. Figure 10 displays this label, designated J1344. This SAE standard, based on the international standard ISO 1043-1, should facilitate the accurate sorting of plastics and the culling of those with low material value.

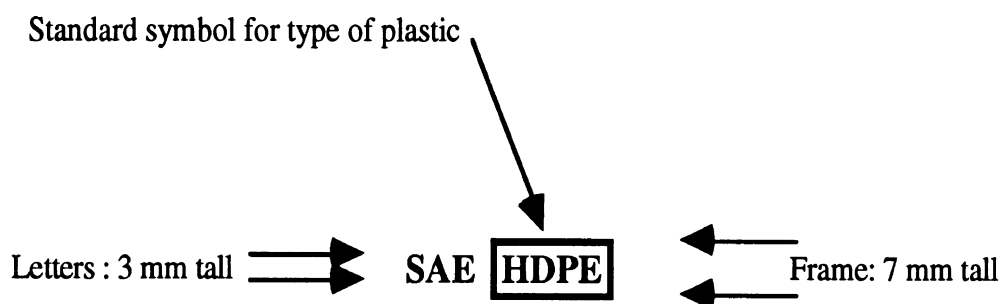


Figure 10 The SAE preferred plastic labeling standard J1344 (actual size)⁷⁹

Part Composition and Contamination The individual recyclability of each type of plastic in an automotive application does not always guarantee the recyclability of that plastic part or component. Designers take advantage of the characteristics of the wide variety of plastics available, mixing many different plastics together in order to achieve the desired attributes. For example, they may combine plastics with preferred texture

⁷⁷ Winter, "Recycling a Top Issue; Steel Making Big Gains," *Ward's Automotive Yearbook 1992*, Ward's Communications, Detroit, MI, 1992, 35.

⁷⁸ SAE presentation, 1993.

⁷⁹ *1993 SAE Handbook* 1, 11.115.

qualities and plastics with appropriate strength for a visible structural part in the vehicle interior. Such multiple plastics are currently used in the construction of 90 percent of passenger cars in North America.⁸⁰

We discussed above the use of snap-fit designs to make dismantling the instrument panel easier. But the instrument panel is also a good example of a different challenge—the combination of different types of plastics. The different types of plastics used in the instrument panel still greatly reduce its recyclability, and therefore its profit potential as a material. Carpet is another automotive material that contains numerous types of plastics, and therefore presents a major challenge to effective recycling. These applications are displayed in figure 11.

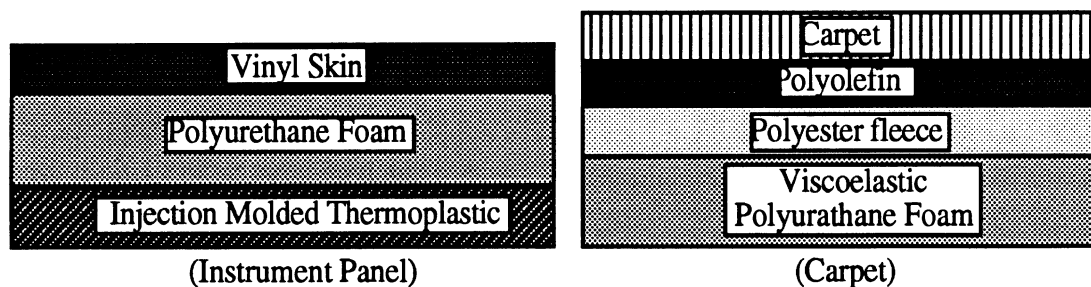


Figure 11 Cross section of Typical Instrument Panel and Carpet Composition⁸¹

Each different polymer group of plastics (for example, polyurethane, fluoropolymer, polycarbonate, etc.) must be recycled using a different method or with different criteria, as discussed above. If a part consists of numerous types of plastics joined together, as in an instrument panel, then separation becomes virtually impossible. According to BMW's U. S. product information manager Christopher Huss, "a dashboard is a group of different plastic materials. It's foam. It's skin. It's a mixture that is absolutely not recyclable."⁸²

Dependence on unpredictable scrap supply has been a chronic problem for some companies that have set recycled-content goals for their products. One recycling operation handling postconsumer bottles found that their process no longer yielded usable material; an investigation revealed that recently collected bottles caused contamination

⁸⁰ Philip J. Jeszke, "Are Instrument Panels Becoming Global?" and Dennis McCullough, "Viscoelastic MDI-Based Polyurethane Foam for Sound and Vibration Dampening in Automobiles," *Plastics in Automobile Instrument Panels, Trim and Seating* (Warrendale, PA: SAE, Inc., 1990), 114.

⁸¹ *Ibid.*, 47, 111.

⁸² Christopher A. Sawyer, "Recyclability," *Automotive Industries*, September 1990, 40-41.

because of a shift by soda companies from aluminum to polypropylene bottle caps.⁸³ As R. Kaskel, of GE Plastics' Polymerland, says in his description of GE's recycling efforts:

It's one thing to establish the physical properties desired and then build a monomer or polymer from prime raw materials or chemicals to achieve those desired physical properties. It is quite another to build up to desired physical properties when your starting feedstocks are variable by nature.⁸⁴

For the resin producer, any recycled content quota, whether imposed by government or customer, requires that a steady supply of a particular type of scrap must be available, and the scrap must be sufficiently free of contamination.

Procter and Gamble and Rubbermaid are two examples of companies that have had great difficulty getting a consistent supply of scrap to meet recycling goals; they have had to push up scrap prices and advertise for certain types of postconsumer plastic to meet their needs.⁸⁵ Management advisor F. C. Sutro, Jr. points out that in the case of the market for recycled HDPE, as many as 100 companies often are advertising to buy or sell the postconsumer material without any uniform system for communicating the level of contamination of each company's product.⁸⁶ A resin company executive complained in 1989 that "there is absolutely no standard market for recycled materials -- it's hit or miss."⁸⁷

Most materials used in the manufacture of automobiles are altered in use, and plastic parts and components are often contaminated. Contaminants can undermine the economic feasibility of recovery by decreasing the quality of recovered material and by making the recycled stock unusable. There are three basic types of contaminants: permanent, material, and penetrating. To be sure, many contaminants are removable, but such removal adds costs to the material recovery process, and that again affects recyclability.

⁸³ "Major Technology and Market Factors Which Drive Successful Plastics Recycling Programs," Society of Plastics Engineers/Plastics Engineering ANTEC 1992 Conference Proceedings, 2355.

⁸⁴ R. Kaskel, "Demand Driven Recycling of Engineered Thermoplastics," Society of Plastics Engineers ANTEC 1992 Conference, 2371.

⁸⁵ *Ibid.*, note 8, 2355.

⁸⁶ F. C. Sutro, Jr., "Marketing Recycled Resins," Society of Plastics Engineers ANTEC 1992 Conference, 2360.

⁸⁷ "A New Wave of Plastics Recycling," *Chemical Week*, May 10, 1989, 9.

Permanent contaminants typically pose the most problems. They include undercoating, adhesives, sealants, material inserted during molding, etc. Paint or finish is put on virtually all visible parts, and protective coatings are often used for parts that need extra protection. These additives help plastic perform and look better during the consumer use stage, but create problems at the material recovery stage. Bumper systems constitute 10 percent by weight of all plastic application by weight, and can be designed for efficient disassembly. Yet most bumpers are painted, so plastic bumpers regularly pose a problem for material recovery.

However, plastic bumpers are a good example of the automobile industry designing for the retirement of a product. Originally, plastic materials recycled from scrapped car bumpers was contaminated by paint, causing streaky appearance, cracks, and reduced shock resistance qualities in reuse. Nissan Motor Co., Ltd. has now developed a paint-removal system for the bumpers. The propylene bumpers are pulverized and then submitted to an aqueous solution that physically and chemically breaks down the paint. The recycled propylene is less contaminated and closer to its original quality. The leftover paint residue is treated and then also reused.⁸⁸

Material contaminants within plastic parts, such as metal, are also a problem. In the example of Ford Motor Company's Econoline van windows, discussed above, the plastic used in conjunction with the glass and adhesive is also contaminated with metal. During the manufacturing process "metal attachment studs are imbedded in the PU encapsulating material."⁸⁹ This technique may decrease costs and enhance the appearance of the windows, yet it makes recycling the glass or windows far more difficult. Glass, minerals, and other materials used to improve the characteristics of the plastic are examples of other widespread contaminants.

Penetrating contaminants include gasoline, brake fluid, and other fluids that literally penetrate the chemical structure of the plastic. These contaminants often occur in radiator end tanks, windshield washer tanks, brake fluid reservoirs, and other holding containers on an automobile. Recycling such penetrated plastics requires more processing and that adds to the cost, thereby reducing the value of the material.

⁸⁸ "Nissan Develops Paint Removing Technology to Aid Plastic Bumper Technology," *News from Nissan*, Release # NNA-32-1291.

⁸⁹ Roger Rowand, "New method gives windows better fit," *Plastic News*, May 13, 1991.

Incineration and Energy Recycling Incineration has been a useful process in the past for the disposal of many different materials in the municipal waste stream, and was once considered the likely solution for the problem of ASR disposal. Since the energy in ASR is nearly equivalent to coal, incineration and subsequent heat or energy recovery appeared to be cost-effective. Even though only about 40 percent to 50 percent of automotive shredder residue is combustible, it contains about 5,400 btu/pound.⁹⁰ This reflects the high content and combustibility of the plastics, wood, and rubber it contains, as illustrated in table 7.

Table 7 Estimated composition of lightweight ASR, by weight, from three sources⁹¹

Material	Source 1 ⁹²	Source 2 ⁹³	Source 3 ⁹⁴
Plastics	43	25	33
Elastomers (Rubber)	12	11	29
Fibrous materials (wood, cardboard, etc.)	7	35	10
Metals (Fe, Al, Cu, etc.)	9	7	1
Dust, paint residues	—	15	11
Glass, sand	—	—	16
Unidentifiable materials	17	5	—
Operating agents	2	2	—

Polyethylene contains 19,900 btu/pound, polypropylene contains 19,850 btu/pound, and polystyrene contains 17,800 btu/pound, while rubber contains 10,900 btu/pound and wood contains 6,700 btu/pound; it is the nonplastic, nonwood, and nonrubber content of ASR that lowers its overall energy content. Theoretically, if the plastic could be separated out, it would be an even more valuable and efficient energy source. However, incineration reduces the weight of ASR by 50 percent and reduces the volume by 75 percent, greatly reducing the amount of material for landfilling. Therefore, if incineration can be done safely, the incineration of all ASR might be the optimal strategy, and the plastic content would become the fuel for reducing its less combustible content.

⁹⁰ B. J. Jody and E. J. Daniels, "Automobile Shredder Residue: Treatment Options," *Hazardous Waste and Hazardous Materials* 8, no. 3, Mary Ann Leibert, Inc., 1991.

⁹¹ Gunter Walter, "Activities for Recycling and Disposal of Used Vehicles," *Plastics in Automotive Engineering: Applications and Recycling*, VDI-Verlag GmbH, Dusseldorf, 1991.

⁹² Fa. Hoesch/Celler GmbH, shredder operation, Dortmund, 1990.

⁹³ Busse, "Elastomere in Automobilen der Zukunft und Recycling," Dissertation for the University of Hanover, 1989.

⁹⁴ H. J. Knopf, BASF, Ludwigshafen, 1990.

Two kinds of waste streams result from incineration—ash and airborne particles and gasses (often called flue gasses), each with its own problems of hazardous by-products. The flue gasses released from incinerators can be especially harmful if they are released into the air because they could contaminate vast geographic areas. However, once these hazardous substances were recognized, filtration technology was developed that decreases the airborne waste stream from smoke stacks. Filtering techniques, such as gas scrubbers for chlorine and sulfur, remove the harmful residues. In fact, incinerator by-products from ASR have been brought well within emissions standards by 1988, as shown in table 8.

Table 8 Flue gas emissions from incinerated ASR in 1981 and 1988.⁹⁵

Flue gas emissions (mg/Nm ³)	Refuse incineration plants		Required by 1986 Clean Air Act
	1981 status	1988 status	
Dust	50	10	30
Cl	450	5	50
F	4	0.5	2
SO ₂	230	25	100
NO _x	220	100	500
Heavy Metals:			
Cd, Hg, Ti	2.0	0.1	0.2
As, Co, Ni, Se, Ti	4.0	0.5	1.0
Sb, Pb, Cr, Cu, Mn, Pt, Pd, Rh, V, Sn	no entry	1.0	5.0
Equivalent of dioxins and furans	0.1ng/m ³	0.1ng/m ³	0.1ng/m ³ *

* Required by the Federation Pollution Control Regulation. The Clean Air Act does not limit dioxins and furans.

Even though these results seem acceptable, there is reason to keep working towards even cleaner by-products. Fluidized bed, rotary tube, mass burn combustors, and high temperature gasification (HTG) are examples of even cleaner incineration methods. These methods are each able to process plastics, and operate well below government

⁹⁵ Ibid.

standards for emissions.⁹⁶ For example, toxic flue gas by-products from high temperature gasification are almost nonexistent.

HTG was developed by Voest-Alpine. In this process, a coke bed is preheated to a temperature of 1,600 degrees Celsius in a special incinerator. When plastics are added to the incinerator the waste is gasified into hydrogen and carbon monoxide. The resultant gasses are extremely hot, and the heat can generate steam for use as heat or energy. The nongasified material residue is a liquid slag, which exits the incinerator into a water bath and cools into glassy granules. The fuel gas emanating from the process may be used to generate energy as well, increasing the efficiency of energy recovery from the material to 80 to 85 percent.⁹⁷ The granules are safe to landfill, or they can be used as building material. The hazardous flue gas emissions from HTG are also well below government standards, as displayed in table 9.

Table 9 Flue gas emissions from ASR in a High Temperature Gasification demonstration plant⁹⁸

Flue gas emissions (mg/Nm³)	Required by 1986 Clean Air Act	High Temperature Gasification
Dust	30	<5.0
Cl	50	1.7
F	2	<0.03
SO ₂	100	60
NO _x	500	60
Heavy Metals:		
Cd, Hg, Ti	0.2	0.01
As, Co, Ni, Se, Ti	1.0	0.02
Sb, Pb, Cr, Cu, Mn, Pt, Pd, Rh, V, Sn	5.0	0.74
Equivalent of dioxins and furans	0.1ng/m ³ *	<0.02ng/m ³

* Required limit actually from the Federation Pollution Control Regulation. The Clean Air Act does not limit dioxins and furans emissions.

Not only are flue gasses from incinerators safe, but the resultant ash from incineration is also relatively safe, though it does contain some heavy metals. Tested regularly and

⁹⁶ R. H. Burnett and G. A. Baum, "Engineering Thermoplastics," *Plastics Recycling: Products and Processes* (Germany: Grafische Kunstanstalt Josef C. Huber KG, DieBen, 1992).

⁹⁷ Ibid.

⁹⁸ Walter, op. cit.

landfilled according to the contents, most incinerator ash can be disposed of in a standard landfill. If the levels of toxicants are high enough the material can be landfilled as a hazardous substance (depending on geographic location, type of vehicles shredded, type of scrap, etc.), with higher tipping fees. The toxicity of the ash from ASR springs partially from the heavy-metal-containing pigments and stabilizers used on plastics. If heavy metals can be eliminated from these pigments and stabilizers, incinerator ash from ASR would have less toxicity, although stray wheel weights and batteries would still pose a problem.

The United States relies on incineration far less than do other industrialized countries. In fact, most developed economies incinerate most of their municipal waste stream (MWS) and have an extensive incinerator infrastructure. For example, Switzerland incinerates 80 percent of its MWS, Japan, 70 percent, Sweden and Denmark, 60 percent, and the Netherlands, 40 percent, while the U.S. incinerates only 15 percent.⁹⁹ If a large incineration infrastructure existed in the United States, the cost of incineration might be greatly reduced by the resulting economies of scale. This might make it economically feasible for shredders to ship their ASR to incineration facilities.

However, the capacity does not exist, and the costs of incinerating waste in the United States are significantly higher than landfilling it. Moreover, the public tends to view incinerators skeptically, and they may therefore be an unpopular option. Public outcry and government regulation often make starting an incineration operation difficult at best.

Theoretically, shredders could themselves operate incinerators, conveying the ASR directly to the incinerator. They could also use the energy from incineration to power their shredding operation. However, incineration and the recent advances in this method are costly. Although technically possible, even ordinary incineration is typically too costly for an individual business, and when the technological advancements are added the costs are often astronomical. By the end of 1973, when incineration was first identified as an answer to ASR landfill problems, an estimated 23 incinerators were built by shredders and nonferrous separators explicitly for the incineration of ASR. Today, none of these incinerators is in operation.¹⁰⁰ Either they were too expensive to operate, or the businesses found that landfilling was the less expensive option for the disposal of ASR.

⁹⁹ "Municipal Waste Combustion: Toxic Threat or Trivial Pursuit," *Issue Analysis*, American Legislative Exchange Council, April, 1990.

¹⁰⁰ K. D. Dean, J. W. Sterner, M. B. Shirts, and L. J. Froisland, "Bureau of Mines Research on Recycling Scrapped Automobiles," U.S. Department of Interior Bulletin, 1985, 684.

One of the most technologically sophisticated shredding operations in the country (located in Detroit, Michigan) maintains that it cannot economically justify an in-house incinerator at the current operating cost levels.¹⁰¹ In order for incineration to be an economically viable option, the capital and operating costs must significantly decrease.

Commingled Plastics Recycling Recycling plastics from the ASR waste stream would be a viable option with current technology and infrastructure, if the plastics could be easily separated into compatible polymer groupings. This separation is extremely difficult at best, and often impossible. Recycling commingled plastics offers a reasonable goal for the industry, because it would lower the costs of and probably increase the markets for recycled automotive plastics. Thermoplastics in particular are more readily recyclable because they can be remelted and then reformed into new parts. This makes commingled recycling an especially attractive option, because the thermoplastics content of the plastic component of ASR is typically 70 percent to 80 percent.

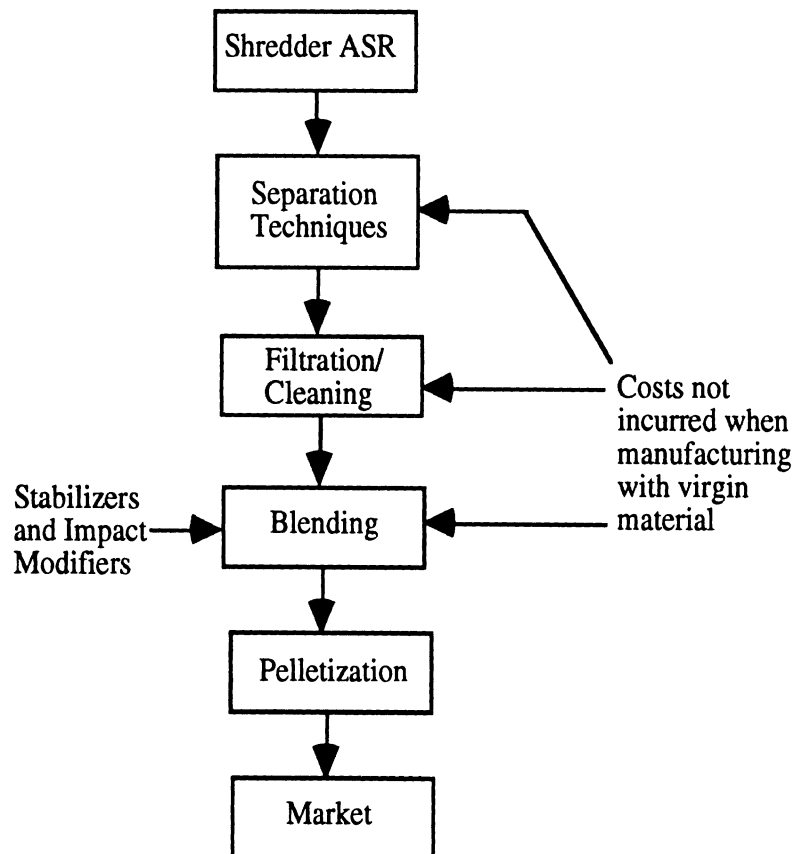


Figure 12 Process flow chart for commingled plastics separation by shredders

¹⁰¹ Conversations with Jeff Cole, owner, Ferrous Processing and Trading Co., Detroit, Michigan, 1993.

Figure 12 details the cost challenge to recycling plastics. The use of recycled plastics incurs costs at three stages that are essentially absent when virgin resins are used. These stages include the separation, filtration, and cleaning of the plastics, and the addition of additives to assure desired attributes and characteristics, such as stability. However, the recycling of commingled plastics eliminates much of the cost in the separation stage. To be sure, the plastics must still be separated from the rest of the ASR; but at least some of the cost of separation among the plastics themselves will be eliminated.

Unfortunately, there are incompatibilities across different types of plastic—even among recyclable thermoplastics. Figure 13 illustrates one estimate of the degree of compatibility across some prevalent plastics.¹⁰² Differences in melt points and thermal stability are often a source of incompatibility. For example, PET will not remelt at the same processing temperatures as PVC, and PET/PVC mixes may cause discoloration.

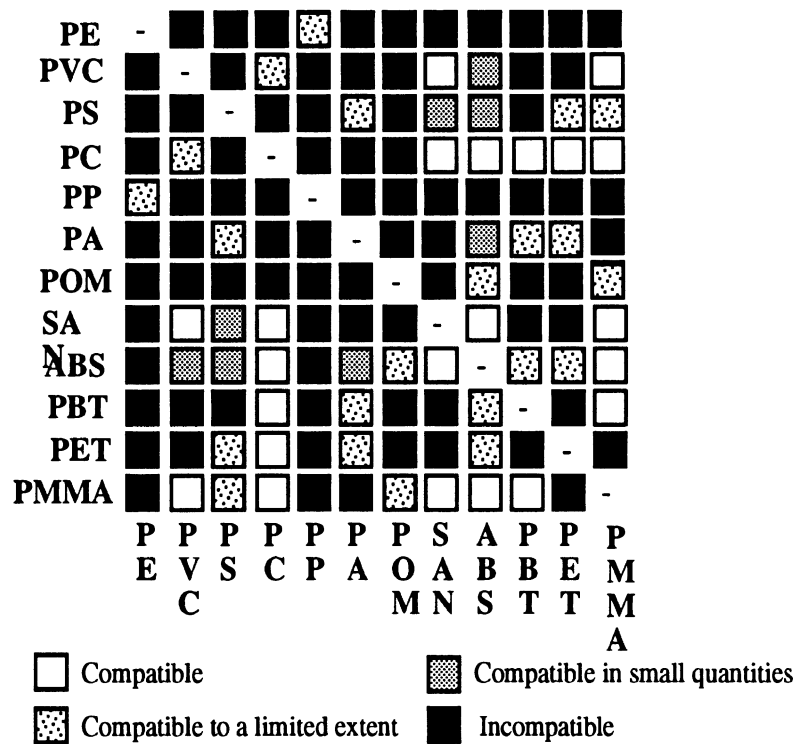


Figure 13 Mutual compatibility of important thermoplastics¹⁰³

¹⁰² Peter Boettcher, "Environmental Compatibility of Polymers," *Emerging Technologies in Plastics Recycling*, American Chemical Society, 1992.

¹⁰³ Adapted from: Peter Mast, Siegfried Schaper, and Dieter Wagner, "Conservation of Resources by Recycling Plastic Parts from Automobiles," *Plastics in Automotive Engineering: Applications and Recycling*, VDI-Verlag GmbH, Dusseldorf, 1991.

However, more recent research suggests that compatibility is even more complex than this illustration suggests. Thus PVC may in fact be compatible in small quantities with PA, PBT, and PET, and may even be more generally compatible with ABS. Moreover, the compatibility of two plastics often depends on their relative proportions in the material. For example, relatively small quantities of PVC mixed in PET degrade the material, but the reverse does not always hold, since whether small quantities of PET in PVC contaminate the material depends on the specific application. Thus PET can be tolerated in sound deadening material or body side molding cores made of recycled PVC, but not in recycled PVC bottles.¹⁰⁴

Automotive applications frequently combine distinct types of plastics, reflecting their different attributes. Effective recycling must process these specific applications, and that is why commingled plastics recycling represents an important element in successful recycling. The attributes of the recycled stock compared with virgin material depend on many factors, and is itself a complex issue. Recycling of commingled streams must balance design constraints, application requirements, processing techniques, and material compatibility. For example, if the part has a knit line, material compatibility becomes critical to the part's strength. Thus a part made of a compatible PVC/ABS recycled stream will be stronger than one made from an incompatible olefin/ABS recycled stream. Not surprisingly, then, interior trim composed of ABS with vinyl skin is a more promising candidate for recycling without separation than is interior trim with an olefin skin, when postrecycling applications require greater strength.¹⁰⁵

Fortunately, commingled recycling is a reasonable target, although it faces some important current limitations. First, some plastics tend to degrade over time and use, and recycled plastics may expose and leach out toxic and organic substances that are improperly cleaned from the recycled stock. Second, partial separation of contaminants and the addition of appropriate additives can enhance the quality of the recycled stock, but they add cost to the product. Third, the shifting composition of ASR plastics demands wide tolerances in both product and process design, and thus prohibits some applications.¹⁰⁶ The first limitation can be removed by proper handling, but the second two again raise fundamental issues of the economics of recycling.

¹⁰⁴Data provided by The Geon Company.

¹⁰⁵Data and analysis provided by The Geon Company.

¹⁰⁶ B. J. Jody and E. J. Daniels, "Automobile Shredder Residue: Treatment Options," *Hazardous Waste and Hazardous Materials* 8, no. 3, Mary Ann Leibert, Inc., 1991.

The easiest way for the Big Three to produce a more environment-friendly automobile is to replace virgin plastics with recycled or recycled-content plastics of equal quality and price. While this makes sense from their perspective, it puts a great burden on plastics suppliers to develop a resource recovery technique that makes recycled plastic profitable at the same price as new plastic. Significant progress through this technique alone, however, is unlikely. Resin makers may need to convince automakers that they should reexamine their specifications for plastic components where those specifications serve to prevent the use of postconsumer resins.

Finding markets for such products is difficult, yet many possibilities have been discussed. The commingled plastic may be used for only the inner structures of a product, if visibility is a concern. It might be used as a filler in products such as cement. Its use might be restricted to products that do not require strength, consistency, and/or appearance.

Recycled commingled plastics have been used for highway guardrails, park benches, fence posts, picnic tables, trash cans, as a building material replacing wood, and so forth. For example, North Carolina experimented with using 1,500 pounds of recycled plastics in a road construction project in 1991. The plastics were used for a variety of products including:

- Delineator posts (the side road marking posts with reflectors on them)
- Fencing posts used for traffic control
- Components of rail fence used at exits and entrances
- Traffic control barricades
- Plastic lumber
- Small experimental sections of pavement with finely ground plastics as a filler

The contractor for the project estimated that using the recycled plastics added costs to the project, and that plastic lumber is particularly expensive compared with wood. However, the total increase in costs was just 1.5 percent of the total project.

There may be some potential use for virtually any type of recycled plastic, but the industry cannot rely on low-end uses such as traffic pylons and park benches to soak up all of the supply, since these products can be made from easy-to-obtain commingled plastics of various composition. For materials that are having trouble finding their way

back to consumers, plastics companies should use their understanding of the market potential of plastic to develop new uses.

Although there are many limitations in recycling commingled plastics, the possibility for producing these types of products ultimately depends on whether it is economically viable to produce, if the material characteristics meet the needs of the product use, and if there are markets for their use.

To date, even though there are some marketable uses for such products, these markets are too small, and the cost of producing these products is higher than producing them from conventional materials. If oil stays near current prices (less than \$25 per barrel) the costs of producing products from virgin plastic resins will remain lower. Given this pricing situation, resin buyers will continue to prefer virgin materials unless government mandates or consumer preferences required recycled plastics content.

However, the strategy for using recycled plastics has typically been one of recovering the material, then seeking applications and markets for it. GE Plastics' Polymerland pursued this route. Despite the failure of the Luria partnership, GE plastics (which only works with engineering thermoplastics, the most easily recycled of automotive plastics) continues to look into the potential for recycling this material. According to R. Kaskel, Polymerland initially "... set out to solve the landfill issue by buying all of the engineered thermoplastics that we could, and to attack the purchased scrap with Ph.D. chemistry to create world problem-solving polymers. We failed!" All of their initial products, Mr. Kaskel says, either were affordable but lacked demand, or were in demand but not affordable.¹⁰⁷

Their response was to change their strategy to "market-driven recycling," whereby the needs of the market are assessed first, and the combinations of scrap plastics capable of meeting this need are developed second. In pursuing this strategy, Polymerland scientists found a way around the chronic problem of unstable and unpredictable scrap supply. They identify particular physical properties for which demand exists, then develop a "feedstock matrix," which specifies several combinations of scrap plastic feedstock that can be used to achieve the desired characteristics. They can change the recipe when necessary, to use whatever the scrap market has to offer at the time.

¹⁰⁷ "Built to Last--Until It's Time to Take it Apart," *Business Week*, September 17, 1990, 102.

This strategy of "market-pulling, rather than market-pushing" has enabled Polymerland to serve the automotive aftermarket's demand for affordable materials that meet engineering thermoplastic requirements. They are also supplying recycled plastics to the printer-ribbon, plumbing, and materials-handling markets, and are planning entry into the construction and extrusion markets. Postconsumer plastics currently being processed for recycling at Polymerland include pizza trays, water bottles, and car bumpers. Mr. Kaskel says that the strategy has been successful enough that recycling of engineering thermoplastics is profitable for Polymerland.¹⁰⁸

The recycling database under development by Rutgers University may prove to be a boon for companies pursuing market-driven recycling, if it succeeds in helping them identify and meet end markets with mixed scrap materials.

The broader implications of their experience for recycling efforts depends on their success in increasing the postconsumer portion of the feedstock they use for recycling, currently 20 percent of the total. Factory-floor and chemical plant scrap, which make up the rest, has been recycled for a long time; postconsumer scrap is the linchpin of the solid-waste problem. Moreover, in order to satisfy the FTC's guidelines setting standards for claims of "recycled content," companies must be able to show that the materials have been "recovered or otherwise diverted from the solid waste stream, either during the manufacturing process or after consumer use." Factory-floor scrap does not count unless the company can prove that it would have gone to the landfill without the postconsumer use in question.¹⁰⁹

SUMMARY

The automotive plastics industry faces serious demands to increase the recyclability of its products, springing from public opinion and government action. Meeting those demands requires solving extremely complex and daunting problems. These challenges span the identification or creation of markets for recycled plastics, the development of innovative recycling technologies and approaches to serve those markets at acceptable quality and cost levels, and the maintenance of a healthy recycling infrastructure to supply the postconsumer scrap. If the industry fails to make progress on any of these dimensions, it risks the loss of substantial automotive markets.

¹⁰⁸ Ibid., note 9, 2372.

¹⁰⁹ "FTC Releases Guidelines for Green Marketing Claims," *Recycling Times*, August 11, 1992, 1.