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Recent Trends in Automobile Recycling: an Energy and Economic Assessment

T. Randall Curlee
Sujit Das
Colleen G. Rizy
Susan M. Schexnayder

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RECENT TRENDS IN AUTOMOBILE RECYCLING: AN ENERGY AND ECONOMIC ASSESSMENT

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Date Published: March 1994

Prepared for the
Office of Environmental Analysis
U.S. Department of Energy

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6205
managed by
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for the
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under contract DE-AC05-84OR21400

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ACRONYMS

ABS	acrylonitrile butadiene styrene
ACEA	Association of European Car Manufacturers
ACORD	European Automotive Consortium on Recycling and Disposal
ADAC	German Motorists' Association
AEO93	*Annual Energy Outlook '93*
ANL	Argonne National Laboratory
APC	Automotive Plastics Council
ARV	Auto-Recycling-Verbund
ASR	automobile shredder residue
BACT	best available control technology
Btu	British thermal unit
CAFE	Corporate Average Fleet Economy
DEQE	Department of Environmental Quality Engineering (Massachusetts)
DM	Deutschmarks
EC	European Community
EP	extraction procedure
EPA	Environmental Protection Agency
EPDM	ethylene propylene diene monomer
EURHEKAR	European Producers' Circle for Recycling
FARE	Fiat Auto Recycling
GAVS	German Rubber Manufacturers' Association
GE	General Electric
ICAR	International Consortium on Automobile Recycling
ISO	International Standards Organization
JAMA	Japanese Automobile Manufacturers' Association
JCAR	Japanese Consortium on Automobile Recycling
KAA	Kloeckner Kunststoff-und Automobilrecycling Company
MIT	Massachusetts Institute of Technology
mpg	miles per gallon
MSL	Materials Systems Laboratory
NRDC	Natural Resources Defense Council
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzodioxins (dioxins)
PCDFs	polychlorinated dibenzofurans (furans)
Pds	British pounds
PP	polypropylene
ppm	parts per million
PUR	polyurethane
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RIM	reaction injection molding
SAE	Society of Automotive Engineers

SMA	styrene maleic anhydride
SMC	sheet molding compound
SPI	Society of the Plastics Industry
TCLP	toxic characterization leaching procedure
TSP	total suspended particulates
UK	United Kingdom
VRP	Vehicle Recycling Partnership (of the Big three automakers--i.e., Ford, General Motors, and Chrysler)

EXECUTIVE SUMMARY

Recent and anticipated trends in the material composition of domestic and imported automobiles and the increasing cost of landfilling the non-recyclable portion of automobiles (automobile shredder residue or ASR) pose questions about the future of automobile recycling. This report documents the findings of a study sponsored by the U.S. Department of Energy's Office of Environmental Analysis to examine the impacts of these and other relevant trends on the life-cycle energy consumption of automobiles and on the economic viability of the domestic automobile recycling industry.

More specifically, the study (1) reviewed the status of the automobile recycling industry in the United States, including the current technologies used to process scrapped automobiles and the challenges facing the automobile recycling industry; (2) examined the current status and future trends of automobile recycling in Europe and Japan, with the objectives of identifying "lessons learned" and pinpointing differences between those areas and the United States; (3) developed estimates of the energy system impacts of the recycling status quo and projections of the probable energy impacts of alternative technical and institutional approaches to recycling; and (4) identified the key policy questions that will determine the future economic viability of automobile shredder facilities in the United States.

The study's conclusions are suggestive of the severities of different aspects of the problem and point to future research needs. The study found that the material composition of automobiles has changed during the past decade and is expected to follow recent historical trends. Quantities of plastics and aluminum in automobiles are expected to continue to increase. Between 1992 and 2000, the weight of plastics and aluminum used will almost double, while the use of carbon steel will decrease. These changes will have significant impacts on the life-cycle energy use of the typical automobile, but not just at the point of disposal and not necessarily in ways that a cursory examination would suggest. A life-cycle analysis performed in this study found that the quantity of energy used in the manufacture of automobiles will increase (reflecting the high Btu contents of plastics and, especially, aluminum); the energy consumed during the life of the automobile will decrease in response to new technologies and lighter weight vehicles; and, somewhat surprisingly, the energy savings from the recycling of automobiles will increase (due mainly to the anticipated recycling of high-Btu aluminum).

The most important conclusion of this study's assessment of the energy implications of the recycling status quo is that trends in material composition and the viability or non-viability of recycling the non-metallic components of the typical automobile are of secondary importance compared to the energy consumed during the life of the automobile. Small changes in the fuel efficiency of a vehicle overshadow potential energy losses associated with the adoption of new and possibly non-recyclable materials. If there is no change in the recycle status quo, this study projects that the life-cycle energy consumed for the typical automobile will decrease from 599 million Btus in 1992 to 565 million Btus in 2000. Energy consumed during the manufacture of the typical car will increase from about 120 to 140 million Btus between 1992 and 2000, while energy used during vehicle operation will decrease from 520 to 480 million Btus. This study projects that energy saved at the recycle step will actually increase from 41 million Btus in 1992 to 55 million Btus in 2000.

This study also investigated the energy impacts of several changes to the recycle status quo, including the adoption of technologies to retrieve the heat value of ASR by incineration and the recycle of some or all thermoplastics in the typical automobile. The study found that under the most optimistic conditions -- i.e., the recycling of all thermoplastics and the incineration with heat recovery of all remaining ASR -- only about 8 million Btus could be saved per automobile -- i.e., an increase from about 55 to 63 million Btus. In the more realistic scenario -- i.e., the recycling of easy-to-remove thermoplastic components (bumper covers and dashboards), the energy savings are only about 1 million Btus per vehicle.

Therefore, the changes in energy use due to changes in material composition and changes in the recycle status quo are not expected to alter greatly the life-cycle energy requirements of the average vehicle. From an energy perspective, the more important issue concerns the public's acceptance of non-recyclable materials and increasing quantities of ASR for disposal. If public pressures lead to the rejection of new automotive technologies on the basis of non-recyclability, the potential energy savings foregone during the operational life of the vehicle could far exceed the potential energy losses that may occur at the manufacturing and recycle steps.

Aside from questions about the energy implications of shifts to new and possibly non-recyclable materials, concern has been raised about the increasing quantities of ASR and potential environmental problems associated with ASR disposal. This study projects that under the recycling status quo, the quantity of ASR to be landfilled will increase from about 4,478 million pounds in 1992 to about 5,000 million pounds in 2000. However, these quantities must be placed in perspective. Currently and during the coming decade, ASR quantity is expected to be less than 1.5% of the size of the municipal solid waste (MSW) stream in the United States. In Europe, ASR accounts for only about 2% of sanitary landfill mass.

The annual quantity of ASR in the United States could be reduced from about 5,000 million pounds to about 1,000 million pounds of ash if all ASR is incinerated. Alternatively, ASR quantity could be reduced to about 4,000 million pounds if all thermoplastics in automobiles are recycled. However, in the more realistic case of recycling only thermoplastic bumper covers and dashboards, the quantity of ASR would be reduced by only 200 million pounds. A significant reduction or increase in the size of the ASR waste stream will not in itself have a large impact on the solid waste stream in the United States.

The question of potential environmental damages from the disposal of ASR in conventional landfills is less tractable and was not a major focus of this study. This study did find, however, that all ASR currently generated in the United States is disposed of in RCRA Subtitle D landfills -- i.e., conventional MSW landfills. Although some states have placed restrictions on ASR disposal, methods have been developed to meet those requirements. The cost and environmental implications of more severe environmental restrictions on ASR disposal were not a major focus of this study.

The findings of this study concerning life-cycle energy use, ASR quantities, and environmental regulations do not suggest that the problems faced by automobile recycling are trivial. Public policy with respect to recycling and waste disposal is often based on public perceptions, and questions about the inability to recycle automobiles or significant portions thereof can lead to very visible and identifiable public concerns. Of equal importance is the very real possibility that current trends may lead to an automobile recycling industry in the United States that is not economically viable.

Current conditions in Europe are suggestive of the situation that may exist in the United States in future years. While scrapped automobiles have an average price of about $100 in the United States, retired vehicles have a negative value in much of Europe. Available information suggests that this difference is due largely to the higher cost of ASR disposal in Europe. In addition, many European countries face greater public opposition to ASR disposal than in the United States.

The current and pending problems with automobile recycling have gotten the attention of automobile shredders and automobile manufacturers world wide; and various approaches are being pursued to reduce the quantity of ASR and to increase the recyclability of automobiles. However, the approaches differ significantly. Public opinion and legislative initiatives in Europe are leaning toward placing responsibility for automobile recycling on automobile manufacturers; and manufacturers have responded by developing new approaches for hand-disassembly and designing vehicles that are easier to disassemble. The Europeans have also formed a number of teams that combine the talents of automobile manufacturers with suppliers and automobile recyclers to address relevant technical and institutional issues. Some European companies claim to manufacture automobiles that are 100% recyclable, if recycled in their prototype hand-disassembly facilities. Public and legislative pressures have been less in the Untied States, and the response has been less radical. Approaches in the United States have been targeted at labeling all plastic parts, removing selected plastic components for recycle prior to shredding, developing approaches to separate and recycle plastics in ASR, and developing acceptable incineration technologies to retrieve the heat energy of ASR.

The future of automobile recycling raises legitimate concerns for automobile manufacturers, automobile shredders, and consumers. During recent decades, the technology to recycle automobiles varied very little among industrialized countries. However, recent trends are leading to new approaches to recycling that may be country specific -- e.g., conventional shredders with conventional ASR landfill, pre-shredder dismantling of selected plastic parts in combination with shredding, and total hand-dismantling. Automobile manufacturers have legitimate concerns that some countries will mandate approaches to recycling that cater to specific automobile designs, resulting in market barriers for some automobile manufacturers in some countries. Automobile manufacturers are also concerned about proposed mandates to place the responsibility for (and the cost of) recycling on the manufacturers.

Automobile shredder firms are concerned about trends that reduce their economic viability -- i.e., fewer quantities of recyclable materials, larger quantities of ASR, higher landfill costs, and more restrictive environmental regulations. Some shredder operators have concerns about the greater involvement of automobile manufacturers in recycling, in terms of having less control of their industry and facing new approaches to recycling that may compete with the current shredder capacity they own.

Consumers are concerned for several reasons. Current trends may eventually require owners of scrap automobiles to pay for their disposal, as is the case in much of Europe. The number of abandoned vehicles may increase as a result. Automobile prices may increase because of requirements for easy disassembly or because certain materials are not allowed in the construction of vehicles. Possible restrictions on the use of selected materials also could result in less fuel efficient vehicles. Finally, the controversy about the environmental implications of ASR disposal continues.

As the debate ensues, U.S. policy makers will be faced with decisions about mandates on

automobile material composition, restrictions on the disposal of ASR, and required automobile designs to facilitate recycling. Automotive technologies designed to respond to Corporate Average Fleet Economy (CAFE) standards (e.g., lightweight plastic materials) may be incompatible technically and economically with requirements for recyclability. New approaches to recycling in Europe may create additional market barriers for U.S. automobile manufacturers, to which the U.S. government may wish to respond.

An intelligent public debate about automobile recycling will require additional and more defensible information about the various costs and benefits associated with the alternatives. Within the coming decade, a primary focus of the debate will be on the future economic viability of the domestic automobile recycling industry, and it is here that this study suggests additional research. If current and anticipated trends result in a domestic recycling industry that is not economically viable, public concern will be increased significantly. Technologies being developed and adopted to improve the fuel efficiency of automobiles may be at risk if the adoption of those technologies is perceived to contribute to a less viable recycle industry.

1. INTRODUCTION

Historically, scrapped automobiles in the United States and most developed countries have been recycled to retrieve their ferrous and, more recently, non-ferrous metals. Prior to the early 1960s, compact, "baled" automobiles, which included ferrous and non-ferrous metals as well as non-metallic materials, were sold as a low-quality feedstock to steel mills. In the mid 1960s, automobile "shredders" were introduced to reduce the labor required for recycling and to improve the quality of the materials recovered. Capable of separating ferrous, non-ferrous, and other components, automobile shredders have become the industry standard. The remaining components, e.g., plastics, rubber, fabrics, and dirt, are commonly referred to as automobile shredder residue (ASR) or "fluff" and are currently landfilled.

Unfortunately, the automobile recycle industry that has developed around the shredder is facing trends that may threaten its future economic viability -- trends that indirectly may call into question the energy and economic viability of new automobile technologies. More specifically, the automobile recycling industry faces two main challenges. First, the material composition of automobiles is changing. To improve the fuel efficiency of automobiles, manufacturers have turned to light-weight plastics and aluminum. Although aluminum can be separated and sold as a high-value material, plastics are currently landfilled along with other components of ASR. From the perspective of the shredder, larger percentages of non-metallics decrease the economic viability of automobile recycling by reducing the percentage of the automobile that can be sold for recycling and increasing the quantity of material that must be landfilled. From a broader perspective, the increasing percentage of non-metallics calls into question the life-cycle energy implications of adopting light-weight materials that are not recycled.

The second challenge to the automobile shredder industry is the increasing cost of landfill and stricter environmental regulations that may threaten the future disposal of ASR in conventional landfills. The cost of conventional landfilling has increased sharply in most parts of the United States during the past decade in response to requirements for new environmental controls and difficulties in siting new landfill facilities. Environmental concerns about some of the components in ASR have also been raised -- in particular, automotive oils and lubricants found in ASR, and polychlorinated biphenyls (PCBs) contained in some "white goods" (e.g., refrigerators and other household appliances) that have often been processed with automobiles. Although approaches have been found to address these environmental concerns, the landfilling of ASR remains controversial.

Threats to the current system of recycling automobiles have not gone unnoticed in the United States, Europe, or Japan. Methods for addressing those threats do differ, however. In general, research has focused on either reducing the quantity of ASR that must be disposed of or, alternatively, developing new processes to turn ASR from a waste into a resource. Activities in Europe have focused on hand-disassembly of automobiles, with the objective of collecting and recycling plastics and other hard-to-recycle materials, in addition to metallics. In many cases, plastics can be recycled economically if individual resins remain separated and contaminants are kept at low levels. Companies, such as BMW, have established disassembly centers to retrieve plastics and other materials that would otherwise be landfilled. Although these programs can recycle a very large percentage of the vehicle, the economic viability of such programs when operating full scale has been

questioned and is yet undetermined. Whereas shredders were adopted in part to avoid the high cost of labor, these disassembly centers depend primarily on hand-dismantling.

Efforts in the United States have been targeted at (1) the removal of selected plastic parts (e.g., dashboards and bumper covers) prior to shredding and (2) the utilization of ASR. Several technologies have been considered for the utilization of ASR, including incineration to retrieve the substantial heat value of ASR and sophisticated physical and chemical separation technologies to retrieve individual plastic resins. Unfortunately, these methods raise environmental concerns in some cases and questions of economic viability in others. Additional efforts in the United States, Europe, and Japan have focused on designing the automobile for recycling. These efforts include, for example, limiting the number of different resins used in manufacture, labeling parts to indicate material content, and designing fasteners to facilitate hand-dismantling.

How will future trends in automobile material composition and landfill costs affect the economic viability of the current automobile recycle industry? Will new automotive materials and technologies, developed with fuel efficiency improvements in mind, be threatened if those materials and technologies lead to larger quantities of waste entering our landfills? Are these new technologies and materials attractive from a life-cycle energy perspective if recycling is not possible? If future trends lead to an automobile recycling industry that is no longer economically viable, who will take responsibility for automobile recycling or disposal? Will owners of automobiles be forced to pay to have their vehicles disposed of or recycled; will taxpayers be forced to directly subsidize the automobile recycle industry; or will automobile manufacturers be forced to assume responsibility for the recycle/disposal of the vehicles they produce? Will the adoption of radically different approaches to automobile recycling in countries other than the United States result in market barriers for U.S. automobile makers?

This report presents preliminary information to assess these questions. Section 2 presents background information on automobile recycling in the United States. That section contains information on the number and average lives of vehicles in the United States, an overview of current recycling practices and technologies, the structure of the U.S. automobile recycling industry, the current regulatory environment, and trends in the material composition of automobiles. Section 2 also provides information on the disposal of ASR, developmental technologies to utilize ASR, and methods to reduce the quantity of ASR.

Section 3 reviews automobile recycling in European countries and Japan with an emphasis on identifying differences between automobile recycling in the United States and these countries. Europe and Japan face different challenges in terms of their solid waste disposal, and these countries have taken different approaches to promoting automobile recycling. In addition to reviewing these approaches, Section 3 reviews public perceptions and the economic viability of automobile recycling in Europe and Japan.

Section 4 presents detailed information on the energy impacts of the recycling status quo, as well as several scenarios that reflect probable future trends concerning materials composition and recycle. This section investigates whether the energy benefits from using light-weight materials during a vehicle's operational life balance against the energy losses incurred at the disposal stage. Information is provided on (1) the material content of the average car over the period 1976 to 2000, (2) the average energy contents of materials used in automobile manufacture, (3) estimated energy savings from the use of recycled vs. virgin materials, and (4) estimates and projections of the average

fuel efficiency of cars over the 1976 to 2000 time frame. This information is used to estimate the life-cycle energy consumption of a "typical" car manufactured in selected years given, the recycling status quo and given several scenarios that depict possible future approaches to recycling. Information is also provided on the life-cycle energy consumption for the fleet of U.S. automobiles under different scenarios. Conclusions from this study are summarized in Section 5.

2. AUTOMOBILE RECYCLING IN THE UNITED STATES

Reclaiming materials from scrapped automobiles is commonly practiced in the United States (as in most developed countries) at facilities called "shredders." This chapter discusses the existing automobile recycling industry in the United States, issues related to changing automobile composition and shredder residue disposal, and approaches that have been adopted or are being considered to overcome particular problems with or barriers to automobile recycling.

2.1 BACKGROUND

To understand the energy and economic implications of current and possible future automobile recycling practices, general information regarding current automobile recycling practices is necessary. The following sections discuss recycling rates and practices, as well as the structure of the recycling industry.

2.1.1 Automobile Use and Life in the United States

In 1991, there were over 180 million automobiles and trucks in use in the United States.[1] This marks a 45% increase since 1976. Not only do Americans own more cars now, but they are using their cars longer. The average age of automobiles and trucks in use in 1991 was 7.9 and 8.1 for cars and trucks, respectively.[2] This compares to 1970 when the average car was 5.6 years old and the average truck was 7.3 years old. Furthermore, 50% of the total automobile population was 6.7 years or older in 1991, compared to being only 4.9 years or older in 1970. The current average vehicle life (cars and light trucks combined) is approximately 14 years.[3] Each of these vehicles is driven approximately 100,500 miles during its lifetime.[4]

2.1.2 Historical Percentages of Automobiles Recycled

The practice of automobile recycling, in some form, is long-standing. Automobile junkyards specialize in collecting, reconditioning, and offering for reuse various parts of junked cars. Materials recovery at shredders is a much newer phenomenon, the process having been introduced in the 1960s. By the mid-1970s, 80% of scrapped cars were being recycled in some process, while over 50% were being processed at shredders.[5,6] In 1980, 90% of scrapped cars were being recycled; over 60% were processed at shredders.[7] Currently, it is estimated that 90% of scrapped cars are being processed at shredders.[8]

2.1.3 An Overview of Current Recycling Practices in the United States

2.1.3.1 The Adoption of Automobile Shredders

Prior to the 1960s, various processes were used to recover the steel in junked cars.[9] Through the late 1950s, usable parts were removed and open burning of automobiles was performed to remove the combustible, non-metal components.[9] This process was discontinued as prohibitions against open

burning were enacted. In response, some processors developed incinerators in which the junked automobiles were burned. Energy use and costs were prohibitively high, however, and pollution control was inadequate.

Another technique employed was "baling." In baling, all materials remain present in the automobile hulk resulting in a material which is used as ferrous scrap without further processing.[7] However, because the material is contaminated and non-homogeneous it is not a highly marketable material. Because these processes failed to produce homogenous metal scrap efficiently and with adequate pollution control, shredding technology was introduced in the 1960s.

2.1.3.2 Current Technology

Shredding systems are designed and employed primarily to remove the ferrous portion from the non-ferrous portion of discarded items. Discarded items processed at shredders include automobiles, white goods (appliances), and other waste objects containing sheet and light-structural steel.[9]

Some hand-dismantling (e.g. of radiators, tires, batteries, and fuel tanks) occurs before automobiles are fed into a shredder.[6,7] The automobile is then fed by crane or conveyor belt to a grate-discharge hammermill-type shredder.[6,10] The mill actually shreds the object into approximately fist-sized fragments.

The pieces of shredded material are then conveyed through a series of separators.[6,9,10] Approximately 95% of the ferrous metals are recovered by initial magnetic separation.[6] The lightweight material, "fluff" or automobile shredder residue, is separated by air cyclone. The remaining material is a mixture of high density materials, containing between 20 and 80% (by weight) recoverable nonferrous metals depending on variabilities among shredders (e.g., grate spacing and type of cleaning processes).[9] Other components include glass, dense plastics, rubber, and residual ferrous metals.

Prior to 1970, this nonferrous, dense material, with the exception of large homogenous pieces, was landfilled. However, the value of the materials (e.g., aluminum, copper, and zinc) and the development of separation processes (e.g., employing the use of liquids of different densities to separate out materials of different specific gravities) made separating various metals possible and feasible. The separation and recycling of nonferrous materials often occurs away from the primary shredder facility at central recovery sites.[6]

Fluff generated from automobiles accounts for about 25% (by weight) of the shredded material. Industry representatives report that fluff produced at all U.S. shredders is currently being disposed of in RCRA Subtitle D landfills.[11] Table 2.1 lists the components of fluff by weight. It does not, however, include dirt, stones and glass fines. Elsewhere, dirt has been estimated to account for 15% of the fluff.[12,13]

2.1.3.3 Structure of the U.S. Automobile Recycling Industry

The most recent (1988) survey of the U.S. shredder industry shows that there are about 180 shredders operating in the United States.[14] Although this number equals the number reported in a

Table 2.1 Components of fluff

Component*	Percent by Weight
Fiber	42.0
Fabric	3.1
Paper	6.4
Glass	3.5
Wood splinters	2.2
Metals	8.1
Foam	2.2
Plastics	19.3
Tar	5.8
Wiring	2.1
Elastomers	5.3

*Dirt, stone and glass fines are not included in this breakdown.
Source: Hubble, W.S., I.G. Most and M.R. Wolman 1987. *Investigation of the Energy Value of Automobile Shredder Residue.* DOE/ID/12551-1. U.S. Department of Energy, Office of Industrial Programs, Washington, D.C.

1980 survey,[15] the industry has experienced some change with new installations and machines replacing old ones. The facilities are distributed across the four major regions of the United States as follows: northeast, 43%; northwest, 5%; southeast, 27%; and southwest, 25%. U.S. shredders process approximately 150,000 cars per week (or 7.8 million annually). Annual production in 1987 was estimated to have been 12 million tons, keeping most shredders "near capacity".[14]

Among the factors that affect the economic viability of shredders is the price that can be obtained for marketable products--the ferrous and nonferrous metals. Another factor includes operating costs such as costs for energy, labor, and disposing of the waste produced during processing--the automobile shredder residue.

2.1.3.4 Regulatory Environment

Two separate areas of federal regulations have potential effects on the shredding industry. The first is the Corporate Average Fleet Economy (CAFE) regulations that require automobiles to achieve increasingly higher fuel efficiencies. Automobile manufacturers have responded by reducing the size of cars, improving their aerodynamic quality, and decreasing the weight by substituting lighter-weight materials for steel in order to reduce overall vehicle weight and improve gas mileage. Issues

related to these material substitutions and their potential effects on the viability of automobile shredders are discussed next in Section 2.2.1.

The second type of regulations potentially affecting the shredding industry are those related to waste disposal, particularly as they affect the disposal of automobile shredder residue. These issues are discussed in Section 2.2.2.

2.2 ISSUES

2.2.1 Trends in Materials Composition and Challenges to Recycling

2.2.1.1 Historical, Current, and Projected U.S. Automobile Composition

The primary component of automobiles, both historically and currently, is steel. However, changes in the amount of steel, both in terms of total number of pounds and weight relative to other components, has been decreasing as automobile manufacturers reduce the size of automobiles and substitute lighter weight materials for steel in order to reduce the total weight of the vehicle. These changes have occurred in response to public demands for and government requirements for more fuel efficient vehicles, i.e., CAFE standards.

Chapter 4 of this report provides a detailed breakdown of historical, current, and projected automobile composition. In general, the data show that as the amount (in weight) of steel has been decreasing in the average automobile (25% between 1976 and 1992), the amount of plastics has increased 49.5% between 1976 and 1992 (162.5 lbs. to 243 lbs.).[16] Aluminum content has increased 103% during the same period (85.5 lbs. to 173.5 lbs.). This trend is expected to continue, with the weight of plastics increasing to 400 lbs. in 2000,[17] and aluminum increasing to 340 pounds, marking 52% and 75% increases, respectively. Weights of other components, such as glass, rubber, and fluids have remained relatively constant and are expected to continue to do so.

2.2.1.2 MPGs vs Recycling Viability

In their haste to meet CAFE standards, automobile manufacturers gave less than primary importance to automobile recyclability. (See Section 2.3 for a discussion of automobile manufacturers' recent investigations of and improvements in recyclability). However, the shredding industry, as early as 1977, noted the potential effect of changing automobile composition on shredders' output, although concerns were expressed in terms of reduced quantities of scrap available for the steel industry rather than in terms of the economic viability of the shredding industry.[15]

The increases in plastics and decreases in steel that increased the average MPG of automobiles have decreased the recyclability of the automobile. On a per car basis, less steel is available for retrieval and sale, reducing the income of the shredders; and more shredder residue is produced and must be disposed. The net result is increased costs and decreased revenue per car.

The increased use of aluminum has had less detrimental effects on the viability of shredders because it--as a component of the mixed nonferrous metals--has had value and has been marketable. However, whether increased aluminum use can improve shredder viability depends on the recyclability of the aluminum. (The use of different additives can result in problems with aluminum recyclability).

2.2.2 Automobile Shredder Residue Disposal or Reuse

According to the Big 3 U.S. automakers (Chrysler, General Motors, and Ford), 2.5 to 3.0 million tons of ASR are landfilled annually in the United States.[18] This represents 1.5 to 2% of the size of the municipal solid waste stream in the United States. Because of contaminants found in ASR, disposal methods have caused concern, scrutiny, and in some cases regulation. The following sections discuss those components of ASR that cause environmental concern and the costs and availability of various ASR disposal methods.

2.2.2.1 ASR and Environmental Concerns

Although the components listed previously and in Table 2.1 are those that primarily constitute ASR, various toxic or hazardous materials can be included in small quantities in the mixture. These materials include oil(s) and other fluids that cling to the foam and fibrous materials within the ASR. Also present among the small amounts of metals contained in ASR are lead, cadmium (used to coat steel), and other heavy metals.[10,19,20] Polychlorinated biphenyls (PCBs) have been found to be present in some samples of ASR (Section 2.2.2.2 discusses this situation).

2.2.2.2 ASR Disposal in Landfills

All ASR generated by the shredding industry is currently being disposed of in RCRA Subtitle D landfills (i.e., municipal solid waste landfills required to maintain minimum standards for protecting human health and the environment).[11] However, the increasing amounts of ASR and the escalating costs of landfill disposal have engendered concern among industry representatives and shredder operators who fear that disposing ASR will become too costly for them to remain in business. Recent disposal costs are estimated to range from approximately $10 to $100 per ton, depending on the area of the country.[20,21] Landfill disposal costs, even without additional restrictions, are expected to continue to increase, possibly doubling within ten years.[22]

There also exists the possibility that because of environmental risks ASR may be classified as a special or hazardous waste. Over the last several years, state regulators and the U.S. EPA have begun closer monitoring of ASR and shredders. Regulators closed a California shredder in 1986 because of ASR contamination, subsequently allowing it to reopen after it paid penalties and agreed to use a lead-encapsulating process when ASR was being stored.[23] More recently, federal and state regulators cracked down on New England facilities. In 1988, two Massachusetts facilities were forced to close by the Massachusetts Department of Environmental Quality Engineering (DEQE) when the DEQE declared the ASR to be a hazardous waste because of excessive levels of PCBs.[23,24] The remaining four shredders in New England independently closed until the disposition of ASR became certain. Federal agents closed a Missouri shredder, also in 1988, to test its ASR. Throughout this period, independent laboratory tests showed PCBs to be below regulated levels (50 ppm).[24] These facilities have since resumed operation, but have limited their throughput of appliances in order to reduce the level of PCBs in the ASR.[11]

At this time, the ASR is considered a non-hazardous waste, except in California (because of cadmium restrictions).[20] However, even in California, disposal is occurring in Subtitle D landfills only after a chemical fixation process is employed (at a cost of about $20 per ton). Other states have begun to require ASR treatment to fix and immobilize heavy metals before landfilling or have imposed other regulations.[17] For example, Massachusetts requires shredders to close if more than

7 percent of fluff is oily substance. The U.S. EPA is currently examining testing protocols by which to determine the toxicity of ASR.[8] It is also possible that the forthcoming reauthorization of the RCRA will mention ASR disposal.

2.2.2.3 ASR Incineration

Although shredder operators currently dispose ASR in landfills, many did consider and plan to use incineration to dispose of their ASR. It has been estimated that by the end of 1973 over 20 incinerators for ASR had been built by shredding operations, but due to problems with economics, acceptance, and environmental restrictions (especially the Clean Air Act), these facilities were never operated or were soon closed.[17] The costs of ASR incineration would depend on the composition of ASR, local landfill costs, the type of pollution control equipment required to meet regulatory standards for emissions, and the type of incinerator.[17]

Several organizations have since reexamined the possibility of incinerating ASR. An Idaho company determined that a fluidized bed combustion process could be an economical disposal alternative.[17] Based on its test runs with tires and electrical hardware, Westinghouse proposed using plasma incineration to dispose of ASR.[25] Energroup, Inc. of Maine conducted test burns of ASR in order to estimate the energy value of ASR. They also sampled air emissions and tested fly and bottom ash for contaminants.[10] It was found that using the then-current (1987) Best Available Control Technology (BACT) kept emissions below State of California Guidelines. However, total suspended particulates (TSP) were only marginally acceptable, indicating that the fabric filter that was used was undersized for the system. The researchers acknowledge the potential for the emission of dioxins (PCDDs) and furans (PCDFs) and the need for further assessment, but they did not measure their emission during the test runs. A 1987 U.S. EPA study showed that a costly high-temperature afterburner would be required to prevent emissions of dioxin.[17] The Energroup study also found "substantial" lead levels in its one sampling of fly ash.[10]

Using the extraction procedure (EP) test for toxicity, the Energroup study found that combustion bottom ash samples could be classified as hazardous waste because of their high lead content, although various results were received from different laboratories.[10] The U.S. EPA has replaced the EP test with the toxic characteristic leaching procedure (TCLP), and it is unknown whether ash from ASR combustion could be classified as hazardous using the TCLP test.

It is possible, however, to treat incineration ash so that metals leaching is reduced or eliminated, allowing the treated ash to be disposed of in a RCRA Subtitle D landfill. At least two processes for ash treatment are known to exist currently.[20]

2.2.2.4 ASR Recycling

The concept of ASR recycling is relatively new and involves retrieving various components of the ASR for reuse. Retrieval of ASR components can occur prior to the shredding process by dismantling all or certain parts, or after shredding by separating out individual components of ASR. Plastics have received considerable attention relative to other components of ASR because they represent a large portion of the ASR and are recyclable. Ongoing research and developments related to ASR recycling are discussed in Section 2.3.

Concerns related to automotive plastics recycling include 1) plastics being contaminated by paint, metal, adhesives, and other plastics; 2) deriving a homogeneous material from the recycled plastics; 3) having or creating an infrastructure sufficient to conduct the recycling (including transportation, storage, and processing); and 4) identifying and developing markets for the recycled materials.

The problems of plastics contamination and homogeneity are being addressed by research and programs geared toward designing cars for recycling and developing effective separation techniques.[26,27] However, the processes proposed require the use of solvents, which can pose environmental questions and may require special disposal methods themselves.

Assuring an adequate infrastructure for handling the recycled plastics and assuring the commercial viability of the recycled plastics may be tasks as difficult as developing the technology for recycling. Although the auto industry acknowledges that the existing recycling infrastructure in the United States is better than in other countries,[28] it also recognizes that improvements in the infrastructure are necessary.[29] These improvements include having more dismantlers who can and will handle plastics,[30] and forging relations among the dismantlers, the recyclers, and the potential markets.[29]

2.3 CURRENT APPROACHES TO OVERCOMING PROBLEMS ASSOCIATED WITH AUTOMOBILE RECYCLING

Restating the problems associated with ASR may contribute to a greater understanding of the approaches being developed to overcome them. The increasing use of non-metal components raises potential economic and environmental problems. From an economic perspective, the viability of automobile shredders is reduced as (1) the percentage of the vehicle that must be landfilled increases, and (2) the cost of landfilling rises. To increase profitability, shredders would like to maximize the percentage of the vehicle that is recyclable (and marketable) and minimize the percentage that must be disposed of. Moves to ban non-recyclable materials from automobiles could jeopardize automobile manufacturers' current and developmental fuel efficiency technologies unless recyclability is improved. In addition, automobile manufacturers want to promote the economic health of the automobile recycling industry to avoid being forced, by legislation or regulations, to assume responsibility for recycling or disposing of the vehicles they produce.[31]

From an environmental perspective, ASR may pose risks when landfilled. Automobile shredders and manufacturers are interested in assuring that ASR quantities are minimal and the toxicity of ASR is consistent with regulatory requirements. Public concerns about ASR toxicity could encourage the classification of ASR as a hazardous or special waste. Note that hazardous waste landfills are an order of magnitude more expensive than the currently used RCRA Subtitle D landfills.

2.3.1 Technological Solutions

2.3.1.1 Designing for Recycling and Pre-Shredding Disassembly

Technological advances are currently proceeding in the development and adoption of methods to facilitate the removal of selected non-metallic components prior to shredding. These advances,

where they are applied to new automobile designs, are commonly referred to as "designing for recycling." Most of these approaches are targeted at the pre-shredder collection of automotive plastics, and various sophisticated and relatively simple approaches are being considered and, in some cases, adopted. Large and easy-to-disassemble plastic components, such as dashboards and the plastic covers on bumpers, can be removed for recycling prior to shredding. Trial systems to collect plastic bumper covers have been put in place by a handful of shredders in cooperation with resin manufacturers that can utilize the collected clean resin in their recycling operations. The move toward plastic body panels has also created recycling opportunities. For example, GE Plastics, a major producer of plastics for body panels, reached an agreement with a metal scrap company in 1991 to accept thermoplastic body panels for recycle. The panels must be removed prior to shredding.[32]

Employing a system whereby the 60 or more plastic types used in automobile parts[33] can be easily identified is another approach to advancing automobile recycling. The Big 3 U.S. automobile manufacturers have ordered their plastic parts suppliers to mark those parts with a universal code that identifies the specific resin contained in the part.[34]

Automobile manufacturers are also considering a reduction in the number of different plastic resins used in vehicles to increase the overall viability of plastics recycling. For example, moves are currently underway to replace various plastic resins with polypropylene (PP) in the manufacture of interior components. One report suggests that by 1995, the use of PP in automobiles will be 70% more than the 1990 levels (from 22.4 kg/car in 1990 to about 38 kg/car in 1995).[35]

Certain types of plastics are more difficult to recycle than others. For example, the class of plastics known as thermosets cannot be melted and, therefore, these plastics cannot be remolded into new products. Thermosets can be ground into a fine powder and used as a filler with virgin resins or, alternatively, thermosets can be burned to retrieve their heat energy. However, the economic viability of these approaches to recycling are suspect at this time.[36]

The other main class of plastics, thermoplastics, can be melted down and reformed into new products. Fortunately the majority of plastics used in automobiles are thermoplastics. Unfortunately, the numerous plastics that are classified as thermoplastics cannot, as a general rule, be mixed together, melted, and reformed into new products. One thermoplastic may differ from another as much as aluminum differs from steel. The current lack of low-cost and reliable systems for the separation of different thermoplastics from a commingled stream limits the recycling of automotive as well as other plastic wastes. (The following Section discusses research in this area.) The absence of a process to remove plastics from a commingled stream may be inconsequential if an economically viable system can be put in place to segregate plastics by hand-dismantling or otherwise disassembling plastic components.

2.3.1.2 Alternative/Innovative Methods to Recycle ASR

The adoption of automobile shredders in the 1960s and 1970s resulted in part from the need for clean, uncontaminated wastes streams and the high cost of hand-dismantling.[37] A move away from shredding and toward hand-dismantling will raise questions about total cost. If hand-dismantling is not a viable economic option, solutions must be targeted at recycling or otherwise utilizing/disposing of ASR.

One area of research is focusing on technologies to separate materials from ASR for recycling. These methods have focused primarily on plastics, which make up about 20% of ASR. With a view toward sustaining the current shredder industry's viability, Argonne National Laboratory (ANL) has worked toward the development of a process to recover specific thermoplastics from ASR.[21,38] The plastics would be of sufficient purity to serve as inputs to secondary recycling process, i.e., processes that produce products with physical and/or chemical properties less demanding than those of the original product. The ANL process involves three steps: physical separation, solvent treatment, and solvent extraction of the thermoplastics.[39] The process is targeted at the removal of acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), PP, and polyethylene. According to ANL, extracted ABS and PVC have been 90% pure.[40] The PP and the polyethylene are removed in one common stream. In the lab, 92% of the solvents used in the process has been recovered, which is both environmentally and economically crucial to the success of the process. ANL reports that this process has recovered up to 50% of the plastics from the ASR.[41]

With further technological progress, the plastics portion of ASR may also be utilized through the adoption of alternative technologies, such as hydrolysis, methanolysis, and pyrolysis.[42] Although these systems may hold promise for automotive plastics and waste plastics from other sources, a relatively clean waste stream will be required. Current initiatives with these technologies are focused on the relatively clean plastic wastes generated during the manufacture of automotive parts. If these technologies are to be applied to the plastics found in current ASR, some sort of front-end separation technology to obtain a sufficiently pure stream of plastics will be required--a non-trivial obstacle.

Another technical approach to ASR utilization is the retrieval of ASR's energy content through combustion. These approaches, which raise environmental questions (discussed in Section 2.2.2.3), would retrieve energy from the high-Btu waste stream and also reduce the weight and volume of residue that would require disposal. The U.S. Department of Energy has previously investigated the energy value of ASR.[9,10]

2.3.2 Industry Initiatives/Institutional Solutions

2.3.2.1 Industry Attempts to Recycle Automobile Plastics

Several industry efforts are underway to recycle plastics from scrapped autos. These efforts, almost without exception, are cooperative efforts among automobile manufacturers, the plastics industry (Society of the Plastics Industry [SPI] and the Automotive Plastics Council [APC]), plastics materials and parts suppliers, and the automobile scrapping and shredding industries (Automotive Dismantlers and Recyclers Association). For example, the APC with the assistance of members of the Automotive Dismantlers and Recyclers Association are jointly investigating recycling methods and infrastructure requirements;[43] BMW and the Automotive Dismantlers and Recyclers Association are establishing recycling centers to investigate needed improvements in design for disassembly;[44] and there is a jointly developed pilot plant process that recycles styrene maleic anhydride (SMA) from instrument panel supports.[45,46] DuPont has developed a thermoplastics recycling process that can renew thermoplastics into "first-quality polymers" and can potentially be applied to various automotive plastics.[22]

2.3.2.2 The Big 3's Vehicle Recycling Partnership (VRP)

The VRP was formed by the Big 3 U.S. automakers to study ways to recycle plastics from scrapped automobiles. VRP's main areas of concentration are: (1) issues related to ASR; (2) recovering recyclable parts with selective disassembly; (3) establishing guidelines and designing for disassembly; and (4) communications.[29] The VRP endeavors to provide recycling applications, facilitate recycling in design considerations, connect the recyclers with the dismantlers, and provide technical assistance to those interested in entering the auto recycling industry.

NOTES FOR CHAPTER 2

1. Data based on vehicle registration. Davis, S.D. and S.G. Strang 1993. *Transportation Energy Data Book: Edition 13.* ORNL-6743. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

2. Davis, S.D. and S.G. Strang 1993. *Transportation Energy Data Book: Edition 13.* ORNL-6743. Oak Ridge National Laboratory, Oak Ridge, Tenn.

3. Shaw-Pin Miaou, in unpublished research conducted at Oak Ridge National Laboratory (1990), estimates the median lifetime of vehicles to be 11.77 years for passenger cars and 16.05 years for light trucks (based on vehicle scrappage/survival rates). We derive the average vehicle life of 14 years by approximately averaging these two figures. The possible vehicle lifetime overestimation thus derived based on simple averaging rather than weighted averaging is justified because motor vehicle records are maintained for vehicles not more than 15 years old (and therefore may under-report old vehicles). These estimates are higher than previous figures by Holcomb and Koshy (1984), who estimated car and truck lifetimes to be 10.9 and 14.9 years, respectively. Much of the general literature to date has used an average automobile lifetime of 10 years.

4. The number is rounded to 100,000 in the analysis presented in Chapter 4. Farrissey, W.J. 1991. RIM parts for automobiles--Life cycle energy and ecobalance. In *Designing for Recyclability and Reuse of Automotive Plastics,* SP-867. Society of Automotive Engineers, Inc., Warrendale, Penn., pp. 1-8.

5. Bilbrey, J.H. Jr., J.W. Sterner, and E.G. Valdez 1978. Resource recovery from automobile shredder residues. Paper presented at the First World Recycling Congress, Swiss Industries Fair, Basel, Switzerland. March 6-7.

6. Harwood, J.J. 1977. Recycling the junk car. *Technology Review* **79**(4):32-37.

7. Bever, M.B. 1980. The impact of materials and design changes on the recycling of automobiles. *Materials and Society* **4**(3):375-385.

8. "Old autos pave road to making new steel" 1993. *American Metal Market,* February 18, p. 13A.

9. Wolman, M.R., W.S. Hubble, I.G. Most, and S.L. Natof 1986. Power generation from automobile shredder waste fuel: Characterization and system feasibility. In *Proceedings of 1986 National Waste Processing Conference.* The American Society of Mechanical Engineers, New York, pp. 91-103.

10. Hubble, W.S., I.G. Most, and M.R. Wolman 1987. *Investigation of the Energy Value of Automobile Shredder Residue.* DOE/ID/12551-1. U.S. Department of Energy, Office of Industrial Programs, Washington, D.C.

11. Cutler, Herschel 1993. Executive Director, Institute of Scrap Iron and Steel, Inc. Washington, D.C. Personal communication with T. Randall Curlee, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June 16.

12. Vandermerwe, S. and M.D. Oliffe 1991. Corporate challenges for an age of reconsumption. *Columbia Journal of World Business* **26**(3):6.

13. Furukawa, Tsukasa 1993. Japanese companies research fluff problem; form group to study recycling alternatives. *American Metal Market* **100**(165):8.

14. "U.S. Shredder Survey Shows Little Change" 1988. *Recycling Today* March, p. 58-64.

15. "Exclusive Updated Survey of Automobile Shredding" 1980. *Scrap Age* October, p. 91-98.

16. *Ward's Automotive Yearbook* 1977-1993. Ward's Communications, Inc., Detroit, Mich.

17. Jody, B.J. and E.J. Daniels 1991. Automobile Shredder Residue: Treatment Options. *Hazardous Waste and Hazardous Materials* **8**(3):219-230.

18. Wrigley, A. 1991. Car recycling consortium to be formed. *American Metal Market* September 27, p. 2.

19. "Recyclable car not too far away, say AIC" 1991. *Aftermarket Business* August 1, p. 76.

20. Schmitt, R.J. 1991. Automobile shredder residue--The problem and potential solutions. In *Second International Symposium Recycling of Metals and Engineered Materials*, The Minerals, Metals and Materials Society, pp. 315-331.

21. Bonsignore, P.V., B.J. Jody, and E. Daniels 1991. Separation techniques for auto shredder residue. In *Designing for Recyclability and Resuse of Automotive Plastics* SP-867. Society of Automotivie Engineers, Inc., Warrendale, Penn., pp. 59-63.

22. "Second look" 1993. *Automotive News* March 29, p. 6i.

23. Worden, E. 1988. Car shredding industry hit by EPA crackdown. *American Metal Market* **96**(June 28):1,8.

24. "DEQE must act to end abandoned car crisis; shutdowns New England-wide threaten public health and safety" 1988. PR Newswire, June 27.

25. Goodwin, M.E. 1991. Westinghouse may incinerate fluff. *American Metal Market* **99**(4):7.

26. "Plastics recycling plant joins big three chemicals" 1992. *Chemical Marketing Reporter* December 12, p. 5.

27. "Recycling recovered plastics from scrapped cars" 1992. *High Performance Plastics* Elsevier Advanced Technology Publications, November.

28. The amounts of plastic and other recycled materials being recovered in Germany (as per laws requiring return of packaging materials) have completely overwhelmed the recycling infrastructure and have resulted in the recovered materials being shipped out of the country for recycling or disposal (Protzman, Ferdinand 1993. Germany's push to expand the scope of recycling, *The New York Times* July 4, p.8). This has led many to question the economic viability and the practical feasibility of recycling products, such as automobiles, themselves.

29. "Car dismantling efforts will rely on scrap industry" 1992. *American Metal Market* December 3, p. 12A.

30. Miller, Bernie 1992. SPI (Society of the Plastics Industry) launches car-recycling program. *Plastics World* **50**(5):16.

31. As is discussed elsewhere in this report, moves are currently underway in Europe to shift the responsibility for recycling from the automobile scrap industry to automotive manufacturers.

32. Rogers, Jack K. 1991. Redesigning Autos. *Modern Plastics* **68**(5):86-91.

33. "All recyclable car on auto show card" 1993. *American Metal Market* April 5, p. 10.

34. Gittleman, D. 1992. *Prospects for recycling automotive polymer waste*. Thesis, Tufts University, Medford, Mass.

35. Forcucci, F. and D. Thompkins 1991. Automotive interiors--Design for Recyclability. In *Designing for Recyclability and Reuse of Automotive Plastics* SP-867. Society of Automotive Engineers, Inc., Warrendale, Penn., pp. 41-46.

36. The automobile industry is currently experimenting with the recycle of thermoset wastes that are generated in the manufacturing process. For example, processes have been developed to grind and reuse reaction injection molding (RIM) and sheet molding compound (SMC) thermosets as filler with virgin resins. In addition, pyrolysis can be used to convert these thermosets to fuel-grade gas and oil. The SMC Automotive Alliance, a branch of the Society for the Plastics Industry, has sponsored the development of a pyrolysis unit to convert SMC scrap from manufacturing operations to oil. The process could be applied to SMC from scrap vehicles if the SMC is removed prior to shredding. [Leaversuch, R.D. 1991. Chemical recycling brings real versatility to solid-waste management. *Modern Plastics* July, pp. 40-43.]

37. Curlee, T.R. 1985. Plastic Waste and the Market Penetration of Auto Shredders. *Technological Forecasting and Social Change* **28**(1):29-42.

38. "New Technology Recovers Plastics from Scrap Cars" 1993. *World Waste* April, p. 8.

39. The ASR is first agitated by air in a separator, and the polyurethane foam in the ASR goes to the top of a column. The small particles (less than 0.25 inches in diameter) of mostly dirt and glass fall out of the mixture. Solvents are then used to separate thermoplastics from the remaining, plastic-rich material.

40. "Process Recovers More from Junked Cars" 1993. *Research and Development* 35(1):14.

41. "Recycling recovered plastics from scrapped cars" 1992. *High Performance Plastics*, November. Elsevier Advanced Technology Publications.

42. In hydrolysis, super-heated steam and catalysts are used to reduce polymers to one or more monomers that can be repolymerized and recycled. Batelle Laboratories and SERI (Solar Energy Research Institute, now the National Renewable Energy Laboratory) have conducted research in this area. [Leaversuch, R.D. 1991. Chemical recycling brings real versatility to solid-waste management. *Modern Plastics* July, pp. 40-43.] Methanolysis uses methanol, rather than super-heated steam, to break down polymers. In pyrolysis, plastics and rubber are subjected to a high-temperature, oxygen-deficient environment, resulting in fuel-grade gas and oil. The SMC Automotive Alliance, a branch of the Society of the Plastics Industry, is investigating pyrolysis of SMC scrap. ["Auto plastics being tested for recycling potential" 1993. *Automotive News*, April 5, p. 38.]

43. "Auto plastics being tested for recycling potential" 1993. *Automotive News* April 5, p. 38.

44. "BMW wins award for automobile recycling effort" 1992. *Environment Week* 5(37).

45. "Car plastics recycling examined" 1993. PRS Automotive Service, March 2.

46. Several projects are being tested on plastics scrap (from production) with the goal of eventually applying them to scrapped automobiles. These include GM and its parts supplier investigating the making of major structural components from recycled SMC; GM, the SMC Automotive Alliance, the Vehicle Recycling Partnership, the Society of the Plastics Industry, and SMC producers developing an infrastructure for SMC recycling; and Ford and GE Plastics making and testing parts made from recycled automotive plastic scrap and PET.

3. AUTOMOBILE RECYCLING IN EUROPE AND JAPAN

Each year there are more than five million cars scrapped in Japan.[1,2] Estimates of the number of vehicles scrapped annually in Europe range from ten to 14 million,[3,4,5] with some industry watchers estimating that the number may be as high as 20 million by 2000.[6,7] Germany and the UK account for large portions of the European total, each year scrapping approximately 2.5 and 2 million cars, respectively.[8,9,10] What has been and is being done with these millions of cars is discussed in this section.

3.1 THE SITUATION IN EUROPE AND JAPAN

3.1.1 Current Recycling Methods

Automobile recyclers in the United States, Japan, and Europe have traditionally used very similar processes.[2] Once the cars are delivered to one of the world's 550 shredders,[11] processors inspect the cars for sealed containers, drain their fuel tanks, and feed them into a shredder. The steel is then magnetically separated from nonferrous materials, and it and other metals are cleaned and sold for reprocessing.[11] These recycled materials account for approximately 75% of the car's weight.[2,12] More than 95% of the recycled materials are metals; in 1989 only 2.5% of automotive plastics were recycled.[6]

The ASR that remains consists primarily of plastics, fibrous materials, glass and elastomers.[1,13] A breakdown of weight of ASR components is provided in Table 2.1 and Section 2.1.3.2. In Europe, Japan, and the United States, the fluff has been disposed of in landfills.[2] In Europe the fluff--estimated to be between 3 and 5 million tons annually--accounts for 2% of landfill mass.[14,15] Germany, alone, landfills an estimated 550,000 tons of fluff annually.[12] Estimates of the amount of automobile fluff disposed of annually in Japan vary considerably, ranging from approximately 700,000 tons per year[2] to 1.38 million tons per year.[1] Because the rate of vehicle registration in Japan between 1980 and 1989 was twice that of the United States, Japan is likened to have the fastest growing need for fluff disposal. If 1980-1990 automobile disposal methods were to continue, Japan is likely to double its fluff disposal requirements by 2010.[2]

3.1.2 Waste Management Issues: Costs and Environmental Controls

Among the three industrial regions--the United States, Europe, and Japan--it is the United States that generates the most waste on a per capita basis and recycles the least.[13] Japan has limited landfill space (given that it is only 20% of U.S. land area and much of it is mountainous)[2], and consequently recycles more and resorts to incineration more so than Europe or the United States. Most landfills in Europe are already at capacity and 70% of U.S. landfills will be so within 15 years.[13]

Europe's very limited landfill capacity combined with new regulations, both resulting in rapidly escalating landfill costs, are making current practices of disposing fluff much more difficult.[16] The

problems seemed to have occurred first in Germany[6] which is characterized as having a "growing landfill crisis."[17] Costs for general landfill disposal were $15/metric ton in 1980, $25/metric ton in 1985, and were expected to rise to $50/metric ton by this year.

The costs of disposing auto plastics in Germany was $1 million in 1980 and $3 million in 1986, but jumped to $13 million in 1987[18] primarily because of tougher environmental controls. For example, Germany has recently downgraded fluff from an industrial waste that costs $80 per metric ton to dispose of, to hazardous waste that costs $400 per metric ton.[14,19] In the early 1990s, German landfills began refusing elastomer (rubber-like resin) parts altogether or classifying them as requiring special handling, increasing their disposal costs ten-fold.[20]

3.1.3 Composition of Autos in Europe and Japan

Comparing the composition of European-made, Japanese-made, and U.S.-made automobiles is less than exact because the data are less frequently compiled and reported differently. For example, available data for European cars is presented in ranges of percentages per material type, while other data is reported by sales-weighted averages. Table 3.1 presents car composition data for European-, Japanese-, and U.S.-made cars. Generally, U.S.-made cars contain more plastics than European models, although plastics use can vary widely depending on the type of car and the country of manufacture.[6]

Table 3.1 Automobile composition, percentages by weight

Material	European middle class cars (ca.1989)[1]	Japanese cars[2]		U.S. cars[3]		All cars (sales weighted)[4]	
		1973	1989	1976	1992	1980	1990
Steel and Iron	57.0-76.5%	81.1%	75.7%	74.1%	66.9%	70.9%	62.1%
Aluminum	2.0-10.4			2.3	5.5	6.3	11.9
Other nonferrous metals	2.5-4.7	5.0	7.4	2.7	4.0	2.9	3.0
Plastics	1.2-12.6	2.9	7.5	4.3	7.7	6.7	9.2
Glass		2.8	3.0	2.3	2.8	2.6	2.8
Rubber	balance	8.2	6.4	4.1	4.2	5.1	5.0
Other non-metal				10.2[5]	8.7	5.9	6.0

[1] The processing of non-magnetic fractions from shredded automobile scrap: A review. 1989. *Resources Conservation and Recycling*. Elsevier Science Publishers, B.V./Pergamon Press.
[2] Tsukasa Furukawa, 1991. Japan automakers rev recycling (parts 2). *American Metal Market* 99(182):4.
[3] *Ward's Automotive Yearbook* 1977, 1933. Ward's Communications, Inc., Detroit, Michigan.
[4] Don Mathew and Andrew Rowell, *The Environmental Impact of the Car*, (Amsterdam, Greenpeace International, 1991), p.44, as cited in Dena Gittelman, *Prospects for Recycling Automotive Polymer Waste.* MA Thesis, Tufts University.
[5] Includes some quantity of "other ferrous" that was not reported separately by *Ward's* until 1983.

During the last few decades, automobile composition has changed considerably. Lighter weight materials are being used with much greater frequency. Plastics use has increased to improve the vehicle's efficiency by reducing its weight and improving its aerodynamics. In the 1960s, plastics contributed only 1 to 2% of vehicle weight, whereas it now comprises over 10% of the car by weight.[6,21,22] Modern cars often contain as many as 20 different resin types.[21,23] Projections of plastics content were recently as high as 20% of vehicle weight by 2000, due primarily to expected use of sheet molding. Because this material presents recycling difficulties, projections are now a more moderate 15% of vehicle weight by 2000.[16]

Of all plastic types, PP is experiencing the greatest increase in use. In 1991, new cars in Japan and Europe averaged 55 pounds of PP (about twice as much as the American-made counterparts). It is estimated that this could increase 30 to 50% by 1996. PP use is increasing as vehicle manufacturers attempt to improve the recyclability of their autos by reducing the number of resins used.[24]

Only Japan has experienced a trend of increasing vehicle weight (due to the increasing size of its cars). While the average U.S. vehicle weight decreased 13% during the 1980s, Japanese automobiles increased in weight by 10 to 20%.[1,2]

3.1.4 Public Perceptions

Concern for the environment has been on the rise in Europe and Japan. A 1990 survey in the European Community (EC) revealed that the environment was considered the most urgent and immediate problem, even more so than unemployment.[13] Consumers there are paying premiums for recyclables and recycled items. However, there are some differences among EC countries. For example, 80% of the market in Germany is willing to pay such premiums, while only 50% of the French market is. In Japan, a recent surge in environmental concern has been led by a grassroots consumer group. A 1990 poll among Japanese corporate chief executive officers cited the environment as the issue requiring the most attention and being the most important strategically during the upcoming decade.[13]

The literature regarding automobile recycling offers considerably more information about the German public's perceptions of and influence over recycling in general, and automobile recycling in particular, than about other European countries or Japan. This likely reflects several things, including Germany's urgent problem with landfill capacity and the highly vocal and effective environmental lobby in Germany, which seems to have been strengthened since German unification. The opening of East Germany has provided "dramatic proof of the consequences of ignoring the environment."[25]

Furthermore, the German public strongly supports recycling (including automobile recycling) but opposes incineration, and German officials seem disinclined to act against public opinion on this matter. The French are apparently "less vociferous" about incineration than the Germans, and it is "understood" that German automobile waste is currently being disposed of in French incinerators.[5]

3.1.5 Economic Viability of Auto Recycling

The economic viability of automobile shredding ventures in Europe and Japan depends on the same factors that influence American shredders: revenues from the metals recovered, processing costs, and the costs of disposing ASR.[11] Where disposal and processing costs are less than the value

of the materials recovered, scrapped automobiles have a negative value. This is the case currently in Europe and Japan (where the cost to the owner for disposing a car is 20,000 to 30,000 yen).[26,27] In the United States, however, junk cars have a positive value of approximately $100.

Existing and anticipated changes in automobile composition (see Section 3.1.3), particularly increased amounts of plastics, have caused car shredding companies in Germany to fear for their viability, and as a result German shredder operators, at one point, called upon the automotive industry to maintain a steel content of 70%.[28]

The economic viability of "stepped up" automobile recycling depends largely on the cost effectiveness of recycling the plastic components, as they currently comprise such a large portion of ASR and because the use of plastics is increasing. Although incineration is considered by many industry representatives to be the most cost-effective means of disposing plastics scrap,[5,6,29] it is not a viable option in many places due to various reasons including regulations and public acceptance.

To date, pilot programs--particularly European ones--for recycling automotive plastics require disassembly and segregation of parts, a labor intensive and potentially costly activity (especially given that the bulk of cars that will be recycled during the next ten years were not designed for easy disassembly). Research and pilot programs at Ford in Europe have found that 20 to 30 minutes of disassembly is cost efficient.[30] Beyond that time, costs begin to exceed the potential value of the removed parts.[29,31] Although Ford claims its results apply to most cars, BMW finds that the "optimum yield of parts" occurs at 90 minutes.[32] Pilot programs in Germany, which have had high levels of plastics recovery as their goal, have found the recycling to be non-profitable, with each car requiring 200 to 600DM to dispose of.[27]

Economies of scale should improve as the amount of plastic per car increases.[31] It is also anticipated that auto disassembly time (and thus labor costs) will be lessened once disassemblers begin handling coded plastic and parts fastened in easy-to-disassemble methods.[29,31] This, however, will not have any effect until the first generation of cars designed and manufactured for recycling reach their useful lives.

Another factor in the equation of economic viability of automobile recycling is the value of the recycled parts. It is currently estimated that virgin materials are less expensive than the recycled plastics, given an average dismantling cost of $0.27 per pound and the additional costs of transportation, regrinding, and processing.[21] Marketability of recycled plastics may be further hindered if the quality of the material is reduced.[33] Some European pilot programs have attempted to circumvent difficulties with marketability and value by implementing closed loop recycling, a system wherein parts are recovered specifically for reprocessing into other parts needed by the manufacturer. There is also concern that a surge of recycled plastics on the market could disrupt other economically fragile plastics recycling programs.[31] For example, the German system set up to recycle packaging, Duales System Deutschland, has operated deeply in the red, has had to store 70,000 tons of plastics, and is shipping some plastics out of the country for disposal.[34]

3.2 INTERNATIONAL APPROACHES TO AUTOMOBILE RECYCLING

The following sections investigate approaches adopted by European and Japanese government and industry to stimulate and implement automobile recycling.

3.2.1 Legislative Initiatives in Europe and Japan

3.2.1.1 Europe

Throughout Europe a flurry of activity--usually in the form of threats, planned and pending legislation--has occurred. It is widely acknowledged that automobile manufacturers' recycling programs have resulted from the threats of legislation, largely because the industry was trying to ward off legislation by proving it could take the initiative independent of government interference.[35] In Germany, the government is said to have granted the automobile industry an "unofficial grace period," during which time the industry could prove its willingness and ability to establish recycling without government mandates.[36]

European Community (EC)

EC legislation concerning automobile recycling is anticipated in 1995. However, some representatives of the automobile industry think the EC has given them insufficient guidance regarding automobile recycling, allowing demonstration and pilot recycling programs to proceed haphazardly. The concern in the industry is that the resources that have been devoted to recycling programs will have been wasted if the EC imposes legislation requiring a single recycling process.[34,35,37] The EC is expected, minimally, to require all cars sold within the Community to have certificates guaranteeing that disposal will occur through approved channels.[35]

Germany

Automobile recycling legislation in Germany is within the purview of the Minister of the Environment, who has threatened and proposed within the last few years various regulations regarding automobile recycling. As early as October of 1990, the Minister of the Environment submitted to Parliament a proposal requiring manufacturers to recycle 100% of automobile materials.[17] Although the legislation was not acted upon, it did indicate the German Government's seriousness about automobile recycling.

Subsequent legislative proposals focused on automobile manufacturer take-back programs. Because the minister was particularly concerned with the disposition of older cars,[38] the minister required manufacturers to take back their cars but distinguished between existing and new cars. The proposal required that owners of existing cars pay to scrap their cars if the cost would exceed the value of the materials recovered.[39] Another proposal attached to the take-back legislation set a goal for 1994 of 25% of the weight of plastic in cars to be made from recycled materials.[40]

The most recently proposed legislation would require all automakers (including importers) to take back for recycling their cars sold beginning in mid-1993. The draft law requires 20% of the plastics to be recycled now, and 50% by 2000, regardless of the economics. Auto manufacturers would be required to report their progress annually.[31,41] Industry is voicing opposition to the law because it believes the quotas are neither achievable nor economically feasible to implement.[41]

Some industry watchers have suggested that the proposed German requirement for automakers to take back their cars implies "more than a hint of protectionism" because it would be more difficult for foreign automobile manufacturers to take back obsolete automobiles. In effect, it could present "an effective barrier to free trade under the guise of environmentalism."[27]

United Kingdom

UK government involvement in automobile recycling has been limited to date to funding a consortium to study recycling.[42] No information regarding specific legislation has been identified.

France

Opposition from the automobile industry and the French Ministry of Industry caused the French government to cancel a decree that would have established a 95% minimum recycling rate to be achieved by 2003.[43] In lieu of the decree, automakers and the government have reached an agreement whereby the automobile manufacturers, with the assistance of the recycling industry, will work to improve recyclability of automobiles to 95% by 2010.

Netherlands

In keeping with the Dutch government's goal of recycling 60% of all waste by 2000, legislation is anticipated that will require recycling of cars and use of recycled materials in automobile manufacture. Although the automobile manufacturers will be required to take back their cars, the specific mechanism by which they are recycled and through which the costs are recouped will be left to the individual companies.[44,45]

3.2.1.2 Japan

In October 1991, the Ministry of Trade and Industry enacted regulations for the "Promotion of Utilization of Recycled Resources"; the Japanese Diet (congress) followed in April 1992 by enacting "Laws to Promote the Regulation of Recycled Resources."[2] Both actions were taken to encourage industry, including the automobile industry, to design products for easy recycling. The Ministry of Transport has also adopted a policy to support the use of recycled materials in automobiles, believing that automobile disposal costs will decrease and fewer automobile abandonings will occur.[26]

3.2.2. Recycling Initiatives in Europe and Japan

Automakers in Europe, particularly Germany, are leading their Japanese and American counterparts in recycling initiatives.[46] It appears that emphasis in the UK is towards dismantling before shredding, while Germany is aiming for complete disassembly.[6] The recycling programs of European car manufacturers, as a whole, are looking at several issues. Issues on the agenda include: instituting routines for auto disassembly; designing for easier disassembly; investigating robotic disassembly; reducing the number of composite parts in automobiles; designing parts with non-recyclable elements for endurance and possible re-use; reducing the number of different plastics used; increasing, as much as possible, the number of components that use recycled plastics; and utilizing shredder residue as a fuel.[13]

Three features, particularly of the European programs, are remarkable. The first is the tremendous cooperation occurring among automakers and between automakers, automobile parts manufacturers, and the existing shredding industry. The Europeans, as their programs have matured, likely have recognized that such cooperation is essential to program feasibility.

The second notable feature is that the abundance of automobile recycling programs (see Appendices A and B) have occurred without direct government intervention or mandates. Apparently, public concern, government threats of intervention, and public relations and marketing strategies have driven the automobile manufacturers to action.

Finally, the goals of and processes employed by the programs, specifically the European ones, are remarkable--and possibly radical--in that neither 100% recyclability nor total (or substantial) hand-disassembly may be technically or economically feasible.

A detailed listing of the efforts of individual firms and organizations in Europe is provided in Appendix A. Japanese initiatives are discussed in Appendix B.

NOTES FOR CHAPTER 3

1. Furukawa, Tsukasa 1993. Japanese companies research fluff problem; form group to study recycling alternatives. *American Metal Market* **101**(57):7.

2. "Recycling and the Automobile" 1992. *Automotive Engineering* **100**(10):41-57.

3. "Fiat presents car recycling plan" 1992. PRS Automotive Service, December 22..

4. "Schenck receives order for car recycling plant in E Germany" 1992. PRS Automotive Service, December 10.

5. Grace, Ken 1992. One day, my son, all this will be your...*British Plastics and Rubber* March, p. 38.

6. White, Liz 1992. Imperative: Recycle that car! *European Rubber Journal* **174**(2):27.

7. A lower projection is provided by Grace 1992. (Grace, K. 1992. One day, my son, all this will be your... *British Plastics and Rubber* March, p.38.)

8. "Toepfer wants automakers to be liable for car recycling" 1992. PRS Automotive Service, September 17.

9. "Recycling of cars by manufacturers in Germany" 1992. *Europe Environment* February 17, no. 0381.

10. "Ministers and automotive executives to meet on car recycling" 1992. PRS Automotive Service, March 13. Abstracted from *Financial Times* March 13, p.8.

11. Bird, A.P. 1990. Reclamation and recycling--the motor car and white goods. *Plastics and Rubber Processing and Applications* **13**(4):213.

12. "VW in car recycling project" 1990. PRS Automotive Service, March 8. Abstracted from VDI *Nachrichten* March 2, p.24.

13. Vandermerwe, Sandra and Michael D. Oliffe 1991. Corporate challenges for an age of reconsumption. *Columbia Journal of World Business* **26**(3):6.

14. Feast, Richard 1992. The greening of Europe: Germany is pacing Europe toward reduced shredding, buy-back policies and a 100% recyclable vehicle. *Automotive Industries* **172**(9):58.

15. Regan, James G. 1992. Design for disassembly gets a nudge in Europe. *American Metal Market* **100**(165):8.

16. Smock, Douglas 1992. Plastics in new Opels will be easily recyclable. *Plastics World* **50**(5):12.

17. "Car recycling catches on in Germany" 1990. *New Technology Week* **4**(44).

18. "German industry ponders automobile plastics recycling" 1987. *Plastic Industry Europe* **6**:1,21.

19. "Carmakers work to create plastics recycling program" 1992. *Plastics News* November 2, p.1.

20. Davis, Bruce 1991. Car firms press for recyclability. *European Rubber Journal* April, p.6.

21. Culp, Eric 1992. Push to recycle parts may narrow resin use in cars. *Modern Plastics* October, p.68.

22. "Aluminum [sic] in car production promoted by recyclability" 1990. PRS Automotive Service, February 21. Abstracted from *Frankfurte r Allgemeine* February 20, p.4.

23. "Pressure to increase recycling properties of cars" 1990. PRS Automotive Service, January 25. Abstracted from *Automobile Revue* January 11, p.23.

24. Kreisher, Keith R. 1991. Recyclability keys PP growth in European autos. *Modern Plastics* October, p. 56.

25. Keller, Ryann 1991. Europe recycles. *Automotive Industries* 171(11):9.

26. "Ministry of Transport to promote recycling of scrapped cars" 1991. *Comline Transportation* September 18, p.2.

27. Gittelman, Dena 1992. Prospects for Recycling Automotive Polymer Waste. Thesis, Tufts University, Medford, Mass.

28. "Car crusher cry wolf over plastics scrap" 1987. *British Plastics and Rubber* March, pp. 37-39.

29. "Pragmatism needed" 1993. *Urethanes Technology* February 1993, p.28.

30. We assume these estimates to be in person-minutes, though the literature does not specifically report it as such.

31. "Car breakdown takes priority" 1993. *Engineer* February 18, p.25.

32. "Are automakers ready for Germany's 1993 recycling decree?" 1992. PRS Automotive Service, September 23.

33. "The possibility of recycled cars" 1990. PRS Automotive Service, November 28. Abstracted from *Motor Industry Management* October 1990:42-43.

34. Protzman, Ferdinand 1993. Germany's push to expand the scope of recycling. *The New York Times* July 4, p.8.

35. "Conflicting views as car makers anticipate EC recycling law" 1992. PRS Automotive Service, December 3.

36. "German car men see green: Want to act on recycling before government steps in" 1991. *American Metal Market* April 4, p.1.

37. "French car recycling starts early" 1992. *American Metal Market* May 29, p.9.

38. "Car recycling schemes not adequate, according to Toepfer" 1991. PRS Automotive Service, September 20. Abstracted from *Frankfurter Allgemeine* September 20.

39. "Recycling of cars by manufacturers in Germany" 1992. *Europe Environment* February 17, no. 0381.

40. Naitove, Matthew H. 1992. Europe leads in car-parts recycling. *Plastics Technology* 38(5):101.

41. "German auto industry criticizes scrap bill" 1993. PRS Automotive Service, January 12.

42. "Ministers and automotive executives to meet on car recycling" 1992. PRS Automotive Service, March 13. Abstracted for *Financial Times* March 13, p.8.

43. "Recyclage des voitures: les professionels evitent le decret" 1993. *Echos* February 15, p.10.

44. "Dutch to force recycling of cars and other goods" 1992. *Food and Drink Daily* 2(374).

45. "New law would boost Netherlands recycling" 1992. *American Metal Market* September 10, p.2.

46. "Peugeot, Renault team up: Recycling venture targets up to 200 junked cars daily" 1992. *American Metal Market* July 23, p.7.

4. ENERGY IMPACTS OF THE RECYCLING STATUS QUO AND SELECTED DEVELOPMENTAL RECYCLING TECHNOLOGIES

The efficient use of energy in transportation continues to be a major issue as this sector accounted for more than 7% of the United States' (U.S.) energy consumption in 1991.[1] Automobiles accounted for almost 40% of total energy consumption in the transportation sector.[2]

Weight reduction in automobiles has been an attractive way to increase gasoline mileage. It is estimated that over the life of an average passenger car (about 100,000 miles), each pound of weight reduction saves about one gallon of fuel.[3] In the struggle for weight savings over the past two decades, there has been a continuous shift towards the replacement of ferrous metals in automobiles with lighter materials such as aluminum and plastics. The fuel economy of passenger cars has gone up from 13.5 miles per gallon (mpg) to 20.9 mpg between 1970 and 1990,[2] and no doubt the substitution of lighter weight materials has contributed to higher mpg's. However, total energy consumption by vehicles must consider energy consumed during automobile manufacturing including during the production of the materials at the mining stage; and net energy retrieved during recycling (i.e., the cradle-to-grove approach). Compared to steel, the use of energy-intensive materials like aluminum and plastics may require more energy to manufacture comparable automotive parts. Furthermore, higher contents of plastics may reduce the amount of energy that can be recovered by recycling during the disposal stage. Therefore, estimates of the energy system implications of the recent trend toward reduced-weight fuel efficient vehicles must take into account the manufacturing and disposal stages.

To date, most research in this area has been limited to the manufacturing and vehicle-use stages for a specific automobile part. That work does not typically address life-cycle energy use, i.e., inclusive of manufacture, automobile use, and disposal/recycle. For example, Farrissey (1991) examines recycling activities for the largest volume of thermoset material used in autos (i.e., polyurethanes) and the consequences of recycling activities on the life-cycle energy requirements for automotive parts.[4] Similarly, a life-cycle cost analysis has been made of the bumper system on the automobile.[5] Ford Motor Co. intends to fund research by Franklin Associates, Inc., Colorado to examine life-cycle energy implications of automobiles (similar to the one discussed in this Section).[6]

This Section addresses the energy system implications of the status quo with respect to auto recycling in the United States. Specifically, we address trends in the composition of automobiles by material types and fuel efficiency, the embodied energy of those materials, and the implications for overall system energy use (manufacturing to disposal) of current automobile recycling approaches. In addition, the energy implications of potential changes in the methods and technologies to recycle automobiles are addressed.

4.1 BACKGROUND: EMBODIED ENERGY AND ENERGY USE OF AUTOMOBILES

4.1.1 Material Composition of Automobiles

Table 4.1 shows trends in the composition of automobiles by material types during the period 1976-2000. *Ward's Automotive Yearbook* provides historical (i.e., 1976-1992) average material composition of U.S.-built cars.[7] Fourteen broad material categories considered for material composition are plastics, aluminum, copper, zinc, lead, other ferrous, iron, carbon steel, high speed steel, stainless steel, glass, rubber, fluid, and other. The "fluid" category mainly includes lubricants. The category "other ferrous," which includes powdered metal parts, was initiated in 1983. Magnesium and other materials (e.g., other alloy steels, cloth, cardboard, etc.) are included under the "other" category. The "plastics" category has been further disaggregated into 18 specific resin types based on the distribution of actual resin usage in the-transportation sector.[8] Thus, Table 4.1 shows average material composition for the U.S. built automobiles organized into 31 different material categories. Currently, there exists no detailed and reliable material composition information on imported automobiles.[9]

While no projections on the material-specific composition of automobiles have been identified, it is widely agreed that the challenge to improve fuel economy will lead to lighter automobiles. By the year 2000, an average car is forecasted to weigh about 3,000 lbs and contain about 400 lbs of plastics (corresponding numbers for the year 1992 are 3135.5 lbs and 243 lbs, respectively).[10] It has also been projected that the aluminum content in automobiles will double by the year 2000.[11] Using the above information and assuming aluminum and plastics contents of 400 lbs and 340 lbs (aluminum content in 1992 was 173 lbs), respectively, we estimate that carbon steel content in the year 2000 will be reduced to 70% of its 1992 value in order for the average weight of a car in the year 2000 to be around 3,000 lbs (actual weight estimated to be 3,045 lbs). The distribution of total plastics content among 18 specific resin types for the year 2000 was based on the 1992 distribution, despite our general awareness that the proportional distribution may change. The assumption being made here is that there will be no changes in material composition other than in plastics (in general), aluminum, and carbon steel during the period 1993-2000. Projections of material composition for the intermediate years (i.e., 1993-1999) are based on a linear extrapolation of the corresponding material composition values for 1992 and 2000, approaching towards the material composition for the year 2000 as indicated in the literature.

Figure 4.1 shows the variation in average automobile materials content of U.S.-built cars for the period 1976-2000. Thirty one specific material categories (discussed previously) have been grouped into six major categories, (i.e., thermoplastics, thermosets, aluminum, other non-ferrous, ferrous, and other materials). The thermoplastics and thermosets categories include the 18 specific plastic resins considered here. Thermosets differ from the more popular thermoplastics because their interlinking bonds prevent melting and reforming into new products. The "other non-ferrous" category includes all non-ferrous materials, excluding aluminum.

As shown in Fig. 4.1. the contents of thermoplastics, thermosets, and aluminum in automobiles have continued to increase and are projected to continue their recent trends. Comparatively, ferrous content has decreased more, causing an overall weight reduction in automobiles. The share of ferrous materials weight to the total weight of the average U.S. automobile is projected to decrease from 74% in 1976 to 58% in 2000. Two consecutive periods (1981-1982 and 1989-1990) show a large reduction in ferrous materials content, causing the sharpest decline in the weight of an automobile.

Table 4.1 Average automobile materials content (lb)

Material	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
PLASTICS	182.5	170.5	180	185	195	198	200	200	204	211.5	218	221.5	223	224.5	222	238	243	263	282	302	322	341	361	380	400
ABS	15	15	16	16	18	18	13	12	17	23	22	23	21	22	19	28	33	38	39	41	44	47	49	52	55
Acrylic	4	4	5	5	4	4	3	4	3	3	4	4	4	4	6	7	6	7	7	8	8	9	9	10	10
Nylons	4	4	5	7	6	8	12	14	14	18	16	15	17	17	15	15	15	16	17	19	20	21	22	23	25
Phenolic	5	5	5	4	4	3	3	2	2	2	2	2	2	3	2	2	2	2	2	2	2	3	3	3	3
Polyacetals	2	0	0	0	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	5	5	5	6	6	6
Polycarbonate	1	0	0	0	2	3	2	2	3	3	4	5	6	7	5	5	8	6	7	7	8	8	9	9	9
Polyester Elastomer	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	3	3	3	3	3	3	4	4
Polyester Thermpolastic	2	0	0	0	2	2	3	2	4	4	5	5	5	6	5	5	6	6	7	7	7	8	8	9	9
Polyester Unsaturated	22	29	37	40	39	39	23	24	24	23	23	21	21	15	17	17	18	18	19	20	22	23	24	26	27
Polyethylene	1	0	0	0	2	2	8	8	9	9	10	10	15	16	20	22	22	24	26	27	29	31	33	34	36
Polyphenylene Based Resins	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	4	5	5	6	6	6	7	7	8	8
Polypropylene	29	30	34	35	34	34	40	40	36	39	43	41	38	29	21	28	28	31	33	35	37	40	42	44	47
Polypropylene EPDM-Modified	0	0	0	0	0	0	0	0	0	0	0	0	0	8	10	8	8	8	9	10	10	11	11	12	13
Polyurea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Polyurethanes	45	39	39	41	52	55	48	46	58	52	54	57	57	48	59	59	59	64	69	73	78	83	88	93	97
Polyvinyl Chloride	27	28	30	26	25	22	23	21	21	21	21	24	23	25	20	18	17	19	20	21	23	24	25	27	28
SMA	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	8	8	7	7	8	8	9	9	10	10
Other Plastics	6	17	9	10	5	5	22	21	10	10	10	12	13	7	8	6	7	8	8	9	9	10	11	11	12
Aluminum	85.5	98.5	112.5	119	130	130	134	136	136.5	138	139.5	148	149	155.5	158.5	166	173.5	194	215	236	257	278	298	319	340
Copper	32	30.5	29	28.5	28	27.5	28	39	43.5	44	46	46	49	49.5	46	45	45	45	45	45	45	45	45	45	45
Zinc	44	38	31	25	20	17	15.5	17.5	17.5	18	18	18	19.5	20	19	17.5	16	16	16	16	16	16	16	16	16
Lead	25	25	24	23	23	22.4	23.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Ferrous	0	0	0	0	0	0	0	71.5	54	73.5	55	75	45	88.5	78	65	67	67	67	67	67	67	67	67	67
Iron	562	540	512	498	484	470	481	474	461	468	465.5	460	457	459	398	431	429.5	429.5	429.5	429.5	429.5	429.5	429.5	429.5	429.5

Table 4.1 Average automobile materials content (lb) continued

Material	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Carbon Steel	2075	1995	1915	1846	1737	1602	1489	1511	1526	1481	1470	1450	1440	1416	1246.5	1341	1379	1327	1276	1224	1172	1120	1069	1017	965
High Speed Steel	120	127.5	133	150	175	190	203	207	210	217.5	223.5	228	232	234	233	240.5	247	247	247	247	247	247	247	247	247
Stainless Steel	28	27	26	27	27.5	28.5	27	28	28.5	29	30.5	32	31	31	31.5	37	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5
Glass	87.5	86	86.5	85	83.5	83	84	85	85.5	85	85.5	86	85	85	82	86	86	86	86	86	86	86	86	86	86
Rubber	153	150	146.5	137.5	131	133	135	137.5	138	136	134.5	135.5	134	134.5	126	135.5	133	133	133	133	133	133	133	133	133
Fluid	190	200	198	189	178	175.5	179	183	189	184	181	183	178	179.5	167	174	177	177	177	177	177	177	177	177	177
Other	196	185	175	162	151	153	155	103	118.5	101.5	105	97	124.5	83	88	75.5	96	96	96	96	96	96	96	96	96
Average Weight	3760.5	3673	3568.5	3475	3363	3227.9	3114	3192.5	3232	3187	3170	3178	3167	3140	2896.6	3060	3135.5	3124.2	3112.9	3101.6	3090.3	3078.9	3067.6	3056.3	3045

Sources: *Ward's Automotive Yearbook*; *Modern Plastics*; and ORNL Projections

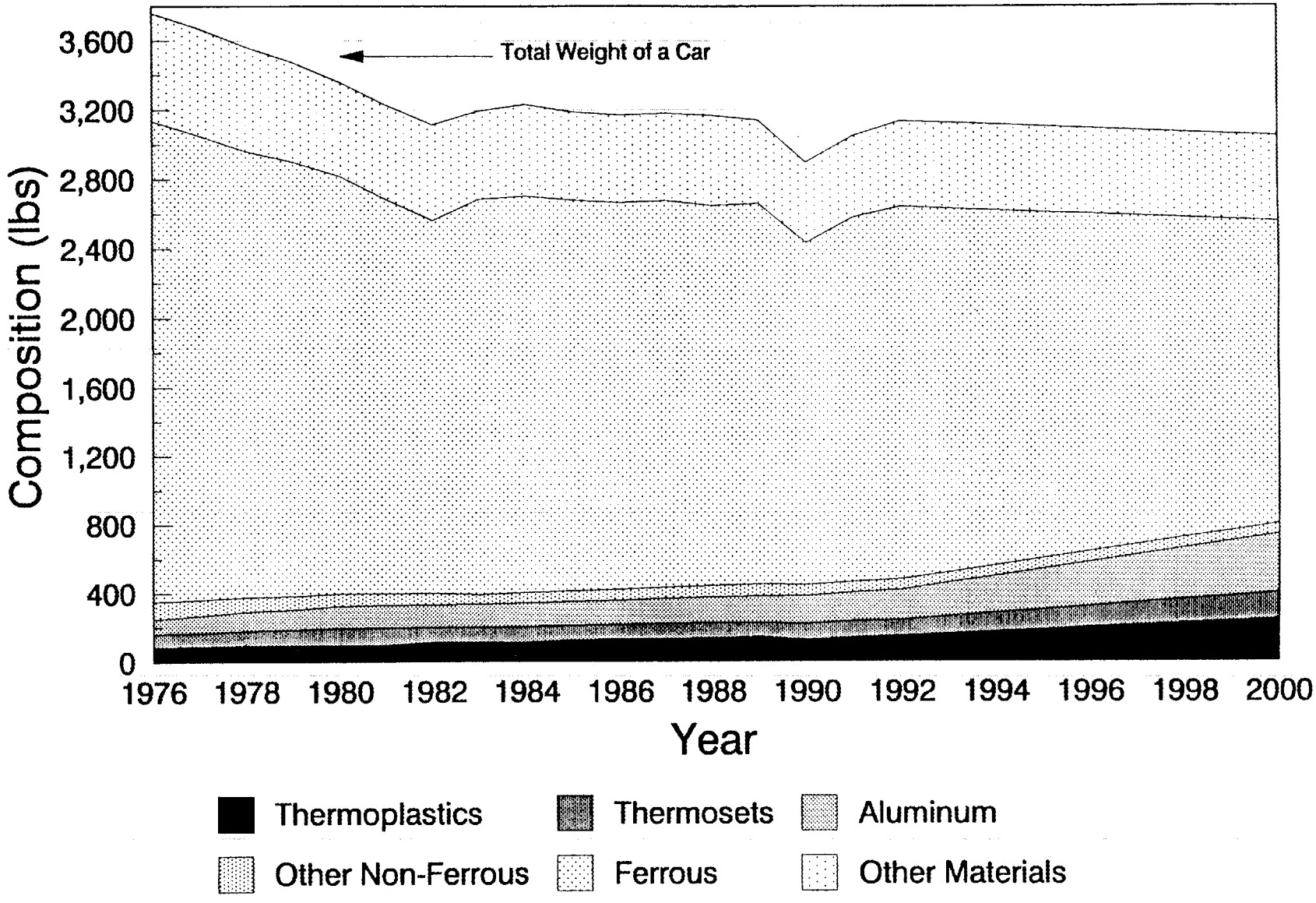

Fig. 4.1. Average automobile materials content (1976-2000).

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Overall, there is a declining trend in the weight of automobiles, with a minimum weight of 2,985.5 lbs in 1990. From 1990 onwards, the reduction in weight of an automobile stabilizes, remaining at a level maintained during 1985-1988. Note that the increase in plastics content is mainly in recyclable thermoplastics.

4.1.2 Energy Contents in Automotive Materials

4.1.2.1 Embodied Energy

Embodied energy in materials is defined as the energy contained in a fabricated material part, reflecting the energy required to process the material from raw material to finished product. For metals, this energy includes mining the ore, smelting, rolling into sheets, etc. Similarly, for plastic material the energies for oil production and refining, for monomer synthesis, and for polymer processing, as well as the fuel value of the material itself are included. Energy content in scrap generated during the stages of raw material production and fabrication of parts is also included in the embodied energy of materials.

Table 4.2 presents the embodied energy contents of the various automotive materials discussed in the previous Section. The table also provides the specific assumptions made for the materials where information was unavailable. Energy estimates vary widely among various sources because of their sensitivity to the quality of raw material and technology used. The estimates used here are based on average values and from different sources for plastics and non-plastics materials using similar concept methodology. Estimates of the embodied energy for most plastic materials are obtained from Curlee and Das (1989),[12] which are primarily based on Gaines and Shen (1980).[13] Gaines and Shen define the total energy embodied in the final product as the sum of the heat of combustion of the feed and the net process energy. Chapman and Roberts (1983) provide embodied energy estimates for most non-plastic materials.[14] Their embodied energy estimates are based on the summation of specific energy estimates at the various production steps (i.e., mining of the ore, concentration of the ore, smelting and refining of the metal, and finally processing ingots into semi-fabricated products). Note that the energy content of aluminum is the highest among the materials considered here. It is almost five times more energy intensive than ferrous, and three times more than plastic materials.

4.1.2.2 Energy Savings

Currently, almost 100% of the metals (both ferrous and non-ferrous) contained in automobile scrap is recycled (the exception is the small quantity that is not separated from the ASR or fluff). The remaining ASR is landfilled. Recycling of metals conserves energy by requiring less energy to produce a ton of metal with recycled metals, as compared to starting from the ore. Chapman and Roberts (1983) provide estimates of net energy savings from the use of recycled metals versus virgin metals taking into account the energy consume d during recycling.[14] The overall use of fuel is estimated to be substantially lower for secondary production using scrap metals than for primary production. Estimated energy savings (i.e., Btu/lb) based on the use of average metal scrap recycled from automobiles are shown in Table 4.3. Note that the use of recycled aluminum gives the maximum energy savings (i.e., 120,200 Btu/lb) as compared to other materials.

Table 4.2 Energy contents of automobile materials

Material	Embodied Energy (Btu/lb)	Source of Information
ABS*	32,900	Curlee and Das (1989)
Acrylic	36,500	"Other Thermoplastics" in Curlee and Das (1989)
Nylons	90,400	Curlee and Das (1989)
Phenolic	48,700	Curlee and Das (1989)
Polyacetals	47,400	Same as Polyethylene
Polycarbonate	47,400	Same as Polyethylene
Polyester, elastomer	47,000	Same as Polyethylene
Polyester, thermoplastic	47,400	Same as Polyethylene
Polyester, unsaturated	48,700	Curlee and Das (1989)
Polyethylene	47,400	Chapman and Roberts (1983)
Polyphenylene-based resins	34,300	"Polystyrene" in Curlee and Das (1989)
Polypropylene	52,100	Chapman and Roberts (1983)
Polypropylene, EPDM*-modified	52,100	Same as Polypropylene
Polyurea	48,700	Same as "Urea & Melamine" in Curlee and Das (1989)
Polyurethanes	46,600	Farrissey (1991)
Polyvinyl chloride	37,700	Chapman and Roberts (1983)
SMA*	32,900	Same as ABS
Other Plastics	42,600	Avg. of "Other Themoplastics" & "Other Thermosets" in Curlee and Das (1989)
Aluminum	147,000	Chapman and Roberts (1983)
Copper	54,500	Chapman and Roberts (1983)
Zinc	45,600	Chapman and Roberts (1983)
Lead	14,700	Chapman and Roberts (1983)
Other Ferrous	27,500	Chapman and Roberts (1983)
Iron	27,500	Same as carbon steel
Carbon Steel	27,500	Chapman and Roberts (1983)
High Speed Steel	27,500	Chapman and Roberts (1983)
Stainless Steel	54,500	Chapman and Roberts (1983)
Glass	23,700	Chapman and Roberts (1983)
Rubber	66,100	Chapman and Roberts (1983)
Fluid	20,200	Davis and Strange (1993)
Other	27,500	Same as carbon steel

*Note: Acrylonitrile-Butadiene-Styrene (ABS); Styrene Maleic Anhydride (SMA); Ethylene Propylene Diene Monomer (EPDM)

Table 4.3 Estimated net energy savings from the use of recycled metals vs. virgin metals

Material	Net Energy Savings (Btu/lb)
Aluminum	120,200
Copper	37,000
Zinc	17,500
Lead	14,200
Iron	10,700
Carbon Steel	10,700
High Speed Steel	10,700
Stainless Steel	10,700
Other Ferrous	10,700

Source: Chapman and Roberts (1983)

4.1.3 Fuel Efficiency

Figure 4.2 shows the fuel efficiency (mpg) of passenger cars, light trucks, and the fleet (for both domestic and imported vehicles) for the period 1976-2000.[15] The fuel efficiency of fleet vehicles is calculated as the harmonic average of the sales-weighted fuel efficiencies of passenger cars and light trucks. Also included in this figure is the average weight of U.S.-built cars (discussed earlier in Section 4.1.1). In most years, the sales-weighted fuel efficiencies of passenger cars and light trucks have, on average, met the fuel economy standards (CAFE) set by the federal government.[2]

The fuel efficiency of imported passenger cars is higher than that of domestic ones; however, the difference between them has been decreasing since 1988. For example, the mpg difference between imported and domestic passenger cars decreased from 9.2 mpg in 1976 to 1.3 mpg in 1992. Similarly, the fuel economy differences between domestic and imported light trucks, particularly during the 1980s, was significantly higher than in the case of passenger cars. The fuel efficiency of imported light trucks was higher by 9.1 mpg in 1984, compared to a corresponding value of 6.1 mpg for passenger cars. Because of these differences, the fleet fuel efficiency of imported vehicles is always higher than for domestic vehicles (e.g., 31.1 mpg for imported and 23.1 mpg for domestic in 1983). The fleet fuel efficiency difference came to a minimum value of 3.2 mpg in the year 1992.

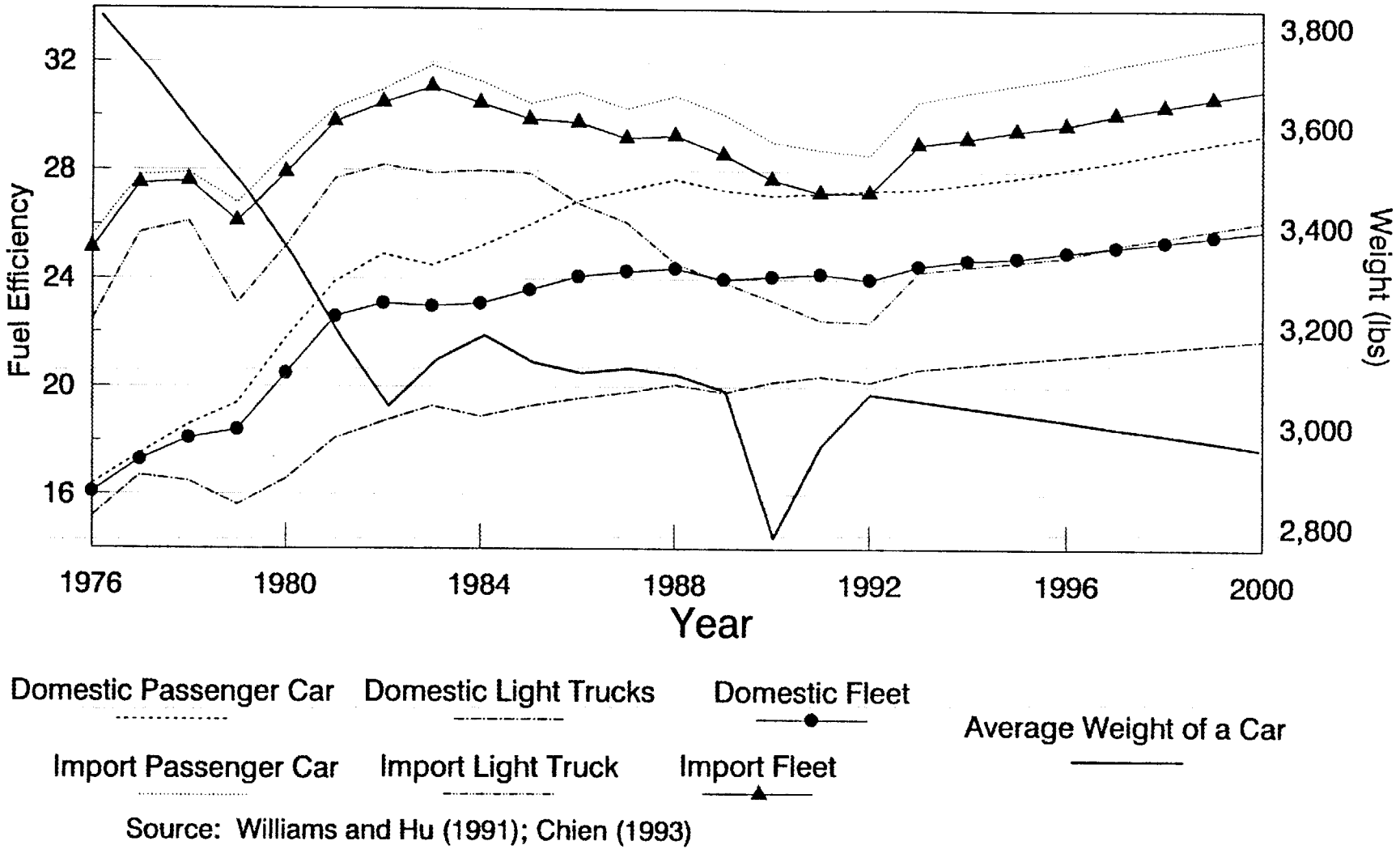

Fig. 4.2. Fuel efficiency (mpg) estimates for passenger cars, light trucks, and fleet (1976-2000).

4.2 ANALYSIS APPROACH TO ESTIMATE ENERGY SYSTEM IMPACTS

As discussed earlier, an estimation of the total energy system impacts of auto recycling must include energy impacts at the manufacturing stage, during vehicle use, and at the time of disposal. The analysis presented here is annual for the period 1976-2000. Energy expended during the manufacturing stage is estimated by the sum of products of energy embodied in the individual materials (i.e., Btu/lb, discussed earlier in Section 4.1.2.1) and the material content, (i.e., weight in lbs., discussed in Section 4.1.1) for each specific material in the vehicle. It is assumed that the energy required to assemble automotive parts during manufacturing is insignificant compared to the energy embodied in those parts, and therefore, no energy value for the assembly of automobile parts is included in this analysis. Energy consumed during vehicle use is determined by the product of the energy content of gasoline (i.e., Btu/gallon) and the number of vehicle-miles driven annually, divided by vehicle fuel efficiency (mpg).

Energy required at the vehicle disposal stage is the sum of two components: the energy expended during the shredding operation and the energy saved from the use of recycled metals rather than virgin metals. It is assumed here that (1) 90% disposed of cars are being sent to shredders (see Section 2.1.2), (2) 100% of ferrous and non-ferrous metals in a vehicle are recycled, and (3) 32 Btu/lb is required during the shredding operation.[16] Energy savings from the use of recycled metals versus virgin metals is calculated as the sum of individual quantity (i.e., lbs) of each material recovered for recycling times the corresponding net energy saving potentials (i.e., Btu/lb, discussed in Section 4.1.2.2).

Energy system implications of auto recycling have been examined at two different levels: (1) for the average automobile and (2) for the entire fleet of automobiles in the United States. In the former case, energy implications are examined on a life-cycle basis for a single vehicle for different model years. The latter scenario examines the aggregate energy implications. The following Sections discuss in detail these scenarios, underlying assumptions, and energy impacts.

4.2.1 Life-Cycle Energy Impacts for the Average Automobile

The first scenario examines the life-cycle energy requirements of an average vehicle for the model years 1976-2000. This scenario allows us to examine the changes in energy requirements at the three stages of a vehicle's life-cycle (i.e., manufacturing, use, and disposal) caused by changes in material composition from one model year to another. Energy expended at the manufacturing stage is based on the average material composition of U.S.-built cars. The average fleet fuel efficiency of domestic vehicles (discussed in Section 4.1.3) is used for estimating the energy used during the life of a vehicle. The total number of miles driven per vehicle is assumed to be 100,000 miles.

Table 4.4 shows the estimated and projected life-cycle energy consumption of an average U.S. built car in the model years 1976-2000; and the breakdown of life-cycle energy requirements for the five different model year vehicles are exhibited in Fig. 4.3. Energy expended at the manufacturing stage remains fairly constant in the range of 110-120 million Btus until 1994. Beyond the 1994 model year, energy requirements at the manufacturing stage are projected to increase, and by the year 2000 those requirements are projected to be 138 million Btus (12% higher than the 1976 value). Larger quantities of energy-intensive aluminum and plastics increase energy requirements; whereas, a reduction in vehicle weight resulting from a decrease in the use of carbon steel decreases energy

Table 4.4 Life-cycle energy impacts analysis (1976-2000)

		Energy Requirements per Vehicle (million Btus)			
Model Year	Average Fleet MPG	Manufacturing	Use	Disposal	Life-Cycle
1976	16.1	123	776	-38	861
1977	17.3	122	723	-38	806
1978	18.1	121	691	-39	772
1979	18.4	119	679	-39	759
1980	20.5	117	610	-39	688
1981	22.6	113	553	-37	629
1982	23.1	111	541	-37	615
1983	23.0	114	543	-38	619
1984	23.1	115	541	-39	618
1985	23.6	115	530	-38	606
1986	24.1	114	519	-38	595
1987	24.3	115	514	-39	591
1988	24.4	116	512	-39	589
1989	24.0	116	521	-40	596
1990	24.1	109	519	-38	590
1991	24.2	115	517	-40	591
1992	24.0	118	521	-41	597
1993	24.5	120	510	-43	587
1994	24.7	123	507	-45	585
1995	24.8	125	504	-47	583
1996	25.0	128	500	-48	580
1997	25.2	131	496	-50	576
1998	25.4	133	492	-52	573
1999	25.6	136	488	-54	570
2000	25.8	138	484	-55	567

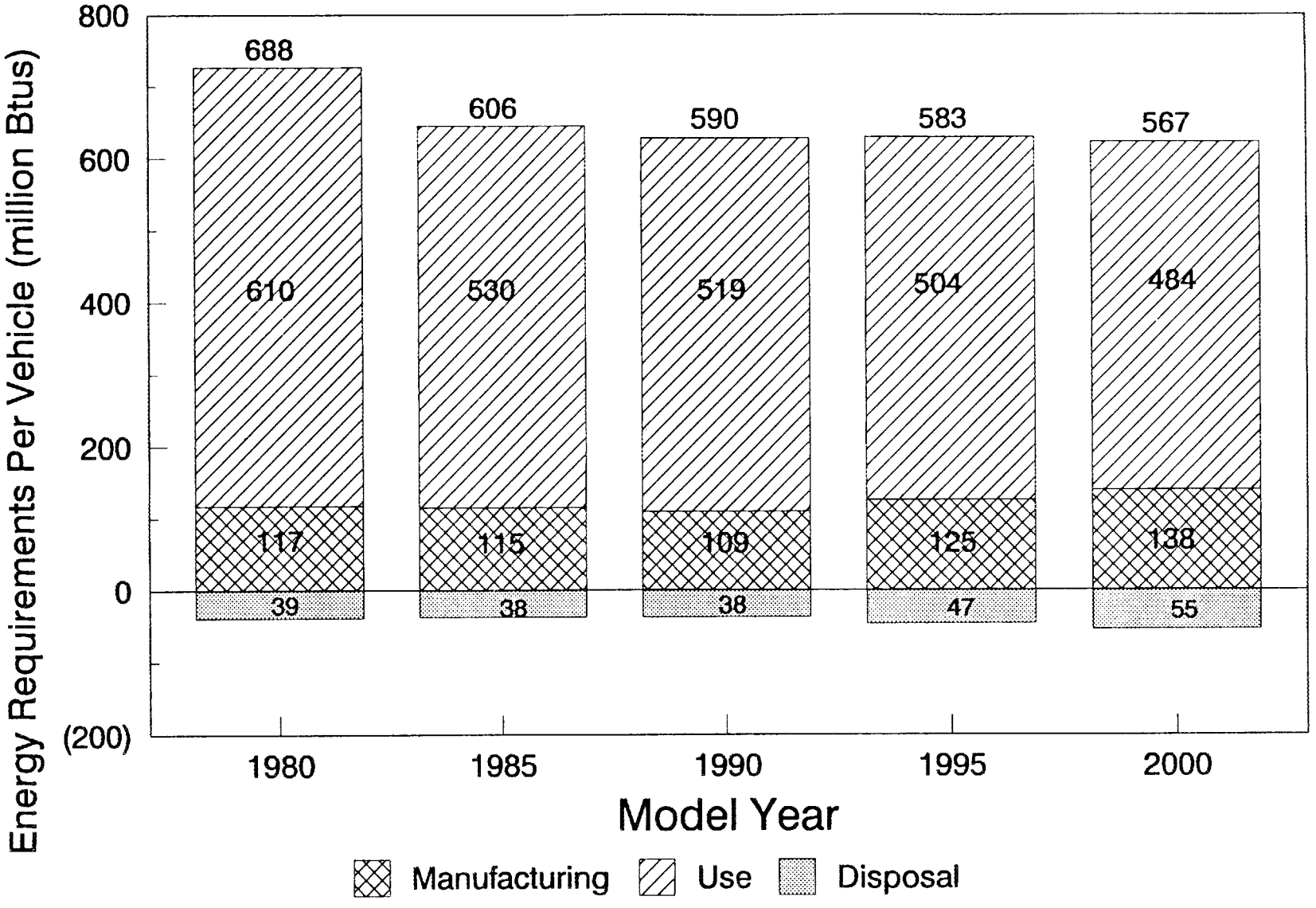

Fig. 4.3. Life cycle energy impacts of different model year vehicles

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requirements. As discussed earlier, aluminum is almost five times more energy intensive than ferrousmetals and three times more than plastic materials. Thus, an increase in total energy requirements for manufacturing due to a one pound increase in the aluminum content of a vehicle will be completely annulled if accompanied simultaneously by a five pounds decrease in ferrous material content. A comparatively smaller decrease in ferrous materials content during post-1994 model year vehicles (see Fig. 4.1) in addition to a higher increase in the contents of aluminum and plastics, causes overall higher manufacturing energy requirements for post-1994 model year vehicles.

With the improved fuel efficiency of the U.S. fleet, energy consumed during vehicle use has declined continually, and is projected to be 38% less in 2000 than it was in 1976.[15] Similarly, the ratio of energy requirements for vehicle use to that for manufacturing has decreased from 6.3:1 in 1976 to 3.5:1 in 2000. Because of the higher content of aluminum in vehicle composition, there also has been an increase in energy savings from the recycle of vehicles. Between 31 and 40% of total energy expended during vehicle manufacturing is estimated and projected to be recovered at the recycle stage during the period 1976-2000. Energy savings at the recycle stage are projected to increase from 38 million Btus in 1976 to 55 million Btus in 2000--due primarily to the increase in aluminum content because energy savings (Btu/lb) from the recycle of aluminum is 12 times higher than that for ferrous materials.

Thus, energy requirements during vehicle manufacturing have increased due primarily to the increased contents of plastics and aluminum; whereas, substantial energy savings have occurred because of improved fuel economy and to a lesser extent energy savings at the recycle stage. Life-cycle energy requirements of a model year 2000 vehicle are projected to be 567 million Btus, or about 66% of the energy requirements for a 1976 model year vehicle (see Table 4.4).

4.2.2 Aggregate Energy Impacts

The aggregate-energy-impacts scenario examines changes in total energy consumption by automobiles in the United States for the period 1989-2000. The three distinct life-cycle stages considered under the previous scenario are also included in this scenario analysis. Because of data limitations, only passenger cars and light trucks are considered here. (Passenger cars and light trucks have constituted more than 96% of the total vehicle fleet sales during the last 10 years.)[17] Passenger cars and light trucks are further disaggregated into domestic and imported to take into account the fuel economy variations between domestic and imported vehicles (as discussed in Section 4.1.3).

To assess the aggregate energy impacts due to the operation of vehicles, vehicle sales data are required to estimate the number of operating vehicles in a given year. Table 4.5 shows the U.S. retail sales of domestic and imported passenger cars and light trucks for the period 1976-2000. Sales data for the period 1976-1991 were obtained from *Ward's Automotive Report*;[18] whereas sales projections from 1992 through 2000 are based on the Base Case scenario in the *Annual Energy Outlook '93* (AEO93).[19] AEO93 projections are not disaggregated into domestic and imported; thus, the 1991 domestic-imported distribution was used for all the projection years. To estimate total energy expended in manufacturing vehicles in a given year, an additional assumption was made -- i.e., the material composition of imported vehicles is the same as that of domestic vehicles. Only general quantitative information on the material composition of imported vehicles has been identified (see Table 3.1). Qualitative information indicates that imported vehicles are lighter because they contain less steel, magnesium, and powdered metals than domestic vehicles.[9]

Table 4.5 U.S. retail sales of domestic and import passenger cars and light trucks

Year	Annual Retail Sales (in millions)								
	Passenger Cars			Light Trucks			Total Vehicles		
	Domestic	Import	Total	Domestic	Import	Total	Domestic	Import	Total
1976	8.5	1.2	9.7	2.2	0.20	2.4	10.7	1.4	12.1
1977	8.8	1.7	10.5	2.2	0.31	2.5	11.0	2.0	13.0
1978	9.1	1.9	11.0	2.6	0.33	2.9	11.7	2.2	13.9
1979	8.6	2.2	10.8	2.3	0.48	2.8	10.9	2.7	13.6
1980	6.8	2.3	9.1	1.7	0.53	2.2	8.5	2.8	11.3
1981	6.6	2.3	8.9	1.4	0.49	1.9	8.0	2.8	10.8
1982	5.5	2.1	7.6	1.7	0.42	2.1	7.2	2.5	9.7
1983	6.5	2.3	8.8	2.2	0.50	2.7	8.7	2.8	11.5
1984	7.9	2.3	10.2	3.0	0.64	3.6	10.9	2.9	13.8
1985	8.4	2.6	11.0	3.4	0.83	4.2	11.8	3.4	15.2
1986	8.1	3.0	11.1	3.6	0.95	4.6	11.7	4.0	15.7
1987	7.3	3.1	10.4	3.6	1.00	4.6	10.9	4.1	15.0
1988	7.3	3.0	10.3	4.0	0.75	4.8	11.3	3.8	15.1
1989	7.4	2.8	10.2	4.1	0.66	4.8	11.5	3.5	15.0
1990	6.8	2.4	9.2	3.9	0.63	4.5	10.7	3.0	13.7
1991	6.3	2.1	8.4	3.5	0.56	4.1	9.8	2.7	12.5
1992	6.5	2.1	8.6	3.8	0.60	4.4	10.3	2.7	13.0
1993	7.5	2.4	9.9	4.1	0.65	4.8	11.6	3.1	14.7
1994	7.7	2.5	10.2	4.4	0.69	5.1	12.1	3.2	15.3
1995	7.8	2.6	10.4	4.7	0.74	5.4	12.5	3.3	15.8
1996	7.8	2.5	10.3	4.7	0.74	5.4	12.5	3.2	15.7
1997	7.8	2.5	10.3	4.8	0.75	5.6	12.6	3.3	15.9
1998	8.0	2.6	10.6	5.0	0.79	5.8	13.0	3.4	16.4
1999	8.1	2.6	10.7	5.2	0.82	6.0	13.3	3.4	16.7
2000	8.1	2.7	10.8	5.3	0.83	6.1	13.4	3.5	16.9

Sources: *Ward's Automotive Reports* (1977-1993) and Chien (1993)

Total energy consumed due to vehicle use in a given year depends on (1) the number of vehicles operating in a given year (which in turn depends on the vehicle scrappage rate) and (2) miles driven annually per vehicle for a given model year. In comparing energy system impacts from one year to another, it is assumed that the number of model years of vehicles operating in a given year remains the same. The expected life of a vehicle is assumed to be 14 years, which is an average of the estimated life of a passenger car and a light truck.[20] Thus, for any given year, only 14 model year vehicles are considered. For example, for 1989, the first year under consideration here, vehicles of model years 1976-1989 are assumed to be operating; similarly for the year 2000, model years from 1987 to 2000 are included.

Estimates of the total number of vehicles of a particular model year scrapped in a given year (consequently the number of vehicles of a particular model year running in a given year) are based on the recent work of Miaou (1990)[20] on scrappage rates. Miaou assumes that the factors affecting the economic decision to scrap an automobile involve stochastic elements, and thus, some scrapping is observed to occur at all vehicle ages. His estimates on the scrappage rates of passenger cars and light trucks as a function of vehicle age are based on vehicle registration data for the period 1978-1989.[21]

U.S. Department of Energy (1988)[22] estimates of miles driven annually per vehicle by its vintage are used in this model. The number of miles driven annually decreases as vehicle age increases. For example, a passenger car is driven 12,791 miles in its first year, but only 8,201 miles in its 10th year and beyond (corresponding numbers for light trucks are 13,421 miles and 9,013 miles, respectively).

Table 4.6 shows the aggregate energy requirements of vehicles for the period 1989-2000. With an increase in the number of vehicles operating (as indicated by sales figures in Table 4.5), total energy consumed is projected to increase from 9,721 trillion Btus in 1992 to 11,296 trillion Btus in 2000. For comparison purposes, note that the United States consumed a total of 81.5 quads of energy (1 quad = 1×10^{15} Btus) in 1991. A lower level of retail sales during the 1990-1991 period (refer to Table 4.5) as compared to 1989 results in the lower total energy requirements reported for the former period. Fluctuations in annual retail sales of automobiles are reflected in the fleet's total annual energy requirements.

Passenger car fuel efficiency has increased significantly, but not enough to offset increases in the number of vehicles operating. Total annual energy requirement for vehicle use have increased continually with the increase in the number of vehicles operating every year. Of particular note is the expected increase from 8,906 trillion Btus in 1996 to 9,268 trillion Btus by the year 2000. Total annual energy consumption for vehicle use is four to five times higher than for vehicle manufacturing. Energy savings at disposal are expected to increase from 265 trillion Btus in 1989 to 309 trillion Btus in 2000 due to (1) a continuous trend toward higher quantities of recyclable energy intensive aluminum and (2) to a lesser extent, an increase in the number of vehicles scrapped. To place the number in perspective, the recycling of ferrous and non-ferrous materials from automobiles has resulted in annual energy savings equivalent to around 48 to 56 million barrels of crude oil (1 barrel of crude oil = 5.5×10^{6} Btus) or 3 days of U.S. petroleum consumption.

The last three columns in Table 4.6 give annual average energy requirements per vehicle at the stages of manufacturing, use, and disposal; based on total annual energy requirements at the stage

Table 4.6 Aggregate energy impacts analysis (1989-2000)

Year	Total No. of Vehicles (millions)		Total Energy Requirements (trillion Btus)				Average Annual Energy Requirements Per Vehicle Manufactured (million Btus)	Average Energy Consumed Per Vehicle Operated (million Btus)	Average Energy Requirements Per Vehicle Scrapped (million Btus)
	Operating	Scrapped	Manufactur-ing	Use	Disposal	Total			
1989	155	6.9	1727	8795	-265	10257	116	57	-38
1990	156	6.9	1496	8716	-266	9947	109	56	-38
1991	156	6.9	1423	8565	-263	9726	115	55	-38
1992	156	6.8	1532	8449	-259	9721	118	54	-38
1993	158	6.8	1770	8446	-259	9957	120	54	-38
1994	161	7.0	1881	8566	-267	10180	123	53	-38
1995	165	7.2	1983	8741	-279	10445	125	53	-39
1996	169	7.6	2010	8906	-295	10622	128	53	-39
1997	171	7.7	2064	9024	-304	10784	131	53	-39
1998	174	7.7	2184	9116	-307	10992	133	53	-40
1999	176	7.6	2267	9193	-308	11152	136	52	-40
2000	178	7.5	2337	9268	-309	11296	138	52	-41

divided by the total annual number of vehicles manufactured, operating, and scrapped, respectively. Note that units are in million Btus, compared to trillion Btus used for total energy requirements. Average annual energy consumption per vehicle decreases because of improved vehicle fuel efficiency. By the year 2000, a vehicle is projected to consume 9% less energy annually than the average vehicle did in 1989. Energy savings per vehicle at disposal also increase due to a higher content of aluminum (38 million Btus in 1989 as compared to 41 million in 2000).

4.2.3 Scrap Composition and Recyclability

Figure 4.4 shows the variation in the composition of the total quantity of scrap generated annually. The six categories of materials indicated in this figure are the same as the ones in Fig. 4.1. The total quantity of automobile scrap generated annually averages to 20 billion lbs. Ferrous materials comprise more than 70% of total scrap generated. The quantity of ferrous metals in scrap decreases from 15.6 billion lbs in 1989 to 14.4 billion lbs in 2000 (the corresponding contributions to the total quantity of scrap are 73% and 69%, respectively). A higher number of vehicles scrapped during 1996-98 causes higher quantities of total scrap and ferrous scrap compared to the previous years. Other material contents, particularly aluminum and plastics, increase. Aluminum content in scrap increases from 3.4% in 1989 to 5.7% in 2000. Thermoplastics and thermosets contribute 4.0% and 2.4%, respectively, to total scrap composition in 2000. The corresponding values for the year 1989 are 2.5% and 1.5%, respectively.

Since near 100% of ferrous and non-ferrous metals are currently recycled, the amount of automobile shredder residue (ASR) to be landfilled annually is estimated to be around 4 to 5 billion lbs.[23] (For comparison purposes, about 200 million tons of municipal solid waste is generated annually in the United States). The replacement of aluminum for ferrous metals may cause problems with regard to scrap recyclability.[24] However, given that plastics in automobile scrap are not recycled currently, increased percentages of plastics mean a larger percentage of scrap will be landfilled as ASR. The plastics content of ASR is projected to increase from 19% in 1989 to 29% in 2000.

The following Section examines the energy implications of alternative recycle options, i.e., (1) 100% recycling of thermoplastics; (2) incineration of ASR; (3) combining recycling of thermoplastics and incineration of the remaining ASR; (4) recycling of selective hand-dismantled plastic automobile parts (e.g., bumpers, dashboard, etc.); and (5) combining selective recycling and incineration.

4.3 ENERGY SYSTEM IMPACTS OF THE ALTERNATIVE RECYCLE OPTIONS

This section discusses the potential energy impacts of diverting a portion of ASR from landfill to alternative recycle options. The first step in this process is to develop a set of realistic scenarios, followed by the estimation of the potential energy impacts of those scenarios. Five scenarios are considered here and they are based on several technological solutions (discussed in Section 2.3.1) that are currently being considered to improve ASR recyclability. An additional "status quo" scenario provides energy implications given current recycling practice (discussed in Section 4.2) and facilitates the comparisons of potential energy impacts from alternative recycle scenarios.

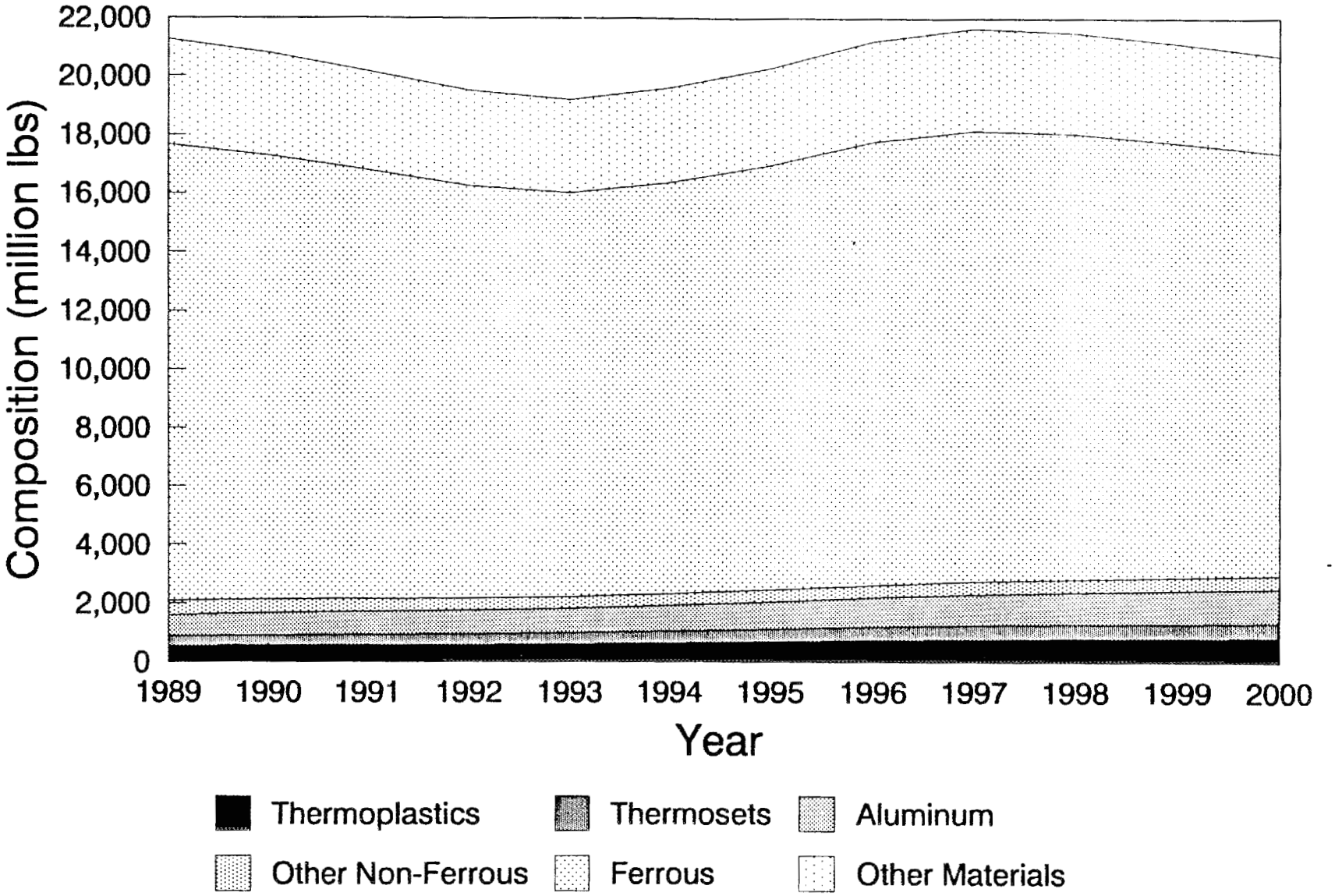

Fig. 4.4 Automobile Scrap Composition (1989-2000)

4.3.1 Scenario Description

4.3.1.1 Scenario A: Thermoplastics Recycling

In this scenario, it is assumed that technological and/or economic conditions are such that the recycling of all thermoplastics (i.e., the category of plastics that can be melted down and reformed into new products) in automobiles is viable. We assume that the recycled thermoplastics would be used to manufacture products that would otherwise be made from virgin resins, thereby reducing the overall demand for virgin resins and the energy embodied in those resins. The Natural Resources Defense Council (NRDC) (1992) has compared the energy benefits of plastic recycling and incineration.[25] NRDC considered only a few plastic resins, and based on these comparisons, it is estimated that the energy benefits of recycling plastic is equivalent to 67% of its embodied energy (discussed in Section 4.1.2.1). ASR remaining after recycling of all metals and thermoplastics is assumed to be landfilled.

4.3.1.2 Scenario B: ASR Incineration

This scenario considers the retrieval of ASR energy content through combustion of ASR. Incineration utilizes the heat energy of ASR to generate electric power and/or steam for on-site use or commodity sale. It also reduces the weight and volume of residue that requires disposal. Although the heating value of ASR ranges from 5,400 Btu/lb (wet) to 11,600 Btu/lb (dry), the current state of incineration technologies provides a net retrievable energy context of ASR of 1,100 BTU/lb.[26] This scenario further assumes that the ash generated due to incineration is landfilled and its amount equals to 20% of the total quantity of ASR incinerated.[27]

4.3.1.3 Scenario C: Thermoplastics Recycling in Combination with Incineration

This scenario is the combination of the above two scenarios. This scenario assumes incineration of the quantity of ASR remaining after recycling of all thermoplastics. Only the ash generated due to incineration is to be landfilled, and its amount equals to 20% of the total quantity of ASR incinerated.

4.3.1.4 Scenario D: Bumper and Dashboard Recycling

This scenario looks at the option of removing selected non-metallic components prior to shredding, with the objective of collecting a readily recyclable material and reducing the quantity of ASR that must be disposed of. Recycling is assumed to be limited to large and easy-to-disassemble plastic components such as the plastic covers on bumpers and dashboards. The remaining quantity of ASR is landfilled. We assume that bumpers and dashboards are made of thermoplastics[28] and the total weight of these components is 29 lbs (11 lbs each for front and rear bumper and 7 lbs for the dashboard).[29] To estimate the energy implications, we assume that polypropylene is used to manufacture both bumpers and dashboards.

4.3.1.5 Scenario E: Bumper and Dashboard Recycling in Combination with Incineration

In this scenario, incineration of ASR is considered in addition to the recycling of automobile bumpers and dashboards (discussed in Section 4.3.1.4). This scenario assumes that incineration will

be limited to the quantity of ASR remaining after the recycling of bumpers and dashboards. The quantity of ash generated (i.e., 20% of the total quantity of ASR incinerated) is landfilled as was done in scenarios B and C (Sections 4.3.1.2 and 4.3.1.3).

4.3.2. Estimated Energy Impacts

The energy implications of the alternative recycle options were examined at two different levels: (1) for the average automobile and (2) for the entire fleet in the United States, as was done in the earlier Section which examined the energy impacts of the recycling status quo. In the former case, energy savings at disposal and its effect on the life-cycle energy requirements per vehicle for different model years are estimated. The second level considers total energy savings at disposal and the total quantity of ASR to be landfilled annually. The energy impacts of the five recycle scenarios are discussed primarily with reference to the "status quo" scenario where recycling is limited to metals.

4.3.2.1 Energy Impacts for the Average Automobile

Table 4.7 shows the estimated energy impacts of the previously discussed recycling and disposal options at the disposal stage and on the life-cycle energy requirements of a vehicle for the model years 1976-2000; and Fig. 4.5 shows particularly for the model year 2000 vehicle. Because recycling plastics obviates the oil feedstocks otherwise required to make an equivalent virgin plastic product, the recycling of all thermoplastics has significant energy savings potential at the disposal stage and, thus, for the life-cycle energy requirements of a vehicle. Additional energy savings in the range of 2 to 7 million Btus (or the equivalent of 0.4-1.3 barrels of crude oil) are projected at the vehicle disposal stage due to the recycling of all thermoplastics. Life-cycle energy requirements of a model year 2000 vehicle with recycling of all thermoplastics are projected to be 560 million Btus, compared to 567 million Btus for the same model year vehicle without thermoplastics recycling. The magnitude of energy savings is not large. Note that thermoplastics contribute less than 6% of the total weight of a model year 2000 automobile.

The effect of incineration of all ASR on the energy impacts of automobile recycling is insignificant relative to total life-cycle energy requirements. Note first that the overall available "fluff energy" from shredding automobile scrap is 1,100 Btu/lb, considerably less than the recycling of thermoplastics which is in the range of around 30,000 Btu/lb. Second, only a fraction of the total vehicle weight goes to incineration (as only 25% of the total weight of a vehicle becomes ASR). Thus, the additional energy savings per vehicle at the disposal stage due to ASR incineration is projected to be around only 1 million Btus.

The energy impacts of recycling all thermoplastics in combination with the incineration of the remaining ASR are not very different from the option of recycling all thermoplastics. As discussed previously, incineration does not have significant energy contribution given currently available incineration technologies. However, this recycling option, a combination of thermoplastic recycling and incineration, provides the least energy requirements among the options being considered here. Life-cycle energy requirements of a model year 2000 vehicle with the recycling of all thermoplastics and incineration of ASR are projected to be 559 million Btus, about 98.5% of the energy requirements for the same model year vehicle given current recycling approaches (i.e., the status quo option).

Table 4.7 Estimates of the energy impacts of various recycling scenarios for the average automobile

Model Year	Recycling Sscenarios											
	Status Quo		A		B		C		D		E	
	1	2	1	2	1	2	1	2	1	2	1	2
1976	-38	861	-40	859	-39	860	-41	858	-39	860	-40	859
1977	-38	806	-41	804	-39	805	-42	803	-39	805	-40	804
1978	-39	772	-41	770	-40	772	-42	769	-40	771	-40	771
1979	-39	759	-41	757	-39	759	-42	756	-40	758	-40	758
1980	-39	688	-42	685	-40	687	-42	684	-40	687	-41	686
1981	-37	629	-40	626	-38	628	-41	625	-38	628	-39	627
1982	-37	615	-40	612	-37	615	-41	611	-38	614	-38	614
1983	-38	619	-42	616	-39	619	-43	615	-39	618	-40	618
1984	-39	618	-42	615	-39	617	-43	614	-40	617	-40	616
1985	-38	606	-42	602	-39	605	-43	601	-39	605	-40	604
1986	-38	595	-42	591	-39	594	-43	590	-39	594	-40	593
1987	-39	591	-43	587	-40	590	-44	586	-40	590	-41	589
1988	-39	589	-43	585	-40	588	-44	584	-40	588	-41	587
1989	-40	596	-44	592	-41	596	-45	591	-41	595	-42	595
1990	-38	590	-42	586	-39	589	-42	585	-39	589	-40	588
1991	-40	591	-44	587	-41	590	-45	586	-41	590	-42	589
1992	-41	597	-46	593	-42	597	-46	592	-42	596	-43	596
1993	-43	587	-48	583	-44	587	-48	582	-44	586	-45	586
1994	-45	585	-50	580	-46	584	-51	579	-46	584	-47	584
1995	-47	583	-52	578	-47	582	-53	577	-48	582	-48	582
1996	-48	580	-54	574	-49	579	-55	573	-49	579	-50	578
1997	-50	576	-56	570	-51	576	-57	569	-51	575	-52	575
1998	-52	573	-58	567	-53	572	-59	566	-53	572	-54	571
1999	-54	570	-60	564	-54	570	-61	563	-55	569	-55	569
2000	-55	567	-62	560	-56	566	-63	559	-56	566	-57	565

Note:
1 = Energy Savings *at Disposal (million Btus)*
2 = Life-Cycle Energy Requirements Per Vehicle (million Btus)
A = Thermoplastics Recycling
B = ASR Incineration
C = Thermoplastics Recycling in Combination with Incineration
D = Bumper and Dashboard Recycling
E = Bumper and Dashboard Recycling in Combination with Incineration

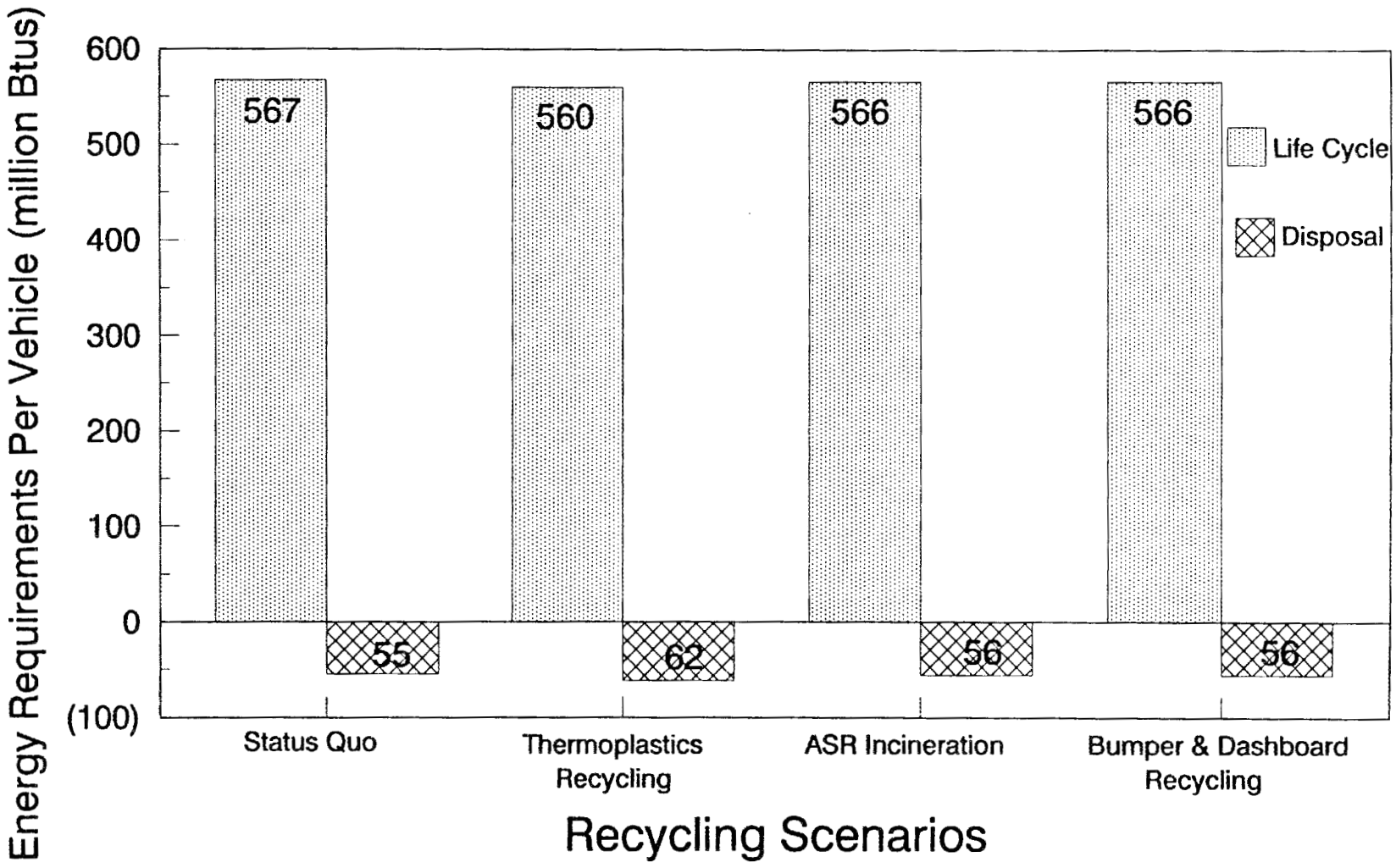

Fig 4.5. Life cycle energy impacts of various recycling scenarios for the model year 2000 vehicle C:\U1\FL\Ene-Auto.DRW

Recycling the bumper covers and the dashboard of a vehicle does not change the existing energy requirements of a vehicle by much. These parts contribute only 29 lbs (i.e., 1%) to the overall weight of a vehicle and thus the energy saving potential is around 0.5 million Btus (or the equivalent to 0.2 barrels of crude oil) per vehicle. If the recycling of bumpers and dashboards is followed by the incineration of ASR, the energy savings potential increases additionally by 1 million Btus (as previously discussed). Thus, compared to the status quo option, the life-cycle energy requirements of a vehicle is reduced by less than 2 million Btus under the option of recycling bumpers and the dashboard followed by the incineration of ASR.

4.3.2.2 Aggregate Energy Impacts

The estimates of the aggregate energy impacts at the automobile disposal stage and the quantity of ASR to be landfilled for the five alternative recycling options considered are shown in Table 4.8. Compared to the use of the existing recycling approach (i.e., the status quo option), the additional energy savings potential at the vehicle disposal stage due to the recycling of thermoplastics increases from 20 trillion Btus in 1989 to 33 trillion Btus in 2000. To place the number in perspective, the recycling of thermoplastics from automobiles is projected to result in annual energy savings equivalent to between 4 to 6 million barrels of crude oil. The energy savings potential increases every year because of the increasing thermoplastics content of automobiles. The quantity of ASR to be landfilled decreases as a result of the recycling of thermoplastics. It is projected that the recycling of thermoplastics will reduce ASR quantity by 1 billion lbs by the year 2000.

As was the case with the energy impacts of an average automobile, aggregate energy impacts are not significantly affected by the incineration of ASR. The energy savings potential at the vehicle disposal stage due to incineration increases by 5 trillion Btus or the equivalent of 0.9 million barrels of crude oil. However, the reduction in the quantity of ASR to be landfilled because of incineration is substantial -- about 80% from the current level of ASR landfilling. The quantity of ASR to be annually landfilled is projected to decrease from the current level of 5 billion lbs to 1 billion lbs.

The quantity of ASR to be landfilled if ASR incineration is preceded by the recycling of thermoplastics (Scenario C) is not significantly lower (i.e., 100-200 million lbs) than the incineration of all ASR. The recycling of high energy content thermoplastics in combination with the incineration of ASR maximizes the total energy savings potential. The total energy savings at the vehicle disposal stage is estimated to be 346 trillion Btus by the year 2000 -- 12% higher than if the current recycling approach is followed. The recycling of thermoplastics in combination with incineration results in the maximum aggregate energy savings and the least quantity of ASR for landfilling.

The aggregate energy impacts of the recycling of bumpers and the dashboard are low, but higher than in the case of complete ASR incineration. For example, 316 trillion Btus of energy savings at the disposal stage are projected by the year 2000 in the former case, compared to 314 trillion Btus in the latter case. However, the difference in the quantity of ASR to be landfilled between these two alternate recycle scenarios is substantial. Bumper and dashboard recycling will have little effect on the current annual quantity of ASR that is landfilled, reducing the quantity by 218 million lbs. Incinerating the ASR that is generated after bumper and dashboard recycling would result in an additional energy savings (above that gained through bumper and dashboard recycling alone) of 5 trillion Btus annually. ASR to be landfilled annually in Scenario E is projected to about the same as incinerating all ASR.

Table 4.8 Estimates of the aggregate energy impacts of various recycling scenarios

Model Year	Recycling Scenarios											
	Status Quo		A		B		C		D		E	
	1	2	1	2	1	2	1	2	1	2	1	2
1989	-265	4746	-285	4129	-270	949	-290	826	-272	4546	-277	909
1990	-266	4700	-287	4058	-271	940	-291	812	-273	4500	-277	900
1991	-263	4600	-285	3936	-268	920	-290	787	-270	4401	-275	880
1992	-259	4478	-282	3795	-264	896	-286	759	-266	4281	-271	856
1993	-259	4438	-283	3723	-264	888	-287	745	-266	4242	-270	848
1994	-267	4558	-293	3790	-272	912	-298	758	-274	4356	-279	871
1995	-279	4711	-307	3882	-284	942	-312	776	-286	4502	-291	900
1996	-295	4914	-325	4023	-300	983	-329	805	-302	4695	-307	939
1997	-304	5055	-336	4116	-310	1011	-341	823	-312	4830	-317	966
1998	-307	5057	-340	4082	-313	1011	345	816	-315	4833	-321	967
1999	-308	5019	-341	4026	-313	1004	-345	805	-315	4797	-321	959
2000	-309	4977	-342	3963	-314	995	-346	793	-316	4759	-322	952

Note:
1 = Energy Savings at Disposal (trillion Btus)
2 = Quantity of ASR to be Landfilled (million lbs)
A = Thermoplastics Recycling
B = ASR Incineration
C = Thermoplastics Recycling in Combination with Incineration
D = Bumper and Dashboard Recycling
E = Bumper and Dashboard Recycling in Combination with Incineration

4.4 SUMMARY

Life-cycle energy use in the average U.S. automobile has declined and is expected to continue to decline over the time period 1989 to 2000. A shift to more plastics and aluminum and away from ferrous metals has contributed to an increase in the embodied energy content of the average vehicle; and, somewhat surprisingly, the energy retrieved at the recycle stage has increased due to the large energy savings associated with recycling aluminum. (The status quo does not provide for plastics recycling.) The shift to plastics and aluminum has also contributed to a significant decrease in the energy consumed during the vehicle's operational life, and these energy savings far exceed any energy losses associated with the increase in embodied energy or energy losses due to the disposal of automotive plastics. The life-cycle energy requirements for a 2000-model-year vehicle are projected to be about 66% of the life-cycle energy requirements for the average 1976-model-year vehicle. For the U.S. fleet as a whole, energy use has increased and is projected to continue to increase due to the larger number of automobiles in operation. The quantity of ASR is projected at between 4 to 5 billion pounds per year over the projection time frame.

This Section also considered the potential impacts (in terms of life-cycle energy use and ASR quantity) of changes in the recycle status quo. From an energy perspective, the option of recycling all thermoplastics in combination with the incineration of the remaining ASR provides the least life-cycle energy requirements per vehicle -- savings of 3 to 8 million Btus, depending on the model year. However, the more realistic option of recycling selected thermoplastic parts provides savings of only one million Btus. From a fleet perspective, the adoption of the alternative recycling scenarios considered here is projected to result in total energy savings in the range of 25 to 37 trillion Btus, or the equivalent of 4.5 to 6.7 million barrels of crude oil. Alternatives to the recycle status quo would also reduce the quantity of ASR to be landfilled. The current 5 billion pounds per year could be reduced to between 1 and 4 billion pounds depending on the approach adopted. Incineration would be most effective in reducing the quantity of material to be landfilled, turning the 5 billion pounds of ASR into about 1 billion pounds of ash.

NOTES FOR CHAPTER 4

1. U.S. Department of Energy, Energy Information Administration 1992. *Monthly Energy Review of March 1992.* Washington, D.C., p.25.

2. Davis, Stacy C. and Sonja G. Strang 1993. *Transportation Energy Data Book: Edition 13.* ORNL-6743. Oak Ridge National Laboratory, Oak Ridge, Tenn.

3. The Aluminum Association, Inc. 1980. *Use of Aluminum in Automobiles - Effect on the Energy Dilemma.* Report T12. Washington, D.C., April.

4. Farrissey, W. J. 1991. Recycle of Thermoset Polyurethanes. RecyclingPlas VI - Conference: Plastics Recycling as a Future Business Community, Technomic Publishing Company, Inc., Lancaster, Penn., p. 15.

5. Lemons, J. F. 1989. Materials Systems Analysis of the Domestic Passenger Car. Bureau of Mines, November.

6. Sullivan, J. 1993. Ford Motor Co., Scientific Research Lab., Dearborn, Mich. personal communication with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 29.

7. *Ward's Automotive Yearbook* 1977 (and successive years through 1993). Ward's Communications, Inc., Detroit, Mich.

8. *Modern Plastics*. "Plastics in Transportation," Jan. issues, 1977-1993.

9. Wrigley, A. 1993. American Metal Market, Detroit, Mich, personal conversation with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 23.

10. Jody, B. J. and E. J. Daniels 1991. Automobile Shredder Residue: Treatment Options. *Hazardous Waste and Hazardous Materials* 8(3):219-30.

11. "NY utility burns tires for energy" 1993. *Tire Business* March 22, p.17.

12. Curlee, T. R. and S. Das 1989. *Plastics Recycling in the Industrial Sector: An Assessment of the Opportunities and Constraints*. ORNL/TM-11258, Oak Ridge National Laboratory, Oak Ridge, Tenn, November.

13. Gaines, L. L. and S. Y. Shen 1980. *Energy and Material Flows in the Production of Olefins and Their Derivatives.* ANL/CNSV-9, Argonne National Laboratory, August.

Gaines and Shen define the terms as follows: Heat of combustion of feed is the sum of the heats of combustion of all feedstocks entering into a process sequence, starting with oil and gas. Net process energy is the total fuel required to complete all steps of a manufacturing process minus the heat of combustion of any by-product fuels not burned within that process sequence.

14. Chapman, P.F. and F. Roberts 1983. *Metal Resources and Energy*. Butterworths & Co (Publishers) Ltd., United Kingdom.

15. Fuel economy for the period 1976-1992 is based on Williams, L. and P. Hu (1991). (ORNL-6672, Oak Ridge National Laboratory, Oak Ridge, Tenn.); and for 1993-2000 on Chien, D. (1993). [Energy Information Administration, U.S. Department of Energy, Washington, DC, personal communication with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, Tenn., July 7.]

16. According to Stratton (1993), a 1500 HP shredder capacity can process at least 60 tons/hr of automobile scrap. [Stratton, Jeff 1993. Southern Founders Supply, Inc. Knoxville, Tenn. Personal communication with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, Tenn., July 15.]

17. *Ward's Automotive Yearbook* 1993. Ward's Communications, Inc., Detroit, Mich.

18. *Ward's Automotive Reports*. 1977-1993. Factory Installation Report, Ward's Communications, Inc., Detroit, MI, various pages.

19. Chien, D. 1993. Personal communication. Energy Information Administration, U.S. Department of Energy, Washington, DC, July 7.

20. Miaou, Shaw-Pin 1990. *Study of Vehicle Scrappage Rates*. (unpublished) Oak Ridge National Laboratory, Oak Ridge, Tenn. See note number 3 of Chapter 2 for description of how the estimate was made.

21. Miaou (1990) used a logistic curve for the scrappage rate, earlier developed by Greene and Eric Chen (1981). Vehicle scrappage rate at age t (R_t) is defined as:

$$R_t = \frac{1}{a + \exp\{-(b+ct)\}}$$

where t represents vehicle age and a, b, and c are model coefficients.

Greene, D. L. and C. K. Eric Chen 1981. "Scrappage and Survival Rates of Passenger Cars and Light Trucks in the U.S. 1966-77," *Transportation Research* **15A**(6):383-89.

22. U.S. Department of Energy 1988. *Residential Transportation Energy Consumption Survey: Household Vehicle Energy Consumption 1988*. DOE/EIA-0464(88), Energy Information Administration, Washington, DC.

23. This compares favorably to the Big 3's estimate of 2.5 to 3.0 million tons of ASR (see Section 2.2.2).

24. The use of different additives in different aluminum alloys results in problems with aluminum recyclability.

25. Natural Resources Defense Council 1992. Comparison of Energy Benefits for Plastic Recycling and Incineration, Memorandum, NRDC, New York, Sept. 9.

26. Wolman, M. C. Hubble, W. S. Most, I. G. and S. L. Natof 1986. "Power Generation from Automobile Shredder Waste Fuel: Characterization and System Feasibility." *12th National Waste Processing Conference*, American Society of Mechanical Engineers, NY.

27. Curlee, T. R., S. M. Schexnayder, D. P. Vogt, A. K. Wolfe, M. Kelsay, and D. L. Feldman (In Press). *Waste-to-Energy in the United States: A Social and Economic Assessment*. Quorum Books, Westport, Conn.

28. Currently, automobile bumpers are mostly made of polyurethanes, a thermoset material. On the other hand, dashboards are mostly made of SMA, and in some cases may also contain different plastics for upper and lower components.

29. Best, J. R. 1993. Market Search Inc., Toledo, Ohio, personal conversation with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, Tenn., August 9.

5. CONCLUSIONS

The future of automobile recycling in the United States will be shaped by current and anticipated trends -- trends that may challenge the economic viability of the recycling status quo and raise questions about the life-cycle energy requirements of vehicles. Three trends are key. First, the composition of automobiles is shifting from ferrous metals toward plastics and aluminum. This trend reduces the quantities of materials that have been recycled historically and increases the quantities of automobile shredder residue (ASR) that have been disposed of historically in landfills. Less materials available for recycle means fewer energy savings at the recycle step and fewer dollars for the automobile shredders. Second, the cost of landfilling ASR is increasing and future landfill capacity is suspect. Thus, in addition to paying for the disposal of larger quantities of waste per vehicle, the per-unit cost of that disposal is increasing. Third, the environmental consequences of ASR remain controversial. Debate centers on whether ASR should be disposed of in RCRA Subtitle D landfills -- along with common municipal solid waste -- or whether ASR should be treated as a hazardous or "special" waste that requires more technologically sophisticated and expensive landfills or pre-disposal treatment.

The study documented in this report examined the likely implications of these trends. More specifically, the report (1) reviews the status of the automobile recycling industry in the United States, including the current technologies used to process scrapped automobiles and the challenges facing the automobile recycling industry; (2) examines the current status and future trends of automobile recycling in Europe and Japan, with the objectives of identifying "lessons learned" and pinpointing differences between those areas and the United States; (3) presents estimates of the energy system impacts of the recycling status quo and projections of the probable energy impacts of alternative technical and institutional approaches to recycling; and (4) identifies the key parameters that will determine the future economic viability of the domestic automobile recycling industry.

The study draws several interesting conclusions that are suggestive of the severities of different aspects of the problem and which point to future research needs. The study found that trends in the material composition of automobiles during the past decade are expected to continue. Specifically, quantities of plastics and aluminum in automobiles are expected to continue to increase. Between 1992 and 2000, the average weight of plastics and aluminum per car will about double, while the use of carbon steel will decrease. The study found that these changes will have significant impacts on the life-cycle energy use of the typical automobile, but not just at the point of disposal and not necessarily in ways that a cursory examination would suggest. Our life-cycle analysis found that the quantity of energy used in the manufacture of automobiles will increase (reflecting the high Btu contents of plastics and, especially, aluminum); the energy consumed during the life of the automobile will decrease in response to new technologies and lighter weight vehicles; and, somewhat surprisingly, the energy savings from the recycling of automobiles are expected to increase (due mainly to the anticipated recycling of high-Btu aluminum).

The most important conclusion of our assessment of the energy implications of the recycling status quo is that trends in material composition and the viability or non-viability of recycling the non-metallic components of the typical automobile are of secondary importance compared to the energy consumed during the life of the automobile. Small changes in the fuel efficiency of a vehicle

overshadow potential energy losses associated with the adoption of new and possibly non-recyclable materials. If there is no change in the recycle status quo, this study projects that the life-cycle energy consumed for the typical automobile will decrease from 599 million Btus in 1992 to 565 million Btus in 2000. Energy consumed during the manufacture of the typical car will increase from about 120 to 140 million Btus between 1992 and 2000, while energy used during vehicle operation will decrease from 520 to 480 million Btus. This study projects that energy saved at the recycle step will actually increase from 41 million Btus in 1992 to 55 million Btus in 2000.

This study also investigated the energy impacts of several changes to the recycle status quo, including the adoption of technologies to retrieve the heat value of ASR by incineration and the recycle of some or all thermoplastics in the typical automobile. The study found that under optimistic conditions -- i.e., the recycling of all thermoplastics and the incineration with heat recovery of all remaining ASR -- only about 8 million Btus could be saved per automobile, increasing the total energy recovered in recycling from about 55 to 63 million Btus. In the more realistic scenario -- i.e., the recycling of easy-to-remove thermoplastic components (bumper covers and dashboards), the energy savings are only about 1 million Btus per vehicle.

Therefore, the changes in energy use due to changes in material composition and changes in the recycle status quo are not expected to greatly alter the life-cycle energy requirements of the average vehicle. From an energy perspective, the more important issue concerns the public's acceptance of non-recyclable materials and increasing quantities of ASR for disposal. If public pressures lead to the rejection of new automotive technologies on the basis of non-recyclability, the potential energy savings foregone during the operational life of the vehicle (due to failure to adopt new technologies) could far exceed the potential energy losses that may occur at the manufacturing and recycle steps.

Aside from questions about the energy implications of shifts to new and possibly non-recyclable materials, concern has been raised about the increasing quantities of ASR and potential environmental problems associated with ASR disposal. This study found that under the recycling status quo, the quantities of ASR to be landfilled will increase from about 4,478 million pounds in 1992 to about 5,000 million pounds in 2000. However, these quantities must be placed in perspective. Currently and during the coming decade, ASR quantity is expected to be less than 1.5% of the size of the municipal solid waste (MSW) stream in the United States. In Europe, ASR accounts for only about 2% of sanitary landfill mass. For further perspective, ASR contributes less solid waste than do newspapers (about 6.6% of MSW) and office paper (about 3.3% of MSW). ASR contributes about the same quantity of waste as do disposable diapers, clothing and footwear, or paper bags.

The study of alternative recycling methods estimates that the annual quantity of ASR in the United States could be reduced from about 5,000 million pounds to about 1,000 million pounds of ash if all ASR is incinerated. Alternatively, ASR quantity could be reduced to about 4,000 million pounds if all thermoplastics in automobiles are recycled. However, in the more realistic case of recycling only thermoplastic bumper covers and dashboards, the quantity of ASR would be reduced by only 200 million pounds. Because ASR quantities are small compared to other forms of waste entering RCRA Subtitle D landfills, a significant reduction or increase in the size of the ASR waste stream will not in itself have a large impact on the solid waste stream in the United States.

The question of potential environmental damages from the disposal of ASR in conventional landfills is less tractable and was not a major focus of this study. This study did find, however, that

all ASR currently generated in the United States is disposed of in RCRA Subtitle D landfills -- i.e., conventional MSW landfills. Although some states have placed restrictions on ASR disposal, technologies exist to meet those requirements. The implications of more severe environmental restrictions on ASR disposal were not explored.

The findings of this study concerning life-cycle energy use, ASR quantities, and environmental regulations do not suggest, however, that problems related to automobile recycling are trivial. Public policy with respect to recycling and waste disposal is often based on public perceptions, and questions about the inability to recycle automobiles or significant portions thereof can lead to very visible and identifiable public concerns. Of equal importance is the very real possibility that current trends may lead to an automobile recycling industry in the United States that is not economically viable.

Current conditions in Europe are suggestive of the situation that may exist in the United States in future years. While scrapped automobiles have an average price of about $100 in the United States, retired vehicles have a negative value in much of Europe. Available information suggests that this difference is due largely to the higher cost of ASR disposal in Europe. In addition, public opposition to ASR disposal is greater in parts of Europe than in the United States.

The current and pending problems with automobile recycling have gotten the attention of automobile shredders and automobile manufacturers world wide; and various approaches are being pursued to reduce the quantity of ASR and to increase the recyclability of automobiles. However, the approaches differ significantly. Public opinion and legislative initiatives in Europe are leaning toward placing responsibility for automobile recycling on automobile manufacturers; and manufacturers have responded by developing new approaches for hand-disassembly and designing vehicles that are easier to disassemble. Some European companies claim to manufacture automobiles that are 100% recyclable, if recycled in their prototype hand-disassembly facilities. Public and legislative pressures have been less in the Untied States, and the response has been less radical. Approaches in the United States have been targeted at labeling all plastic parts, removing selected plastic components for recycle prior to shredding, developing approaches to separate and recycle plastics in ASR, and developing incineration technologies to retrieve the heat energy of ASR.

The future of automobile recycling raises legitimate concerns for automobile manufacturers, automobile shredders, and consumers. During recent decades, the technology to recycle automobiles varied very little among industrialized countries. However, recent trends are leading to new approaches to recycling that may be country specific -- e.g., conventional shredders with conventional ASR landfill, pre-shredder dismantling of selected plastic parts in combination with shredding, and total hand-dismantling. Automobile manufacturers have legitimate concerns that some countries will mandate approaches to recycling that cater to specific automobile designs, resulting in market barriers for some automobile manufacturers in some countries. Automobile manufacturers are also concerned about proposed mandates to place the responsibility for (and the cost of) recycling on the manufacturers.

Automobile shredders are concerned about trends that reduce their economic viability -- i.e., fewer quantities of recyclable materials, larger quantities of ASR, higher landfill costs, and more restrictive environmental regulations. Some shredder operators have concerns about the greater involvement of automobile manufacturers in recycling, in terms of having less control of their industry and facing new approaches to recycling that may compete with the current shredder capacity they own.

Consumers must be concerned for several reasons. Will current trends eventually require owners of scrap automobiles to pay for their disposal, as is the case in much of Europe? Will the number of abandoned vehicles increase significantly as a result? Will the price of automobiles increase because of requirements for easy disassembly or because certain materials are not allowed in the construction of vehicles? Will restrictions on the use of selected materials result in less fuel-efficient vehicles? Are the environmental risks associated with ASR disposal significant?

As the debate ensues, U.S. policy makers will be faced with decisions about mandates on automobile material composition, restrictions on the disposal of ASR, and required automobile designs to facilitate recycling. Automotive technologies designed to respond to CAFE standards (e.g., lightweight plastic materials) may be incompatible technically and economically with requirements for recyclability. New approaches to recycling in Europe may create additional market barriers for U.S. automobile manufacturers, to which the U.S. government may wish to respond.

An intelligent public debate about automobile recycling will require additional and more defensible information about the various costs and benefits associated with the alternatives. Within the coming decade a primary focus of the debate will be on the future economic viability of the domestic automobile recycling industry, and it is here that this study suggests additional research. If current and anticipated trends result in a domestic recycling industry that is not economically viable, public concern will be increased significantly. Technologies being developed and adopted to improve the fuel efficiency of automobiles may be at risk if the adoption of those technologies is perceived to contribute to a less viable recycle industry.

BIBLIOGRAPHY

"ADAC starts car recycling project" 1990. PRS Automotive Service, December 4. Abstracted from *Handelsblatt* December 3, p. 19.

"All recyclable car on auto show card" 1993. *American Metal Market* April 5, p. 10.

"Aluminium [sic] in car production promoted by recyclability" 1990. PRS Automotive Service, February 21. Abstracted from *Frankfurter Allgemeine* February 20, p. T4.

Aluminum Association, Inc. (The) 1980. *Use of Aluminum in Automobiles - Effect on the Energy Dilemma*. Report T12. Washington, D.C., April.

"Are automakers ready for Germany's 1993 recycling decree?" 1992. PRS Automotive Service, September 23.

"Austrian car dealers to take back autos ready for scrap pile" 1992. *American Metal Market* September 10, p.2.

"Auto plastics being tested for recycling potential" 1993. *Automotive News* April 5, p. 38.

Bever, M.B. 1980. The impact of materials and design changes on the recycling of automobiles. *Materials and Society* 4(3):375-385.

Bilbrey, J.H. Jr., J.W. Sterner, and E.G. Valdez 1978. Resource recovery from automobile shredder residues. Paper presented at the First World Recycling Congress, Swiss Industries Fair, Basel, Switzerland. March 6-7.

Bird, A.P. 1990. Reclamation and recycling--the motor car and white goods. *Plastics and Rubber Processing and Applications* 13(4):213.

"BMW launches pilot car recycling plant" 1991. *Advanced Composites Bulletin* May.

"BMW is opening the first car recycling plant in the United Kingdom" 1991. *Green Marketing Report* 2(7).

"BMW pilot shreds pounds; tests research least-waste to take apart clunkers" 1992. *American Metal Market* December 8, p. 4.

"BMW wins award for automobile recycling effort" 1992. *Environment Week* 5(37).

Bonsignore, P.V., B.J. Jody, and E. Daniels 1991. Separation techniques for auto shredder residue. In *Designing for Recyclability and Reuse of Automotive Plastics*, SP-867. Society of Automotive Engineers, Inc., Warrendale, PA, pp. 59-63.

"Britain gets used-car buster: First BMW deal of possible 15 salvage partnerships" 1992. *American Metal Market* December 8, p. 9.

Brooke, Lindsay, Gerry Kobe, John McElroy, and Christopher A. Sawyer 1992. "Recycling: What's the problem?" *Automotive Industries* 172(9):44.

"Car breakdown takes priority" 1993. *Engineer* February 18, p. 25.

"Car crushers cry wolf over plastics scrap" 1987. *British Plastics and Rubber* March, pp. 37-39.

"Car dismantling efforts will rely on scrap industry" 1992. *American Metal Market* December 3, p. 12A.

"Car importers form recycling association in Germany" 1992. PRS Automotive Service, August 25. Reprinted from TUB Bayern Press Release July 9.

"Car importers look at possible recycling in Germany" 1992. PRS Automotive Service, April 27. Abstracted from *Frankfurter Allgemeine* April 27, p.20.

"Car plastics recycling examined," 1993. PRS Automotive Service, March 2.

"Car recycling association set up in Germany" 1991. PRS Automotive Service, September 9. Abstracted from *Le Lloyd* September 6, p.2.

"Car recycling catches on in Germany" 1990. *New Technology Week* 4(44).

"Car recycling schemes not adequate, according to Toepfer" 1991. PRS Automotive Service, September 20. Abstracted from *Frankfurter Allgemeine* September 20.

"Carmakers work to create plastics recycling program, 1992. *Plastics News* November 2, p.1.

Chapman, P.F. and F. Roberts 1983. *Metal Resources and Energy*. Butterworths & Co (Publishers) Ltd., United Kingdom.

Chien, D. 1993, Energy Information Administration, U.S. Department of Energy, Washington, D.C. Personal communication with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, TN July 7.

Chynoweth, Emma and David Rotman 1993. Germany is in the fast lane as recycling gains speed. *Chemical Week* 152(7):18.

"Commitment to recycling cars in France" 1992. *Advanced Composites Bulletin* December.

"Companies to work together in car recycling in Cologne area" 1992. PRS Automotive Service, December 8.

"Conflicting views as car makers anticipate EC recycling law" 1992. PRS Automotive Service, December 3.

Culp, Eric 1992. Push to recycle parts may narrow resin use in cars. *Modern Plastics* October, p.68.

Curlee, T.R. 1985. Plastic waste and the market penetration of auto shredders. *Technological Forecasting and Social Change* 28(1):29-42.

Curlee, T. R 1986. *The Economic Feasibility of Recycling: A Case Study of Plastic Waste.* Praeger Publishing, New York, NY.

Curlee, T.R. and S. Das 1989. *Plastics Recycling in the Industrial Sector An Assessment of the Opportunities and Constraints.* ORNL/TM-11258, Oak Ridge National Laboratory, Oak Ridge, TN November.

Curlee, T. R., S. Das, and U.S. Environmental Protection Agency 1991. *Plastic Wastes: Management, Control, Recycling, and Disposal.* Noyes Data Corporation, Park Ridge, NJ.

Curlee, T. R., S. M. Schexnayder, D. P. Vogt, M. Kelsay, and D. L. Feldman 1994. *Waste-to-Energy in the United States: A Social and Economic Assessment.* Quorum Books, Westport, CT.

Cutler, Herschel 1993. Executive Director, Institute of Scrap Iron and Steel, Inc., Washington, D.C. Personal communication with T. Randall Curlee, Oak Ridge National Laboratory, Oak Ridge, TN June 16.

Das 'Auto im Baukastensystem' kommt" 1992. Presse, August 26, p. 16.

Das, S. and T.R. Curlee 1988. Ceramic heat exchangers: Cost estimates using a process-cost approach. *American Ceramic Society Bulletin* 67(10):1684-89.

Das, S. and T.R. Curlee 1992. The cost of silicon nitride powder and the economic viability of advanced ceramics. *American Ceramic Society Bulletin* 71(7):1103-11.

Davis, Bruce 1991. Car firms press for recyclability. *European Rubber Journal* April, p.6.

Davis, S.D. and S.G. Strang 1993. *Transportation Energy Data Book: Edition 13.* ORNL-6743, Oak Ridge National Laboratory, Oak Ridge, TN.

"DEQE must act to end abandoned car crisis; shutdowns New England-wide threaten public health and safety" 1988. PR Newswire June 27.

"Dutch to force recycling of cars and other goods" 1992. *Food and Drink Daily* 2(374).

"Environment: Accord de cooperation PSA-Sachsering (RFA)" 1992. *Tribune (Cote Defoses)* December 2, p. 13.

"Exclusive updated survey of automobile shredding" 1980. *Scrap Age* October, p. 91-98.

Farrissey, W.J. 1991a. RIM parts for automobiles--Life cycle energy and ecobalance. In *Designing for Recyclability and Reuse of Automotive Plastics* SP-867. Society of Automotive Engineers, Inc., Warrendale, PA, pp. 1-8.

Farrissey, W. J. 1991b. Recycle of thermoset polyurethanes. *RecyclingPlas VI - Conference: Plastics Recycling as a Future Business Community.* Technomic Publishing Company, Inc., Lancaster, PA, p. 15.

Feast, Richard 1992. The greening of Europe: Germany is pacing Europe toward reduced shredding, buy-back policies and a 100% recyclable vehicle. *Automotive Industries* 172(9):58.

"Fiat and PSA in talks for cooperation in car recycling" 1992. PRS Automotive Service, December 3.

"Fiat and Rover study recycling joint venture" 1993. PRS Automotive Service, April 22.

"Fiat auto presents key elements of FARE car recycling" 1993. PRS Automotive Service, April 22.

Fiat, Himont, Falck and Ada to join forces in car recycling" 1992. PRS Automotive Service, July 6. Abstracted from *Il Sole 24 Ore*, July 3, p.3.

"Fiat presents car recycling plan" 1992. PRS Automotive Service, December 22.

"Fiat, PSA, Renault and Volvo join Forces in car recycling" 1993. PRS Automotive Service, January 5.

"Fiat turns to scrap" 1992. *European* December 20, p. 39.

Field, F.R. III and J.P. Clark 1991. The recycling dilemma for advanced materials use: automobile materials substitution. *Materials and Society* 15(2):109-147.

Forcucci, F. and D. Thompkins 1991. Automotive interiors--Design for Recyclability. In *Designing for Recyclability and Reuse of Automotive Plastics*, SP-867. Society of Automotive Engineers, Inc., Warrendale, PA, pp. 41-46.

"Ford commissions first car recycler in eastern Germany" 1993. PRS Automotive Service, April 13.

"French car makers stepping up recycling efforts" 1991. PRS Automotive Service, July 3. Abstracted from *Financial Times* July 3, p.14.

"French car recycling starts early" 1992. *American Metal Market* May 29, p.9.

Furukawa, Tsukasa 1991. Japan auto makers rev recycling (part 2). *American Metal Market* 99(182):4.

Furukawa, Tsukasa 1993. Japanese companies research fluff problem; form group to study recycling alternatives. *American Metal Market* 101(57):7.

Gaines, L.L. 1981. *Energy and Materials Use in the Production and Recycling of Consumer-Goods Packaging.* ANL/CNSV-TM-58. Argonne National Laboratory, Argonne, IL, February.

Gaines, L. L. and S. Y. Shen 1980. *Energy and Material Flows in the Production of Olefins and Their Derivatives.* ANL/CNSV-9, Argonne National Laboratory, Argonne, Ill., August.

"German auto industry criticizes scrap bill" 1993. PRS Automotive Service, January 12.

"German automakers unite on recycling" 1992. *Modern Plastics* May, p. 15.

"German car men see green: Want to act on recycling before government steps in" 1991. *American Metal Market* April 4, p.1.

"German industry ponders automobile plastics recycling" 1987. *Plastic Industry Europe* 6:1,21.

"German venture plans to start auto shredding" 1992. *American Metal Market* November 12, p. 7.

Gittleman, D. 1992. *Prospects for recycling automotive polymer waste.* Thesis, Tufts University, Medford, MA.

Goodwin, M.E. 1991. Westinghouse may incinerate fluff. *American Metal Market* 99(4):7.

Grace, Ken 1992. One day, my son, all this will be your.... *British Plastics and Rubber* March, p.38.

"Green horn: Automakers are touting the use of salvaged plastic in new cars" 1993. *Automotive News* April 12, p. 20i.

Greene, D. L. and C. K. Eric Chen 1981. "Scrappage and Survival Rates of Passenger Cars and Light Trucks in the U.S. 1966-77," *Transportation Research* Vol. 15A, No. 6, pp. 383-89.

Harwood, J.J. 1977. Recycling the junk car. *Technology Review* 79(4):32-37.

Hubble, W.S., I.G. Most, and M.R. Wolman 1987. *Investigation of the Energy Value of Automobile Shredder Residue.* DOE/ID/12551-1. U.S. Department of Energy, Office of Industrial Programs, Washington, DC.

"IML draws up plan for disassembly plants for scrap cars" 1993. *PRS International* March 4.

Jody, B.J. and E.J. Daniels 1991. Automobile Shredder Residue: Treatment Options. *Hazardous Waste and Hazardous Materials* 8(3):219-230.

Keller, Ryann 1991. Europe recycles. *Automotive Industries* 171(11):9.

"Kloeckner sets up plastics/car recycling company" 1992. PRS Automotive Service, December 9.

"Kloeckner looking for 20% of German car recycling market" 1993. PRS International, March 25.

Kreisher, Keith R. 1991. Recyclability keys PP growth in European autos, *Modern Plastics* October, p. 56.

Leaversuch, R.D. 1991. Chemical recycling brings real versatility to solid-waste management. *Modern Plastics* July, p. 40-43.

Lemons, J. F. 1989. Materials systems analysis of the domestic passenger car. Bureau of Mines, November.

"Makers move into recycling" 1991. *Motor Report International* November 25(627):5.

"Mazda expands car bumper recycling in Germany" 1993. PRS Automotive Service, March 2.

"Mercedes-Benz sucht ein Stahlwerk" 1992. *Sueddeutsche Zeitung* December 2, p. 35.

Miaou, Shaw-Pin 1990. *Study of Vehicle Scrappage Rates.* (unpublished) Oak Ridge National Laboratory, Oak Ridge, TN.

Miller, Bernie 1992. SPI (Society of the Plastics Industry) launches car-recycling program. *Plastics World* 50(5):16.

"Ministers and automotive executives to meet on car recycling" 1992. PRS Automotive Service, March 13. Abstracted for *Financial Times* March 13, p.8.

"Ministry of Transport to promote recycling of scrapped cars" 1991. *Comline Transportation* September 18, p.2.

Modern Plastics 1977 (and successive years through 1993). "Plastics in Transportation" Jan. issues.

Naitove, Matthew H. 1992. Europe leads in car-parts recycling. *Plastics Technology* 38(5):101.

"New car recycling association aims to recycle 100% of cars" 1991. PRS Automotive Service, September 5. Abstracted for *Handelsblatt* September 4, p.19.

"New law would boost Netherlands recycling" 1992. *American Metal Market* September 10, p.2.

"New technology recovers plastics from scrap cars" 1993. *World Waste* April, p. 8.

"NY utility burns tires for energy" 1993. *Tire Business* March 22, p.17.

"Old autos pave road to making new steel" 1993. *American Metal Market* February 18, p. 13A.

"Opel to follow VW with car recycling guarantee" 1991. PRS Automotive Service, August 20. Abstracted from *Handelsblatt* August 19, p.1.

"Peugeot and CFF share know-how" 1993. *American Metal Market* 101(18) January 28, p. 7.

"Peugeot, Renault team up: Recycling venture targets up to 200 junked cars daily" 1992. *American Metal Market* July 23, p.7.

"Peugeot sets up car recycling facility" 1991. *Haznews* July, no.40.

"Plastics recycling plans joins big three chemicals" 1992. *Chemical Marketing Reporter* December 12, p. 5.

Poggiali, B. 1985. *Production Cost Modeling: A Spreadsheet Methodology*. Thesis Massachusetts Institute of Technology, Cambridge, MA.

"Pragmatism needed" 1993. *Urethanes Technology* February 1993, p.28.

"Pressure to increase recycling properties of cars" 1990. PRS Automotive Service, January 25. Abstracted from *Automobil Revue* January 11, p.23.

"Preussag increases its car recycling activities" 1993. PSA Automotive Service, February 8.

"Preussag sets up first European car recycler" 1993. PRS Automotive Service, April 26.

"Process recovers more from junked cars" 1993. *Research and Development* 35(1):14.

Protzman, Ferdinand 1993. Germany's push to expand the scope of recycling. *The New York Times* July 4, p.8.

"PSA and CFF to help with Sachsenring car recycling plant" 1992. PRS Automotive Service, December 3.

"Recyclable car not too far away, say AIC" 1991. *Aftermarket Business* August 1, p. 76.

"Recyclage des voitures: les professionels evitent le decret" 1993. *Echos* February 15, p.10.

"Recycled PUR for RIM bumpers, panels" 1992. *Modern Plastics* May, p. 15.

"Recycling recovered plastics from scrapped cars" 1992. *High Performance Plastics* Elsevier Advanced Technology Publications, November.

"Recycling of cars by manufacturers in Germany" 1992. *Europe Environment* February 17, no. 0381.

"Recycling and the Automobile" 1992. Automotive Engineering **100**(10):41-57.

Regan, James G. 1992. Design for disassembly gets a nudge in Europe. *American Metal Market* **100**(165):8.

"Renault & PSA recycling 16 cars/day" 1992. PRS Automotive, December 4.

"Renault and BMW agree to recycle scrapped cars" 1992. PRS Automotive Service, October 22.

"Renault and PSA join forces in car recycling" 1992. PRS Automotive Service, July 21. Abstracted from *La Tribune de l'Expansion* July 17, p.10.

Rogers, Jack K. 1991. Redesigning Autos. *Modern Plastics* 68(5):86-91.

"Rostock company begins recycling cars" 1992. PRS Automotive Service, October 7.

"Rover and Bird group sign deal to recycle cars" 1991. PRS Automotive Service, October 25. Abstracted from *The Times* October 25, p.32.

"Schenck receives order for car recycling plant in E Germany" 1992. PRS Automotive Service, December 10.

Schmitt, R.J. 1991. Automobile shredder residue--The problem and potential solutions. In *Second International Symposium Recycling of Metals and Engineered Materials*, The Minerals, Metals and Materials Society, pp. 315-331.

"Second look" 1993. *Automotive News* March 29, p. 6i.

Shanoff, Barry 1993. Europe considers scrapped cars for recycling uses. *World Wastes* 36(2):14.

Smock, Douglas 1992. Plastics in new Opels will be easily recyclable. *Plastics World* 50(5):12.

"Sommer Metallwerke in car recycling" 1990. PRS Automotive Service, December 19. Abstracted from *Suddeutsche Zeitung* December 18, p.26.

Stratton, Jeff 1993. Southern Founders Supply, Inc. Knoxville, Tenn. Personal communication with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, TN, July 15.

Sullivan, J. 1993. Ford Motor Co., Scientific Research Lab., Dearborn, Mich. personal communication with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, TN, June 29.

"The possibility of recycled cars" 1990. PRS Automotive Service, November 28. Abstracted from *Motor Industry Management* October 1990:42-43.

"The processing of non-magnetic fractions from shredded automobile scrap: A review" 1989. *Resources Conservation and Recycling.* Elsevier Science Publishers, B.V./Pergamon Press.

"Thyssen Handelsunion to intensify car recycling activities" 1992. PRS Automotive Service, October 9.

"Toepfer wants automakers to be liable for car recycling" 1992. PRS Automotive Service, September 17.

"Toyota and Fiat proposing car part recycling solutions" 1992. *Plastics News* October 12, p. 46.

"Un Accord-Cadre" 1993. *Revue Hebdomadaire de l'Industrie Electrique & Electronique* April 9, p. 2.

U.S. Department of Energy 1988. *Residential Transportation Energy Consumption Survey: Household Vehicle Energy Consumption 1988.* DOE/EIA-0464(88), Energy Information Administration, Washington, DC.

U.S. Department of Energy 1993. *Annual Energy Outlook 1993: With Projections to 2010.* DOE/EIA-0383(93), Energy Information Administration, Washington, DC.

U.S. Department of Energy 1992. *Monthly Energy Review of March 1992*, Energy Information Administration, Washington, D.C., p. 25.

"U.S. shredder survey shows little change" 1988. *Recycling Today* March, p. 58-64.

Vandermerwe, Sandra and Michael D. Oliffe 1991. "Corporate challenges for an age of reconsumption." *Columbia Journal of World Business* **26**(3):6.

"VDA draws up new scrap car disposal concept" 1993. PRS Automotive Service, February 26.

"VDIK proposed trial recycling scheme for old cars" 1991. PRS Automotive Service, September 24. Abstracted from *Frankfurter Allgemeine* September 21, p.15.

"Volkswagen now using recycled plastics in polo models" 1993. *Automotive Service* March 19.

"Volvo plans to increase car recycling" 1991. PRS Automotive Service, October 29. Abstracted from *Svenska Dagbladet* October 27, p.8.

"VW body panels use recycled plastics" 1993. *Automotive News* January 25, p. 2i.

"VW planning to set up national car recycling network" 1992. PRS Automotive Service, January 14. Abstracted from *Suddeutsche Zeitung* January 10, p.31.

"VW in car recycling project" 1990. PRS Automotive Service, March 8. Abstracted from *VDI Nachrichten* March 2, 1990, p.24.

Ward's Automotive Reports 1977 (and successive years through 1993). Factory Installation Report, Ward's Communications, Inc., Detroit, MI.

Ward's Automotive Yearbook 1977 (and successive years through 1993). Ward's Communications, Inc., Detroit, MI.

Ward's Automotive Yearbook 1993. Ward's Communications, Inc., Detroit, MI.

"West German Mercedes-Benz studying car recycling" 1990. PRS Automotive Service, June 14. Abstracted from *Frankfurter Allgemeine* June 5, p.T1.

White, Liz 1992. Imperative: Recycle that car! *European Rubber Journal* **174**(2):27.

Williams, L. and P. Hu 1991. *Highway Vehicle MPG and Market Shares Report: Model Year 1990.* ORNL-6672, Oak Ridge National Laboratory, Oak Ridge, TN.

Winter, Drew 1992. DFD: Don't forget disassembly (design-for-disassembly applied to automobiles). *Ward's Auto World* **28**(11):38.

Wolman, M.R., W.S. Hubble, I.G. Most, and S.L. Natof 1986. Power generation from automobile shredder waste fuel: Characterization and system feasibility. In *Proceedings of 1986 National Waste Processing Conference.* The American Society of Mechanical Engineers, New York, pp. 91-103.

Worden, E. 1988. Car shredding industry hit by EPA crackdown. *American Metal Market* **96**(June 28):1,8.

"World's first automobile disassembly plant" 1992. *BioCycle* February 2, p. 82.

Wrigley, A. 1993. American Metal Market, Detroit, Mich. Personal Communication with Sujit Das, Oak Ridge National Laboratory, Oak Ridge, TN, June 23.

Wrigley, A. 1991. Car recycling consortium to be formed. American Metal Market, September 27, p. 2.

APPENDIX A

RECYCLING INITIATIVES IN EUROPE

APPENDIX A. RECYCLING INITIATIVES IN EUROPE

A.1 INDIVIDUAL AUTOMAKERS

A.1.1 BMW

According to a BMW executive, the company's approach to the problem of auto recycling is to acquire the knowledge needed to develop, train, and to some extent control, a decentralized network consisting of dismantlers and scrap car companies. BMW's approach is widely agreed upon by the European motor industry and several large plastics producers, who each have agreed to take back one or more types of plastics for recycling regardless of the original source.[1] By establishing authorized recycling centers in Europe, the United States and Japan, BMW is attempting to develop "environmentally safe and efficient methods for properly dismantling and recycling all BMW cars."[2]

In 1990 at Landshut (Bavaria) Germany, BMW launched its automotive recycling program by opening one of the first dismantling and recycling centers in Europe.[3,4] This was Germany's first car recycling plant (in response to proposed new recycling requirements), and materials reclamation methods and materials procurement policies to assist in recycling are being investigated at the facility. Estimates are that it will take two to seven hours to dismantle each car at an approximate cost of $264 per car. BMW's recycling project manager, Horst-Henning Wolf, has been quoted as saying that "if a vehicle's raw material and used-parts value are assessed at a lower value, it could mean the last owner would have to pay to have it dismantled."[4] New processes being developed at Landshut are reportedly reducing shredder waste from the Series 5 car: 309 pounds of waste after shredding currently vs. 573 pounds previous to the new process.[5] Wolf said that this reduction of 46% is expected to be reduced more than half again in the future. Recently, BMW published a manual on the new processes, and the company's findings are being incorporated in a series of ventures that are planned with independent auto dismantlers. The first of these ventures was initiated last November in Britain and is expected to eventually process 2500 BMW cars annually. According to Wolf, 82% of the weight of the Series 3 and Coupe models is recyclable.[5]

As a result of research at Landshut, BMWs of the future will be designed with recycling in mind. Avoiding components that combine materials (e.g., metal and plastics) is a critical factor.[6] Specifically, BMWs will be designed with more recycled materials (trunk liners are now made from recycled bumpers)[7], greater ease of disassembly, and parts identified with standard codes in order to facilitate sorting.[8] Special tools to speed disassembly operations are being developed at Landshut. In current recycling operations, gasoline, transmission, steering and brake fluids can become mixed with fluff, making the fluff toxic and potentially dangerous. So, special equipment has been developed by the researchers at Landshut that removes these fluids before the autos are disassembled and shredded. Other tools that have been developed speed disassembly by facilitating the easier removal of awkwardly shaped parts. Other design-for-disassembly (DFD) difficulties have been revealed, such as one-way screws being used in the assembly of steering column parts in some BMWs. BMW hopes to increase the efficiency of auto recycling by sharing their findings with automobile dismantlers.[10]

A.1.2 Mercedes

Mercedes, like BMW, is attempting to use more recycled parts in their cars. Recycled materials will be used in every sixth kilogram of plastics in the new Mercedes 190.[9] The wheel-well liners and insulation of Mercedes use recycled plastics.[7]

A.1.3 VW

In the summer 1991, VW initiated a takeback program for recycling 1992 Golfs free of charge. VW was the first manufacturer to introduce such a program.[3] VW is reportedly planning a Germany-wide car recycling network to be in place by the mid-1990s.[10] The bumpers of VW's Golf and Jetta use recycled plastics, which are derived from old bumpers collected at VW's sales and service organizations.[7] In addition to recycling bumpers, VW is evaluating radiator grills, fuel tanks, and wheel hub liners to meet the goal of recycling 30% of the plastics in VW cars. VW desires to reduce the number of different plastic types in parts to only five or six.[1]

Additionally, VW is supposedly the first car manufacturer to use recycled reinforced plastics in exterior body panels.[11] Recycled reinforced plastics were tested as insulation under the hood of the Polo, and the positive results of those tests has led to use in exterior body panels of the Polo. It is expected that the use of recycled reinforced plastics will reduce waste volume by 100 metric tons annually.[12] However, no details of this use of recycled reinforced plastics have been identified that would indicate whether this was one-time recycling or repeated recycling. Thus, it is unclear whether the recycling problem is solved, or merely delayed by this use of recycled reinforced plastics.

A.1.4 Opel

Opel began coding plastic parts in 1979 and since 1990 has had three materials recycling loops: 1) PP from battery cases and bumpers to make new fender liners, 2) polycarbonate/PBT from old painted bumpers made into new spoiler supports, and 3) converting ground-up urethane foam seating material into sound-insulating mats. Reducing polymer variety and eliminating thermosets are key to Opel's recycling plan.[13] Following the VW plan, Opel plans to take back standard-condition Astra models free of charge. [14] Currently, Opel uses 1600 tons of post-consumer recycled plastics in their cars each year.[7] Opel estimates its demand for recycled plastics will be 10,000 tons per year in 1993.[15]

A.1.5 Volvo

According to an autumn 1991 report, Volvo was initiating a project to increase the proportion of its cars that are recycled.[16] However, no further details of the program or its status have been identified thus far.

A.1.6 Fiat

Although there is no legal obligation in Italy to recycle at this time, Fiat (the Italian automaker) has established the Fiat Auto Recycling program (FARE) in several regions of Italy and plans to extend the program nationwide eventually.[17] The main objective of Fiat's FARE program is to recycle automobiles in a manner that is economically self-supporting. The program uses existing

industrial and car demolishing facilities, licensed by Fiat to participate. Fiat supervises the operation to insure environmental responsibility.[17] Ten demolishers in northern Italy have been recovering materials from scrap cars since September of 1992. Fiat plans to expand its activities in dismantling and recycling to achieve a target of 25000 cars in 1993.[18] It is projected that 500 tons of plastics and 100 tons of glass will be recovered in 1993.[19] The ultimate goal is to recycle all scrapped autos, of which there were almost 1.2 million in Italy in 1991.[19]

FARE seeks maximum cleanliness in scrapping the car metals. Repetitive reutilization of components is expected to subsidize the demolition costs, avoiding a consumer charge for scrapping. In addition to the recycling of metals, the majority of plastics, glass, and other synthetic materials is intended for recycling.[20] Fiat is also labeling certain parts according to resin type to facilitate recyclability.[21]

As a means of cost-effectively recycling plastic parts, Fiat is promoting the cascade concept. Specifically, recovered plastics are used in auto components for which the appearance and performance criteria are less demanding than those of the original uses for the plastics. Salvatore Di Carlo, the manager of Fiat's plastics department, admits that recycled material is at present slightly more expensive than raw material, but that Fiat is committed to using the recycled materials in the hope of opening a market for them.

A.1.7 Renault

In July 1991, Renault organized collection of recyclable parts from its dealers (in Germany and parts of France). Parts include plastic bumpers and catalytic converters.[22]

A.1.8 Peugeot

One of Peugeot's goals has been to integrate materials recycling technologies into automobile design as an important phase of auto recycling. The Citroen ZX and Peugeot 106 models reflect this. To accomplish this, there are four issues: 1) give preference to easily recyclable materials like PP, 2) use one type of plastics for major components, 3) code all plastics for identification, and 4) design parts to be easily disassembled.[23]

A.2 JOINT AUTOMAKER ACTIVITIES

A.2.1 Germany

Seven auto makers in Germany (Audi, BMW, Ford of Europe, Mercedes, Opel, Porshe, and VW) have united in their recycling efforts, forming the German Automobile Industry Life-Expired Vehicle Recycling Project. The goal is to establish a network of authorized, independent dismantlers across the country that would sort, regranulate, and return vehicles to the car makers or the material suppliers. The dismantlers will have to be capable of processing 500 to 1000 cars annually of at least three different models and be able to process a variety of resins.[24]

The German automotive industry association (VDA) has drafted a new concept for old car disposal that it has passed on to the Federal environment minister. The plan relies on voluntary efforts of car manufacturers rather than on efforts legislated by the government.[25]

A.2.1.1 Fiat and PSA Peugeot

Fiat and Peugeot are negotiating a possible cooperative agreement in car recycling. Peugeot is considering adoption of FARE. The companies may decide to recycle each other's scrapped cars in their respective countries (Italy and France).[19]

A.2.1.2 PSA Peugeot and Renault

Peugeot and Renault are cooperating to develop car recycling strategies and technologies. The two manufacturers are establishing a factory at Athis-Mons, France, that will be able to recycle the plastic components of 44,000 vehicles annually.[26] (Peugeot has previously been researching and implementing automobile recycling at its plant near Lyon, which recycled 95% of the content of 3500 cars in 1991).[27,28] As of November 1992, 20 workers at the Athis-Mons plant were dismantling approximately 15 scrapped Peugeot, Renault and Volvo cars per day.[27] Structures like bumpers will be recycled into new parts, and other plastics and parts with reinforced plastics will be incinerated. About 1.8 million cars are scrapped annually in France, which result in 280,000 tonnes of untreated scrap material. This amount of material will require that about 30 plants, similar to the size of the one in Athis-Mons, be established. Renault plans to open its own pilot plant in Lille, France that will use a grinding facility to process materials.[26] Peugeot is set to open an experimental waste treatment site.[29]

Peugeot began its recycling program in June of 1991 with Compagnie Francaise des Ferrailles (CFF), France's largest scrap processor, and a French cement maker, Vicant.[28] At that time, Peugeot began operating a facility (the value of which has been estimated at between $3.5 and $5 million)[30] located at Saint-Pierre de Chandieu near Lyon.[31] The facility was expected to process 7,200 cars in the first two years. The goals are to eventually eliminate landfilling of waste from cars, recycle and reuse as many parts as is economically feasible, and use combustible non-recyclable materials in the cement kilns.[31] The facility uses the following processes: 1) dismantling and decontaminating, which includes draining fluids and removing seat cushions and coverings (which alone can reduce ASR volume by 20%),[32] 2) removing and reconditioning suitable parts, 3) using conventional crushers to recover metallic parts,[31] and 4) treatment of crusher residue, which involves separating the polymers by densities and weights through various separation technologies. The thermoset plastics are ground into a fine dust and are subsequently remixed with primary material to make new components; thermoplastics are granulated and remelted for remolding into new components (also investigating laser material identification).[32] The remaining ASR (rubber and plastics) pellets are used to fuel the cement kilns.[31] The goal is to refine recycling techniques and improve car design for recyclability[22] to achieve "zero waste".[23]

In March of this year, Renault and Peugeot entered into an agreement for recycling wrecked automobiles. It is anticipated that ten years from now the current recycling ratio of 75% of total weight will be increased to 85%.[33]

A.2.1.3 Fiat and Rover

Fiat and the British automaker, Rover, are holding talks about collaborating on auto recycling. The effort would start with a pilot project to pave the way for a commercial venture. They would recycle each other's cars in their respective countries. Fiat is currently experimenting with the Rover

Mini in Italy, and Rover is experimenting with "older" Fiats. There are technical problems to overcome.[34]

A.2.1.4 BMW and Bolney Motors

Approximately 16,000 of the cars scrapped annually in UK are BMWs. An auto recycling plant in Bolney, West Sussex, which is a joint venture of BMW and Bolney Motors, became operational last December. It has an annual capacity of 2500 cars. BMW plans for this to be the first of 15 similar plants that will be a network throughout the UK. The second plant is planned to open in 1993, with five more opening in 1994. The goal is to achieve a recycling capacity of 16,000 cars annually by the end of the decade. BMW estimates its current recycling costs to be Pds 175 per car, which includes the cost of transportation, labor, and capital.[35] Parts are to be reconditioned and resold; the plastics are to be recycled. A car's owner will be paid the value of parts minus the approximately Pds 200 dismantling charge.[36]

A.2.1.5 BMW and Renault

BMW and Renault have reached an agreement to cooperate in a recycling effort. In France, CFF will recycle BMWs that have been scrapped, while scrapped Renaults will be recycled by BMW's Wuerzburg plant.[37]

A.2.1.6 Mercedes and Alpine Stahl

In Austria, vehicle waste management policies will be studied by a group formed by Alpine Stahl AG and Mercedes Benz AG. The first car recycling facility of the group will be the site of a former steel plant in what was East Germany.[38]

A.2.1.7 The Association of European Car Manufacturers (ACEA)

ACEA is promoting a two part scheme across Europe: 1) research into better design for disassembly and 2) better materials selection for recyclability. The goal is volume reduction of shredder residue. In addition to dismantling, recycling and reusing, ACEA wants to develop material processing cycles for plastics, glass and elastomer; and to use some shredder residue for energy production. The program calls for automotive suppliers to train scrap dealers to take apart their cars thereby establishing a European network of expert (and licensed) disassemblers. The BMW program works on these principles.[1]

A.3 IMPORTERS

A.3.1 Germany/Ford

In 1991, Ford of Germany began operating a pilot vehicle dismantling plant at its Cologne-Niehl factory in Germany. The goal is to develop techniques for removing fluids and recyclable materials from its old and current models.[39]

The foundation stone for the first authorized Ford car recycler (a partner company of Preussag Recycling) in eastern Germany was laid in April of this year. The plant is intended to dismantle up to 1000 cars (built since 1975) to begin with, recycling parts that can be used again.[40]

The Ford 'world car', which is being marketed in Europe as the Ford Mondeo and will replace Ford's U.S. Ford/Tempo and Mercury/Topaz probably in 1994, is Ford's first car designed and developed with the environment in mind. The intent is to develop a "part-by-part recycling plan." All the plastic parts are marked by material type according to worldwide standards to facilitate recycling. Eighty-five percent of the car is recyclable.[2]

Ford and GE are cooperating in Germany to collect the Ford Sierra's foam-filled polycarbonate bumpers. The Ford Mondeo has bumper brackets made from this recycled polycarbon.[2]

A.3.2 Germany/Toyota

In Germany, Toyota has begun a test program for recycling PP bumpers. Toyota distributors would pick up bumpers that their dealer collision-repair shops have collected and would deliver them to a local facility for grinding. The ground material would be made into pellets at a material recycling plant, and the pellets would be used to make new bumpers. The production technology for this program is under development. Toyota may begin using this bumper material in its UK plant by the end of 1993.[2]

A.3.3 Other Importers to Germany

Honda, Lada, Mazda, Rover, Subaru, and Toyota, in conjunction with the German automobile association and two recycling companies, are investigating how to establish networks of auto recyclers to recycle different makes of cars (in response to anticipated German guidelines).[41]

The Association of German car importers (VDIK) proposed a recycling scheme whereby owners would be exempted from taxes for handing in old cars. The plan's goal is to prevent car dumping.[42]

In February of this year, the bumper recycling operations of Mazda's German sales unit were expanded nationwide. Old bumpers are now recycled at approximately 1000 Mazda dealers in Germany. It is expected that about 75,000 bumpers (300 tonnes) per year will be recycled. The bumpers are pelletized and sent to Japan, where they are re-used. The recycled material is intended to be used in mass production cars.[43]

A.3.4 EURHEKAR

The European Producers' Circle for Car Recycling (EURHEKAR) is a recycling association of European auto makers who import cars into Germany. Association members are Citroen, Fiat, Alfa Romeo, Lancia, Peugeot Talbot, Renault, and Volvo; others can also be admitted. EURHEKAR has commissioned the Mainz company, Fahrzeug Recycling Technik, to dismantle their cars scrapped in Germany. The plan is modeled on Fiat's FARE system.[44] Owners of cars manufactured by the EURHEKAR members can take old cars to designated spots and be assured of "environmentally friendly" disposal.[45]

A.3.5 Ford/UK

Ford has been working with Southampton University for two years to develop two techniques for plastics identification, which would facilitate the recycling process. In the first technique, six polymers will be identified with electrostatics, and the device to do this will be a scanner that is hand-held. In the second technique, infra-red scanning is used. This device will most likely not be hand-held, and will be more expensive than the first device. However, it will be able to deal with a wider variety of materials. The scanner will identify a plastic part as it is presented by a worker. It is hoped that the scanner will eventually be fast enough that plastic parts can be identified as they come off a conveyor.[46]

A.4 AUTO WITH NON-AUTO

A.4.1 Germany

The automobile industry, particularly BMW, is calling on the elastomer industry to develop a recycling program for its products. A GAVS (German rubber manufacturer's association) program proposes burning elastomer scrap; whereas car manufacturers feel recycling should play the central role.[47]

In the Cologne area of Germany, car dealers and companies in the areas of transportation, recycling, and disposal plan to coordinate their efforts in a joint venture being called the "Koelner Modell Autorecycling".[48] The German company, Thyssen Sonnenberg, will handle the majority of the recycling and disposal. This project is different from other recycling approaches because any industry segment involved in the life of an automobile or its materials is able to participate. Supposedly this venture is a pilot project for similar ventures in the rest of Germany.[48]

The German auto industry and material suppliers formed PRAVDA to develop auto recycling projects and recycled materials uses. The initial focus of plastics producers has been labeling to aid in sorting. GE Plastics offers discounts on virgin material if firms buy its recycled product.[49]

A group of auto makers, engineering and disposal companies and several vehicle trade organizations commissioned the Frauenhofer-Institute fuer Materialfluss Logistik to produce a concept for disassembly plants for scrap cars. The plants would be able to disassemble 50 cars per day with plans to build the first plant in the Ruhr region in the fall of 1993. Owners would offload their cars at licensed collection points and they would be sent from there to the disassembly plants. It is estimated that 12 disassembly plants would be required to adequately cover the Ruhr region. Despite the high amounts of recycled parts and materials that the system is expected to achieve, it is not expected to be profitable. The cost of disposal is predicted to be between DM 200 and DM 600 per car.[50]

The maker of the Trabant car, Sachsenring Automobilwerke, plans to build a recycling center in Zwickau, eastern Germany.[51,52] CFF and Peugeot have supposedly signed an agreement with Sachsenring Automobilwerke to provide technical assistance.[28,57] The plant in Zwickau will use the same technology as that used at CFF's plant in Athis-Mons.

A.4.2 Italy

Fiat, Himont, Falck and Ada (National Association of Demolishers) are cooperating on an experimental project that will test various technologies. Ada is to collect recyclables, and Falck and Himont will reprocess them.[53]

A.4.3 Peugeot

Peugeot is cooperating with Fiat and chemical companies (plastics suppliers in Italy and the UK) to find ways to recycle the plastics and polymers used in cars. The project is called RECAP-Recycling of Automobile Plastics.[31]

A.4.4 Rover and Bird

The British car manufacturer, Rover, and the Bird Group (the leading European scrap processor) have a joint venture project on research into car recycling. A demonstration plant is expected to open this year. Reportedly, Rover is the only UK car manufacturer to have engaged in an auto recycling research program.[34] One of the goals of the research is to increase the recyclability of Rover cars to close to 100%.[54] Bird and Rover have a joint dismantling scheme, the purpose of which is to determine what can be reused and recycled and at what cost; and to look at better design for dismantling.[1]

A.4.5 Auto-Recycling-Verbund (ARV)

An association of companies, including car, steel, glass, and plastic companies along with waste disposal and recycling firms, has been formed in the Ruhr region of Germany with the goal of achieving 100% recycling of old cars.[55] ARV is supported by the Rhine-Westphalian Economic Ministry,[56] is managed by Opel, and will use existing recycling techniques. ARV was formed partly because of enormous amount of metal waste generated in the region annually (it is 257,000 tons currently and is expected to reach 450,000 tons by 2000).[55]

A.4.6 BMW, Mercedes, and Austrian Government

The Austrian government and the country's auto industry (BMW and Mercedes) have reached a voluntary agreement requiring the nation's car dealers to take back old cars from a consumer purchasing a new or later-model car. If the owner is not buying another car, the dealer can impose a fee for taking the car. The agreement will not add to the government costs of waste disposal. Junked cars will be turned over to dismantlers.[57]

A.4.7 Mercedes and Voest Alpine

Mercedes is following a dual strategy to develop more recyclable cars. The first component of the strategy is coding plastic parts by type and cooperating with BMW in dismantling technologies. The second part of the strategy is the separation of steel from car scrap in high-temperature furnaces.[58] Mercedes is developing the recycling process with the cooperation of Voest Alpine, an Austrian steel producer. The engine, electronic systems, glass, tires, gas line, oil, large segments of recyclable plastic, and copper are removed. The remainder, including scrap plastics is crushed and

burned at 2,000 degrees Celsius. In the smelting process, "dioxane" and other poisonous gases are burned off to yield a high-grade industrial steel. Until recently, the process was considered too expensive. The cost is about $330 per car, to be paid by consumers (when purchasing new cars). An economical method to reprocess plastics (primarily thermoplastics) is needed but will likely require redesigning components to make them easier to remove.[59]

Mercedes is seeking a partner in the steel industry to join a melting aggregate for car recycling. The aggregate was formed jointly with Voest Alpine of Austria. Construction costs are estimated at between DM 120 to DM 150 million. The annual recycling capacity is projected to be 300,000 cars.[60]

A.4.8 VW

VW has several efforts ongoing with non-auto industries. The car maker has an arrangement with the Dutch State Mining Company in Holland to chip reclaimed plastics. VW also collaborates with the German scrap dealer, Evert Heeren, to recycle processed metals from scrapped autos.[61] In addition, VW, a car-scrapping company, and a plastics producer are cooperating on a car recycling project. The goal of the project is to develop equipment for demolition, which currently is done manually. Plastic components are to be reprocessed into material to be used in shock absorbers, according to VW specifications. It is hoped the recycling ratio will be increased by 5%.[62]

A.5 NON-AUTO INDUSTRY EFFORTS

A.5.1 Germany

Kloeckner Kunststoff - und Automobilrecycling (KAA) is a subsidiary jointly owned by Kloecner-Werke and Kloeckner & Company, which shreds approximately 300,000 cars annually,[63] and is attempting to capture 20% of the German car recycling market.[64] The company feels that if the proposed German legislation passes, auto manufacturers will turn to recycling specialists rather than do the recycling themselves.[63] The first phase of the company's plan is to set up 20 regional centers of scrap car operations, with the goal of a nationwide network by 1996, which would consist of between 120 to 150 sites of scrap car collection points, between 20 and 30 disassembly points, and a few shredding operations.[63,64] KKA's plan is to set up an operation in Hamburg with Kiesow, Germany's largest car recycler, where approximately 25,000 cars per year will be recycled (10,000 to 12,000 in the first two years, reaching 25,000 by the third year).[65] This is the number of cars needed for the venture to break even financially. Thus, that is the number to be used as the minimum for the other planned centers. The cost of the Hamburg plant is estimated to be approximately $9.4 million. According to reports in November of last year, the plant was expected to be operating in April or May of this year[65], but no confirmation of its operation has been identified. Kloeckner hopes to reach an exclusive contract with BMW in Hamburg.[63] KAA has also signed an agreement with Mercedes to dismantle Mercedes cars and send them back to the automaker.[65]

The new recycling technology division of Schenck Engineering has received its first order for a commercial car recycling facility. The facility will meet the requirements expected to be set out in pending German legislation. The company that placed the order is based in east Germany and has plans to become the first firm to have a commercial recycling business in the region.[66]

Thyssen Handlesunion has five shredders in eastern Germany and is planning to build three more, which will bring its total capacity to 700,000 tonnes per year. The company estimates that they handle approximately one third of Germany's annual scrapped car volume of 2.5 million tonnes. The company plans to build an incineration plant in Duisburg to dispose of the shredding activity residue.[67]

In September 1992, Neptun, a company based in Rostock, eastern Germany, began scrap car dismantling. Currently it dismantles only Trabants. However, if this project proves to be viable economically, Neptun plans to become an independent car recycling company.[68]

Preussag Recycling (a unit of the German steel and metals company, Preussag) plans to increase its recycling activities. By 1996, it hopes to have set up from 80 to 100 independent disassembly centers in a nationwide network.[69] The centers will disassemble cars ready for recycling. The company plans to invest DM 700 million in this effort. Additionally, the company is setting up the first German car recycling plant for Ford cars in Halle. There are a number of similar plants expected to be set up by the company after the Ford Mondeo (which claims to be 85% recyclable) is introduced. It is forecasted that approximately 1,000 Ford cars will be disassembled and recycled annually.[70]

The German metals company, Sommer Metallwerk, is acquiring business holdings to facilitate developing full recycling for used cars. Sommer Metallwerk is providing information about environmentally acceptable dismantling of car residues with plastics, as well as information on their conversion to energy without dioxin emissions. Another partner produces building board using plastic car components as raw material.[71]

German aluminum producers are considering a program wherein car producers could lease the material for the time of the product life (because of aluminum's high cost relative to iron and steel). Recyclability of aluminum makes it an attractive material.[72]

The German Motorists' Association, ADAC, started a pilot program in February 1991 in which cars are dismantled and sorted according to raw materials, rather than shredded. The goal is to find ways to reduce non-metal waste material.[73]

The German machine-building firm, Krauss-Maffei, claims that it has a new reaction injection molding (RIM) system that uses reinforced polyurethane to produce exterior body panels. The panels have up to 30% recycled content.[74]

A.5.2 Austria

The Austrian government has allocated funds for recycling 240,000 cars annually. Most of the money will be spent on shredder plants. The government intends to set up a pilot recycling project to promote reuse of old materials.[75]

A.5.3 Dutch/Danish

Dutch and Danish trade groups have formed the European Group of Automotive Recycling Associations (EGARA) to represent auto scrap handlers before the European Commission. EGARA is seeking members from each European country. They desire to participate in transboundary

legislation that affects auto recycling.[37]

A.5.4 Italy

Maachi, an Italian processor, has a commercial system that recycles in-house scrap from bumpers of reinforced polyurethane RIM. The scrap is being reprocessed by Maachi back into bumpers.[74]

A.5.5 ACORD

The European Automotive Consortium on Recycling and Disposal (ACORD) has stated its belief that the responsibility for vehicle disposal should be shared by government and industry. ACORD feels that government responsibilities should be to: certify car dismantlers, oversee environmental considerations of the process, and enact legislation that requires the last owner of the car to be responsible for taking it to an accredited dismantler. Industry responsibilities would be to develop dismantling methods, improve recyclable materials markets, and embody the ultimate goal of car disassembly and materials recovery into the auto assembly process.[37]

NOTES FOR APPENDIX A

1. White, Liz 1992. Imperative: Recycle that car! *European Rubber Journal* **174**(2):27.

2. "Green horn: Automakers are touting the use of salvaged plastic in new cars" 1993. *Automotive News* April 12, p. 20i.

3. "Recycling of cars by manufacturers in Germany" 1992. *Europe Environment* February 17, no. 0381.

4. "Britain gets used-car buster: First BMW deal of possible 15 salvage partnerships" 1992. *American Metal Market*, December 8, p. 9.

5. "BMW pilot shreds pounds; tests research least-waste to take apart clunkers" 1992. *American Metal Market*, December 8, p. 4.

6. "BMW launches pilot car recycling plant" 1991. *Advanced Composites Bulletin*, May.

7. Brooke, Lindsay, Gerry Kobe, John McElroy, and Christopher A. Sawyer 1992. Recycling: What's the problem? *Automotive Industries* **172**(9):44.

8. Winter, Drew 1992. DFD: Don't forget disassembly. (design-for-disassembly applied to automobiles), *Ward's Auto World* **28**(11):38.

9. "German auto industry criticizes scrap bill" 1993. PRS Automotive Service, January 12.

10. "VW planning to set up national car recycling network" 1992. PRS Automotive Service, January 14. Abstracted from *Suddeutsche Zeitung* January 10, p.31.

11. "Volkswagen now using recycled plastics in polo models" 1993. *Automotive Service* March 19.

12. "VW body panels use recycled plastics" 1993. *Automotive News* January 25, p. 2i.

13. Naitove, Matthew H. 1992. Europe leads in car-parts recycling. *Plastics Technology* **38**(5):101.

14. "Opel to follow VW with car recycling guarantee" 1991. PRS Automotive Service, August 20. Abstracted from *Handelsblatt* August 19, p.1.

15. Grace, Ken 1992. One day, my son, all this will be your.... *British Plastics and Rubber* March, p.38.

16. "Volvo plans to increase car recycling" 1991. PRS Automotive Service, October 29. Abstracted from *Svenska Dagbladet* October 27, p.8.

17. "Fiat auto presents key elements of FARE car recycling" 1993. PRS Automotive Service, April 22.

18. "Fiat turns to scrap" 1992. *European* December 20, p. 39.

19. "Fiat and PSA in talks for cooperation in car recycling" 1992. PRS Automotive Service, December 3.

20. "Fiat presents car recycling plan" 1992. PRS Automotive Service, December 22.

21. "Toyota and Fiat proposing car part recycling solutions" 1992. *Plastics News* October 12, p. 46.

22. "French car makers stepping up recycling efforts" 1991. PRS Automotive Service, July 3. Abstracted from *Financial Times* July 3, p.14.

23. French car recycling starts early" 1992. *American Metal Market* May 29, p.9.

24. "German automakers unite on recycling" 1992. *Modern Plastics* May, p. 15.

25. "VDA draws up new scrap car disposal concept" 1993. PRS Automotive Service, February 26.

26. "Commitment to recycling cars in France" 1992. *Advanced Composites Bulletin*, December.

27. "Renault and PSA join forces in car recycling" 1992. PRS Automotive Service, July 21. Abstracted from *La Tribune de l'Expansion* July 17, p.10.

28. "Peugeot and CFF share know-how" 1993. *American Metal Market* **101**(18), January 28, p. 7.

29. "Renault & PSA recycling 16 cars/day" 1992. PRS Automotive, December 4.

30. "Peugeot, Renault team up: Recycling venture targets up to 200 junked cars daily" 1992a. *American Metal Market* July 23, p. 7.

31. "Peugeot sets up car recycling facility" 1991. *Haznews* July, no.40.

32. Gittelman, Dena 1992. Prospects for Recycling Automotive Polymer Waste. Thesis, Tufts University, Medford, Mass.

33. "Un Accord-Cadre" 1993. *Revue Hebdomadaire de l'Industrie Electrique & Electronique* April 9, p. 2.

34. "Fiat and Rover study recycling joint venture" 1993. PRS Automotive Service, April 22.

35. "Conflicting views as car makers anticipate EC recycling law" 1992. PRS Automotive Service, December 3.

36. "BMW is opening the first car recycling plant in the United Kingdom" 1991. *Green Marketing Report* **2**(7).

37. "Renault and BMW agree to recycle scrapped cars" 1992. PRS Automotive Service, October 22.

38. Shanoff, Barry 1993. Europe considers scrapped cars for recycling uses. *World Wastes* **36**(2):14.

39. "Makers move into recycling" 1991. *Motor Report International* November 25(627):5.

40. "Ford commissions first car recycler in eastern Germany" 1993. PRS Automotive Service, April 13.

41. "Car importers look at possible recycling in Germany" 1992. PRS Automotive Service, April 27. Abstracted from *Frankfurter Allgemeine* April 27, p.20.

42. "VDIK proposed trial recycling scheme for old cars" 1991. PRS Automotive Service, September 24. Abstracted from *Frankfurter Allgemeine* September 21, p.15.

43. "Mazda expands car bumper recycling in Germany" 1993. PRS Automotive Service, March 2.

44. "Fiat, PSA, Renault and Volvo join Forces in car recycling" 1993. PRS Automotive Service, January 5.

45. "Car importers form recycling association in Germany" 1992. PRS Automotive Service, August 25. Reprinted from TUB Bayern Press Release, July 9.

46. "Car breakdown takes priority" 1993. *Engineer* February 18, p. 25.

47. Davis, Bruce 1991. Car firms press for recyclability. *European Rubber Journal* April, p.6.

48. "Companies to work together in car recycling in Cologne area" 1992. PRS Automotive Service, December 8.

49. Chynoweth, Emma and David Rotman 1993. Germany is in the fast lane as recycling gains speed. *Chemical Week* **152**(7):18.

50. "IML draws up plan for disassembly plants for scrap cars" 1993. *PRS International* March 4.

51. "PSA and CFF to help with Sachsenring car recycling plant" 1992. PRS Automotive Service, December 3.

52. "Environment: Accord de cooperation PSA-Sachsering (RFA)" 1992. *Tribune (Cote Defoses)* December 2, p. 13.

53. "Fiat, Himont, Falck and Ada to join forces in car recycling" 1992. PRS Automotive Service, July 6. Abstracted from *Il Sole 24 Ore*, July 3, p.3.

54. "Rover and Bird group sign deal to recycle cars" 1991. PRS Automotive Service, October 25. Abstracted from *The Times* October 25, p.32.

55. "Car recycling association set up in Germany" 1991. PRS Automotive Service, September 9. Abstracted from *Le Lloyd* September 6, p.2.

56. "New car recycling association aims to recycle 100% of cars" 1991. PRS Automotive Service, September 5. Abstracted for *Handelsblatt* September 4, p.19.

57. "Austrian car dealers to take back autos ready for scrap pile" 1992. *American Metal Market* September 10, p.2.

58. "West German Mercedes-Benz studying car recycling" 1990. PRS Automotive Service, June 14. Abstracted from *Frankfurter Allgemeine* June 5, p.T1.

59. "Car recycling catches on in Germany" 1990. *New Technology Week* **4**(44).

60. "Mercedes-Benz sucht ein Stahlwerk" 1992. *Sueddeutsche Zeitung* December 2, p. 35.

61. "World's First Automobile Disassembly Plant" 1992. *BioCycle* February 2, p. 82.

62. "VW in car recycling project" 1990. PRS Automotive Service. March 8. Abstracted from *VDI Nachrichten* March 2, 1990, p.24.

63. "Kloecner sets up plastics/car recycling company" 1992. PRS Automotive Service, December 9.

64. "Kloeckner looking for 20% of German car recycling market" 1993. PRS International, March 25.

65. "German venture plans to start auto shredding" 1992. *American Metal Market* November 12, p. 7.

66. "Schenck receives order for car recycling plant in E. Germany" 1992. PRS Automotive Service, December 10.

67. "Thyssen Handelsunion to intensify car recycling activities" 1992. PRS Automotive Service, October 9.

68. "Rostock company begins recycling cars" 1992. PRS Automotive Service, October 7.

69. "Preussag increases its car recycling activities" 1993. PSA Automotive Service, February 8.

70. "Preussag sets up first European car recycler" 1993. PRS Automotive Service, April 26.

71. "Sommer Metallwerke in car recycling" 1990. PRS Automotive Service, December 19. Abstracted from *Suddeutsche Zeitung* December 18, p.26.

72. "Aluminium [sic] in car production promoted by recyclability" 1990. PRS Automotive Service, February 21. Abstracted from *Frankfurter Allgemeine* February 20, p.T4.

73. "ADAC starts car recycling project" 1990. PRS Automotive Service, December 4. Abstracted from *Handelsblatt* December 3, p.19.

74. "Recycled PUR for RIM bumpers, panels" 1992. *Modern Plastics*, May, p. 15.

75. "Das 'Auto im Baukastensystem' kommt" 1992. *Presse*, August 26, p. 16.

APPENDIX B
RECYCLING INITIATIVES IN JAPAN

APPENDIX B. RECYCLING INITIATIVES IN JAPAN

B.1 INDIVIDUAL AUTOMAKERS

B.1.1 Nissan

Nissan has used recyclable thermoplastic PP bumpers for approximately 70% of its vehicles since 1979[1] and has developed a technique to chemically remove paint from indelibly painted bumpers.[2] Nissan has also developed a technology to make plastic sheet from old car parts such as dashboards and bumpers. Parts are ground and mixed with glass fiber, thermoplastic resin powder and water.[3] Nissan established the Recycling Promotion Committee in late 1990, which has a three pronged recycling program: 1) using materials that are easily reclaimed, such as readily recyclable plastics and labeled (coded) plastic components, 2) developing structures for easy dismantling, and 3) increasing the use of "environmentally friendly materials."[2] Nissan is designing its cars with as few different materials as possible to simplify the recycling process. Designing with recycling in mind has been likened to preventive medicine.[4] There are new scrap processing machines that can separate materials by density, but manufacturers must design with this in mind. That is, there must be only a few different materials and each one must have a "clearly distinguishable density".[4]

Nissan started a bumper recycling program in the Kanagawa Prefecture a year ago and is now planning to expand the program in Japan. The project is located near the Oppama and Zama plants and covers 17 service centers and dozens of dealerships in the area. The expanded network will include Tokyo, eastern Japan, and the Osaka area. It is estimated that it will take 5 years to get the nationwide structure. If the Kanagawa experiment succeeds, there is a significant market potential since Nissan supplies 800,000 bumpers per year to auto dealers. This is almost twice the levels of Honda and Mazda. Nissan is hoping to recycle more than 90% of all discarded bumpers eventually. Nissan is taking the lead among Japanese automakers in numerically coding rubber parts on new cars. The markings are common industry abbreviations.[5]

B.1.2 Toyota

Toyota established a Recycling Committee in 1990 for corporate activity in the area of auto recycling.[6] That committee became part of the Environmental Committee formed in 1992. There are short-term (3 years or less) and long-term (4 years or more) programs. The short-term programs involve: establishing guidelines to reduce materials that are not recyclable; developing technology to enable the use of recovered waste material; developing waste-to-energy technology; and developing technology for recycling in conjunction with suppliers and research groups. The long-term programs deal with: practicing designs for recycling; developing components and processes to use recycled materials; developing materials and components that are more easily recycled; reducing the number of different materials in vehicles; and developing energy recovery technology that is clean and efficient. Toyota has coded its plastic components since 1981 with its own system that is similar to that of the International Standards Organization (ISO). Now recognizing the importance of international consistency, Toyota planned to begin in October 1992 coding parts according to

standards of the Society of Automotive Engineers (SAE) SAEJ1344 and Vorband der Automobilindustrie VDA260. Other steps being taken to accomplish both the short-term and long-term goals are developing a variety of recycling technologies; seeking cooperation of suppliers; monitoring recycling trends in other countries; analyzing Germany's regulations; and investigating the adaptability of practices of designing for recyclability and optimal material selection. A target recyclability rate of 85% by 1996 has been set by the Recycling Committee. There have been 25 auto parts that account for 80% of the plastic weight targeted for recycling priority. Toyota is investigating methods for recovering for energy use plastic parts that cannot be removed economically for recycling. Post-use PP bumpers are being tested for recycling, and in December 1992 Toyota began a pilot bumper recycling program in western Tokyo.[7] Currently, the material is used for shipping pallets.[6]

B.1.3 Honda

In October 1991, Honda announced plans to initiate a plastic bumper recycling program (throughout Japan by autumn 1992). Thermoplastic resin bumpers are to be collected at dealerships and repair shops at the time of replacement. Bumpers are to be converted to resin pellets to be used in the manufacture of parts delivery cases and, eventually, new bumpers. Honda was supposedly the first Japanese manufacturer to undertake such a project.[8] Currently, Honda's recycling efforts are in two areas: (1) dealing with vehicles currently in use (i.e., cars manufactured with old technology) and (2) new cars that incorporate recycling in their design and manufacture. In the first area, there is a program to recycle PP bumpers and this involves testing the deterioration of used parts. This entails developing paint separation technology. There is also the need to determine a recycled material's cost effectiveness and a way to grade it for reuse. In the second area, important issues are: plastic material classification; research on vehicle construction with disassembly in mind; application of easily recyclable materials; and developing materials that do not release toxics during combustion.[6]

B.1.4 Mazda

A 1991 Mazda program collected plastic parts that were then ground by a recycling firm and sent to Mazda headquarters in Hiroshima to determine ways to reuse them.[9] With its 1992 models, Mazda began numerically coding plastics in its cars to simplify recycling.[10] Recently, the automaker has developed two substances which should lead to an increased and more effective use of recycled plastics.[6,11] The first is a thermoplastic resin that can be recycled repeatedly (up to five times). The material took three years to develop and is mainly used in bumpers, but can be used in the chassis. The second new substance that has been developed is a catalyst for decomposition that will facilitate the recovery of petroleum derivatives from all plastics. This substance was developed at a pilot plant, Mazda established in September 1992. A recovery rate of 80% has been attained. However, commercialization will be delayed by the high costs of development.[12]

B.2 JOINT AUTOMAKER ACTIVITIES

B.2.1 JAMA

The recycling efforts of the Japanese Automobile Manufacturers' Association (JAMA) have focused on automaker cooperation on recycling and the abandoned vehicle problem. The Technical

Committee has a Recycling Technology Task Force and the Marketing Committee has a Post-Use Vehicle Solutions subcommittee.[6]

B.2.2 ICAR (International Consortium on Automobile Recycling)

The purpose of ICAR, which the Japanese Research Institute, Ltd. is attempting to organize, is to create international guidelines for auto recycling.[13] The guidelines will be based on the results of feasibility studies the consortium conducts on auto recycling systems. The strategy is to initiate a countermeasure by the world's automakers to the tightening legislation concerning auto recycling. The consortium fears that if the legislation is not slowed down, billions of dollars in costs will be added to the auto industry. The members are from the US, Japan, and Europe. The Japan Research Institute, Ltd. is to coordinate communication among members. There are three phases to the effort: (1) consortium members exchange information on regulations, technology and current recycling systems; (2) "research and experiment of recycling system feasibility, environmental adaptability, and economic rationality";[13] and (3) proposed international guidelines publicly announced. The consortium was scheduled to start in first half of 1992.

B.3 IMPORTERS

B.3.1 BMW

BMW intends to start a car part recycling program in Japan. The automaker will work with Japanese chemical processing and recycling firms. Bumpers and batteries will be recycled first. In 1994, it is expected that a variety of car parts will begin to be recycled.[14] Itochu and Idemitsu Petrochemical, along with two other Japanese companies, have developed a new system that will be employed to recycle PP car bumpers without the use of solvents. In the system, the bumpers are pulverized, compressed and fed into rotary equipment. Paint is removed with centrifugal force. Car bumpers can then be made with the recycled PP.[15]

NOTES FOR APPENDIX B

1. "Nissan process improves recyclability of bumpers" 1991. *American Metal Market* **99**(180):5.

2. Furukawa, Tsukasa 1991. "Japan automakers rev recycling: car materials tied to reclamation ease." *American Metal Market* September 23, p. 4.

3. "Used thermoplastic car parts to be recycled: Nissan Motor" 1992. *Japan Chemical Week* April 16, p. 6.

4. "From cars to chemicals, recycling is on the agenda" 1992. *Engineer* Nov. 19, p. 35.

5. "Environnement: Accord de cooperation PSA-Sachsering (RFA)" 1992. *Tribune (Cote Desfosses)* Dec. 2, p. 13.

6. "Recycling and the Automobile" 1992. *Automotive Engineering* Dec., p. 41.

7. Schreffler, Roger 1993. Recycling roundup: Toyota joins Nissan in marking rubber for recycling, while plastic bumper recovery increases. *Automotive Industries* **173**(1):23.

8. "Honda first Japanese car maker to recycle plastic bumpers" 1991. PRS Automotive Service, October 31. Abstracted from *Nikkan Kogyo* October 10, 1991, p. 13.

9. "Makers move into recycling" 1991. *Motor Report International* November 25, (627):5.

10. "Recycling code for automobile plastic" 1991. *Market Alert* **2**(6).

11. "Five-cycle recyclable resin used by Mazda" 1992. PRS Autormotive Service, Oct. 30.

12. "Japan moves toward auto part recycling" 1992. *Rubber & Plastics News* Nov. 23, p. 34.

13. "ICAR: International Consortium on Automobile Recycling," handout prepared by the Japanese Research Institute, Limited.

14. "BMW to start car recycling in Japan with local firms" 1993. *Japan Chemical Week* Jan.14, p. 1.

15. "Car bumpers recycled at low cost; most paint removed" 1992. *Japan Chemical Week* Oct.22, p. 1.

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