Auto Recycling Demonstration Project

Final Report

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AUTO RECYCLING DEMONSTRATION PROJECT

EXECUTIVE SUMMARY

The Great Lakes Institute for Recycling Markets was engaged by the Michigan Department of Environmental Quality (DEQ) to demonstrate the commercialization of automotive material recovery systems. Funding was provided by the U.S. EPA's Jobs Through Recycling (JTR) program. The focus of the project was to work within the existing automotive dismantling infrastructure and facilitate links between existing sources of post-consumer auto materials and potential end markets for those materials.

This project was designed to identify methods of collection and vehicle disassembly that optimize the net value of post consumer vehicles in terms of recyclable material recovery in addition to conventional recovery of reusable parts. The project included pilot field studies to evaluate the use of ôon-siteö collection and dismantling methods where materials were separated into target material categories at the point of generation prior to collection. Field trials were also conducted to evaluate sorting and identification of parts by plastic resin type. Sorted material was then sent to end markets for evaluation to confirm material delivery requirements and to determine their acceptability as an alternative feedstock in manufacturing processes.

The most important feature of the ARD project was the focus on field-based trials to generate data to serve as a platform for benchmarking actual expected costs for market driven dismantling. Major objectives of ARD project included:

ò Benchmark field-based dismantling processes;
ò Identify / describe prototype tools required for recovery of target materials;
ò Refine end-market material specifications; and
ò Identify potential commercial system opportunities.

The first two chapters of the report present background information on current vehicle recycling practices and summarize the results of previous research on those practices. The third chapter describes the data and findings associated with the removal of targeted materials in the field trials and material identification / sorting. The fourth chapter assesses end markets for seat foam and targeted engineering plastics including market prices and requirements.

The report then addresses potential business relationships in automotive recovery system development based on the data collected in the field trials and economic modeling. Two potential business development scenarios for high and low volume recovery respectively are envisioned and evaluated with respect to the economic and technical barriers and opportunities associated with each. This section also discusses the results from our informal survey of vehicle dismantlers to assess the immediate potential for increased nonmetal material recovery. An analysis of the automotive recycling industry and potential job creation or retention concludes the discussion of the project. Finally, the report summarizes all the findings from the project and recommendations for further demonstration pilots and market development.

The recommendations emphasize strategically designed, field-based pilot demonstrations to commercialize automotive non-metal material recovery by benchmarking and / or developing tools and techniques for cost effective vehicle disassembly and parts removal for material recovery.

Summary of Findings and Recommendations

The key findings and recommendations to commercialize automotive nonmetal material recovery operations are grouped according to each stage of recovery and recycling as follows:

- End-of-Life Vehicle (ELV) Material Recovery Field Trials;
- Material Identification / Decontamination / Processing Field Trials; and
- End Market Assessments.

Two key aspects are reviewed in detail:

- ELV Material Recovery System Economic Findings; and
- Emerging / Potential Commercialization Strategies.

Findings

The Auto Recycling Demonstration Project documented real world opportunities for the recovery of non-metal components from end-of-life vehicles for recycling material as feedstock into new product applications. These opportunities focus on material recovery in pre-shredder disassembly operations. The results of the ARD Project show that these opportunities are already being taken advantage of by private entrepreneurs in some cases.

In other cases, however, significant barriers remain that must be overcome. These barriers include issues of material logistics, tools / technology, and economics. None of these barriers are insurmountable, but in many cases will require coordinated efforts by many players working to create a more efficient automotive material recovery infrastructure. An extensive development process is needed to move from current conditions to a future system that can effectively divert an additional 170-200 pounds per vehicle for recycling, or in aggregate over 1,000,000 tons per year, to bring recycling of the average vehicle into the 80-85 percent range from current levels.

Seven key findings follow:

- The key to successful post consumer vehicle material recycling in the near term is to sell target plastics to processors and compounders who can take wide specification material and use the recovered material in non-visible interior and exterior automotive applications;

- Three distinct levels of market development can be delineated from our preliminary findings: 1) strong rebond market demand exists for auto seat foam; 2) a limited number of potential customers exist for polyolefins, TPO, polycarbonate, ABS, and other high end plastics; and 3) elastomer end market customers will require additional research and development prior to actual market opportunities;

- Currently available information systems do not assist material recycling since they focus on parts recovery and exchange;

- The current seat foam recovery infrastructure is clearly inadequate for recovery of high volumes of post consumer seat foam. Two areas for improvement in the efficiency of foam recovery were identified: 1) rapid removal of seats from vehicles and 2) efficient separation of foam from steel wire frames, or dewiring. The key to cost effective disassembly is to identify "piggyback" opportunities in existing field operations;

- Some combination of manual and automated methods are required to identify recovered resin types. Three basic methods were identified: 1) Reference or "checklists; 2) Manual Materials Properties Testing; and 3) Resin Identification Equipment;

- The development of field ready resin identification equipment, especially at prices affordable to dismantlers, would enhance the technical and economic feasibility of material recovery at dismantling facilities;

- Our analysis indicates that small scale harvesting systems will need a price that equates to $25-30 per vehicle (or $30-40 per hour) to create the incentive for dismantling operations and harvesters to initiate and sustain material recovery and recycling from vehicles. The number of intermediate processors and their size will be a major determinant in minimizing the additional costs associated with small scale gypsy harvesting.

Recommendations

The recommendations emphasize additional field-based demonstrations to commercialize automotive nonmetal material recovery by benchmarking and/or developing tools and techniques for cost effective vehicle disassembly and parts removal for material recovery.

These 28 recommendations are specifically directed at acquiring greater field experience and knowledge of real world nonmetal material recovery from ELVs in the global economy. These recommended field demonstrations are designed to accelerate development of a commercial automotive nonmetal material recovery system driven by market forces and incentives.

Finally, implementation of these recommendations is highly improbable without strong strategic support and commitment from the automotive industry and its suppliers. These recommendations are therefore framed within a context that automotive original equipment manufacturers (OEMs) will participate in their implementation.

Ten key recommendations are:

- Develop a user-driven data base in cooperation with the Tier 1 suppliers, OEMs, resin producers, compounders, and molders to provide reliable data on major plastic parts and their specific material composition;

- Identify disassembly operations with the capacity to input data and identify material composition of parts with Tier 1 suppliers to establish this data base;

ò Identify target materials and component parts with target materials based on sufficient volume, purity of target material in identified component parts, market value, and ease of removal;

ò Identify existing or prototype tools for foam removal and identify and work with industrial tool manufacturer(s) to assist in the development of tools for rapid seat removal;

ò Conduct field disassembly trials in the following two environments: 1)áremoval of seats and / or foam in a state of the art or prototype disassembly facility; and 2) removal of seats and / or foam in a clean and efficient salvage yard operation;

ò Develop a data base of seat designs and applications in cooperation with auto seat manufacturers that identifies those seats which facilitate foam removal and those that do not;

ò Compile and evaluate time studies data and methodological data to identify the most technically feasible and economically effective methods of foam removal in field based disassembly and high volume disassembly facilities;

ò Conduct field demonstrations of available resin identification tools and perform technical assessments of those trials to produce a comparative analysis of speed, accuracy, ruggedness / durability, and cost-effectiveness of these tools in various field applications (Such field applications should include both shredder-based identification as well as dismantler-based identification.);

ò Conduct additional field trials with emphasis in three areas: 1) Continue benchmarking of recovery methods, techniques, tools, and costs; 2) Integrate new data into user friendly database applications. This information and data would include vehicle type, part identification, nonmetal material content, and cost effective dismantling techniques into a data base model; and 3)áDevelop a training component based on field based dismantling demonstrations; and

ò Conduct a feasibility analysis of a comprehensive auto material recovery facility, potentially in cooperation with a specific manufacturer.

In conclusion, the development of a vehicle recycling infrastructure to recover nonmetal material from ELVs is commercially feasible in the short term. Such development, however, is predicated on finding solutions in the areas of material logistics and tools / technology to produce a profitable market scenario.

The implementation of these 28 recommendations to find those solutions is designed to facilitate the recycling of targeted nonmetal materials from post consumer vehicles in the near term and to systematize automotive recovery operations for comprehensive material recovery in the long term.

I. INTRODUCTION

The Auto Recycling Demonstration Project (ARD Project) is a collaborative effort based in Michigan to demonstrate the commercialization of automotive material recovery systems. The Michigan Department of Environmental Quality (DEQ) has participated in the ARD project through funding provided by the U.S. EPA's Jobs Through Recycling (JTR) program. In its role in assembling funding for the ARD project, DEQ contracted with the Great Lakes Institute for Recycling Markets (GLI) , a program of the Center for Environmental Policy, Economics and Science (CEPES), a Michigan non-profit 501(c)3 organization. The Great Lakes Institute implemented the ARD project in collaboration with the Big 3's Vehicle Recycling Partnership (VRP), American Plastics Council (APC), and the Automotive Recycling Association (ARA) acting in an advisory capacity. Resource Recycling Systems, Inc. acted as technical consultant to the project.

The VRP operates the Vehicle Recycling Development Center (VRDC) in Highland Park, and serves as the auto industry's pre-competitive research consortium to address automotive recycling primarily through design for disassembly (DFD) approaches. The American Plastics Council has a Durable Products program that focuses on plastics recovery in autos, appliances, electronic goods and other similar products. The ARA is the national trade association for vehicle dismantlers. RRSI provided technical assistance and support to the project team in developing and evaluating recycling system processes, techniques, and tools.

The ARD project team conducted a series of pilot projects to demonstrate and document current methods and costs of automotive non-metal material recovery. Target materials included auto glass, polyurethane foam, high end plastics (such as polyethylene, polypropylene, ABS, TPO, polycarbonate), textiles, and elastomers. Recovered materials were sent to potential end market customers for evaluation. This is the final report for the ARD project.

Overview of Auto Recycling Demonstration Project

The focus of the project was to work with the existing automotive dismantling infrastructure and facilitate links between the existing sources of post-consumer auto materials and potential end markets for those materials. It is assumed that this infrastructure will remain in place with sufficient volumes of vehicles and profit margins to support its continued operation. (It should be noted that automotive and vehicle are used interchangeably to describe the recovery infrastructure under discussion here.)

The vehicle recovery infrastructure might benefit from collection and processing technologies developed in other economic sectors or technologies in early development stages. Source separation, co-collection, and commingled collection of materials from generators, for instance, can be expected to offer improved collection economies. Centralized, or intermediate processing facilities, or prototype auto material recovery facilities (AMRFs) may also offer improved economies for automotive disassembly.

The connection of sources of recycled feedstocks and markets for these materials rests on the commercial feasibility of three intermediate stages: 1) dismantling vehicles for material recovery in a cost effective manner; 2) collection of material from existing sources; and 2) preparation of collected material to meet end market specifications. A major issue addressed in this study is the estimation of benchmark costs associated with the different stages of material recovery from end-of-life vehicles within profit margins that may foster the development of additional infrastructure capacity.

The following data and information were measured in the implementation of the Auto Recycling Demonstration project: 1) quantity of material collected in the pilot by material type and generator type; 2) performance characteristics of dismantling and processing methods (i.e., time studies for separation processes, per ton labor and equipment requirements); 3) price profile, quality evaluation, and capacity review for each test market; 4) projected economic outcomes (cost and quantity) of two potential methods of material recovery; and 5) number of job positions potentially created or saved as a result of commercial application of successful technologies regionally and nationally.

Project Goal

The principal goal of the ARD project was to identify opportunities to develop commercial-scale recycling of post-consumer, end-of-life vehicle (ELV) materials and to demonstrate and support further commercialization of enhanced ELV material recovery systems. The major features of the Auto Recycling Demonstration Project included:

ò Total recovery system focus: Disassembly, collection, sorting, identification, decontamination, processing, shipping, end-market re-manufacturing; and
ò Multi-material focus: Seat foam, selected plastics, textiles, elastomers, glass.

Project Objectives

Major objectives of the ARD project included:

ò Benchmark field-based dismantling processes and costs;
ò Identify / describe prototype tools required for recovery of target materials;
ò Refine end-market material specifications; and
ò Identify potential commercial system opportunities.

Scope of Tasks: Auto Recycling Infrastructure Demonstration

This project was designed to identify collection methods and vehicle disassembly techniques that optimize the net value of post consumer vehicles in terms of both reusable parts and recyclable material recovery. Developing end markets for plastics indicate a viable market exists if post-consumer feedstocks were available at lower costs. The ARD project specifically targeted post-consumer polyurethane seat foam, a range of engineering plastics, elastomers, and glass. The project was designed to accomplish the following tasks:

Collection of Material

Prior research by the project team also suggested the evaluation of four collection methods: 1) gypsy harvesting, 2) super harvesting, 3) stockpile-based collection and 4) post shredder recovery. These methods are described in Section III: Recovery Commercialization Field Trials. This pilot study addressed the use of ôon-siteö collection and dismantling methods where materials are separated into target categories at the point of generation prior to collection.

Preparation of Collected Material to Meet End Market Specifications

Prototype dismantling of collected automotive parts for their material content was undertaken by disassembly contractors where methods of disassembly, processing for shipment, and delivery were evaluated. Plastic sorting and identification by part type, resin and/or composite type were a priority of this pilot using both manual and automated approaches.

The ARD Project team undertook two kinds of material preparation trials: 1) resin identification of plastics; and 2) manual decontamination of foam and plastics, both based on preliminary specifications of the end markets indicating interest in evaluating material. In addition, ARD project staff arranged for processing the decontaminated plastics by an existing processor, Industrial Resin Recycling of Howell, MI, and processing and evaluation of the elastomers by two existing processors, Midwest Elastomers of Wapakanetta, OH and Custom Cryogenics of Simcoe, Ontario.

End Market Evaluation of Prepared Materials

The ARD Project team arranged to deliver materials recovered from the field trials to identified end markets for price and quality verification. End markets included several automotive tier 1 suppliers and other processors. Priority markets initially included: 1) resin reclaimers for recovered post consumer plastics; 2) the use of shredded textiles as insulation/sound proofing in auto body panels; and 3) the use of reclaimed fiberglass as an insulation product in the building industry. End markets evaluated the material to confirm material delivery requirements and to determine acceptability as a substitute feedstock in their production operations. SectionáIV:áAssessment of End Markets identifies the end market customers and describes the evaluation process.

Business Relationships and Economic Evaluation

An economic analysis of alternative business relationships including dismantling, sorting, identification, processing, and delivery system, and end market responses was conducted. Cost and revenue analysis associated with the recovery of targeted materials is a key component of the decision to expand automotive material recovery beyond ferrous metals. An economic analysis of two selected recovery system options, Gypsy Harvesting and Integrated High Volume Super Processing, is examined in detail in this section and are only intended to illustrate potential market and cost relationships. The analysis of material recovery represents the marginal costs and marginal revenues.

Survey/Information Review by Dismantlers

The ARD project team, working in cooperation with the ARA and VRP, surveyed a targeted list of 15 dismantlers of various types (late model, etc.) and evaluated the survey data. Data from this important survey were used to test project assumptions, verify project findings, identify dismantler needs, and craft project recommendations for maximum impact. The results of this survey are reported on page 87.

II. Automotive Recycling Infrastructure

Overview

The infrastructure for recycling end-of-life vehicles(ELVs) in the U.S. has been remarkably successful, especially since the introduction of shredders to process and recycle automotive hulks and other durable goods in the mid-seventies. However, the recycling industry faces ever higher performance expectations. Public, political, and environmental pressures can be expected to insist on optimizing vehicle material recovery. Such expectations are driven in part by principles of sustainable development that will require more energy efficient and environmentally sound performance in the 21st century global economy.

Current automotive recycling infrastructure performance is impressive as measured by two key recycling performance standards. One, ôcapture ratesö for end-of-life vehicles exceed 90% of all vehicles processed through the recycling infrastructure of dismantlers and shredders. This performance contrasts favorably with many other durable goods and packaging materials where capture rates of 50% are rare and considered excellent. Two, the actual ôrecycling rateö for processed vehicles is over 75%, due almost exclusively to the metal recovered from the vehicle. This level of performance exceeds the recycling of most other types of durable goods and packaging material.

The auto recycling industry, however, faces significant challenges in transforming the disassembly and shredding infrastructure to achieve higher rates of nonmetal material recycling. For one thing, the materials used in new vehicles are changing significantly. The non-metallic fraction, especially hard to recycle engineering plastics and composite materials, increased dramatically until recently.

The potential for a decline in the recycling rate of automotive materials exists as more nonmetal materials are used in automotive applications for cost and fuel economy reasons. Many automotive industry leaders are apprehensive that any perceived backsliding in automotive recycling rates might result in serious consideration of European style ôtake backö requirements being adopted by aggressive state legislatures, the U.S. Congress, or EPA ù a development the industry views as unacceptable. This development is relatively unlikely in the near term, but implementation of European automotive recycling goals could dramatically alter the North American playing field.

Secondly, processing end-of-life vehicles continues to be environmentally challenging. Fluid contamination of soils at auto disassembly yards may pose a wider environmental threat that could require regulatory intervention, enforcement, and costly site remediation in the future. Fluid containment is a critical service performed by the current infrastructure but that has not always been the case historically.

Finally, technologies to recover the non-metallic fraction of automotive shredding, or auto shredder residue (ASR), are in the development stage, are quite costly, and not extensively used by shredders or other operations . Shredders recover reusable ferrous and non-ferrous metals but almost nothing else. The remaining fractions of glass, plastics, foam, trace heavy metals, dirt, and fines are landfilled.

A Review of Previous Research

Research previously conducted by Resource Recycling Systems, Inc.(RRSI) in 1996, in collaboration with the Vehicle Recycling Partnership (VRP), began documenting the barriers to additional recycling of this remaining material. That work served as the foundation for the Auto Recycling Demonstration Project.

RRSIÆs original work for the VRP, *An Evaluation of Vehicle Recycling Opportunities* , documented a range of shortcomings in the current infrastructure for recycling of end-of-life vehicles that collectively results in a failure of the marketplace to drive recovery of additional materials. In addition to identifying markets for these materials, this prior work also documented emerging recycling technologies and methods that would make recycling of these materials technically feasible.

Current Status

Market demand drives the current success of vehicle recycling operations in the United States. Approximately 10 million automobiles are discarded per year in the United States. Of this number, some are stockpiled for parts recovery while the rest end up at vehicle shredder facilities. Demand for used parts has always been the principal source of revenue for dismantlers of end-of-life vehicles. Meeting this demand is the primary business mission for most dismantlers.

Demand for ferrous scrap is the next most important source of revenue, providing an economic incentive to the dismantler that pulls the hulk, now depleted of any valued used parts, into the shredding system for scrap steel recovery. Supplementing this process is the revenue stream from recovery of non-ferrous scrap. Nearly 100 percent of ferrous metal is recovered.

Recovery of nonferrous metals is not as high, but continues to climb as dismantlers and shredders work to extract additional revenue from automotive processing. Nonferrous metals include aluminum, stainless steel, copper, brass, and zinc. Shredders commonly use eddy current separators or flotation systems to recover the aluminum and zinc alloys. However, one company, Huron Valley Steel Corp., Belleville, MI, uses an impressive array of proprietary techniques to recover the whole range of nonferrous metals. It is estimated that Huron Valley processes 65% of ASR generated in the eastern half of the country. The company totals around 225,000 tons per year of nonferrous metal recovery from ASR.[1]

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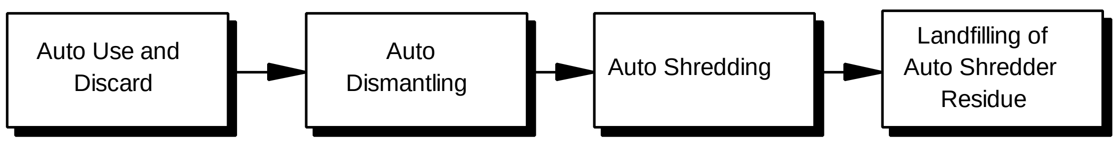
[1]*Recycling Today*, October, 1997, p. 26.

Discarded vehicle processing in North America depends on dismantlers who process the 10 million vehicles each year. About 200 auto shredders then handle final disposal of these vehicles -- handling approximately 15.6 million tons of which 11 million tons of steel and 800,000 tons of non-ferrous metals is recovered for recycling. The residue is estimated at approximately 600 pounds per vehicle or 3 million tons per year. This represents 1.5% of the more than 200 million tons of solid waste generated per year.[2] The portion of the vehicle that cannot be recycled becomes automotive shredder residue (ASR) and is currently landfilled. The volume of ASR is expected to increase unless new recycling techniques can be developed.

The automotive recycling process as shown in Diagram 1 below represents an annual sales volume of $5 billion.[3] Following is a more detailed description of the baseline current conditions.

Diagram 1: Discarded Auto Processing - 1997 Current Conditions



Auto Dismantling

Dismantlers operate throughout the United States with the capability to receive discarded automobiles and process them for usable parts, provide containment of environmentally critical fluids, and perform scrap material recovery. Removal and sale of parts for use in other vehicles is the most profitable activity for the dismantler.

Some of these recovered parts are "re-manufactured" and include clutches, engines, water pumps, starters, power window motors, and alternators.

Of the estimated 10,000 dismantlers in North America, 2,000 are more advanced dismantling operations[4] targeting later model cars (autos less than four years old). The remaining 8,000 are more traditional salvage yards with some dismantling activity.[5] The total of 10,000 dismantlers is down from a reported level of 12,000 dismantlers in 1994. The average dismantler handles about 1,000 cars a year, up from the 1994 average

[2] *An Evaluation of Vehicle Recycling Opportunities* by Resource Recycling Systems, Inc. for the Vehicle Recycling Partnership, 1996 p 7

[3] ibid.

[4] ibid.

[5] ibid.

of 850 cars a year, or about three per day and pays anywhere from $50 to several thousand dollars for a discarded auto depending on its age and parts value.[6]

Auto Shredding

Auto shredders operate throughout the United States with the capability to receive discarded automobiles from dismantlers and process them for their scrap valueùlargely in ferrous and non-ferrous metals. The steel industry has more than ample capacity to move all the scrap steel generated from discarded autos. The industry reports that 37% of all domestic ferrous scrap is supplied by the automotive recycling sector. Shredders also receive discarded appliances and other industrial scrap steel.

Shredders purchase cars from dismantlers and other suppliers for about 3ó per pound or approximately $100 per vehicle. Higher prices can be obtained for hulks that have been processed more thoroughly and are consequently higher in steel content. In North America 204 auto shredders process about 10 million discarded autos per year [7] for an average shredder throughput of 50,000 cars per year or about 200 per day. These shredders process approximately 15.6 million tons of material and recover 11 million tons of steel and 800,000 tons of non-ferrous metals each year. Recovery of other materials for recycling is nominal relative to the volume of metals currently being recovered from end-of-life vehicles.

ASR Landfill Disposal

Landfills throughout the United States receive and dispose of shredder fluff, or auto shredder residue (ASR), in EPA approved cells with long-term care programs. In some cases ASR is used for daily cover in landfill operations due to its high density and relatively uniform characteristics. More than 3 million tons of auto shredder residue is landfilled each year.

This ASR consists of glass, metals, plastics, fines, foam and textile fibers, dirt, and residual fluids that have been absorbed into these other materials. Approximately 25-35% of ASR is plastic material, which represents the largest fraction.[8] These materials are currently landfilled across the country with every auto that is scrapped and represent more than $1.5 billion in market value if they could be recovered economically, creating business opportunities as well as jobs.[9]

Markets

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[6] ibid.

[7] ibid.

[8] ibid.

[9] *American Metal Market, March 5, 1990,* quoted in the *Identification, Characterization, Classification, and Utilization of ASR Final Report. 1997* .

Markets were documented for eight of the typical materials found in ASR. These materials totaled over 275 lbs per vehicle and made up nearly 10% of the vehicleÆs weight and nearly half of the weight of ASR as shown in Table 1. While successful market driven recycling is being achieved for ferrous and non-ferrous metal, approximately 24 % of every vehicle is being buried in a landfill, including ASR[10].

Table 1: Targeted Materials Content in Typical Family Vehicle

Material	**Lbs per Car**	**% of Total Car by weight**	**% of ASR by weight**
Polyurethane Seat Foam	24	0.8 %	4.0 %
Plastics			
Polypropylene	34	1.1 %	5.7 %
ABS	20	0.6 %	3.3 %
Nylon	16	0.5 %	2.7 %
Polycarbonate	7	0.2 %	1.2 %
Elastomers	67	2.2%	11.2%
Glass	89	2.9 %	14.8 %
Textiles	20	0.6 %	3.3%
Total: Targeted Material	277	8.9 %	46.2%
Total: Average ASR	600	19.3%	100.0 %
Total: Typical Vehicle	3,114	100.0 %	

Source: *An Evaluation of Vehicle Recycling Opportunities* by Resource Recycling Systems, Inc. for the Vehicle Recycling Partnership, 1996 and *American Metal Market*, Capital Cities Media, Inc. , 1996

It was clear that recycling markets for these materials had potential but needed development in order to overcome existing barriers. These barriers will be evaluated in this report. Each stage of the recycling process was examined ù from material removal to collection, transportation, separation, cleaning, processing and use as a feedstock in an end market. Pressure points were highlighted ù key points in the recycling process where opportunities existed for strategic impact to improve the performance of the current vehicle recycling system. The emphasis in these recommendations was on implementation strategies that vehicle manufacturers can initiate and have control over ù referred to as ôcontrol points for vehicle manufacturers.ö

The findings were based on a preliminary economic analysis of key decision points that real world players (e.g. a dismantler) would need to respond to in order to function in this upgraded recovery system. Each of the following stages was examined:

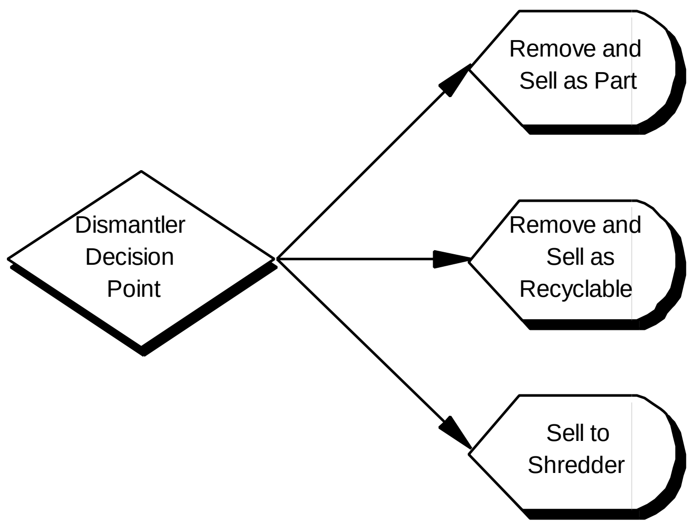
[10] *An Evaluation of Vehicle Recycling Opportunities* by Resource Recycling Systems, Inc. for the Vehicle Recycling Partnership, 1996 p 7.

- Material Removal from Discarded Auto
- Material Collection and Transportation
- Material Separation / Cleaning Technologies
- Material Processing
- Material End Markets

Dismantler Decision Options

The following example from the RRSI report illustrates this key decision point analysis from the perspective of the dismantler. The key decision point analysis focuses on economic factors that influence the choices made by a dismantler in setting priorities for each vehicle. For a vehicle dismantler, the following decision points are available for each separate part or part assembly handled in the dismantling process:

Diagram 2: Dismantler Recycling Decision Point Options



In managing vehicle inventory, a dismantler assesses market conditions for his marketable parts and materials. As with any business, the intent is to maximize revenue from operations and maximize profits from each profit center. As currently practiced, disassembly operations derive most revenue from parts resale and secondarily from sale of the hulks for principally ferrous material recovery by shredder operations.

However, parts recovery for material value is an emerging consideration. Over time before sending the hulk to a shredder for final processing, parts that no longer have value as parts for resale may have value for their material content. Another consideration is that parts recovery for their material (as opposed to parts resale) value is an incremental, or marginal, cost. Parts removal for material recovery may be carried out as part of the disassembly operation that focuses on parts recovery for resale.

The recovery process is a staged process. As conditions change over time and affect demand for parts of each inventoried vehicle in a disassembly operation, parts may be recovered for their material value as parts value diminish for parts resale value. Each disassembler will decide the time to recover parts for their material value.

The key point here is that parts inventory management is highly variable based on location, market conditions, knowledge of the operator, and scope of operation. Most disassembly operations are classified according to the ages of vehicles it takes: late model(1-4 years old), mid range(5-10 years old), or end-of-life.

A final factor is the length of time that a disassembler will hold a vehicle in inventory. Knowledge of this factor was outside the scope of this project. However, both of these time variables will be critical to the determination of when to view a part for material value after its part value for resale has ended.

ò Removing and Selling as Part: In removing a part a dismantler may incur costs that have been shown in American Plastics Council (APC) studies[11] to take anywhere from 1 to 3 minutes on the average and have unit costs for removal and decontamination that range from $.05 per pound to $.25 per pound. If removed without damage, the part may have a resale value as high as 50% of the partÆs actual replacement cost. This can range, on the average, from a few cents per pound to $2 and higher per pound.

ò Removing and Selling as a Recyclable Material: Removing a part may incur the same cost as cited above, or may have a lower cost if damage to the part can help shorten the removal time (i.e.: destructive dismantling). Once removed the material may have a value as a recyclable material that could range from $0 revenue FOB dismantler's site to as high as 35ó + per pound for the more valuable materials.

ò Selling to Shredder: Keeping a part or part system in the auto at the time of sale to the shredder nets the dismantler approximately 3ó per pound since the shredder pays by the weight of the delivered hulk. This serves as a disincentive for recycling. Many shredders are considering modifications to this approach since much of the material they pay the dismantler for has be landfilled after it is shredded. Thus, they pay twice for the same material.

A preliminary assessment in the report set a 50% goal for additional recovery from what is currently landfilled as ASR. This would divert an additional 3 billion pounds each year or 1.5 million tons. With contamination assumed at a level of 10%, it would be necessary to divert 3.3 billion pounds of material to recover 3 billion pounds.

If removal of the targeted material were to take place at the dismantling level, then on average, each dismantler would need to remove 330,000 pounds of material per year, based on 10,000 dismantlers. With a 300 day work year an average dismantler would recover 1,100 pounds from 3.3 cars or roughly 333 pounds per car. The following table

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[11] *Recovery and Recycling of Post-Consumer Automotive Plastics in the United States*, by Michael Fisher, Council for Solid Waste Solutions (now the American Plastics Council) and Economics of Recovery and Recycling Automotive Report Series, American Plastics Council, December 1994

shows the incremental costs that a dismantler would incur per car at varying removal costs for this 333 pounds of material. Note that for each level in the range of removal costs, lost revenue from the sale of the material to a shredder is included.

Table 2: Incremental Costs to Dismantler for Part Removal

Part removal costs in ó/lb *	Incremental removal costs $ per car
10ó	$33.30
20ó	$66.60
30ó	$99.90
40ó	$133.20
50ó	$166.50

* *Includes lost revenue of 3ó/lb that would have been received from shredder.*

Decision points at each stage of the recycling process were examined in this manner. The following action strategies were recommended by RRSI to support improved performance of the vehicle recycling infrastructure:

At the dismantler level:

ò Reduce costs for parts removal through design for disassembly including: easy / difficult to remove parts identification; compatible materials in parts groups and in fasteners; introduction of new / aggressive destructive dismantling tools / techniques; and elimination of all contaminating adhesives, permanently attached clips and other similar items.

ò Strengthen the prices paid for used parts, thus providing the dismantler with more incentives to remove parts which would lower the cost of all parts removal including those targeted for material recycling.

ò Eliminate or minimize the need for contaminant removal by the dismantler through use of intermediary processors or new technologies.

ò Strengthen the prices paid for recyclable material to improve the incentive for part removal and delivery to a processor for recycling.

At the collection level:

ò Encourage processors / suppliers to sponsor hauling system for post consumer recovered materials in order to control availability of collection services, quality of service, low cost and long term commitment to a sustainable working system.

At the material separation, contaminant removal and processing level:

ò Leverage participation of the three groups of potential operators (dismantlers, shredder operators, or end market/processors) in a new generation of processing facilities that receive commingled parts and parts systems from dismantlers and prepare them for final processors and end markets. Accomplish this by providing incentives, technical assistance, and cooperation in ways that further reduce developer risk including the possible adoption of a request for proposal format for soliciting and supporting a limited number of such facilities on a startup basis.

The recommendations in the RRSI report stated that this upgraded recycling system, targeted at the non-metallic material stream currently landfilled as ASR, needs to be robust and able to survive the constantly shifting buying practices of the vehicle manufacturers and their suppliers. For example, a particular end market/processor group may have worked to develop an effective post consumer collection system for plastic resin type ôaö, and then find the vehicle manufacturers moving away from using resin type ôaö to resin type ôbö. Then the original collection infrastructure would be at risk of collapse, and the newly required collection system may not easily be implemented.

It was recommended that the collection system be structured to encourage broad participation across the affected end markets, processors, dismantlers, and possibly shredder operators ù and not just depend on a small number of individual companies ù to prevent this collapse. The current collection system is compelled to collect material-specific, pure streams or do sorting in such small quantities with such poor economics that the services cannot be considered commercially viable at the 3.3 billion pound per year level.

A second important aspect of the RRSI recommendations is the identified need for the capability to separate selected mixes of post consumer auto material through a combination of manual and automated material separation/cleaning operations. It was determined that somewhere around 50 such facilities would be needed across the US. The capabilities of such facilities could be integrated right into larger dismantlers in order to: 1) reduce the cost of capitalizing individual facilities; 2) eliminate double-handling of materials (always a prime area for cost reduction in recycling systems); 3) lower transportation costs; and 4) provide tighter quality control capabilities especially to eliminate avoidable contamination of targeted materials.

Other candidates to develop such facilities include end markets and raw material feedstock suppliers. These facilities could also be developed on a smaller scale if only selected streams of material need to be separated(e.g.: certain commingled plastics). In practice these operations do not currently exist in any form.

The final two stages of the recycling system, processing and end markets, were considered to be well established areas of private sector activity and competition, already very actively linked with the vehicle manufacturers. Their potential roles were defined in the four areas just described and their link to the newly developed system is primarily through the material collection, separation, and cleaning stage.

The summary conclusions of RRSIÆs original work for the VRP, *An Evaluation of Vehicle Recycling Opportunities* , indicated that the market could drive a more thorough reclamation of the materials currently being landfilled. An upgraded vehicle recycling system would rely on dismantlers to remove targeted components and component systems, probably through rapid, cost effective destructive dismantling techniques. A cost effective collection system would deliver these targeted parts and parts systems to special processing facilities designed to efficiently separate, clean, and process incoming material into marketable commodity recyclables. Existing processors and tier 1 suppliers already selling to the auto industry could receive these materials, and use them as feedstock for recycled content parts produced to vehicle manufacturer specifications. Material could also be moved to other non-auto end markets.

III. MATERIAL RECOVERY COMMERCIAL FIELD TRIALS

The purpose of the ARD Project field dismantling trials, building upon previous RRSI and VRP research, was to evaluate and demonstrate technically feasible and economically viable methods of collecting and delivering selected materials to processors and their end markets. Data generated from the field trials was used to evaluate the performance characteristics and cost variables associated with disassembly, collection, and transport of the targeted material streams. Specifically, this section reviews stages of collection that were evaluated during field trials, including:

1) **Disassembly** - methods for removing recyclable parts from vehicles

2) **Decontamination** - removing non-desirable parts / materials from recovered materials

3) **Sorting/I.D.** - methods for identifying and sorting mixed or non-compatible materials such as various plastic resins before shipment to processors.

Four collection methods were initially identified as potential sources of recoverable materials, as part of the preliminary project design. Only twoùsuper harvesting and stockpile-based collectionùactually were evaluated in detail as part of this project. The following defines the terminology developed to characterize these collection methods:

Gypsy Harvesting: A gypsy harvester is a third party specialty recycling firm that sends crews to dismantling yards to harvest specific materials. This approach is also referred to as cherry picking. It relies on obtaining access to smaller salvage operations and U-Pick-It operations. (The ARD project team worked with individual salvage yards to identify participants and established its own crews to collect materials from participating sites.)

Super Harvesting: A super harvester is a third party service provider to dismantlers. A super harvester picks up stockpiled materials on a regular schedule, and performs varying levels of cleaning and decontamination as well as processing at their own facility. This approach relies on the participation of larger, established vehicle disassembly operations.

Stockpile-based Collection: Stockpiled materials at the Vehicle Recycling Development Center (VRDC) operation were collected under the supervision of project staff. These materials were sorted as needed and delivered to selected processors or end markets for evaluation. This method is useful only for this project.

4) **Post Shredder Recovery**: Certain materials such as polyurethane seat foam and elastomers may be recovered from auto shredder residue. Research did not identify any foam or elastomer end markets with specifications tolerant of post-shredder material contamination levels. Post shredder material was therefore not collected. ARD staff focused its material recovery on pre-shredder disassembly operations.

Disassembly Field Trials

The project disassembly field trials were used to: 1) collect material for recycling evaluation; 2) document field based recovery costs under pilot trial conditions; 3) identify tools and techniques that are currently available and can be used immediately in field based material recovery; and 4) identify tools and techniques that are needed to reduce the time required for removal, lower cost of removal, and improve worker safety during removal.

Material was collected from two sources:

- Dismantler Site
- Material Stockpiles

Targeted material types were:

- Seat foam
- Selected plastic (polypropylene, polyethylene, TPO, ABS, PVC, PC, nylon)
- Textiles
- Glass
- Elastomers

Textiles were eventually deleted from the targeted materials list since no end market customers for textile materials were identified by project staff. It was determined that textile recovery was not an effective use of project resources since the material would likely be landfilled. Automotive glass was set aside from the major track of this project and made the focus of a separate, related spin off project funded by the VRP. An automotive windshield collection evaluation project is scheduled for implementation during 1997-98, and is detailed on page 37 of this report.

Disassembly Methodology

The project staff contracted with D & R Auto Parts to assist with disassembly trials. D&R Auto Parts of Belleville, MI has been in full operation since 1976. D&R employs 60-65 people and processes between 4,000-5,000 cars annually. Vehicles are obtained from auctions, insurance companies, municipalities, and consumers. Major sources of revenue include the sale of engines, sheet metal, and drive trains. The sale of miscellaneous core component parts, such as suspensions, also generates significant revenue.

Project staff worked with three D&R field staff including two mechanics and a forklift driver. Trials were conducted over a four-day period in early January, 1997. During that period 35 vehicles were selected for typical parts recovery operations. Vehicles were selected for the disassembly trials from D&R's inventory using their computerized inventory system.

Each vehicle arrived with tickets identifying which parts were to be removed, such as engines, wheels, or windshield wiper motors. Each vehicle was moved into an open garage by forklift where two disassembly mechanics removed the ticketed parts. The vehicle was then evaluated by ARD project staff for material recovery opportunities.

Material Recovery Data

Selected materials were removed from each vehicle by ARD project and D&R staff. Removal times were recorded for each procedure, and the recovered materials were weighed. The times and weight were standardized to pounds per hour for each vehicle for three types of material: seat foam, plastics, and elastomers. Clean weight signifies the weight of the material after contaminants(material fasteners, fabric, non-target materials) are removed. Standard salvage yard tools and methods familiar to the salvage yard crews were used in these trials. This allowed observation of standard operations and for identification of test alternative disassembly methods that could be integrated into these operations.

Foam

A total of 188 pounds (weight after decontamination) of polyurethane seat foam were removed from 25 cars during the D&R field trials. The documented removal times were somewhat erratic due to significant design variation among the seats encountered and are not presented here. Rather, the findings with respect to seat foam are presented in the context of a discussion of removal and decontamination issues later in this section.

Plastic

The project targeted 7 types of plastic for recovery including polypropylene, polyethylene, TPO, ABS, PVC, PC, and nylon. At D&R, 571.6 pounds of plastic were removed from 21 cars. Analysis of the field trial data reveals differences in the times of parts recovery. A threshold weight per hour was used to classify recovery rates into two distinct categories: material recovery rates from easy to remove parts and material recovery rates from difficult to remove parts. Easy parts to recover were defined as those parts that are readily accessible, or easily disassembled with the use of a standard tool. Difficult parts were those that first require removal of other parts, or that require a specialized tool for effective recovery. The easy and difficult removal times are presented in Table 3 below.

Table 3: Plastic Quantities Collected

Total cars	21
Total plastic weight - contaminated	571.6
Total plastic weight - clean	382.97
Easy removal times	1,036 - 2,586 lbs* / hr
Difficult removal times	106 - 542 lbs* / hr

**Clean weight.*

Elastomers

A total of 159.4 pounds of elastomers were collected at D&R from 12 cars. Easy and difficult removal times are presented in Table 4 below. Easy removal consists of peeling door trim and other elastomers from parts that are already removed from vehicles. The times in the tables below do not account for moving the cars into the garage, tool selection, or set up. The time clock started running once the procedure started and ended once the part was completely removed from the auto.

Vehicles are usually selected and brought into the garage due to their parts value. Tool preparation is maintained for the base parts recovery operation. These times are, therefore, more closely based on the marginal additional time required to incorporate materials removal into the current operation of a salvage yard like D&R.

Table 4: Elastomer Quantities Collected

Total cars	12
Total Elastomer weight	159.4 lbs
Easy removal times	262.29 - 362.63 lbs / hr
Difficult removal times	74.67 - 147 lbs / hr

Disassembly Findings and Analysis

This section describes techniques, tools and methods for disassembly that may lower collection or disassembly costs. In some cases, the methods discussed capitalize on efficiencies which were observed in the field. In other cases, the methods address ways that observed inefficiencies might be reduced. In yet other cases, recommendations are made to experiment with collection or disassembly methods which hold the promise of greater efficiency.

Inventory Systems

D&R uses an automated inventory system, which contains basic data about each vehicle acquired. When vehicles are scheduled for disassembly, tickets are generated from this system which identify which parts are to be removed. Field staff collect these tickets, locate the autos, and move them into the garage for disassembly.

The inventory data does not currently include the material composition of each part. As this data is obtained, however, it could be added to this inventory system, easing the identification of recoverable parts. In addition, because certain parts can more readily be recovered if other parts are removed (see discussion of piggybacking below), special material recovery procedures could be added to assignment tickets based on parts recovery priorities.

Piggybacking Opportunities

The project team initially expected parts/materials removal times to be a function of the part itself (e.g. bumper removal, interior panels). In a salvage yard environment, however, removal times are more dependent on the condition of the car and the parts that have already been removed. For instance, engine mounts containing valuable elastomer material are already removed as part of engine removal. If the engine was not slated for removal, the time to access this part would be excessive. Another example includes wheel removal which could facilitate recovery of fender liners.

The key to cost effective disassembly in this environment is to identify "piggyback" opportunities in existing field operations. This could substantially reduce the marginal cost of recovery of many parts for material value. Table 5 below summarizes the types of piggyback opportunities we identified. By systematizing these opportunities, material recovery opportunities can be optimized, whether at a scrap yard or an integrated operation.

Table 5: Inter-related Parts and Material Removal Processes

Material	***Part***	***Method***
Seat Foam	Seat	Some cars arrive with the seats in them already loose.
Plastic	Fan Shrouds	Removal of radiator (usually to get to the engine) often results in removal of bolts holding fan shroud.
	Inner Front and Rear Fenders	When the car is elevated, these parts can be easily pried off with a crowbar. These parts can be removed even more easily if tires and/or wheels are removed, which is done in most cases.
	Interior & Exterior trim	Significant amounts of trim are removed and thrown into the car in the process of removing other parts. These parts can be simply pulled out of the car

		before it is taken away to be crushed.
	Air Cleaner Parts	These parts are usually left loose under the hood or thrown in the passenger seat after the engine has been removed.
Elastomers	Radiator and Other Hoses	Many of these hoses are cut to get to the engine. Once the engine has been removed, many other hoses are exposed and can be quickly cut out of the car.
	Engine Mounts	After removal of the engine, engine mounts either remain inside the car, where they are exposed for relatively easy removal, or they remain attached to the engine and travel with it to another location, where they are removed and be easily collected.
	Side Window Gaskets	These are often removed with a wrench prior to removal of a side window.
	Weather Stripping	These can be manually removed with ease.
	Pedal Covers	These parts can be popped off by hand in seconds from virtually any car that comes into the shed.

Foam recovery

Significant challenges in foam recovery exist in disassembly and decontamination. Foam recovery can be accomplished either by cutting the foam off the seats while the seats remain in the vehicle or by various foam removal methods after seats have been removed from vehicles. Approximately half of the seats selected for foam removal at D&R permitted efficient removal with seats in the vehicle. About half of this foam contained frame wires that were not easily removed. The most important need in commercializing seat foam recovery is efficient wire removal.

For many seats, especially rear bench seats in several models, it was nearly impossible to recover foam efficiently with the tools available at D&R. This was because the wire support frame was thoroughly imbedded in the foam and the wire frame was securely bolted to the auto body. Attempts to remove the whole seat were often thwarted by rusted bolts. For these seats, a method is needed to efficiently cut the seats out, since the foam could not be efficiently removed in place. Workers attempted to cut brackets and bolts with an oxyacetylene torch, but the risk of starting a fire proved too great. Workers indicated that this can be done safely from the bottom side, but this adds significant time to the process.

Fabric was efficiently removed from most seats using a sharp instrument such as a carpet knife. The biggest problem in fabric removal was dulling the cutting tool on a wire or fabric clip. Improved knowledge of seat design and construction would help to avoid this problem

Two areas for improvement in the efficiency of foam recovery were identified: 1) rapid removal of whole seats from vehicles and 2) efficient separation of foam from steel wire frames, or dewiring.

Methods of Seat Removal

Cutting seat mounting bolts from the bottom of car makes most sense in a disassembly line situation where other parts are being freed in the same manner and the car can be turned upside down for optimum access. Cutting would probably be done with an oxyacetylene torch and would have to be done after gas tanks and components obstructing access are removed. The feasibility and efficiency of this approach needs to be analyzed for a number of auto models. This feasibility analysis will provide data regarding the economics and safety of this approach. This approach has the potential to salvage whole seats for resale as well as for foam recovery.

Several different technologies may be reviewed for cutting seat mounting bolts and/or brackets from inside the car. The technologies most likely to succeed include: 1)plasma torch, 2)abrasive cutoff, 3)pneumatic chisel, and 4)mechanical shear. Additional trials are required to evaluate the effectiveness of these technologies.

1) The plasma torch has a significant advantage over the oxyacetylene torch because of its narrow high intensity jet. Its cutting can be completed before surrounding materials are raised to combustion temperatures. Fire is still a possibility and it can produce toxic gases. Intense ultraviolet emissions can also be damaging to the eye.

2) Abrasive cutoff tools come in many forms. For this application, a small handheld unit is needed. Testing is needed to determine if a small cutter can provide suitably rapid cutting. Eye protection for workers in the area will be needed and a spark arrester may need to be improvised to avoid starting fires.

3) Pneumatic chisels with special bits are often used in auto body work. Generally these tools are not designed to cut the heavier gage metal of the seat brackets. Research is needed to determine if suitable tools exist or if suitable tools can be made.

4) Numerous hydraulic and pneumatic hand held shears are available, but most are not suitable for these locations and the type of cutting required. It may be necessary to produce jaws custom made to perform these tests.

Decontamination Field Trials

Following the field trials to evaluate disassembly methods, the project team evaluated a number of materials and techniques for decontamination. Materials were gathered from two sources:

- VRDC stockpiles, and
- Disassembly field trials

Material from VRDC Stockpile

The VRDC had systematically dismantled cars from the major American manufacturers in search of recycling opportunities since 1994. Their operations have resulted in a stockpile on their site of over 200 bins of post-consumer automotive material, including seat foam, plastics, and elastomers. In addition to the collaborative resin identification project described below, the ARD project assumed responsibility for a portion of the contents of this stockpile. Ownership of the stockpile enabled the ARD project to select materials from it as needed to meet the quantitative collection goals of the project. Selection was primarily of plastics in conjunction with the resin identification activity described below.

During the months of January and February, the ARD project drew roughly 3500 pounds of plastic and 150 pounds of elastomers from the VRDC stockpile. Of this material, approximately 2700 pounds, or 77% of the plastic was identifiable and became part of the project's collected materials, and 100% of the elastomers became part of the project's collected materials.

Material from Disassembly

Several categories of materials recovered during the disassembly field trials were identified as needing decontamination prior to shipping to processors or end markets. Those which were evaluated included seats/foam, mixed plastics and some elastomers. Windshield glass is being evaluated under a separate pilot project.

Dewiring: Removing Metal Wire from Foam

A large percentage of auto seat cushions are currently manufactured with the foam formed around a wire frame. When the frame is near either the front or back surface, it is generally possible to manually tear the foam from the wire. An increasing number of seats, however incorporate more wire near the middle of the foam. Manual extraction of this foam is in small pieces and requires a great deal of time and effort. Other methods are required to remove the wire from the foam efficiently. Ideally, all wire could be removed with a method requiring little or no labor.

Evaluation of the following five dewiring techniques is required to identify the most technically appropriate and cost effective technique: 1) Coarse shearing with manual separation, 2) fine shearing with magnetic separation, 3) high pressure water knife with mechanical or manual separation, 4) air cutting, 5) various mechanical scraping methods and variations on the manual cutting methods already tried. For evaluating each technique it is assumed that fabric has already been removed.

Each method benefits from detailed knowledge of wire location in each seat. This information could come from a database of seats developed by field measurement and/or from manufacturer specifications. It could also come from real-time measurement at the disassembly point.

Approximate wire location data can be inexpensively obtained by scanning with narrow focus metal detectors. More accurate wire location data can be obtained using x-ray equipment similar to that used to scan luggage at an airport. Since high sensitivity is not required, an older retired model might perform adequately.

The value of this approach is that the information could be digitized and used to control the path of a cutting device to follow the edge of the wires and allow simple dewiring. While this approach only makes sense in a high production facility, it may be the key to significant levels of foam recovery. The following dewiring, or cutting/separation techniques, require additional evaluation.

Coarse Shearing with Manual Separation

If wire locations are approximately known, the cushions can be sheared with a mechanical shear near each cross wire. Various types of scrap yard shears(alligator and guillotine) already in use may work for this approach. Once sheared, wires are close enough to the surface to allow manual separation. This method requires approximate knowledge of wire placement.

Fine Shearing with Magnetic Separation

Cushions could be shredded with a slow speed rotary shear using knives with a 1-2" separation. material would then pass under an overhead magnet to remove the wire. Depending on the shredding size and seat design, 5-20% of the foam might be removed with the wire. This method requires no knowledge of wire placement.

High Pressure Water Knife

If wire locations are accurately identified or the cutting tool has wire detection capability, the water knife can cut the foam along each wire, allowing the cut pieces to be mechanically removed from the wire frame. Depending on the accuracy of the cutting, 5-20% of the foam might remain attached to the frame. Most of this could be salvaged by the fine shearing method described above. The primary concern expressed about water knife cutting is getting the foam wet. Foam rebond end market specifications consistently require dry foam. A preliminary investigation indicates that several foam fabricators use water knives for shaping parts. The key appears to be the use of a high pressure narrow jet that leaves very little water in or on the foam.

Air Cutting

While it does not appear that air alone can be used to cut foam, air in conjunction with various blast media can be used. Investigation is needed to determine if air cutting can be done with out contaminating the foam. Air cutting would otherwise be very similar to water cutting.

Mechanical Scraping

On many seats, most of the wire frame lies nearly in a single plane. If the frame is drawn through a narrow slot (approximately the dimension of the largest wire diameter) most of the foam will be scraped off the wires. This process might be further refined by drawing the frame between rollers or burrs rotating against the direction of the frame movement. While this might not work for all seats, it would be low cost to implement and test and requires little knowledge of wire location. The level of foam recovery is expected to be at least 90%.

Improved Manual Methods

It is expected that manual cutting of foam from most frames could be cost effective if wire locations are known, more durable cutting edges are available, and through practice. This will not be practical for seats with large amounts of deeply embedded wire. As the market is being developed more difficult models could be avoided altogether.

The field crews involved in the pilot preferred directly removing the foam in comparison to removing the seats. Given standard tool availability, and the time involved in removing bolts, removing the seats was considered excessive. Seat (as opposed to foam) removal may be as or more effective in an auto MRF, disassembly line situation, or a field situation where specialized equipment is available.

Removal times are a function of seat design. The VRP has carefully documented this through their own studies of seat designs. They found that over 200 seat foam assembly configurations are used in vehicles. Some seat designs have metal framing embedded within the foam that restricts foam removal and decreases the rate at which removal can be completed. In other seat designs, the metal framing is located on the surface where it can be removed more easily. And in yet other seat designs, little metal wiring or framing is used. Dewiring, or metal removal, constitutes the single greatest challenge to seat foam removal.

In general, economy cars and vans have simpler seat designs than luxury cars. The result is foam recovery is more efficient in economy cars and vans. During project trials, vehicles were selected on the basis of expectation of acceptable seat designs in vehicles that were available for disassembly. Table 6 summarizes seat design findings from the disassembly trials conducted at D & R Auto Parts.

Table 6: Examples of Acceptable/Unacceptable Seat Designs for Foam Removal

Acceptable Seat Designs for Foam Removal	Poor Seat Designs for Foam Removal
'93 Escort	Aerostar Van
'90 Dynasty (front seat)	'87 Taurus
'87 Cavalier	'86 Sable
'91 Pontiac Lemans	'90 Monaco
'91 Corsica	'90 Plymouth Acclaim (bench)
	'88 Tempo (back)
	Eagle Premier (back)
	'88 Nova

Note: This data would only apply to the interior packages we encountered in the pilot. A single car model may incorporate many seat designs, depending on the interior packages that were made available.

If foam recovery is attempted on a disassembly line, it may be desirable to remove most seats prior to foam removal to maximize worker and space utilization. Whether foam is removed with seats in place or removed, the development of effective dewiring techniques and tools is required.

Recommendations for Commercializing Seat Foam Recovery

The key identified barrier is the lack of tools and technology to one, remove auto seats and two, separate auto seat foam from fabric, fasteners, and wire. Uncontaminated recovered foam is necessary to bring material prices that will cover the cost of recovery and transportation. Inferior quality will drive prices down and undermine the development of this currently immature market. Current operations and our own field studies suggest that seat foam removal and disassembly techniques can be improved.

Additional research should address the following tasks:

ò Identify and work with industrial tool manufacturers to assist in the development of tools for foam removal. Identify existing or prototype tools for foam removal (removing foam and separating foam from fabric, fasteners, and wire). Identify the best tool of each type to do each job. These tools should be tested in field trials, and data and results documented;

ò Identify the best location to cut seat brackets and bolts on a variety of vehicle models appropriate to each cutting technology.

ò Arrange for field disassembly trials to demonstrate: Removal of seats and / or foam in a state of the art disassembly facility environment and in a conventional disassembly facility typical of clean, efficient salvage yard operation.

ò Test both foam removal methods: 1) foam removal cut out (using blades, metal clippers) of cars without removing the seats, 2) whole seat removal for more efficient assembly line foam removal techniques (such as shredding, power washing and other cutting methods);

ò Investigate up to four existing operations and / or pilot studies where seat foam removal is conducted on a commercial scale to compare technique and results;

ò Develop a catalogue of seat designs and applications in cooperation with seat suppliers identifying those which facilitate foam removal and those that do not; and

ò Compile time studies data and data on methodologies reviewed. Evaluate most technically feasible and economically effective methods of foam removal.

Plastic Sorting/Decontamination Field Trials

Existing end markets for recovered plastics require that plastics are sorted by resin type. Initially identifying and sorting resins on-site at D&R. was the project methodology. However, it was found that field-worthy resin identification equipment is not currently available for application in salvage yard operations. As a result, in collaboration with the VRP, a Bruker instrument was used at the VRDC to identify resins.

Plastic Resin Identification: Bruker Infrared Spectrometer

The Bruker instrument relies on a specular-reflectance infrared spectroscopy system that is commercially available and can identify plastic automotive parts in about 5 seconds. However, at $40-50K, the Bruker is priced at a level that is well out of reach for most, if not all, disassembly operations. And it is not field-worthy in terms of ruggedness, weather resistance, and durability.

The accuracy of the Bruker instrument was recently evaluated at the VRDC and found to be 100% for the 30-piece reference library of spectra that plastics are checked against for identification. However, if the resin to be identified is not incorporated in the Bruker data library, no positive ID can be made.

Unfortunately, since the Bruker instrument uses a complicated and sophisticated identification procedure, it precludes addition of new reference spectra by the user. Over 99% accuracy is expected if the material is contained in the reference library. Errors tend to be between closely-similar polymers like ABS vs. SAN, PA6 vs. PA66, or PET vs. PBT.

The Bruker instrument currently identifies 30 different polymers, polymer blends, or polymer/filler composites. It was noted by VRDC that recycling processors need to provide input on recycling issues for similar plastics that may be mis-identified like PA6 and PA66. Input is also needed about requirements for separate streams that have different fillers or fill levels, e.g. polypropylene with different levels of talc filler.

Stronger reflecting signals come from smooth surfaces compared to rough surfaces. Foams and elastomers are not generally identifiable with the Bruker because of poor reflectance and inadequate signals.

Over a period of three weeks in late January and early February, a staff member of the ARD project worked with a VRDC team comprised of a staff researcher, three undergraduate interns, and a forklift operator to sort the collected plastics.

It takes about 5 seconds for the Bruker instrument to identify the resin type of a sample part. A small section of each part must be clean and free of paint or coatings in order to obtain an accurate reading. Recovered parts were stored in wire cages. After they were identified, they were sorted into another set of wire cages labeled by resin type.

Data

Working as a team, two interns processed roughly one bin per hour. On average, a bin held 130 pounds of contaminated material, which produced 90 pounds of decontaminated plastic. The plastic quantities collected after the sorting activity are presented in Appendix A. In addition to these quantities, over 1000 pounds of plastic materials could not be satisfactorily identified by the Bruker camera. These materials were labeled "SKOP" (Some Kind of Plastic) and returned to the VRDC stockpile.

Findings and Analysis

While the cost per pound to identify resins in this way was not in a cost effective range, this method was selected in order use the best available technology to separate the plastics. If markets accept this material to be clean enough for their feedstock materials in their manufacturing operations, then application of spectroscopy-based tools in the field may be worthwhile.

It is clear that some combination of manual and automated methods are required to identify recovered resin types. We identified three basic methods:

- Reference or "checklists." The ARD project team worked with VRDC staff to identify methods for collecting data from the auto companies (OEMs) indicating what resin the part is likely to be made from based on manufacturing records. This approach lacks reliability because resin types frequently change in manufacturing without changes to the molds or resin labels. More extensive work with Tier 1 suppliers is necessary to establish this type of valuable data base. Even if a checklist method were 70 percent accurate, it could assist in reducing the number of resin type possibilities.

- Manual Materials Properties Testing. Some automotive materials engineers and plastics reclaimers with knowledge of the properties of individual polymers indicate that the material can be identified by certain design, visual, and audible features: 1) certain resins have a recognizable background color, 2) some resins have distinctive sounds when they are knocked or dropped, 3) certain parts can be made out of only 2 or 3 different resins.

- Resin Identification Equipment. Instruments are available that can effectively identify resins. But they are not designed for field use. If checklists and manual methods can be used to narrow the range of possible resins to be identified, some existing technologies have potential for field application.

The following is a description of the four main technologies that are being considered for future field testing:

FTIR (Fourier Transform Infrared Spectroscopy)

Fourier Transform Infrared Spectroscopy (FTIR) is the technology of Bruker, Nicolet, Perkin Elmer, MTech, Mattson, Bio-Rad and several other companies. FTIR use of mid band infrared (MIR) seems pretty near fool proof when a clean sample, regardless of fillers, is tested. The accuracy of the technology results from observation of the resin's spectrum which corresponds to the stretching of the carbon chain bonds of the polymer which are specific to each polymer resin family.

Nicolet and Bio-Rad have developed hand-held probes extending up to 2 meters from the detector cabinet. These instruments may have applications in a MRF, plastics reclamation, or scrap yard environment.

Nicolet also has developed a variant technology in which a strong light source is used to heat the target surface and create a small amount of vapor that is sucked into the IR sample chamber. This approach eliminates surface preparation for most samples. The heating could be done with a laser on a conveyor line (if properly enclosed) so that the only critical operation would be grabbing the vapor sample. This approach has potential to meet the field needs anticipated in a mass disassembly operation.

Jobin Yvon-Spex works with a FTIR variant called RAMAN. In this process, the surface of the sample is heated and IR radiated from the heated surface is scanned. This is potentially another accurate ID technique that does not necessarily require surface preparation.

NIR (Near Infrared)

NIR works with the reflectance, transmission, or absorption of infrared light with wavelengths near that of visible light. It is effective in identifying plastic resins because the different crystal structure of each absorbs, reflects, and transmits different Infrared wavelengths in this band. NIR scanning is much faster than FTIR. Buhler, Bran+Luebbe, LT Industries, and Princeton Instruments all have expertise in this area.

Buhler has built high speed plastics ID equipment that works well on plastics without fillers and even works well on most colored plastics bottles. They tested samples from VRDC / auto companies and failed miserably. They claim that free carbon in the fillers used in auto plastics corrupts the accuracy of information. This equipment is probably not an appropriate tool for automotive plastic identification for these reasons.

LT Industries has built a hardened portable NIR instrument designed to tolerate "rolling around" and identify carpet fiber for recycling using a hand-held probe. This type of instrument may have potential for identifying auto plastics. These instruments are reportedly field worthy but testing is required to determine if they can accurately identify automotive application resins.

Triboelectric Devices

Triboelectric devices distinguish two or more unknown resin types from each other by exploiting the fact that different resins take on an electrostatic charge in different ways . One such device, called a tribopen, has been developed by Ford Motor Company of Europe and the University of Southampton. It is a hand-held device that distinguishes polypropylene and ABS. It is reported that it could be programmed to identify other combinations. This device has not been thoroughly evaluated in a field environment, and its accuracy may be an issue. The device was evaluated by MBA Polymers, APC's contractor, with accuracy of 66%. Pricing is attractive: it is in the $1200-1400 range. The vendor is identified as Intex based in England.

A newer device developed by Toyota and Nicolet uses a dielectric clamp and can distinguish between 2 or 3 polymers, for example TPO vs. PUR fascias. Preliminary reports indicate that ease of operation of this device, which handles like a pair of pliers, makes it very appealing for field application. Further evaluation of this device is a priority for subsequent work in Part II of the ARD Project.

Melt Point

There is a need to investigate Melt and Transition Point identification tools. It would not be faster than FTIR, but the low cost may allow adequate speed through simultaneous testing. A multiple probe unit could potentially be built for a few hundred dollars.

Recommendations for the Further Study of Plastics Identification and Recovery

Accurate, rapid, and field-worthy plastic identification equipment will significantly assist efforts to expand plastic recycling by either automotive dismantlers and/or automotive/durable goods shredders.

Field demonstrations of available resin identification tools and technical assessments of those trials should be conducted to produce a comparative analysis of speed, accuracy, ruggedness/durability, and cost-effectiveness of these tools in field applications.

Innovative developments in resin identification need to be evaluated for field applications. To our knowledge, no systems have been thoroughly tested for use and application in field disassembly operations. Evaluation of commercially available identification tools should be conducted in field operations .

The following specific actions are recommended to identify automotive engineering plastics and increase their recovery:

- Conduct field demonstrations of available resin identification tools in dismantler facility environments
- Develop a data base in cooperation with auto OEMs, Tier 1 suppliers, resin producers, compounders, and molders that provides reliable data on major plastic parts and their specific material composition
- Develop checklists to identify component parts with those materials in cooperation with OEMs, Tier 1 suppliers, molders, compounders, and disassemblers for disassembly and collection based on sufficient volume, purity of target material in identified component parts, market value, and ease of removal, and manual identification methods.
- Develop and demonstrate heat probe tool for resin ID in field operations.

Sample Decontamination- Manual Methods

Decontamination of both seat foam and targeted plastics took place at the VRDC facility over a period of three weeks. Using a variety of manual tools, a crew of 2-3 employees from Madias Brothers worked about 6 hours a day for a total of 5 days. The crew began with the bins of plastic that had been sorted by the VRDC team and moved to an area which had been set up for the cleaning process. Subsequently, they processed the foam, which had been delivered to VRDC from D&R by Madias Brothers.

Data - Foam

The weight measurements of seat foam taken at D&R included some fabric, metal, and moisture that could not be readily removed in the field. Our trials were conducted in January when many seats were wet and icy. The collection and decontamination of foam often present the same issue: the removal of foam from the wire frame. For this reason, our analysis of ways to lower the costs of foam decontamination is presented in the previous section on seat foam removal. The results of the decontamination process are presented in the table below.

Table 7: Seat Foam and Contamination Weights

Total cars	25
Total foam weight - contaminated	640 lbs
Total foam weight - clean	188 lbs (29%)
Residue Consisting of fabric and foam that could not be separated from metal.	279 lbs (44%)
Moisture assumptions	173 lbs (27%)

Data - Plastic

The quantities of material that were collected, the quantity after identification, and the quantity remaining after decontamination are presented in Appendix B. Parts recovered during the field disassembly trials were contaminated by foreign materials (any material dissimilar to the targeted material). Removing foreign materials (decontamination) resulted in an average loss of 33% of the gross recovered parts weight. On average, it was found that one crew member could clean 2 bins of plastic per hour, resulting in a production rate of 180 pounds of clean plastic per hour.

It became evident that manual removal of carpeting and glue from carpeted panels required too much time to be cost-effective when the Madias Brothers crew began cleaning the plastic materials. Thus this manual removal step was eliminated, and the crew placed such panels in the refuse pile without wasting any further time on them. This field-based observation at the decontamination stage suggests that carpeted panels are not worth collecting in the first place.

Data - Elastomers

Elastomer parts recovered by ARD project staff included nine part categories: weather stripping, engine coolant hoses, belts, air ducts, running boards, door hinges, pedal covers, various bushings, and cushions. Elastomer materials were collected and sorted by part. Elastomers from D&R and from VRDC stockpiles were sorted by three students for roughly two hours. Most elastomer parts include metal or fiber that may be contaminant to end users. Our baseline estimate of the sorting of elastomers from D&R was based on half an hour of work by one person, paid at the rate of $12/hour.

Arrangements were made with Midwest Elastomers to perform laboratory analyses of these materials to identify or characterize eight different properties including hardness, specific gravity, tensile strength, elongation, compression set, tension set, tear strength, and brittle point. The objective of this elastomer analysis was to determine the extent of differences between properties in post industrial and post consumer elastomers materials, respectively.

Based on this analysis, ARD project staff requested identification of applications for these materials and a determination of whether these materials meet existing market specifications. Finally, information was requested on what measures should be required in the dismantling, shipping, and processing to assure end market quality for these received materials.

Shipment of nine samples derived from the parts listed above was made to Midwest Elastomers. Despite repeated requests for a response, no evaluation data was received. Material samples were also sent to Custom Cryogenics of Simcoe, Ontario. Requests to Custom Cryogenics were made to complete a material evaluation form, but no response was received.

Findings and Analysis - Elastomer Evaluation and Processing

Overview

No significant barriers in the disassembly, sorting, or shipment of elastomer materials were identified. Cyrogenic and chemical processes have been developed that have the potential to facilitate separating metal from rubber. Two rubber reclamation operations, Midwest Elastomers of Wapakanetta, OH and Custom Cryogenics of Simcoe, Ontario, were identified to evaluate the materials.

Extensive and promising work has been conducted by the Rubber Recycling Topical Group (RRTG) of the American Chemical Society (ACS) Rubber Division in the recycling of elastomers and other rubber materials. RRTG members have met with VRP staff to determine an overall work scope to analyze the collection and availability of elastomers, starting with engine coolant and related hoses of predominantly EPDM polymers. The collection analysis will identify potential volumes and appropriate collection measures to recover hose waste materials.

A detailed evaluation of the parts by material and type will result in a more rigorous analysis of this recycled material and its potential applications. Cost of recovery and potential value of end market applications will be determined based on this data. Other elastomer materials that will be analyzed include door trim and trunk and miscellaneous body seals. Potential contaminants include metal inserts, fiber, and plastic fascias.

Extensive end market applications exist for post consumer tire-derived crumb rubber and post industrial sources of rubber in automotive and non-auto areas. Major companies operating in this market include Rouse Rubber Industries, Inc., Syntene, Midwest Elastomers, and Cri-Tech. Emerging research conducted on high quality polymer-grade recycled rubber indicates that recycled rubber can be used in selected auto parts without sacrificing quality. Emerging markets include lower air deflectors (Ford), steering shaft seals, and fender liners as well as splash guards (Chrysler).[12]

Findings

Elastomers represent a high end value material (based on virgin material prices) with "recovery piggybacking" opportunities. However, major material processing and collection infrastructure questions remain before elastomer recycling can be widely practiced. A non-tire elastomer collection infrastructure currently does not exist. No market based evaluations are available at this time. Another major issue is whether the post-consumer material is consistent enough in quality to meet market specifications.

Further Study

Additional research is necessary to develop cost effective and technically efficient processing capability.

[12]RRSI, *An Evaluation of Vehicle Recycling Opportunities,* July, 1996, p. 75.

Post Consumer Auto Glass: Windshield Collection Pilot Project

Glass recovery from auto disassembly operations was determined to be unfeasible in the near term because of the difficulty of removal(and corresponding high recovery costs) and low material prices. High recovery costs and low material prices undermine market development in the absence of some kind of external intervention.

It was decided, then, to focus on recovery of auto glass from glass replacement and collision shops. A set of partners was identified to conduct a glass collection pilot, and additional funding was secured from the VRP to implement this pilot for a 9-month collection period.

The GLI project team is partnering with Strategic Materials, Inc., a national glass recycler with over 100 years of glass recycling experience, and Henderson Glass, an auto glass replacement retail chain, as well as the Michigan Molecular Institute (MMI) and the VRP to evaluate the feasibility of post consumer auto glass recovery. The VRP is funding this study in conjunction with the funding of MMI's research on the feasibility of recovering the poly vinyl butyral (PVB) plastic film from windshields. The project is commencing in September, 1997 and will operate for nine months once the collection program is implemented.

The GLI project team will identify haulers to implement the glass collection pilot project and negotiate with the selected hauler(s) for the purposes of optimizing the collection routing, collection equipment and container selection, site container selection, collection frequency and participant education for the most efficient collection and cost optimization. The contractor will be responsible for material consolidation and material shipment to Strategic Materials.

The GLI project team is working closely with Strategic Materials to design a range of collection options that will be demonstrated in cooperation with Henderson Glass franchises in the Greater Detroit area. As part of this work with Strategic Materials, a detailed project scope with specific steps and tasks is being developed for this pilot project. Partners in the collection project also might include a mix of haulers, and a range of hauling options will also be identified.

A key option to consider is an intermediate consolidation site, that is fed by the individual participating stores, for higher volumes of individual material shipments to Strategic Materials' Detroit facility. Strategic Materials will report volumes received and market data from their glass end markets.

The auto glass collection system design will be based around the participation of the 23 Henderson shops, or some portion of them, in southeastern Michigan. These shops stretch from Adrian on the west to Fraser northeast of Detroit. Currently these shops are served by at least six or more different haulers, including Waste Management, Inc., City Environmental, Inc. BFI, and others. Parameters for this project stipulated by Henderson Glass is that there be no net increase in the cost of waste hauling / material collection by the participating shops.

A survey of Detroit area Henderson shops was conducted to determine the volume of windshields and other glass generated at these shops. The survey indicated that these shops generate approximately 50-70 tons/mo. of windshields that are currently landfilled. The quantity of windshields generated by a shop is 85-400 windshields/mo. with the average generation rate about 175-200 windshields/mo. Prices range up to $20-30 per ton for plate glass but as little as no net price for windshields.

A cost effective PVB recovery technology would provide a plastic material with a high market value. Currently PVB film is land filled because of glass contamination. Market prices for PVB resin are around $1.50/lb and $3.50-6.00/lb for formulated PVB. Such a technology, if proven successful, would have a significant positive impact on the economic feasibility of auto windshield glass recovery.

If MMI research and development of PVB recovery methods is successful, such a development will likely change the way auto glass collection is perceived by generators as well as haulers and glass recyclers. PVB recovery could become an important new profit center for auto glass haulers and recyclers. Higher volumes of recovered clean glass would also result. And generators of auto glass could enjoy the benefits of avoided landfill tip fees.

Field Trial Glass Removal

Glass removal trials were also conducted at D&R, but with limited success. Two methods were used to remove windshield glass but neither method was effective. One, removal by forklift resulted in too much shattering of the material for efficient recovery. Two, cutting the windshield bond with piano wire preserved an intact windshield, but required too much time to be cost-effective. These identified difficulties indicate the need for a tool which could either cut the windshield bond more quickly or simply cause the bond to release.

Side glass field removal trials were somewhat more successful. Field-based testing demonstrated that roughly 90% of side window glass could be recovered by causing it to shatter into a strategically placed container. Methods for removal in a MRF environment should be further explored in the future.

Findings and Analysis

The ARD project will confirm baseline information and inform each location regarding the pilot startup, related guidelines and procedures. At the conclusion of the project, the ARD project will survey all of the participants at the end of the pilot period of nine months to evaluate their level of satisfaction with the project, labor costs, and any other relevant findings. Participants will receive contact information for the ARD project as well as the hauler to contact with any questions or concerns.

The final report on the glass pilot project will evaluate collection economics, operational design and implementation, and participant satisfaction. This evaluation will be performed in cooperation with the designated hauler(s) and Strategic Materials. The final report will also include a Model Request for Proposal (RFP) or contract that could be used by others who want to replicate this project, and a set of guidelines for Windshield Glass Collection based on the pilot experience. The final report will also include a summary of the MMI research to the degree that this data directly impacts the findings and conclusions of the pilot post consumer auto glass collection project.

IV. ANALYSIS OF END MARKETS

This chapter provides marketplace information based on project results for targeted materials--seat foam and targeted plastics--recovered from post consumer vehicles. In conjunction with cost data based on project disassembly field trials and automotive material recovery, this empirical market data provides a baseline for systematic analysis of potential end market development for automotive materials targeted for recovery.

This market analysis is based on project data, findings, and results. The analysis starts with the identification of end market customers and the materials they evaluated. The markets for polyurethane seat foam and targeted plastics (ABS, TPO, polypropylene, polyethylene, and polycarbonate) are treated as two market segments, respectively. Analysis of each market segment consists of an overview, market and commercial requirements. Findings for the overall market as well as each market segment concludes this chapter.

An end market/processor data base of nearly 100 companies was built for the project, and includes basic business information for each company including name, address, phone, fax, email, and contact names. More detailed information about end market customers participating in this project was obtained and compiled using an interview report form developed specifically to generate data for assessing this market. This data includes identification of company type (market, processor, research, association, or other), types of material, material sample requirements including quantity, end market application, and general notes(See Appendix C: Markets Database Entry Form).

Identification of Potential End Market Customers/Processors

The ARD project staff contacted over 50 potential end market customers identified in the markets data base to determine whether these companies were willing to receive material samples, types of materials in which they were interested, sample quantity information, and relevant business data. Confirmation letters were then sent to company representatives who agreed to participate.

In several cases, potential end market customers for post consumer materials were reluctant to participate in a project whose results will be made public. Other companies chose not to participate because of the lack of certainty about the time material supply could be delivered on a reliable, ongoing basis. Given the lack of immediate business incentives for participation in this pilot project, obtaining company participation, especially small or medium size companies, was challenging. Most smaller size companies do not have resources to participate in projects that cannot promise immediate commercial benefits.

Nineteen companies nevertheless agreed to participate with the prospect that this type of automotive material recycling could become a reliable supply source of quality materials (See Appendix D: Market Contacts Expressing Interest). Material samples were sent to intermediate processors and end market customers. Sample sizes ranged from 5-50 lbs depending on the quantity requested by the potential end market customer.

Sample tracking forms were designed for use in the ARD project to track material types and quantities shipped to cooperating potential end market customers. Sample tracking forms include data describing the type of material, assigns a sample ID number, and weight of each sample material. The form also includes company contact name and relevant location information. (See Appendix E: Sample Tracking Form)

Profile of Recovered Material Evaluations

An evaluation form was developed for use by end market processor/customers to report their evaluations of the materials they received. This form includes 10 questions that address material specifications, evaluation procedures, lab tests and results, type of end market application, contaminant issues, pricing, and desired quantities. (See Appendix F: Market Evaluation Form)

Responses were obtained from 17 of the 19 companies that agreed to receive sample materials. Seven evaluation forms were completed by potential end market customers and intermediate processors and returned to the project staff. The range of these potential end market customers is very broad: from a small company of 5-6 employees that processes high density polyethylene to a multinational company, Montell North America, that is the biggest producer of polypropylene in the world and operates a polypropylene recycling facility in Baltimore, Md. The following table identifies end markets by the type of material they received and evaluated.

Table 8: End Market Customers for Material Types

TPO	ABS	Polypropylene	Polyethylene	Polycarbonate
ò Findlay Foam (Findlay, OH) ò Performance Polymers (Brighton, MI) ò Compound Technologies (Holly, MI) ò Polycytek (Battle Creek, MI) òáMontell (Baltimore, MD)	òáFindlay Foam ò Performance Polymers ò Compound Technologies ò Polycytek ò EnviroTech Plastics ò Recycling Separation Technologies (Lowell, MA)	òáFindlay Foam ò Performance Polymers òáCompound Technologies òPolycytek ò Montell ò EnviroTech Plastics ò Rondy and Company òá Blue Water Plastics	ò Performance Polymers ò Compound Technologies ò EnviroTech Plastics ò Rondy and Company (Barberton, OH) ò Michigan Polymer Reclaim (Lansing, MI)	ò Recycling Separation Technologies

ò EnviroTech (Amhertsbur gOntario) ò Blue Water Plastics (Port Huron, MI)				

Five firms received seat foam from the ARD project's inventory of seat foam removed from post consumer vehicles and completed end market evaluation forms:

ò General Foam Corporation Paramus, New Jersey ò Fairmont, Inc. Chicago, Illinois ò Scottdel, Inc. Swanton, Ohio	ò Luxaire Cushion Co. Newton Falls, Ohio ò Appertain, Inc. Pulaski, Tennessee

As seen in Table 8, between 5-7 end market customers were identified for each targeted material except polycarbonate. Identifying additional end market customers is not expected to be very difficult.

Although only one company, Recycling Separation Technologies, was identified that agreed to receive polycarbonate, American Commodities, Inc., (ACI) Flint, MI is a known and established end market for this material. ACI chose not to participate in the project although it was invited, and so did not perform any end market evaluations.

The principal limitation of a pilot project in evaluating immature markets is the absence of undertaking real world commercial negotiations to arrive at terms for material supply contracts and material prices. Prices cited in this report must be considered preliminary price offerings and not actual market transaction prices. Actual market transaction prices for these materials will be based on negotiations to reach agreement on prices as well as market specifications and material volumes. Prices that would be negotiated and received by a commercial scale operation for recovered materials are expected to be higher.

Seat Foam End Market Segment Analysis and Evaluation

Overview

The rebond market exerts strong demand for any kind of recycled polyurethane foam including post-consumer vehicle seat foam. Most of the current supply is from post industrial sources including foam and seat manufacturers. Domestic post industrial foam supply is supplemented by offshore imports of substantial quantities of post-consumer and post industrial foam.

Rebonders grind and re-press recovered polyurethane foam into foam blocks. This product is used for commercial and home carpet padding as well as athletic equipment padding applications. Domestic auto makers are investigating the use of rebond for carpet underlay in vehicle production. Rebond is commonly used by Japanese automotive OEMs for a wide range of applications.

An industry report indicates that over 500 million pounds of foam were recycled for use by the rebond market in 1993.[13] Imported foam amounted to 180 million pounds. According to the same report, up to 180 million lbs of auto seat foam could be recycled by the rebond market for carpet underlay.

Polyurethane foam prices reflect the commodity nature of the material. These prices are extremely volatile. Price fluctuations reflect the contraction and expansion of foam supply in relation to a fairly stable level of material demand, primarily for carpet underlay applications. Other applications identified during this project include athletic equipment padding and automotive filler or sound absorption applications.

Process foam scrap can bring up to $.70/lb in a robust market cycle. Recycled post consumer polyurethane foam may bring as much as $.35/lb in the same market cycle. Price volatility may be less acute for post consumer foam.

Market Requirements

Data and information from our review of background literature and project research interviews clearly indicate strong market demand for polyurethane (PUR) seat foam. Foam buyers were identified in the upper midwest, east coast, and southeast. For purposes of this project, we did not seek to identify buyers at any greater distances from potential auto material recovery operations in the Great Lakes region.

Material quality requirements include that seat foam be dry and free of metal, fabric, and other contaminants. Specific contaminants include fillers, hooks, clips, wire frame, and velcro. Seat foam recovered in this project met the specification requirements of all five potential end market customers. Recycled foam buyers were willing to purchase seat foam recovered from post consumer vehicles if these requirements can be met. Preference was expressed for baled foam.

The quality of the ARD-recovered foam was evaluated as satisfactory by all potential customers and thus higher prices might be achieved on the basis of consistent high material quality. It was further noted that seat foam is soft-skinned, molded HR foam, and this quality is inferior to low density conventional foam. As expected, all foam

[13]The Woodbridge Report, New Polyurethane Foams from Recyclable and Reusable Materials Answer Emerging Material Selection Criteria, The Woodbridge Group, October, 1993

buyers expressed strong interest in purchasing automotive seat foam. However, the pilot nature of this project curtailed any actual contract commitments from potential end market customers.

Market Pricing

Initial price offerings for polyurethane foam were near what was expected: in the range of $.15-.35/lb. Given the strong demand for recovered polyurethane seat foam, it is expected that guaranteed volume supply would bring higher prices over the long term. Two firms stated a purchase price that ranged from $.15-.25. The exact price would be determined by whether the foam was baled or loose. Another firm indicated that it purchased low density conventional foam scrap for $.45/lb., and would pay less for auto scrap foam. Other responses emphasized the fluctuating nature of foam prices.

These quoted prices must be considered preliminary price offers, and a starting place for price negotiations. The major factors that determine actual market prices include the foam grade quality, ability to ship foam in sufficient volumes consistently over time, and whether the foam is free of contaminants. In a word, as with any commodity market, reliability of supply and feedstock quality determine price relative to demand.

A Montreal-based disassembler reports getting up to $.60/lb (Cnd.) for truckload quantities of seat foam. He reports a price range of $.35-.60/lb. (Cnd.)[14] This information confirms that the prices identified from project methods may seriously understate transaction prices that may be obtained for recovered materials.

Obtaining a price of $.35/lb. (US) for post consumer foam may be possible with quality assurances of dry, clean material and reliable and consistent supply. At least two companies followed up with ARD project staff to express their interest in receiving commercial quantities after completing and submitting their evaluation forms. Seat foam recovery for end market delivery would be profitable at a price level of $.35.

Commercial Requirements

Since ARD project staff did not have an available supply of recovered seat foam to deliver to customers, it was not appropriate to enter negotiations with these potential customers to sell material. In a commercial scale operation, however, such negotiations will be important to get the best price possible as well as establishing terms for material specifications and purchase/delivery arrangements.

Regular commercial deliveries of baled seat foam in truckload quantities of 20-25,000 lb are usually expected by end market customers. One customer specified that he was looking for 200,000 lb/month.

Three of the five end market customers actually used ARD-recovered seat foam in production. Scottdel and Appertain used the foam by shredding and blending it into

[14]Personal interview, Claude LaFord, RASF, Montreal, June 26, 1997,

carpet underlay. Scottdel also reported in a market interview conducted in October, 1996 that the seat foam can be used in the production of sound barrier material for OEMs without specifying which companies. Reference was made to EVA backing with .9 density with 6 ml film in car doors for sound and moisture resistance. Luxaire used the seat foam material in exercise machine padding.

None of these end market customers needed any additional samples or additional evaluations of the seat foam, and verified that post consumer seat foam quality is acceptable to these potential customers as is.

Targeted Plastics: End Market Segment Analysis and Evaluation

Overview

Post consumer vehicle plastics represent a highly diverse stream of polymers and polymer blends using both thermoplastics and thermosets. Successful development of this supply source would open up a significant volume material stream that is now being landfilled and therefore provides no current value-added market activity. Automotive plastics consumption reached 3.03 billion pounds in 1995, up from 2.09 billion pounds in 1991 according to Market Search 1996. One estimate is that recapturing just 12% of the current U.S. production of engineering plastics would create a $1 billion annual business.[15]

Five engineering plastics were targeted for recovery by the ARD project. The key is to recover those polymers that can be recovered and separated economically and have end market applications. These polymers, then, must have a set of properties that give the recycled material value in the market place for a specific application. The performance and appearance of a recycled material are the driving factors that determine its market value.

The goal of end market development is to identify a recycled material with the right combination of properties to meet the performance and appearance requirements necessary for high end applications to achieve commercial profitability. High end applications are those applications where the virgin feedstock is priced around $.75 per lb., or higher. Accuracy in resin identification and obtaining material free of contaminants pose important technical obstacles that currently create a major barrier to the development of stronger recycled plastic markets.

It has been reported that for some injection molding, in-mold coating systems are being developed to produce fully colored parts that use a powdered form of the same material as the substrate. Molded parts produced with this technique, it is reported, are capable

[15] Advance Technology Program Project Brief, *Enabling Large-Scale Recovery of Plastics from Durable Goods*, March, 1997.

of being recycled into high end applications.[16] If this assertion is reliable, then a key contaminant barrier will have been effectively addressed.

The multiplicity of polymers used in automotive applications is further complicated by the use of various blends in various component parts. Polypropylene used in one application, for example, may not necessarily be the same polypropylene used in another application.

A research project to develop compatibilizers for use in resins so that different polymers can be blended in a new recycled material is currently underway at the Michigan Molecular Institute. If this project is successful, material separation requirements and associated costs would be reduced. Two blends being investigated include ABS/PP/HDPE and ABS/PP/PC.

The key to successful development of target engineering plastic end markets is to supply clean(contaminant free) and pure resins or resin blends for delivery to end market customers. Such development would have extremely important market implications. As previously cited, the automotive market accounts for over 3 billion pounds of engineering plastic consumption. Although the rate of automotive plastics consumption has reportedly flattened, it is unclear whether this flattening is temporary or permanent.

The question of the optimal means to access and process post consumer automotive plastics remains an important but open question. One potential answer is a plastics material recovery facility such as MBA Polymers is attempting to commercialize in Richmond, CA with APC sponsorship. MBA Polymers is developing thermal, mechanical, and chemical systems to identify and sort plastic parts, grind and separate different polymers, remove metals, and extrude pellets for sale to end market customers. Such a systematic approach would allow MBA Polymers to access a highly diverse range of polymers.

Another potential answer is to work within the existing infrastructure with a combination of companies to recover, separate, and regrind specific target polymers for their higher value, and extrude pellets for sale to compounders and end market customers. American Commodities, Inc., Flint, MI augments this approach by acting as a super harvester that builds its own material supply network to recover targeted plastics and using its proprietary process to produce virgin-competitive recycled feedstocks.

Assembling the right configuration of players to build a cost effective and technically efficient infrastructure poses an enormous challenge to post consumer plastic end market development. The technical issues for the supply side are assuring consistent quality and reliable volumes of feedstock materials; the issues for the demand side are to specify recycled content for specific applications and the willingness to enter long term purchase agreements. Solutions will require multiple drivers and innovative

[16] American Plastics Council, *Designing for the Environment: A Guide for Information and Technology Equipment,* n.d.

arrangements that provide an infrastructure for material collection / recovery and intermediate processing for recycled material conversion to feedstocks for sales to end markets for high end applications.

Market Requirements

This section presents base line market data and information derived from the experience of this pilot project. Given the pre-commercial level of this pilot project, these market findings are preliminary and not intended to be conclusive for immediate commercial purposes. Markets are not firmly established; tend to be primitive and immature, and are highly fluid (more so than comparable historical markets).

A limited number of potential customers for polyolefins, TPO, polycarbonate, ABS, and other high end plastics currently exist. Prices for these materials may not currently cover the cost of disassembly, identification, and intermediate processing to deliver regrind. However, opportunities may be available to develop relationships with those companies willing to nurture new material suppliers.

It is frequently asserted that markets for post consumer automotive plastics do not currently exist. The results of this project indicate that markets do exist for recovered post consumer automotive plastics provided that consistent material quality and reliable volumes of feedstock materials can be assured. End markets exist for recycled post consumer plastics in applications such as plastic lumber and other molded product applications. These applications have the least stringent performance specifications.

More information is needed to determine whether a particular end market customer will buy post consumer automotive plastics at volumes and price levels that make material recovery profitable for disassemblers. One approach may be for disassemblers to consolidate their recovered materials so that sufficient volume levels are achieved to sell truckload quantities of materials to these end market customers. This approach might also include working with a specific processor to furnish regrind to end market customers or working with a super harvester.

Compounders that take recovered materials must be able to address several issues molders have in producing parts for the automotive and other industries. These issues include cost, material quality, processing performance, predictability, availability, technical support, certification, approvals, virgin comparability, price stability, liability, and marketability.

This project utilized an intermediate processor, Industrial Resin Recycling, Brighton, MI to grind auto parts separated by material to produce regrind. Five different recycled engineering plastics, including polypropylene, HDPE, ABS, polycarbonate, and TPO, were supplied as feedstocks to end market customers for evaluation in their various applications. Table 9 summarizes responses from 12 potential end market customers who completed customer evaluation forms and from telephone interviews conducted during the course of the ARD project. The principal categories of information arranged in six columns include responses to issues of contamination, purity, volume, feedstock suitability, material form, and whether the potential customer expressed an interest in purchasing material.

Table 9: End Market Customer Evaluation of Materials

MATERIAL	No. Companies (Confirmed)	Contamination	Purity	Volume	Feedstock Suitability	Material Form	Mkt. Interest
Foam (PUR)	*5(5)*	No	N.A.	TLQs*	Yes	Baled	Yes
Polypropylene	8(5)	Yes	No	TLQ / No min.	Yes	Regrind	Yes
HDPE	5(3)	No	Yes	TLQ / No min.	Yes	Regrind	Yes
ABS	6(2)	No		No min.	Yes	Regrind or parts	Yes
Polycarbonate	2(1)	Not known	Not known	No min.	Yes	Parts or regrind	Yes
TPO	7(4)	No	Yes	No min.	Yes	Parts or regrind	Yes

* TLQ: Truck Load Quantity (TLQ for baled foam = 25-30,000 lb; TLQ for plastic parts = 5,000 lb)

The second column shows the number of companies that indicated that they buy the material listed in the first column. These company responses were tracked and recorded in the sample tracking end markets data base. The number in parenthesis indicates those companies that evaluated that material for the project and indicated they would buy the material.

In the third column of the Table 9, end market customers indicated whether samples they received were contaminated by indicating yes or the samples were not contaminated by indicating no.

In the feedstock suitability column, a "yes" indicates that a potential customer responded that they will take that material as recovered in this project. However, that does not mean that each end market customer who participated in the project indicated they would enter market agreements for material delivery.

Contaminant Issues

Contaminants include paint, metallic coatings, dark pigments, adhesives(glues and epoxies), labels, and metal fasteners. Each contaminant presents unique challenges to material separation and processing. Additives, fillers, and reinforcements are routinely used to engineer a polymer to perform in a highly specific way for a particular application. This is an important strength of polymers as manufacturing material, but poses complicated issues for recycling.

Solutions to some contaminant problems already exist. Metal fasteners, for example, can frequently be replaced with plastic fasteners. Minimizing variability in the type of fasteners used in a product can also speed disassembly. Breakaway joints and panels can also speed disassembly in computer and business equipment design,[17] and this type of design feature could also be incorporated into vehicle design. A vehicle design approach incorporating these design characteristics would enhance the successful recycling of post consumer vehicle materials.

It is important to note that different customers have different requirements regarding material contamination. In the case of Montell for example, their technical requirements for recycled feedstock are very stringent compared to other potential end market customer processors. Montell wants high compatibility between recycled and virgin feedstock so their tolerance for contamination is extremely limited. Other potential end market customers have less stringent technical requirements, but prices for such materials are accordingly lower. Contaminants will frequently undermine recycling efforts by causing removal costs to be prohibitive until the DFD (Design for Disassembly) guidelines are more widely used by OEM's.

Purity Issues: laboratory analysis of recovered materials

Engineering plastics include any combination of colorants, fire retardants, stabilizers, plasticizers, reinforcement materials, and fillers. Common polymer names refer to resin families and wide variation in properties may be seen between family members. This difference is reflected in the difference in their melt points, or melt flow indices. The melt point is that temperature at which the material flows as a viscous semi-solid. This is the temperature of the material's processing viscosity. Mixing resins with different melt points will produce a material with an unknown melt point which limits the uses of the mixed resin material. Copolymers or pigmented polymers also complicate resin purity.

The most complete laboratory analysis of material recovered by project staff was performed by Montell N.A. on the polypropylene and TPO samples using Differential Scanning Calorimetry (DSC). Both samples were found to be either physical blends or heterophasic copolymers (HECO). For the purposes of this company, the purity level of the TPO was acceptable with a PP/PE ration of the crystalline component estimated at 70/30. The polypropylene sample was most likely an 85/15 or 80/20 PP/LLDPE [18]blend.

The physical properties of the polypropylene sample made it comparable to a general purpose homopolymer PP with a similar melt point. The TPO properties were

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[17]American Plastics Council, *Designing for the Environment: A Guide for Information and Technology Equipment*, n.d.

[18]Linear Low Density Polyethylene

comparable to a high atactic TPO grade. However, metal contaminant levels in both samples were significant enough to prevent use of the materials by Montell. It is expected that a more rigorous metal decontamination method will resolve this contamination issue.

Another laboratory analysis was conducted by Michigan State University's Department of Materials and Mechanics. This preliminary laboratory analysis of PE and PP indicated that the HDPE was found to have a melt point of 137°C with high crystallinity. The polypropylene blend had melt points of 127.9°C and 164.1°C with the assumption that the first melt point corresponded to a polyethylene. The PE makes the blend less resistant to surface damage but improves the paint adhesion to the polymer with a minimum reduction in tensile strength of the polymer. This analysis did not report any metal contaminant problems.

Commercial Requirements : volume, material form, market interest

Most customers require the engineered plastic feedstocks to be regrind. This processing represents an additional step after disassembly and recovery at an additional cost. Material volumes need not be truckload quantities for every material. However, the ability to supply truckload quantities would create a stronger market position for that supplier. Reliable supply of predictable volumes of materials would bring higher material prices compared to spot market prices. Exchange Plastics, Akron, OH will broker less than truckload quantities for certain materials when conditions favor such activity.

Seat foam is a thermoset and rebonders take the material in chunks. The key is to supply foam that has been separated from wire and fabric contaminants and baled to achieve cost effective transport costs. No additional processing is necessary for seat foam.

The market interest column indicates that at least one potential end market customer was interested in buying more material based on the sample material shipped to that customer. The affirmative response in this column clearly indicates markets exist for recovered post consumer automotive plastics.

Market Pricing

Prices vary according to market demand, material performance properties, and exact type and grade of the material. Prices for recycled feedstocks targeted in this project are relatively low consistent with the modest technical requirements. High end applications are either absent or not well developed. In all cases for targeted recycled engineering plastics, end market customers pay higher prices for regrind than prices they pay for parts.

The prices in the Table 10 are for post industrial materials (process scrap). These prices are generated by Plastics News from interviews with North American buyers and suppliers. Prices for recycled target polymers reflect prime resin market prices. The information provided is based on sources believed to be reliable but its accuracy or timeliness is not guaranteed and no warranties of any kind are provided. Plastics News does not intend to specify the price of the materials listed. For price quotes on specific materials, suppliers must be contacted.

Table 10: Recycled Plastics Resin Pricing
(cents per pound unless otherwise indicated)

Resin/Grade	Clean regrind or flake	Pellets
ABS		
Mixedácolors,áindustrial	26 - 31	36 - 41
POLYCARBONATE		
Clear,áindustrial	78 - 83	--
Mixedácolors,áindustrial	43 - 48	51 - 56
POLYETHYLENE		
HDPEábottles:		
Natural,ápost-consumer	29 - 34	36 - 41
Mixedácolors,ápost-consumer	24 - 29	31 - 36
Mixedácolors,áindustrial	26 - 31	33 - 38
HMWHDPEáfilm,ápost-consumer	--	27 - 32
LLDPEástretcháfilm	--	29 - 34
LDPEáfilm:		
Clear,ápost-consumer	--	26 - 31
Colored,ápost-consumer	8 - 11	22 - 26
PETáBOTTLES		
Clear,ápost-consumer	27 - 32	37 - 42
Green,ápost-consumer	22 - 27	30 - 35
POLYPROPYLENE		
Industrial	19 - 24	25 - 29
POLYSTYRENE		
Industrial	25 - 30	35 - 40
High-heatácrystal,ápost-consumer	25 - 30	36 - 41
PVC		
Clear,áindustrial	13 - 21	--

Prices are in U.S. cents per pound for prime resin, unfilled, natural color, FOB supplier, unless otherwise indicated.

UP indicates a market-price increase in our chart in the past week.

DN indicates a market-price decrease in our chart in the past week.

P indicates a price increase for that material is pending.

C indicates a correction in the published price.

Source: Plastic News: September 25, 1997

The prices in the Table 11 are based on one brokerÆs (Exchange Plastics, Akron, OH) prices and are current as of early September, 1997. These prices are for post consumer polymers except for polycarbonate where no post consumer prices were available. These prices are lower than those listed in Table 10 for three principal reasons: one, post consumer material is suspect in terms of consistency of material quality; two, these are "generic" prices; and three, prices are for odd lot quantities, not truckload quantities. Since these prices are for odd lot quantities, not truckload quantities, they correspond to prices depressed by such spot market conditions.

Table 11: Broker Prices for Recycled Polymers

REGRIND	PRICE/#
High Density Polyethylene	$.16-.18
ABS	$.21-.23
TPO	$.10-.12
Polypropylene	$.15
Polycarbonate--Clear*	$.78
Tinted Colors*	$.40-.45

Prices FOB destination

*These prices are for post industrial scrap: prices for post consumer were not available.

It is important to note that by putting an infrastructure in place that can recover materials that match the performance and physical characteristics of post industrial scrap, demand and prices for post consumer materials will certainly increase. When materials can be characterized more specifically, prices will differ from the ôgenericö prices listed above depending on the grade, density, melt point, impact, and other material properties. When materials can be identified according to specific grade (e.g., whether polypropylene is a homopolymer or random copolymer), then a higher price can be obtained. In the case of HDPE, the ability to identify whether it is blow molded or extruded can bring a higher price.

End Market Customers: Material Evaluations and Requirements

A summary of participating end market customers for targeted engineering plastics provides a business description, materials sampled, processing capacity and material requirements, and material prices is in Appendix G. This information also includes data and information from telephone interviews that preceded material delivery or telephone interviews that supplemented, or substituted for, written material evaluations. Since ARD staff frequently encountered claims of proprietary information while conducting market research, less information than expected was obtained for inclusion in this final report. The perception of any potential competitive edge by companies operating is this marketplace was acute.

Findings

Prices cited in this report must be considered preliminary price offerings and not actual market transaction prices. Actual market transaction prices for these materials will be based on negotiations to reach agreement on prices as well as market specifications and material volumes. Prices that would be negotiated and received by a commercial scale operation for recovered materials are expected to be higher.

Three distinct levels of market development can be delineated from our preliminary findings: 1) Strong rebond market demand exists for auto seat foam; 2) Limited number of potential customers exist for polyolefins, TPO, polycarbonate, ABS, and other high end plastics; and 3) Elastomer end market customers will require the performance of additional research and development prior to actual market opportunities materializing.

Foam Market Findings

Strong rebond market demand exists for recovered polyurethane seat foam at prices of around $.25. Market requirements for this recovered seat foam include that it is dry and free of metal and fabric contaminants. Quality specifications include preference for baled foam, and that it is dry and free of fillers, hooks, clips, wire frame, and velcro.

Preliminary prices of $.15-.25/lb. were documented. At the high end, foam recovery can be profitable based on project pilot benchmark costs and market price information. At the low end, foam recovery would not be economically feasible. It is expected that foam prices of $.35/lb., or higher, may be possible with material consistently supplied in high volumes by a fully commercial operation.

Three very distinct end market applications were identified: carpet underlay, exercise machine padding, and automotive sound barriers. The identification of potential customers that use foam for different applications indicates a greater mix of end markets than expected for this material. This discrete end market segmentation strongly suggests that market demand for seat foam would be sufficient to support the commercial viability of foam recovery from post consumer vehicles.

Since the rebond market is highly competitive, the motivation to develop new rebond applications is strong. The more applications available to a rebonder, the stronger its market position would become. Potential automotive uses for rebond foams include protective housing for on-board electronics, anti vibration, sound absorption, ceiling gaskets, and certain parts of the flooring system. Such extensive substitution of rebond for other materials would dramatically stimulate rebond market expansion and would likely sustain higher prices.

Markets for rebond could be readily expanded. Vitafoam, the largest polyurethane manufacturer in the world with $2 billion in sales, asserted that more work is needed to educate and inform automotive engineers and furniture manufacturers about the use of rebond for various applications. Citing the extensive use of rebond in European and

Japanese automotive applications, a Vitafoam representative challenged North American auto companies to take advantage of this recycling market opportunity.

The quality of the ARD-recovered foam was evaluated as satisfactory by all potential customers and thus higher prices might be achieved on the basis of consistent high material quality. It was further noted that seat foam is soft-skinned, molded HR foam, and this quality is inferior to low density conventional foam. As expected, all foam buyers expressed strong interest in purchasing automotive seat foam. However, the pilot nature of this project curtailed any actual contract commitments from potential end market customers.

Current commercial viability of marketing post consumer seat foam will depend on the ability of suppliers to collect seat foam at costs at or below $.25/lb. and deliver dry, clean, baled material in sufficient volumes (truckload quantities) to meet customer demand. However, expanded demand will push up and likely result in higher prices for post consumer seat foam.

Current seat foam recovery practices are labor intensive and thus relatively costly. Dewiring foam that has metal embedded in it for automotive seat applications poses a formidable barrier. Appropriate tools that would reduce the cost of seat foam recovery would kick start this niche market that has tried to take root without long term success. Committing a nominal level of resources to develop appropriate tools to solve this technical challenge would probably erase this barrier.

The current seat foam recovery infrastructure is clearly inadequate for recovery of high volumes of post consumer seat foam. The lack of such an infrastructure prevents the recovery of post consumer seat foam in commercial quantities. Two major tracks that will support development of this infrastructure have been identified and need to be addressed: 1) more effective tools to ease the seat foam recovery operation is critical; and 2) the lack of market information available to disassemblers about automotive materials, including seat foam.

Profit margins for foam harvesters are modest, but strategic support of innovative entrepreneurs may encourage capitalization of more sophisticated recovery operations. Such operations might use improved removal techniques and tools or some level of non-manual recovery operation. These steps might lower costs of recovery and increase profitability.

The role of auto makers in the development of markets is pivotal. If domestic auto makers specify the use of rebond for automotive applications, then market demand for seat foam would increase dramatically. This increased demand would virtually assure market prices that support profitable foam collection and recovery operations.

Targeted Plastics Market Findings

Accuracy in resin identification and obtaining material free of contaminants pose important technical obstacles that currently create a major barrier to the development of stronger recycled plastic markets.

Contaminants will frequently undermine recycling efforts by causing removal costs to be prohibitive until the DFD (Design for Disassembly) guidelines are more widely used by OEM's.

Other important barriers to material recovery include the need for paint removal from high end plastics and cross contamination of high end plastics with incompatible materials, including adhesives, fillers, and other polymers.

Sufficient material volumes also pose a barrier to commercial scale recycling of post consumer automotive engineering plastics. Truckload quantities are preferred by most end market customers.

The key to successful post consumer vehicle material recycling in the near term is to sell target plastics to processors and compounders who can take wide specification material and use the recycled material in non-visible interior and exterior automotive applications. This will require the willingness on the part of the auto OEMs to require post consumer content specifications for those applications. Tier 1 suppliers will then exert a strong demand for such materials. Processor/compounders should be willing to pay higher prices that reflect stronger demand for these materials.

This increased demand should support a more robust market for post consumer materials. OEMs, processors, collectors, and end market customers need to cooperate to come up with methods and techniques to achieve design and performance requirements that satisfy both the original product requirements as well as ease the recycling of the product materials.

Any disassembler or material harvester will benefit from building his/her own relationship with the appropriate end market customers. Having the demonstrated capacity to deliver materials to that customer with consistent quality (free of contaminants and material purity consistent with the specifications and requirements of the customer) on a regular basis is the key to successful market entry and a competitive market position.

Compounders that take recovered materials must be able to address several issues molders have in producing parts for the automotive and other industries. These issues include cost, material quality, processing performance, predictability, availability, technical support, certification, approvals, virgin comparability, price stability, liability, and marketability.

As a result of the above finding, material suppliers must be prepared to allocate resources to work with compounders and molders to establish and obtain the necessary documentation of material quality and consistency.

Easy to remove parts with relatively high volumes of materials for which there are markets can be targeted by dismantlers and other recovery operations for removal for material value.

V. BUSINESS DEVELOPMENT RELATIONSHIPS

Introduction

This chapter examines results from the initial stages of the Auto Recycling Demonstration Project that illustrate business development relationships associated with the various sectors (dismantler, processor, end-market) and stages of vehicle dismantling operations. As will be shown in the economic analysis, data compiled by the Auto Recycling Demonstration Project indicates that economic incentives to facilitate more complete recovery of the discarded automotive material exist. The following section discusses possible business relationships comprising an expanded automotive material recycling infrastructure.

Vehicle Dismantling Business Relations -- Future Potential Scenarios

New performance levels will not be achieved without significant developments in a number of areas. New and improved tools need to be developed. New collection systems need to be put in place. And new facilities to separate, clean, and process materials for market need to be built. Clearly, there are underdeveloped markets that could reach higher levels of maturity and reap greater profits. But before this can happen, the current recovery infrastructure must evolve to more fully capture discarded materials.

Most importantly, though, are those developments that must take place at the dismantler level. The Auto Recycling Demonstration Project was specifically designed to further the commercialization of an expanded vehicle recycling system ù working primarily with dismantlers to document requirements and costs for moving targeted non-metallic materials to viable end markets.

Different types of dismantlers will need to approach expanding recycling capability in different ways. The choice of methods used for materials recovery at the dismantler level becomes a key business decision as marginal costs and potential profits will vary according to the average age of vehicles handled by a particular dismantler.

A car's age is the important consideration in determining where it enters the dismantling/reclamation process. Parts recovery for resale dominates the economics of late model vehicles as they are dismantled. But after time, the vehicle reaches an age where processing it for material recovery can become an important economic consideration.

Generally, dismantlers can be divided into three categories according to the average age of the vehicles that they process ù late model, 5 to 10-year-old vehicles, and older than 10-years, or end-of-life (ELV) vehicles.

First are those operations that inventory primarily late-model cars. These dismantlers earn the majority of their revenue from used parts. The automobiles typically range from one to four years old and are worth many thousands of dollars, based on reusable parts. Costs of vehicle acquisition are proportionally higher. These dismantlers are unlikely to attempt material recovery prior to delivery to shredders because of the risk of damaging reusable parts.

Second are dismantlers that predominantly inventory mid-life cars in the 5 to 10 year old range. These cars still contain many reusable parts, but the incentive to recover additional materials is higher due to the potential profits.

Last are the yards that stockpile end-of-life automobiles that are older than 10 years. These yards collect junked cars, or cars that have reached the end of their life. These operations have lower overhead costs due to the low cost of obtaining stock. These operations are perfectly suited to realize the greatest percentage profit compared to the expense of materials recovery. They also have much less concern about damaging reusable parts, of which there are relatively few.

Size of the dismantling operation also is a major factor in considering options for expanded material recovery. While an average dismantler handles approximately 1,000 vehicles per year, many handle only a few hundred vehicles while a limited number of high volume operations process 10,000 and more units. Smaller dismantlers will want to rely on more ôfield-basedö recovery strategies that can make small volume material recovery cost effective. Larger dismantlers have the option of considering large scale, high volume recovery strategies, some of which may require significant additional capital investment and expanded scope in operations ù but with higher financial returns being possible.

Field Based Low Volume Recovery

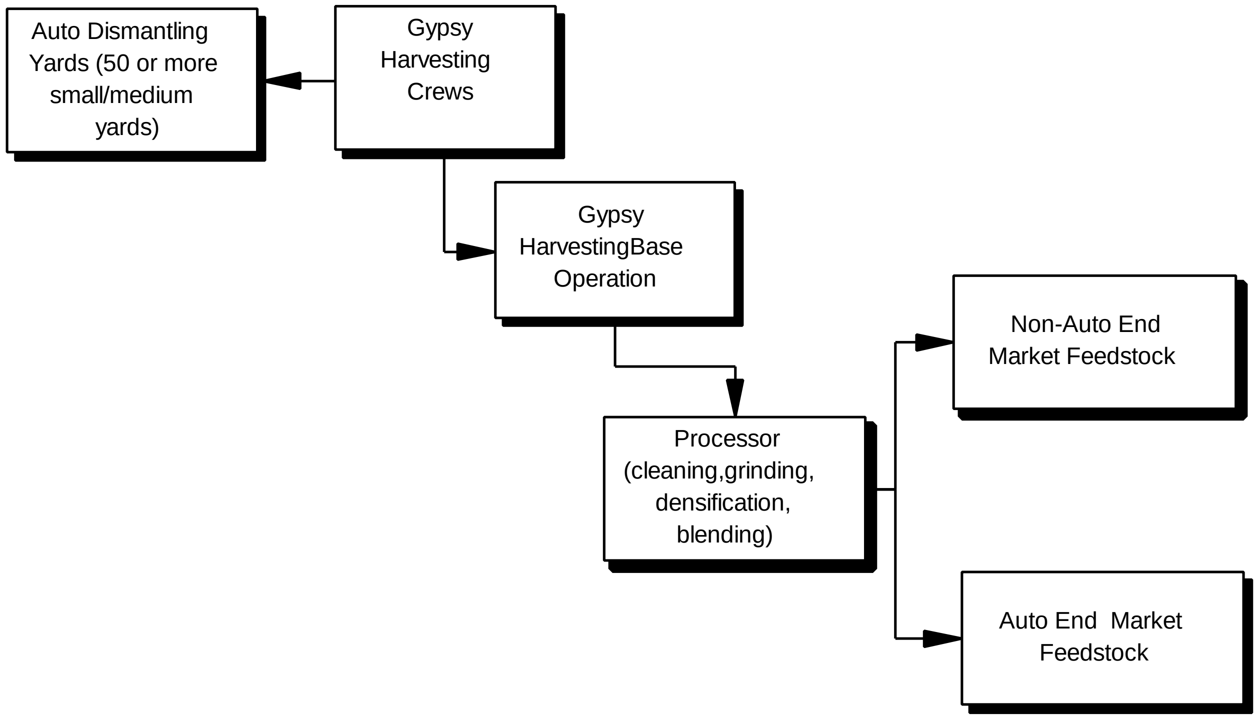
Two types of field-based, small scale low volume recovery systems are expected to evolve and develop primarily to service smaller dismantlers: Gypsy Harvesting and Super Harvesting.

Gypsy Harvesting

A gypsy harvester is a contemporary example of age-old material scavenger services. In this context a gypsy harvester recovers selected materials from ELVs for sale to secondary (recycling) markets. Cherry picking, or selection of high value, high volume materials for maximum profitability while neglecting other available materials, is practiced by these independent harvesters.

A gypsy harvester operates as a third party specialty recycling firm that sends crews from dismantler to dismantler to harvest specific materials as shown in the following diagram. The scale of gypsy harvesting remains very modest as operations come and go depending on their profitability and other operational considerations.

Diagram 3: Field Based Low Volume Recovery through GypsyáHarvestingáw/Dismantlers



A good example of gypsy harvesting is polyurethane foam seating, where some gypsy harvest operations have been known to recover seat foam for sale to rebond markets. Gypsy harvesting crews are equipped with specialty tools to remove only the targeted material. They show up irregularly, do very little on-site processing since they work to take as clean a material as possible and take only those materials that currently offer the highest market price.

Cushion Products Inc. (CPI) was an example of a gypsy harvest operation. CPI sent crews around Milwaukee area salvage yards to remove seat foam from selected vehicles. CPI made arrangements with specific yards for their crews to enter these yards to remove seat foam from selected vehicle types. Vehicles were selected for volume of foam and convenience of removal.

CPI carried out these practices when foam prices exceeded $.30-.35/lb. When prices dipped below this level, CPI ceased its foam removal operations since prices below that level did not cover the costs of material recovery. Low material prices cause relatively rapid market failure for gypsy operators since they do not have any kind of economic safety net.

Gypsy harvesting as a collection technique can work well with materials that are relatively easy to remove. In addition to the seat foam, other materials suitable for gypsy harvesting include some elastomers (door seals, etc.); bumpers, and textiles (seatbelts, etc.). Gypsy harvesters will typically work with the dismantlers that have stockpiled inventories of end-of-life vehicles, mostly in the 5 year and older age range.

A dismantler that works with a gypsy harvester usually gains minimal benefit from the business relationship. The burden on the dismantler is low but the revenue may be only a few pennies more than the 3ó per lb received if the material had remained in the hulk delivered to the shredder. The revenue, however, will come in large amounts as the gypsy harvesting crew pulls material from 100 to 200 vehicles on the lot. Another benefit is that the revenue can be received prior to final hulk disposal helping offset inventory / stockpiling costs or transportation costs.

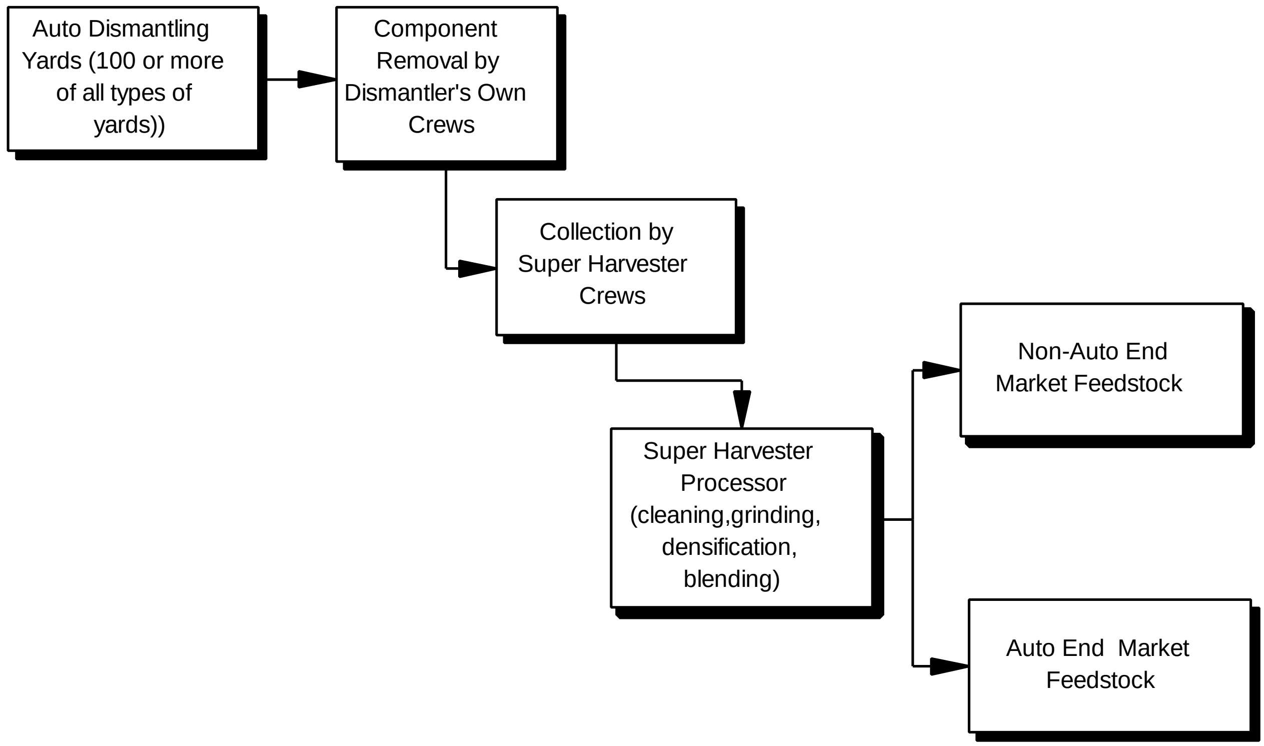
This type of operation, then, is based on five characteristics: 1) knowledge of material values, volumes, and market opportunities; 2) selection of material(s) for harvesting; 3) access material sources for selected materials; 4) recover and decontaminate (if necessary) materials; and 5) deliver materials to end market customers. The key business relationship for the gypsy harvester is with the processor / end market that purchases the collected material. The gypsy harvester must demonstrate ability to deliver quality material that meets delivery specifications especially with regards to prohibited contaminants. The gypsy harvester may need to complete some densification of the material to keep transportation costs down or to build to acceptable end-market load sizes.

Super Harvesting

Super harvesting is a more comprehensive adaptation of the gypsy method. A super harvester is also a third party service provider to the dismantler but has a more stable long term business relationship both with the dismantler and with end-markets. A super harvester has a more fully developed supply network .

A super harvester is a processor and may also be a parts fabricator for eventual end markets. In order for this approach to work in the market place, a super harvester needs a fairly extensive network of dismantlers that are asked to remove and stockpile specific parts from specific vehicles for material recovery. A super harvester picks up stockpiled materials and performs varying levels of cleaning and decontamination as well as processing materials at its own facility.

Diagram 4: Field Based Low Volume Recovery through SuperáHarvestingáw/Dismantlers



American Commodities Inc. (ACI) of Flint, MI has pioneered the super harvester approach by developing an impressive supply network of over 200 disassemblers. ACI notifies its supplier network of what part types (by make and year) are needed to meet its buy orders and obtains its feedstock supplies from this network. ACI has created a highly innovative niche position based on its capacity to separate and process certain materials for production feedstocks. As a result, ACI "super harvests" recovered polycarbonate/acrylic materials as well as bumpers and fascias for its production needs.

A dismantler is asked to take on more responsibility in working with a super harvester. The dismantler's own crews are used for component removal. Materials must meet super harvester specifications. Stockpiling requires space and parts must be accumulated in sufficient quantities to make collection by the super harvester cost effective. In exchange for this effort, the dismantler receives higher revenues per pound for the material that is removed. As an added advantage, a dismantler has greater control over the timing of material removal and is able to move inventory to a positive revenue position earlier in the dismantling process than through gypsy harvesting arrangements.

Super harvesting is likely to target more higher value materials found in parts such as bumpers, headlamp units, and similar components. The component parts selected are typically in the ôeasy to removeö category but may benefit from piggybacking, or ôfree riding,ö as a byproduct of the dismantler's removal of another component for the used parts market. In general, though, a super harvester must look for relatively clean component types with predictable contaminants that are relatively easy for the super harvester to process to meet end market requirements. Super harvesting services will make sense for any type of dismantler (late model, mid and end-of-life) since control over component removal is retained by the dismantler.

It is interesting to note, however, the Dutch experience with the recent creation of Auto Recycling Nederland (ARN), the Dutch auto industry's recycling organization, funded by an auto waste disposal fee. ARN certifies dismantlers who comply with safe and environmentally friendly practices. ARN puts balers for foam at certified dismantling operations to reduce volume and associated transport costs to rebonders. The system was instituted since January 1, 1995. The Dutch system is reportedly the most advanced in the European Union.[19]

Large Scale High Volume Recovery

While field based recovery operations are characterized by their relatively low volume and higher cost of goods sold, large scale, high volume material recovery operations may be possible for dismantlers, with examples of a number of approaches emerging in the commercial marketplace. Each of the following approaches allows the dismantler to move to a large scale operation with much higher volumes.

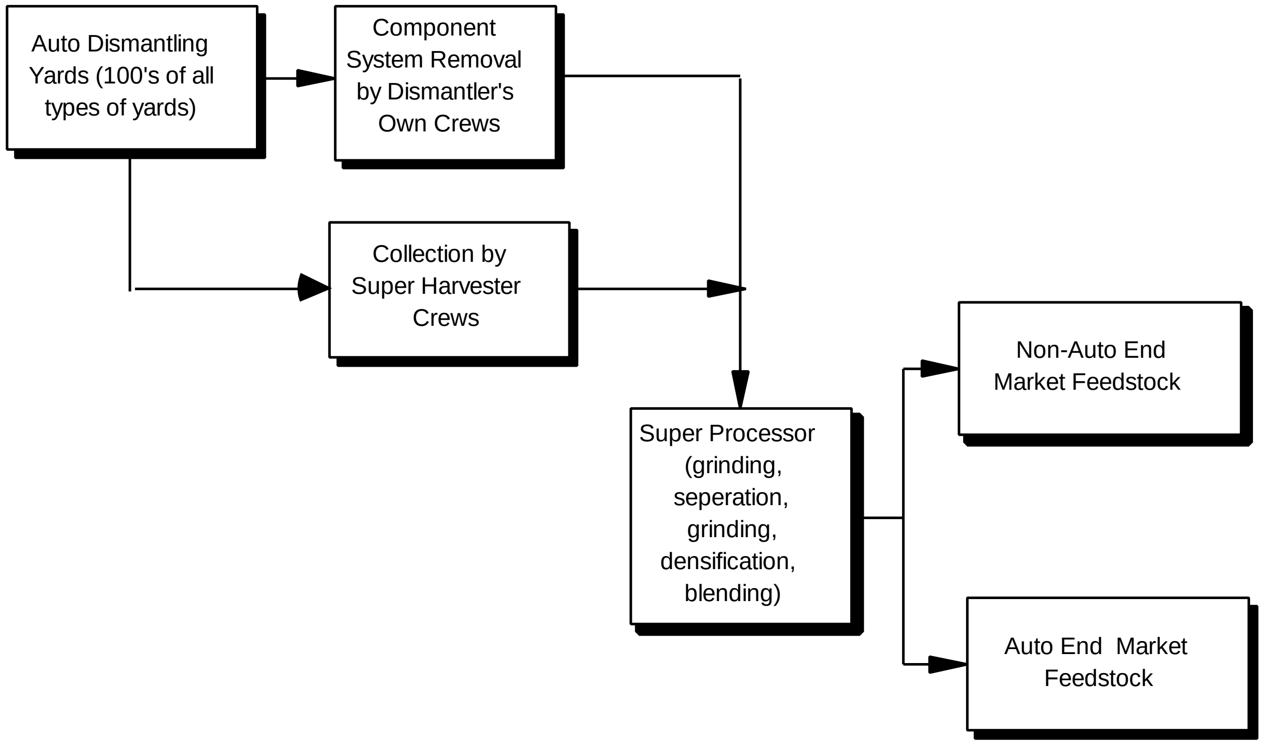
Super Processor

Technology for separation of mixed material non-metallic components is at the prototype or near commercialization level with some operations poised to enter the marketplace at this time. Once they are fully operational, third party ôsuper processorsö will be able to take commingled components that have been removed from the discarded automobile, hand sort these into component types if needed, and then process these mixed material components using different types of mechanical material separation systems in combination to produce marketable recyclable materials.

This capability will allow the dismantler to stockpile larger component systems and to use more destructive dismantling techniques in removing those systems. The net result will be that a dismantler can remove much higher volumes of material per vehicle and complete the dismantling task in much less time, thereby significantly lowering the cost of the recovered material. The following diagram illustrates how the Super Processor would work with existing dismantlers.

Diagram 5: Large Scale High Volume Recovery through aáSuperáProcessor

[19]The foundation Auto and Recycling and Auto Recycling Nederland BV, *Environmental Report: Facts and figures,* 1996, p. 28.



A super processor refers to a facility operation that has the capacity to receive a comprehensive range of multiple material streams and carry out the following functions: 1) identification and sortation; 2) size reduction; 3) metals removal; 4) air classification; 5) density separation; and 6) wash and dry systems.

MBA Polymers of Richmond, CA exemplifies a prototype super processor. MBA's strongest areas is that of plastic identification equipment and an integrated dry/wet separation and processing system. The aim is to achieve higher through puts and more continuous processing runs. The key to successful operation of this facility is very high volume material through puts.

The additional recovery comes at a higher processing cost and has a higher residue level than the field based low volume approaches described earlier. Costs at the processor level are expected to be higher. However, quality of end-product is also expected to be more consistent and more attractive to end-markets.

The super processor function could be integrated into a large dismantler operation to eliminate intermediate shipping costs. This type of operation would also incorporate super harvester business relationships and receive material shipments from off-site harvesters. In this way some larger dismantlers would end up serving as centers of collection, or consolidators, for the targeted materials drawing from a network of smaller dismantlers in that immediate region.

A potential additional benefit is that a super processor may also be able to take some mixed material streams removed from auto shredder residue and process them to remove contaminants and prepare some of the material to meet market specifications.

Automated Disassembly Line

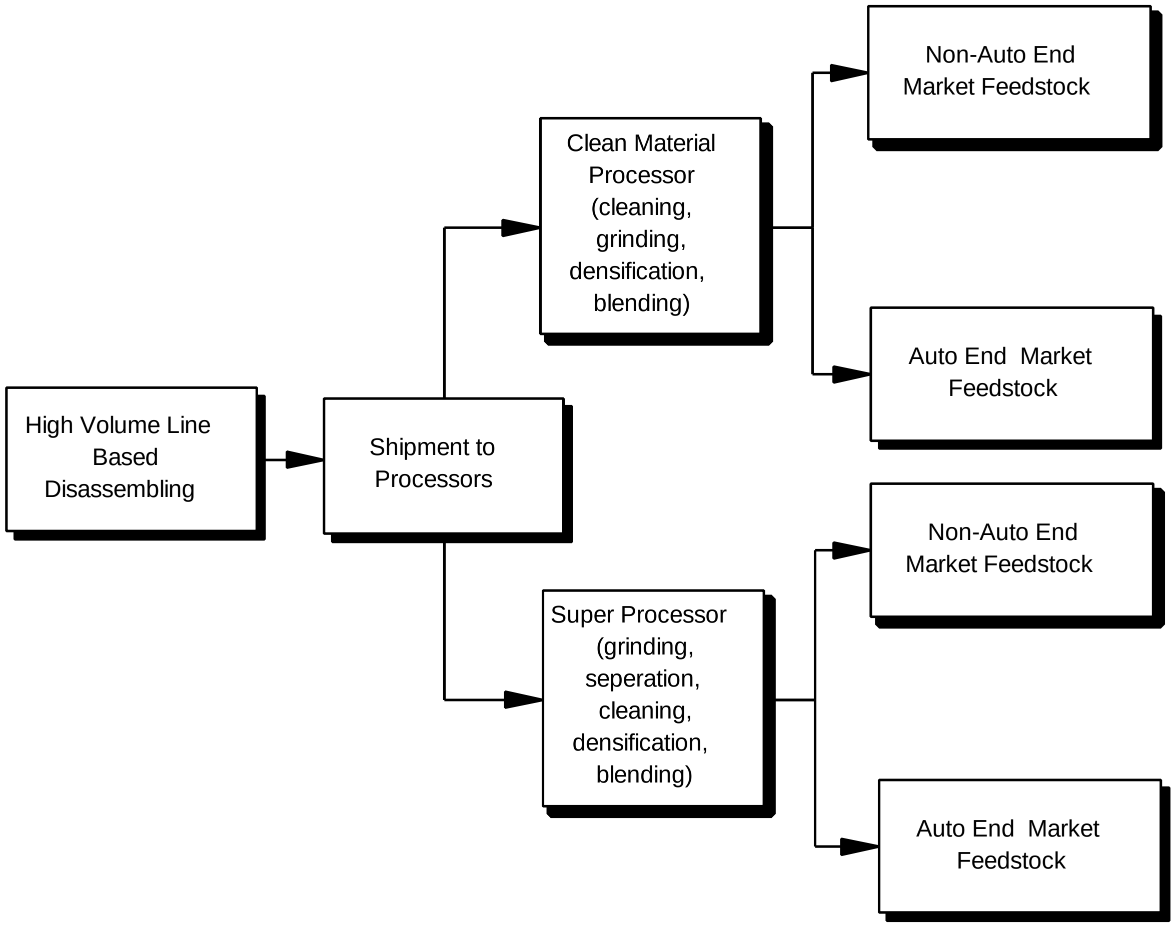
A variety of disassembly equipment systems are being piloted in both Europe and North America. Automated disassembly lines use a combination of mechanical disassembly, destructive disassembly, and assisted material handling/vehicle movement to process discarded automobiles completely to the metal hulk. The metal hulk is then baled and sold to the steel furnace as a direct entry feedstock.

These disassembly line-based operations typically integrate used parts removal for resale with removal of other parts for material value. Costs for removal are thus split between these two separate functions with the recycled material gaining a ôfree rideö on the removal costs that are assigned to the used parts recovery. According to European and US operators of these systems, high volume economies of scale provide for additional reductions in dismantling costs as do specialization of workers/tasks and the additional price premium received from steel mills for the higher grades of ferrous metals.

Automated disassembly lines may also incur a higher capital charge for the sunk cost of the equipment and system. A disadvantage of such a large up-front capital investment is that all material must be moved through the system as soon as possible to effectively utilize that investment. Such an operation typically will not have a large stockpile of unprocessed end-of-life vehicles but instead will move to dismantle those vehicles as soon as possible either to inventory as used parts or to recycling processors. Used parts inventory can be problematic if the expected demand for the part is likely to be delayed by a few years, which is often the case for late model and middle-aged vehicles. These inventory requirements increase the cost of goods sold for some used parts. An additional economic impact of this inventory build-up of used parts, should it occur on a large scale, is an expected decrease in some used parts market prices.

A dismantler operation with an automated disassembly line has greater flexibility to either move component systems to a super processor or to remove more contaminant free components for delivery to either a super harvester or an end-market processor as illustrated in the following diagram.

Diagram 6: Large Scale High Volume Recovery with an Automated Disassembly Line



To achieve sufficiently high volumes of multiple material recovery, automated disassembly techniques are being applied in at least two North American operations: CARS of Maryland in Baltimore, MD and RASF (St. Francis Auto Recycling) in Montreal, Quebec. These operations build on knowledge and expertise from the solid waste Material Recovery Facility (MRF) environment as well as state of the art disassembler information technology. The comprehensive, multiple part and material character of the operation resembles a MRF approach. In addition, a highly sophisticated parts information data base has been developed by CARS of Maryland to optimize parts inventory management.

The CARS of Maryland operation is licensed to operate Car Recycling Systems (CRS), a system developed in the Netherlands. It operates a single disassembly line on which vehicles move and workers remove marketable components as well as parts for their material value. Fluids are drained from vehicles prior to their disassembly. (These fluids are used for fuel for on-site space heating.) The goal of the Baltimore operation is to disassemble 40,000 cars/yr., or 200 cars/day. In the first three months of operation in 1996, the facility dismantled 783 vehicles. The facility employs 50 people and is expected to grow to 125 employees.

Like CARS of Maryland, the RASF facility removes fluids prior to disassembly on a 300' line that disassembles 50 cars/week. This facility makes extensive use of detailed parts dismantling data by make and year for plastics, foam, and aluminum. Four workers disassemble each car--one worker removes the seats after the car is cut across the top of the windshield and then cut into two sections. This facility obtains $.60/lb (Cnd.) for its high density (HD) foam. When fully operational, three lines will be operated with two dedicated to complete disassembly and one dedicated to parts removal for resale. The goal is to process 30-60,000 cars/yr.

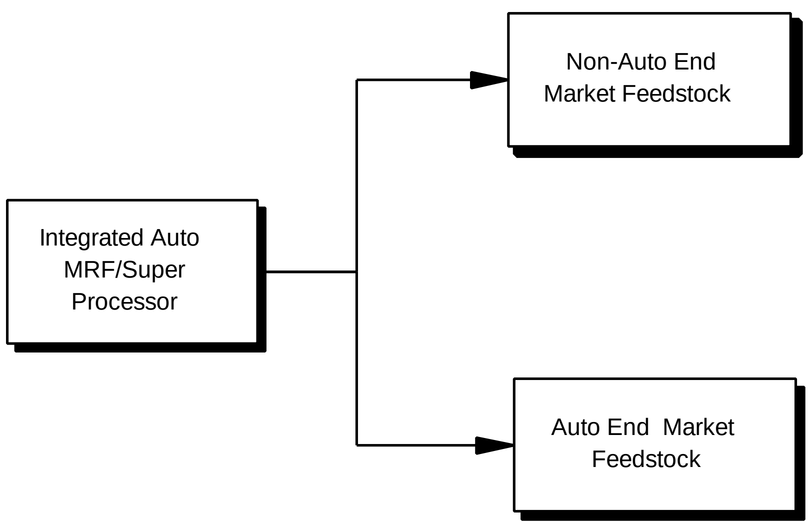
An alternative approach, in which a dismantler installs simpler versions of the automated disassembly equipment, would require a lower level of capital investment. This would bring the advantages of line based disassembly to the high volume dismantler without committing all vehicles to automated disassembly. In this scenario a dismantler could choose immediate full disassembly or inventory of the unprocessed hulk for later used parts harvesting. The dismantler would then later have the option to move hulks that are near the end of their useful parts harvesting life cycle either by full disassembly or by processing and delivery to a shredder. No known examples exist in the U.S. of this lower capital investment approach to automated disassembly by a dismantler although some are in operation in Europe.

Integrated Auto-Material Recovery Facility ôAuto MRFö

Combining the best features of a super processing approach with an automated disassembly line can overcome one of the costlier liabilities for recycling ù dual handling of materials and excessive transportation costs. By integrating both functions in one facility, these costs can be eliminated and further reductions in cost of goods achieved. Such a system is likely to achieve the highest level of recovery at the lowest cost, and thus benefit from receiving the full market value of the recovered material. Integration of the used parts functions into the operation may be the biggest challenge of this approach to high volume large scale recovery given the need to inventory used parts until demand develops.

These potential benefits, however, remain speculative. Currently, no commercial attempt has been made to integrate super processor functions with automated disassembly line capabilities. This is, in part, due to the fact that technology for super processing is still in the early stages of commercialization and the commercial viability of automated disassembly in the U.S. is in its infancy. Such a system, however, would simplify transportation and handling as illustrated in the following diagram.

Diagram 7: Large Scale High Volume Recovery Integrated Auto MaterialáRecoveryáFacility áAuto MRFö



VI: Economic Analysis

Material recovery of targeted materials based on the methods described above may offer economic incentives for entry into these recycled material markets by dismantlers. These methods are not yet extensively practiced. An economic analysis of two selected recovery system options is examined in detail in this section. These two recovery scenarios illustrate widely different scales of recovery operations: Gypsy Harvesting and Integrated High Volume Super Processing.

These scenarios are only intended to illustrate potential market and cost relationships. Cost and revenue analysis associated with the recovery of targeted materials is a key component of the decision to expand automotive material recovery beyond ferrous metals. The analysis performed on material recovery represents the marginal costs and marginal revenues.

In managing vehicle inventory, a dismantler assesses market conditions for his marketable parts and materials. As with any business, the intent is to maximize revenue from operations and maximize profits from each profit center. As currently practiced, disassembly operations derive most revenue from parts resale and secondarily from sale of the hulks for principally ferrous material recovery by shredder operations.

Over time before sending the hulk to a shredder for final processing, parts that no longer have value as parts for resale may have value for their material content. Another consideration is that parts recovery for their material (as opposed to parts resale) value is an incremental, or marginal, cost. Parts removal for material recovery may be carried out as part of the disassembly operation that focuses on parts recovery for resale.

The recovery process is a staged process. As conditions change over time and affect demand for parts of each inventoried vehicle in a disassembly operation, parts may be recovered for their material value as parts value diminish for parts resale value. Each disassembler will decide the time to recover parts for their material value.

The key point here is that parts inventory management is highly variable based on location, market conditions, knowledge of the operator, and scope of operation. Most dismantling and parts recovery operations have a mix of age classes of discarded autos: late model(1-4 years old), mid range(5-10 years old), or end-of-life. The marginal value of materials recovery will vary depending on the age classifications and distribution of any specific operation. A vehicle dismantling operation will determine the method of parts and materials retrieval that maximizes their return given the cost structure of their operation.

Late-model (less than five years old) vehicles are dismantled primarily for parts recovery that can be worth many thousands of dollars. Late-model operations generate high revenue from each vehicle and their average costs are the highest of the three sectors. Mid-life vehicles (5-10 years old) provide fewer reusable parts, but can still provide a sufficient net return. The last category contains end-of-life cars (over 10 years old) that have very few reusable parts to provide a financial return with the majority of their value coming from scrap metal recovery.

A final factor is the length of time that a disassembler will hold a vehicle in inventory. Knowledge of this factor was outside the scope of this project. However, both of these time variables will be critical to the determination of when to view a part for material value after its part value for resale has ended.

Three main cost components, or stages, in the material recycling infrastructure model consist of: 1) vehicle part disassembly for material recovery, 2) sort/ID/decontamination of material parts, and 3) processing material for end market specification.

During the disassembly stage, parts are removed from the vehicle because of their targeted materials content and fasteners and other component parts are removed form the targeted part. The second stage of the vehicle recycling system involves decontamination: the identification and sorting of the parts by the type of material and the separation of material from any contaminates. Processing/cleanup is the third stage and involves preparing the separated and decontaminated material (e.g. grinding and washing) to meet end market specifications. The market evaluations from end market customers to whom sample materials were sent for evaluation were used for the estimates of market value.

The model contains a number of assumptions gathered from field data, interviews, case studies, and other sources. The assumptions are:

1. Parts Targeted for Material Recovery;
2. $15.00 per hour labor costs;
3. Classification of material by easy/difficult parts recovery based on threshold weight, and
4. Ten million cars discarded per year.

Targeted Parts and Materials

In the disassembly field trials, targeted parts were removed during the disassembly stage because they contained materials targeted in the study. In the sort/ID/decontamination stage and processing/cleanup stage we refer to targeted materials. Targeted materials are reusable materials obtained from the recovered parts. The study's costs and revenues are expressed in terms of targeted materials weight illustrated in Table 12. The disassembly field trial results and end market evaluations were used as the baseline for the analysis.

Table 12: Targeted Material Quantities for Modeling

Target Material	Weight in Average Vehicle (lbs.)
Seat Foam	24
Plastics:	

Polypropylene	34
ABS	20
Nylon	6
Polycarbonate	7
Elastomers	67
Total Targeted Materials	168

Baseline Disassembly Cost Data

There are currently more than 10,000 facilities disassembling vehicles across the country. Given that these facilities are already operating, the disassembly costs in the model represent the additional cost per pound of dismantling the targeted parts for materials recovery.

Dismantling field trials were conducted on approximately 35 automobiles in order to gather baseline data for disassembly costs. Project team staff worked with 3 salvage yard staff including two mechanics and a forklift driver. Field trials were conducted over a four day period. For plastics recovery trials, 21 cars were selected. Selected parts were removed from each vehicle by ARD project and salvage yard staff because they contained targeted materials. Table 13 lists possible parts that were targeted for removal. The parts were harvested using conventional dismantling techniques and destructive dismantling techniques familiar to the salvage yard crews.

Table 13: Targeted Plastic and Elastomer Parts

PLASTICS

Body Panels
grilles & panels
door panels
rear end panels
fenders, quarter panels

Electrical Components
battery cases
connectors

Fuel System
vapor canisters

Large Functional Components
interior trim panels
instrument panels
fans & shrouds

Seats
foam

Small Mechanical/ Engine Components
diverse & small
visor pins
misc. parts
air cleaner

Structural Components & Bumpers
bumper beams
bumper trim
bumper fascia

Transparent Components
lenses

Trim, Exterior
appliquTs
grilles & bezels
wheel covers

ELASTOMERS

- bellows
- bumper covers
- belts
- weather stripping
- hoses
- side trim
- engine mounts

Average time of materials recovery, standardized pounds per hour, and a category of easily recovered and more difficult to recover materials were derived from the field data. Total removal time was recorded for the parts, and the recovered parts were weighed. The times and weight were standardized to pounds per hour for each vehicle for three types of material: seat foam, plastics, and elastomers. Based on project trials, we estimate that 230 pounds per hour of contaminated parts can be harvested from automobiles.

Easy and Difficult Part Recovery

The categorization of materials into easy and difficult categories allowed a more accurate estimate of the total removal time of all targeted materials. Extrapolating results from the field trial observations allowed us to approximate the percentage of easily removed parts and difficult to remove parts in an average automobile. Easy to recover is used to describe those parts that are readily accessible, or easily disassembled with the use of a standard tool. Difficult to recover is used to describe those parts that first require removal of other parts, or that require a specialized tool for effective recovery.

The percentages of easy and difficult parts are not intended to be absolute. The percentages will depend on the efficiency of removing targeted parts for material recovery in different operations.

The average recovery rate in pounds per hour was derived for the easy and difficult materials categories for all targeted materials using the removal time and quantities from the field trials. The percentage breakdown (approximately 60% easy and 40% difficult for plastics and elastomers, 100% easy for seat foam) was used to determine the easy and difficult rates of each material per car. The distinction of easy and difficult was carried throughout the model in order to derive costs for each material category and stage.

The table below illustrates the calculated allocation between easily removed material and difficult to remove material.

Table 14: Calculated Targeted Material Classifications by Easily Removed and Difficult to Remove Material by Weight

Material	Total lbs. per Car	Targeted Easy lbs.	Targeted

			Diff lbs.
Polyurethane Seat Foam	24	24.00	0.0
Targeted Plastics:			
Polypropylene	34	20.11	13.89
ABS	20	11.83	8.17
Nylon	16	9.46	6.54
Polycarbonate	7	4.14	2.86
Plastics Subtotal	**77**	**45.54**	**31.46**
Elastomers	67	41.28	25.72
Field Trial Total	**168**	**110.8**	**57.2**

Clean Weight Disassembly Baseline Cost Calculation

The removed parts were sorted, decontaminated, and processed. (See the discussions of Sort / ID / Decontamination and Processing for each material below). Parts recovered during the field disassembly trials were contaminated by foreign materials (any material dissimilar to the targeted material). Removing foreign materials (decontamination) resulted in an average loss of 33% of the gross recovered parts weight. This was used as the conversion factor to calculate the "clean weight" cost per pound for material recovery.

The methodology for calculating the baseline cost per pound per material was:

1. The average weight (lbs.) per hour for each recovered material classified as easy or difficult was calculated from the field data;

2. Clean weight of each targeted material was derived by multiplying the average weight per hour by 67% to derive clean weight; and

3. The hourly rate was divided by the clean weight to derive the disassembly cost peráclean pound. It was determined that an average $15 per hour was a reasonable figure to use for estimating labor costs per hour. This cost per pound for dismantling does not include operation and maintenance (O&M) costs, capital charges or supervisory charges. The hourly rate for dismantling was based on discussions and a small survey with those in the vehicle dismantling industry.

Decontamination /ID/Sort Costs

Facilities that decontaminate, sort, and identify parts for material recovery do not currently exist in a commercial scale. The cost of this stage was therefore the most difficult to ascertain. The costs in the model represent benchmarks that a facility must attempt to achieve given the costs of the other stages and the revenue distribution. The target costs include labor, capital, operating, and maintenance costs.

Sorting/ID in the field trials was undertaken by a two person team processing approximately one bin per hour. The field trial personnel were hand sorting the parts and using a slow Bruker device for resin identification on a piece by piece basis. A bin held approximately 130 pounds of contaminated material, which produced 90 pounds of decontaminated plastic. On average, it was found that one crew member could clean or decontaminate 2 bins of plastic per hour, resulting in a production rate of 180 pounds of clean plastic per hour.

Decontamination field trials consisted of 2-3 people at the test facility working as a team removing foreign materials (metal, fabric and other contaminants) from the seat foam and plastic materials. Using a variety of manual tools, a crew of 2-3 employees worked about 6 hours a day for a total of 5 days to clean seat foam.

Processing

Facilities that process recycled materials into raw feedstock are currently in operation across the country. The cost of processing material (grinding and cleaning) used by the ARD project represent fees we were charged by the processing facilities. The ARD project used quoted prices for processing a pound of material and assumed that these prices include all the processing firms' costs, including profit.

Shipping/Transportation

Shipping costs are identical for each material, with factors applied to account for density differences for each different transportation stages. Gypsy harvesters will probably not identify, decontaminate, or process materials on site but will ship material to a intermediate processor. Integrated super processors will have more sophisticated equipment to identify, decontaminate, or process materials on site.

Intermediate Shipping:

Gypsy operations will need to ship materials to a processing facility. The shipping charge is included in the gypsy operation. Intermediate shipping costs were derived by multiplying the final shipping costs by a factor of three to account for the decreased density of the material which will require more truck volume to carry the same weight.

Final Shipping:

Market research was conducted of longhaul shipping firms in the Midwest and Northeast United States. Costs to ship a standard weight of processed (pelletized) materials different distances in this geographic area revealed an average cost of $.012 per pound based on a two hundred mile round-trip. Shipping costs used in the model are the full costs, including profit, of shipping a pound of material.

Total Costs

Total costs per pound of recovering each material were derived by adding disassembly; intermediate shipping; sorting / identification / decontamination; processing / cleanup; and final shipping. Full costs include capital charges, labor, supervision, and operating and maintenance costs. Costs per pound listed in some stages are the full costs. Other stages show a portion of the full costs that depend on project data or the reliability of financial information the ARD project staff was able to obtain.

Material Prices

Revenues used in the model estimates represent the range of prices quoted by Plastic News and end market customers that received samples of material. The analysis assumed a clean materials average market price of $.40 per pound for plastics based on market evaluations and then subtracted the total costs per pound to determine net revenue. For projecting net revenues, the study assumed a clean foam market price of $.35 per pound. It is assumed the end market price for clean elastomer material is $.50 per pound. A material specific revenue analysis for each plastic type was not conducted but could be easily incorporated into future analyses.

Table 15: Material Prices Used in Model
Cents **per Lb**

	Plastics	Seat Foam	Elastomers
High	$.40	$.35	$.50
Low	$.18	$.15	$.25

Gypsy Harvesting and Integrated Super Processing Analysis

The two tier cost structure for easy or difficult removal is further stratified by the gypsy harvesting and integrated super processing methods to recover parts. This results in a four-tier cost structure for materials recovery. The cost of removal varies widely, depending on the type of part (material) sought and the method used to recover the material. After deriving the baseline clean weight disassembly costs from the field data, an assumption was made that these costs will drop as recovery of targeted materials becomes more prevalent under both approaches to recover parts for material value.

The economic model calculates the vehicle recycling costs and revenues for two recovery methods discussed previously, small scale gypsy harvesting and large scale integrated, high-volume super processing. The baseline costs per pound for each material and stage of recovery were derived from the field trial data. The easy and difficult costs per pound of recovered material are multiplied by the targeted recovery weights for each material to produce gross baseline costs categorized by easy and difficult collection. These costs represent total costs to recover the targeted material over the time that a vehicle is in inventory at a disassembly yard.

Revenue Distribution Analysis and Cost Reduction Factors

The analysis then focused on distribution of the system's revenues to each stage of the model. In order for the system to generate the necessary revenues to cover costs plus profit, the model reduced the cost for each material in each stage. An iterative analysis was performed for each material and stage to calculate the benchmark costs for each stage of recovery while allocating sufficient revenue to maintain the minimum return for each stage. The costs and the projected revenue represent potential benchmark targets necessary to make material recovery cost effective.

Distributing revenues to the various stages of the recovery process, while maintaining a minimum system profit of 15 percent, is one scenario where we set benchmark costs at their highest allowable amount. The model was constrained to minimize the cost reduction factors for each material type at each stage while maintaining a cumulative total 15% minimum net return for each stage: the sum of easy and difficult material costs deducted from the revenue allocated to the stage.

Processing costs were held constant while iterative analysis evaluated sort/ID/decontamination costs and revenue distribution. If either of the sort/ID/decontamination or disassembly stage's net revenues were less than 15% above costs, costs for that stage would be lowered and the revenues would be reallocated until the 15% return above total costs constraint was meet. As a result of the iterative process, the disassembly and sort/ID/decontamination costs represent target benchmarks that the total recovery system would have to attain to ensure profitability.

The target costs that are derived from the iterative process represent the highest levels the costs of each stage of the recovery process can go, given the target revenue per pound. This method of deriving benchmark costs does not rely on assumptions of efficiencies that can be obtained in each recovery stage. It instead indicates the maximum allowable cost levels that will maintain profitability given current target market prices. If costs cannot be brought down to these benchmark levels, profitable materials recovery would remain in doubt.

The benchmark analysis makes no assumptions about the levels of costs in the various stages of the two operations. The analyses instead seek to establish the maximum allowable costs for each recovery stage while still showing the projected 15 percent profit. These are the benchmark costs that must be achieved for a cost-efficient operation.

Another scenario that naturally follows from the benchmark costs method is one in which the cost reduction factors for both the gypsy and integrated operations are held equal and constant. If the cost reduction factors are equal to those of the integrated operations, meaning higher target costs, the gypsy operation will not show the necessary 15 percent profit. On the other hand, if the cost reduction factors are equal to those necessary for gypsy operations, meaning lower target costs, then integrated operations will show a greater profit.

Either of these two analyses indicate that an integrated operation is the preferred method for material recovery and, in fact, gypsy recovery can take place only if greater cost reduction or efficiencies are realized. These scenarios are not presented in this report.

There are sufficient efficiencies that can be met or exceeded by a recovery operation at each stage of the recovery process to achieve the projected profits given the baseline methodology used during our field trials. Disassembly, for instance, can become more efficient through the development of education and information, special tools and techniques.

Gypsy Harvesting Scenario

Gypsy harvester costs would drop from the baseline field costs through the use of special tools and a trained workforce. The following list represents the components of a developed commercial recovery system for Gypsy Harvesting.

Baseline Conditions for Gypsy Harvester Analysis

Selected Parts/Materials Identified
Database Support
Training/Technical Assistance
Field Based Tools Developed
Intermediate Processors Available to Provide Links to End Markets
Labor Cost @ $15/hr

The easy and difficult costs per pound of recovered material are multiplied by the targeted recovery weights for each material to produce gross baseline costs categorized by easy and difficult collection. These costs represent total costs to recover the targeted material over the time that a vehicle is in inventory at a disassembly yard.

Table 16: Maximum Allowable Benchmark Costs and Revenues to Recover Targeted Materials (168 lbs.) by a Hypothetical Gypsy Harvester

Material	**Disassembly**	**Sorting/ID/Cleanup**
Polyurethane Seat Foam	**$2.39**	**$1.20**
Targeted Plastics:		
Polypropylene	$1.76	$7.76
ABS	$1.04	$4.56
Nylon	$0.83	$3.65
Polycarbonate	$0.36	$1.60
Plastics Subtotal	**$3.99**	**$17.57**
Elastomers	**$3.80**	**$6.90**
SUBTOTAL	**$10.18**	**$25.67**

Total Cost	$21.37	$25.67
Revenue	$24.66	$29.63
Net Revenue	**$3.29**	**$3.95**
Percent Profit	**15.4%**	**15.4%**
Profit per Pound	$0.030	$0.036

This table delineates the costs of disassembly and sorting/ID/cleanup to remove 168 lbs of targeted materials by a gypsy harvester from an average vehicle. The gypsy harvesting disassembly costs include only the labor component of the cost structure. A capital cost component is added to the total cost. The disassembly costs in the less cost-efficient gypsy harvesting operations are higher and therefore less of the revenue is available to be allocated to the sort-ID-decontamination stage. The costs of this stage are driven lower to maintain net returns. Gypsy harvesting is a more labor intensive and time-consuming activity and labor is a major component of the disassembly costs. The resulting cost differences between gypsy harvesting (Table 16) and super processing (Table 20) reveal the trade-off between capital and labor necessary to realize the target net revenues.

Material/Component Analysis

The costs of material per pound in this section are the benchmarks that are necessary to ensure profitable plastics recovery given the revenue distribution protocol applied in the previous section. All costs are per pound of clean material. (See **Appendix H: Targeted Material Benchmarks: Estimated Costs and Revenue**)

Plastics Recovery

Table 17. Estimated Costs and Revenue per lb. ($/lb.) of Automotive Plastics Recovery in a Gypsy Harvesting **Operation**

Costs:	**Easy**	**Difficult**
Disassembly	$.011	$.068
Int. Shipping	$.036	$.036
Sort/ID/decontamination	$.162	$.162
Processing	$.108	$.108
Shipping	$.012	$.012
Total Costs	**$.329**	**$.377**
Expected Revenue	$.40	$.40
Net Rev. (per lb)	$.071	$.023

Disassembly: Given the assumptions of database support, tool development, and a labor rate of $15 per hour, a disassembly cost of $.011 and $.068 per pound(easy and difficult respectively) was derived for gypsy operations.

Seat Foam

There is no easy and difficult distinction in the presented data due to the uniform location of seat foam in all automobiles. All costs are per pound of clean material.

Table 18. Estimated Costs and Revenue ($/lb.) of Automotive Seat Foam Recovery

Stage	Costs:
Disassembly	$.063
Int. Shipping	$.036
Decontamination	$.050
Processing	$.108
Shipping	$.012
Total Costs	**$.269**
Expected Revenue	$.035
Net Revenue	$.081

Shipping/Intermediate Shipping: Similar to plastics recovery, intermediate shipping costs to a central processing facility must be included for gypsy harvesters, but not integrated operations.

Elastomers

The table below lists the costs of recovering elastomers from automobiles. These costs are per pound of clean material.

Table 19. Estimated Costs and Revenue ($/lb.) of Automotive Elastomer Recovery for Gypsy Harvesting

	Costs:	
Stage	**Easy**	**Difficult.**
Disassembly	$.030	$.100
Int. Shipping	$.000	$.000
Sort/ID	$.070	$.078
Process/clean	$.108	$.108
Shipping	$.012	$.012
Total Costs	$.220	$.298
Expected Revenue	$.500	$.500
Net Rev. (Costs):	$.280	$.202

Disassembly: In the field trials, elastomer recovery consisted of such parts as weather stripping around doors, hood, and trunk; hoses; belts; and rubber bellows. Elastomer disassembly costs are much greater than the disassembly costs of the other recovered materials. This is a result of the location of elastomers, which are typically attached to or underneath other parts. This indicates that if a more thorough recovery of all parts was occurring, a greater percentage of the targeted elastomers would be recovered.

Sorting/ID: Costs for sorting are relatively low as elastomers are readily identifiable.

Processing/Cleanup: Most processing costs come from grinding elastomers into pellets which are used as feedstock to make new parts. Additional processing costs result from separating elastomers that are bonded to metal, such as engine mounts and muffler mounts.

Shipping: An intermediate shipping charge may need to be applied to those elastomers that contain metals and must be shipped to a different processing facility.

Integrated Super Processing Scenario

Integrated super processing operations, compared to gypsy harvesters, will have an accelerated learning curve due to the volume of hulks processed over time and an accumulation of material recovery data. This knowledge will facilitate more efficient recovery of materials. A super processor would also gain greater cost reductions from job specialization, lower transportation costs, and high volume. The model incorporates the different efficiencies of super harvesting and gypsy harvesting.

The following lists represent the components of a developed commercial recovery system for each of the two scenarios.

Baseline Conditions for Integrated High Volume Super Processor Analysis

- Systematic Disassembly
- Extensive Database Support
- Destructive Dismantling Tools
- Job Specialization
- Integrated System / No Double Handling
- Well Developed and Extensive Links to Markets / Closed Loop
- High Volume Thru-put
- Premium for Clean Steel Hulks
- Labor Cost @ $15 / hr.

The following table breaks out the costs of disassembly and sorting / ID / cleanup to remove 168 lbs of targeted materials by a super processor from an average vehicle in this project. In this scenario, it is clear that an integrated super processing operation is the method of choice for material recovery.

Table 20: Maximum Allowable Benchmark Costs and Revenues to Recover Targeted Materials (168 lbs.) by a Hypothetical Integrated Super Processor

Material	Disassembly	Sorting/ID/Cleanup
Polyurethane Seat Foam	**$1.52**	**$1.20**
Targeted Plastics:		
Polypropylene	$0.95	$9.59
ABS	$0.56	$5.64
Nylon	$0.45	$4.51
Polycarbonate	$0.20	$1.98
Plastics Subtotal	**$2.16**	**$21.73**
Elastomers	**$3.63**	**$6.70**
SUBTOTAL	**$7.31**	**$29.62**
Total Cost	$15.35	$29.62
Revenue	$18.59	$35.70
Net Revenue	**$3.24**	**$6.07**
Percent Profit	**21.1%**	**20.5%**
Profit per Pound	$0.029	$0.055

More revenue is available to be allocated to super processing operations for sorting, material identification, and decontamination than in the gypsy harvesting scenario mostly due to lower intermediate shipping costs. Therefore, an integrated operations benchmark costs can be higher for this stage than those under the Gypsy Harvesting scenario. This table illustrates that integrated operations do not need as great an improvement in efficiency from the project's field trial baseline costs. If an integrated operation can reduce costs below the benchmark costs, additional revenues will result that can be distributed throughout the recovery system.

As a result of lower disassembly costs, integrated super processing can withstand a higher sort/ID/decontamination cost and still remain profitable. Integrated super processing facilities can allow for a different profit distribution method. For example, the sort/ID/decontamination stage need not attain 15% profit if the disassembly stage is returning greater than 15%. The net revenue for the entire operation, including all stages, would need to achieve the desired return.

Material/Component Analysis

The costs in this section are the benchmarks that are necessary to ensure profitable plastics recovery on a per material per pound basis given the revenue distribution protocol applied to Super Harvesting Operations. All costs are per pound of clean material. (See Appendix H: Targeted Material Benchmarks: Estimated Costs and Revenue)

Plastics Recovery

Table 21. Estimated Costs and Revenue per lb. ($/lb.) of Automotive Plastics Recovery in an Integrated Super Harvesting Operation

Costs:	**Easy**	**Difficult**
Disassembly	$.009	$.055
Int. Shipping	$.000	$.000
Sort/ID	$.216	$.189
Process/clean	$.108	$.108
Shipping	$.012	$.012
Total Costs	**$.345**	**$.364**
Expected Revenue	$.40	$.40
Net Rev. (per lb.)	$.055	$.036

Disassembly: With integrated super processing operations, cost reductions through worker specialization and high volume of parts recovery result in lower disassembly costs, $.009 and $.055 per pound (easy/difficult). Difficult parts removal, because of the longer removal times, is a much more costly process.

Sorting/Identification/Decontamination: An assumption is that sorting, identification, decontamination and processing will occur at the same facility, therefore no shipping charges between facilities are necessary. We also assume that a large integrated facility will sort and process at the same facility where disassembly occurs, thus eliminating the intermediate shipping charge.

Seat Foam

There is no easy and difficult distinction in the presented data due to the uniform location of seat foam in all automobiles. All costs are per pound of clean material.

Table 22. Estimated Costs and Revenue ($/lb.) of Automotive Seat Foam Recovery for a Super Processor Operation

Stage	Costs
Disassembly	$.063
Int. Shipping	$.000
Decontamination	$.050
Processing	$.108
Shipping	$.012
Total Costs	$.233
Expected Revenue	$.035
Net Revenue	**$.117**

Disassembly: With integrated super processing operations, further cost reductions through worker specialization and high volume of parts recovery result in even lower disassembly costs. Significant challenges in foam recovery exist in disassembly.

Decontamination/Processing: The greatest potential for increasing profits in seat foam recovery comes from lowering the costs of separating foam from the seat frame. It is nearly impossible to recover foam efficiently with the tools available in the field for many seats, especially rear bench seats in several models. The uncertainty of tools and techniques creates opportunities for developing technology to reduce the costs of both disassembly and shipping. Reducing costs of decontamination will provide increased profits, which can be distributed throughout the entire seat foam recovery system. Higher profits will encourage a more thorough recovery, therefore research and development should be focused on a more cost effective disassembly process.

Elastomers

The table below lists the costs of recovering elastomers from automobiles. These costs are per pound of clean material.

Table 23. Estimated Costs and Revenue ($/lb.) of Automotive Elastomer Recovery for Integrated Super Processing

	Costs	
Stage	**Easy**	**Difficult**
Disassembly	$.030	$.093
Int. Shipping	$.000	$.000

Sort/ID	$.070	$.074
Process/clean	$.108	$.108
Shipping	$.012	$.012
Total Costs	$.220	$.287
Expected Revenue	$.500	$.500
Net Rev. (Costs)	$.280	$.213

Disassembly: In the field trials, elastomer recovery consisted of such parts as weather stripping around doors, hood, and trunk; hoses; belts; and rubber bellows. Elastomer disassembly costs are much greater than the disassembly costs of the other recovered materials. This is a result of the location of elastomers, which are typically attached to or underneath other parts. This indicates that if a more thorough recovery of all parts was occurring, a greater percentage of the targeted elastomers would be recovered. Using this reasoning, an integrated operation would have lower disassembly costs because more complete material recovery is performed on each automobile, resulting in easier access to elastomers.

Processing/Cleanup: Most processing costs come from grinding elastomers into pellets which are used as feedstock to make new parts. Additional processing costs result from separating elastomers that are bonded to metal, such as engine mounts and muffler mounts.

Shipping: An intermediate shipping charge may need to be applied to those elastomers that contain metals and must be shipped to a different processing facility.

Elastomer recovery costs, more than any other material targeted for recovery, depend on piggybacking opportunities. Piggybacking implies that the extent of elastomer parts recovery is a function of other parts recovery. For instance, engine mounts made of elastomer will be recovered for almost no additional cost if the engine has been removed. If the engine has not been removed, it will not be cost effective to recover the engine mounts.

Potential profits due to elastomer recovery are higher than any of the targeted materials. Further analysis of the disassembly methods reveals that integrated super processing operations have a much lower disassembly cost structure and could result in higher profits from elastomer recovery.

Findings

A dismantler, after looking at the costs associated with the various methods of parts and materials recovery and the current price offered by a materials processor/recycler, will make a determination about whether material recovery is economically feasible. The age of a scrap automobile, the net value of parts, and the net value of parts recovered for material will be used by the dismantler to make this determination of which parts to recover from a discarded automobile. The dismantlers decision about whether to recover parts for material value will be based primarily on the timing of recovery and the operation's marginal costs and revenues.

The marginal revenue expected from additional materials recovery by late-model operations, based on a sensitivity analysis of labor costs, will probably not be sufficient to offset the marginal costs needed to recover the materials. This type of operation will probably decide not to recover materials unless they can lower the costs of materials recovery or there is an increases in the value of recyclable material . Mid-life and end-of-life operations generate revenues from the price they receive for a hulk from a shredder plus any parts they recover for resale minus the low price they pay for a discarded automobile. Material recovery from mid-life and end-of-life vehicles represent the sectors that can benefit the most from increased materials recovery. These operations typically have lower marginal costs and can gain the most by entering the materials recycling market.

Vehicle Dismantlers Pro-Forma Analysis

A pro-forma of a vehicle dismantling operation was developed for the American Plastics Council. This model was modified using data on dismantling times generated from ARD project field trials, targeted materials and their weight, and a $15 per hour labor cost to evaluate total and marginal costs of recovering material from discarded vehicles and to compare to dismantling cost estimates in the above analysis.

The baseline pro-forma includes operation and material (O&M) costs for materials, utilities, labor (including supervisory time), transportation, and disposal. Capital and fixed costs are calculated for plant overhead at 100% of O&M labor costs, insurance and property taxes at 2% of the capital investment costs, and a capital charge of 20% of the capital investment costs.

A baseline pro-forma was created based on a 1000 hulk per year operation that included only the costs and revenue associated with parts recovery and scrap metal value (see Appendix I: Vehicle Dismantler Pro-Forma). It did not include the cost or revenue related to material recovery of the targeted list of materials. The total cost for this operation was approximately $222,590 on an annual basis. The revenue from spare parts and the sale of the hulk was calculated at $242,380 per year. The net revenue was $20,790 per year.

A parallel pro-forma was developed that included the additional costs associated with recovering parts for their material value. The marginal costs were calculated using a different rate of time to recover parts for material recovery based on our time trials and a pro-rated increase in supervisory costs and other associated costs. Costs associated with capital charges were increased an additional 3 percent. Additional costs were also included to transport recovered material to a plastics recycling processor. Additional revenues were calculated on a material specific basis.

The total cost for the operation including the recovery of the targeted materials was approximately $252,520 on an annual basis. The revenue from spare parts, the sale of the hulk, and the recycled material was calculated at $276,510 per year. The net revenue was $24,000 per year. The marginal cost was $31,000, the marginal revenue was $34,000, and the net marginal revenue was $3,200 on an annual basis. On a per hulk basis this equates to gross marginal revenue of $34 per hulk and a net marginal revenue of $3.20 per hulk. Averaged across all materials, the marginal cost was $0.18 /lb, the marginal revenue was $0.20 /lb, and the net marginal revenue was $0.02/lb.

Dismantler Interest in Parts Removal for Material Recovery

Project staff conducted an informal survey of 15 Automotive Recycling Association (ARA) members in the Great Lakes region to evaluate the validity of the working assumptions underlying our economic model. The survey was not based on a random sample; respondents were identified in cooperation with ARA staff and officers as likely to cooperate. Eleven survey responses were obtained by phone and fax.

This survey data is not statistically significant. However, these survey responses are helpful for gaining a better understanding of how dismantlers view expanded recovery opportunities and make related business decisions. Survey questions were designed to one, test the assumptions incorporated into our economic model; two, provide a *preliminary* indicator of dismantlersÆ interest and potential participation in parts removal for material recovery; and three, identify what information, tools, and assistance they need before undertaking material recovery. The survey questionnaire was designed in cooperation with ARA and Vehicle Recycling Partnership (VRP) staff.

Of the ARA dismantling yards surveyed, the average annual quantity of processed cars is 1510, with 347 cars, or 23%, less than 5 years old; 951 cars, or 63% between 5 and 10 years old; and 211 cars, or 14%, ten years or older. The largest yard surveyed dismantled 4500 cars per year with the smallest operation handling 250.

Material Recovery Revenue and Cost

The most critical assumption contained in our economic model is that $25-30 per car in revenue from material recovery operations is necessary to make such operations profitable. Survey results corroborated the validity of this assumption. Respondents indicated that an average revenue of $30 per car (or $41 per hr) is necessary, based on current dismantling costs. In response to what hourly return is necessary to recover targeted recyclable materials, the average amount indicated was $41 per hour (or $30 per car), with a high of $70 ($51 per car) and a low of $20 ($15 per car).

While most dismantlers used standard labor time costs to calculate the cost of parts removal, some dismantlers calculated removal costs on a per part basis. One dismantler took his total overhead and divided it by the number of cars purchased per year. This gave a gross cost per car which could be used when considering purchase of a vehicle for inventory. Another dismantler took his overhead costs and divided them by the number of invoices written to derive a cost per invoice. The per invoice cost is then used as a determinant on whether the part will be recovered.

ARD staff developed its economic modeling approach with the purpose of conveying relevant bottom line information to dismantlers (and others) in their consideration of the feasibility of parts removal for material recovery. The price per invoice might be an effective approach for determining costs, understanding that as overhead costs drop, invoice costs would also drop. The average ages of cars in a dismantling yard also determine the per invoice cost. Dismantlers dealing in older model cars would have less per invoice costs.

The results were inconclusive about whether dismantlers understand they would receive a higher price per lb. for clean hulks. A nearly equal division among "yes", "no", and "don't know" responses was elicited to this question. Of the respondents who indicated they would receive a higher price per lb. for clean hulks, they did not indicate what the higher price might be. Surprisingly, a few dismantlers indicated they did not know the price paid per lb. for a hulk. They apparently treat hulk sales as a dividend on the "waste" they generate, and they did not even include this value in their methods to calculate net costs and revenue.

Assessing Needs for Developing Recycling Capacity

A key recommendation derived from our project implementation is the need for a resin identification tool that is field-worthy, accurate, and rapid. Such a tool must be within the economic reach of dismantlers to have any real market value and to have an impact on expanding recovery opportunities.

ARA respondents indicated that the average price they are willing to pay is $1000, from a range of $500-2000, for a plastic resin identification tool that resulted in a net revenue increase of $10 per hour. This tool could be a computer database identifying parts and their material composition.

Nine of 11 respondents indicated they did not need additional tools to recover targeted parts. Heavy duty tools that could cut roofs or tear seats out were cited in the affirmative responses. Use of destructive dismantling techniques could be applied to recover targeted parts and allow the use of unskilled labor at reduced costs. This response suggests support for project model assumptions that the use of more efficient tools might enhance parts removal for material recovery.

Eight of 11 operators indicated that their employees would need additional training to recover the targeted parts, although the majority indicated this training would be minimal.

Most yards (8 of 11) indicated they stockpile scrap parts. This response suggests a general willingness to stockpile targeted parts on site long enough to allow super harvesters to collect such material on a regular or on-demand basis.

Most dismantlers indicated they could fit a roll off container or commercial dumpster on site. Only one dismantler with a capacity of 4500 cars per year indicated he could fit a semi-trailer on site, necessary because of his high volume.

The use of low cost, unskilled labor for material recovery was identified as one method to reduce dismantling costs. However, it was pointed out that the use of unskilled laborers to remove parts using destructive dismantling techniques might increase injury rates and exceed injury rates of trained, skilled workers. This would add a cost associated with employing unskilled labor. Effective work and safety training would probably mitigate this cost factor.

Five respondents indicated that they wanted information about dismantling and recovery techniques. Five indicated that they wanted information on part material preparation for shipping. Six indicated they wanted information on auto make, year and model for recovery and stockpiling. Five respondents indicated that a wall chart would be preferred over using the Hollander system for conveying recycling information; five indicated that the Hollander system would be a preferred method for information dissemination. However, at least one dismantler indicated that the system was an "antiquated platform" that would not be useful for information related to vehicle dismantling for material recycling.

Dismantler Participation and Commitment

Only one dismantler indicated having an agreement with a gypsy harvester for material recovery. However, even this limited response suggests a level of activity that may be greater than expected by parties outside of the automotive recovery industry.

At least three dismantlers expressed a strong preference to increase automotive recycling and avoid landfilling ASR. One dismantler stated that the lack of automotive design for disassembly caused the high costs of dismantling. This operator stated it would take a Congressional mandate before auto makers would widely use manufacturing design for easier dismantling and thereby make the practice of nonmetal material recovery economically feasible.

VII. AUTOMOTIVE RECYCLING INDUSTRY ANALYSIS

The field trials and data focused on costs and revenues per pound of targeted material. The following analysis uses the vehicle as the unit of analysis because the vehicle recycling industry analyzes costs and profits per automobile. The analysis presents information and conclusions based on average expected costs and revenues per automobile. Using the assumption that ten million cars per year are discarded, the analysis also presents findings related to the national auto recycling industry. Finally, job creation potential is estimated for the national auto recycling industry.

Economic Value Added Potential

To examine the entire industry, gross costs and revenues were used and multiplied by the 10 million cars discarded every year. The charts below present the industry costs, expected revenues, and net revenues. (Using a percentage of these costs to represent labor costs, projections for the amount of jobs created are summarized in a section further on in the report.) Sensitivity analyses of these expected costs, revenues, and net revenues are shown for 75 percent recovery of targeted materials, 50 percent recovery, and 25 percent recovery. These scenarios are presented to compare figures at less than full recovery. Somewhat less than full recovery may be closer to reality as it may be impossible to recover every pound of the targeted materials.

The gross costs listed in the table below are the result of the revenue distribution process described in the economic analysis. Even though the integrated operations are assumed to be more efficient than gypsy harvester operations, the costs for both operations are similar. This is because we let the costs of some stages of the integrated operations go higher than comparable stages in the gypsy operations. In other words, we are showing that the costs for integrated harvesting could go as high as gypsy harvesting, therefore reducing the efficiency gain that the system should make to be profitable. Even though the costs targeted for the integrated operations are as high as the gypsy harvester operations, there is less of an efficiency gain necessary to attain those costs.

Table 24: National Vehicle Recycling System Gross Cost Estimates

GROSS COSTS			
	75% RECOVERY	**50% RECOVERY**	**25% RECOVERY**
Gypsy Harvesting			
Seat Foam	$48,501,251	$43,651,126	$24,250,625
Targeted Plastics	$201,263,773	$181,137,396	$100,631,887
Elastomers	$125,538,724	$112,984,852	$62,769,362
Gypsy Harvesting Total	$375,303,749	$337,773,374	$187,651,874
Integrated Super Processing			
Seat Foam	$39,044,660	$35,140,194	$19,522,330
Targeted Plastics	$203,836,239	$183,452,615	$101,918,120
Elastomers	$123,485,242	$111,136,718	$61,742,621
Integrated Super Processing Total	$366,366,141	$329,729,527	$183,183,070

Using 10,000,000 as the number of automobiles discarded per year, the table below shows net revenues for the industry ranging from 60 million to almost 200 million dollars a year resulting from gross revenues ranging from 360 million to almost three quarters of a billion dollars annually. Gross revenues are the same for both gypsy and integrated super processors because they are targeting identical quantities of materials per car. This represents an added net profit of 1.2 to 3.6 percent above the current annual gross sales of five billion dollars currently generated by the auto recycling industry.[20]

Table 25: National Vehicle Recycling System Net Revenue Estimates

NET REVENUES			
	75% RECOVERY	**50% RECOVERY**	**25% RECOVERY**
Gypsy Harvesting			
Seat Foam	$14,498,749	$9,665,833	$4,832,916
Targeted Plastics	$29,736,227	$19,824,151	$9,912,076
Elastomers	$125,711,276	$83,807,517	$41,903,759
Gypsy Harvesting Total	$169,946,251	$113,297,501	$56,648,750
Integrated Super Processing			
Seat Foam	$23,955,340	$15,970,227	$7,985,113
Targeted Plastics	$27,163,761	$18,109,174	$9,054,587
Elastomers	$127,764,758	$85,176,505	$42,588,253
Integrated Super Processing Total	$178,883,859	$119,255,906	$59,627,953

Job Creation Potential

[20] *An Evaluation of Vehicle Recycling Opportunities* by Resource Recycling Systems, Inc. for the Vehicle Recycling Partnership, 1996 p 6

A national approach was taken for this analysis and not a regional approach. There are two basic reasons for this decision. First, defining a region is an arbitrary process, one which is likely to be politically motivated, and we wanted to avoid this. Second, given that there is an agreed upon definition of a region, there has to be a compelling reason to focus on this region. Since the focus is on developing dismantling methods, technology, and market relationships related to three national industry sectors including auto dismantling, material processing, and end markets, a focus on a region is problematic.

This is particularly important when one understands that market prices for material commodities are likely to be based on national trends and that managers of vehicle recovery operations and material processors will naturally try to change priorities and practices to achieve higher levels of return. This is a worthwhile process, but because of it we need to pay particular attention to how the overall market arrangements are structured and what changes in practices and priorities are likely to flow from emphasizing any given method or technology.

Emphasizing the regional economic impact has clear problems if it causes decisions about methods and technology to favor firms from the region over more productive firms who do not happen to be from the region. Such activities would diminish the benefits to the nation from the creation of a market for recovered materials from dismantled vehicles. Given the artificiality of regions in a country, this will not result in sensible national approach or policy.

Jobs Created through Vehicle Material Recovery

The employment levels were projected based on the total costs derived from our baseline model described above. These total cost estimates were then weighted for each step in the auto material recovery system to account for the ratio of capital to labor in include in the estimate. The costs for the dismantling sectors include labor and no capital and the costs for the sorting/decontamination and processing sectors includes labor at a 60/40á(labor/capital) ratio. The projected industry employment levels were then applied to a 75%, 50%, and 25% recovery scenario. The resulting employment was summed across all material recovery sectors to get total employment. The following table presents the estimate of total jobs produced in the development of an infrastructure for recycling automobiles. This includes a secondary job impacts multiplier.

Table 26: Job Creation Based on Total Costs

JOB CREATION: TOTAL COSTS			
	75% RECOVERY	**50% RECOVERY**	**25% RECOVERY**
Gypsy Harvesting			
Seat Foam	1,166	1,049	583
Targeted Plastics	4,838	4,354	2,419
Elastomers	3,018	2,716	1,509
Gypsy Harvesting Total	9,022	8,120	4,511
Integrated Super Harvesting			
Seat Foam	939	845	469
Targeted Plastics	4,900	4,410	2,450
Elastomers	2,968	2,672	1,484
Integrated Super Harvesting Total	8,807	7,926	4,403

General costs (labor / hr)	$15.00
Labor Percentage Factor	60%
Job Multiplier	1.25

The potential jobs created through the development of a vehicle material recovery market system ranges from a low of approximately 4,403 at 25% recovery of the targeted materials through an efficient integrated harvesting system to a high of 9,022 jobs at 75% recovery through gypsy harvesting. It is doubtful that even a mature vehicle material recovery system will be able to recover seventy-five percent of the targeted materials. The targeted materials in this study, however, represent less than 50% of the potential available material in an average vehicle. The distribution of recovery between large integrated approaches and smaller gypsy harvesting and the labor cost will affect this estimate, but the potential jobs created lies somewhere between the two extremes.

The Question of Job Creation

There is a debate in some circles focused on the question of creating or saving jobs. Our view is that this is only an interesting question in the short run context, and that the short run is not what should be important for evaluating the efficacy of a vehicle material recovery market. In the long run, natural market forces will bring the economy toward full employment and therefore jobs will neither be created nor destroyed as the result of any new methods or technology introduced into the vehicle material recovery system.

The alternative approach to job creation is to include the number of jobs saved. This is especially important when evaluating the vehicle dismantling sector that has over 10,000 established operations nationwide. An approximate throughput of 10,000,000 vehicles per year yields an average of 1,000 vehicles per year, or 3.8 vehicles per day working five days per week, processed by each dismantler. There is a wide range of size and processing capabilities in the vehicle dismantling sector. This variance in the size of vehicle dismantling operations complicates any estimate of the jobs created because parts recovery for material value is a marginal cost for existing operations that are currently recovering parts for resale and for scrap metal value.

Based on the field trial data it took approximately 50 minutes per vehicle to remove parts for the targeted material. A large dismantling operation that processes 1,000 vehicle hulks per year, or approximately 4 cars per day during a five day work week, would require approximately 900 additional staff hours to recover parts for material value if they were recovering one hundred percent of the targeted materials.

A critical question is whether a large operation would add additional staff or allocate the additional work among their existing employees. It is clear that the tendency of a smaller operation would be to allocate the marginal work of recovering parts for material value to existing employees. The allocation between existing employees and new employees is difficult to measure without more information on the size and capacity utilization of labor at existing operations.

Another important benefit of a vehicle material recovery market on jobs is not on the number of jobs but rather on the income which can be generated by the jobs.[21] Increases in productivity allow more output to be produced with a given level of input. In other words, increases in productivity allow increases in total income per capita. More income is available for each worker. This means that on average technological progress increases the quality of jobs in the economy, not always the quantity. It is job quality in this sense and increased productivity that could be the focus of measures of the benefits of vehicle material recovery.

[21] Archibald, Robert B., Professor of Economics, David H. Finifter, Professor of Economics, Director of the Thomas Jefferson Program in Public Policy, Nanette R. Smith, Graduate Student, "Measuring the Economic Benefits of Technology Transfer from a National Laboratory: A Primer", Thomas Jefferson Program in Public Policy, The College of William and Mary, Williamsburg, VA 199

VIII. FINDINGS

The Auto Recycling Demonstration Project documented real world opportunities for the recovery of non-metal components from end-of-life vehicles, and then recycling that material as feedstock into new product applications. These opportunities focus on material recovery in pre-shredder disassembly operations. The results of the ARD Project show that these opportunities are, in some cases, already being taken advantage of by a small number of private entrepreneurs.

Important barriers remain connected with issues of material logistics, tools/ technology, and economics. None of these barriers are necessarily insurmountable, but in many cases, coordinated efforts by many players will be necessary to work out solutions and create a more robust automotive material recovery infrastructure for more comprehensive recovery.

This section summarizes the key findings of the ARD project and recommendations to commercialize automotive nonmetal material recovery operations. The following summary of findings is organized around each recovery stage as follows:

- ELV Disassembly-Material Recovery Field Trials;
- Material Identification / Decontamination / Processing Field Trials;
- End Market Assessments.

Two vital areas are then reviewed in detail

- The Economics of ELV Material Recovery Systems
- Emerging and Potential Commercialization Strategies

ELV Disassembly-Material Recovery Field Trials

Documented tonnage of non-metallic material currently recycled from end-of-life vehicles, other than parts for reuse, is negligible. In the future, however, successful development of non-metal recovery by an emerging industrial sector could divert an additional 200 pounds per car for recycling, or an aggregate volume of over 1,000,000 tons per year. This annual volume will likely be greater as the percentage of non-metallic materials in end-of-life vehicles(ELVs) increases. This level of recovery performance would bring recycling of the average vehicle into the 80 to 85 percent range from current levels.

Logistical, technological, and economic barriers affect multiple stages of the recovery infrastructure (dismantling, processing, and end-market feedstock prep) and involve thousands of different business entities (e.g. over 10,000 dismantlers). These barriers are common to growing any recycling system. The currently decentralized infrastructure for collecting the material must have sufficient financial incentives for dismantlers and processors to participate.

Material must then be consolidated, cleaned, and processed with technology that is frequently in the earliest commercial stages. Programs must be designed to disseminate information about such technologies to the regional network of intermediate processors that needs to be in place. Finally, end-market customers, a group made up of both small companies as well as large multi-national corporations, have to provide consistent market demand for these materials at reasonable prices to support the recovery system. The evolution and transformation of the vehicle recycling infrastructure will take time to reach the capacity to move 1,000,000 tons per year of plastics, foam, rubber, textiles and glass from end-of-life vehicles to commercial end market applications.

Staged Material Recovery and "Piggybacking"

Barriers

As currently practiced, disassembly operations derive most revenue from parts resale and secondarily from sale of the hulks for principally ferrous material recovery by shredder operations. However, parts recovery for material value is an emerging consideration. A dismantler, after looking at the costs associated with the various methods of parts and materials recovery and the current price offered by a materials processor/recycler, will make a determination about whether material recovery is economically feasible.

Parts removal for material recovery may be carried out as part of the disassembly operation that focuses on parts recovery for resale. The recovery process is a staged process. As conditions change over time and affect demand for parts of each inventoried vehicle in a disassembly operation, parts may be recovered for their material value as parts value diminish for parts resale value. Each disassembler will decide the time to recover parts for their material value.

The age of a scrap automobile, the net value of parts, and the net value of parts recovered for material will be used by the dismantler to make this determination of which parts to recover from a discarded automobile. The dismantlers decision about whether to recover parts for material value will be based primarily on parts inventory management, the timing of recovery, the inventory lifetime of the vehicle, and the operation's marginal costs and revenues. Parts inventory management is highly variable based on location, market conditions, knowledge of the operator, and scope of operation.

In a salvage yard environment removal times are more dependent on the condition of the car and the parts that have already been removed. For instance, engine mounts containing valuable elastomer material are already removed as part of engine removal. If the engine was not slated for removal, the time to access this part would be excessive. Where wheels are being removed, fender liners can also be quickly removed. In addition, the lack of information related to parts that can be easily removed for material recovery defined as those parts that are readily accessible, or easily disassembled with the use of a standard tool versus difficult parts that first require removal of other parts, or that require a specialized tool for effective recovery.

Opportunities/Challenges

The key to cost effective disassembly by dismantlers is to identify appropriate "piggyback" opportunities in their existing operations. This piggybacking could substantially reduce the marginal costs of recovery of many parts for their material value. Material recovery can be optimized in either a dismantling yard or an integrated operation by systematizing these piggybacking opportunities.

ELV Recycling Information System

Barriers

Many dismantlers rely on a sophisticated computer information system for information about the demand for parts in their vehicle inventories as well as various factors they must consider in deciding to supply parts to meet that demand. This information system drives many of the business decisions made by a dismantler, especially those decisions about what ELVs to bring into inventory, the length of time each vehicle is in inventory, and the prices to pay for those vehicles. This information system, its structure and cost, and the question of who controls its development is so important that a great deal of industry attention is currently being directed at examining options for the future that might serve its users more efficiently.

It is overwhelmingly evident, however, that the currently available information system does not assist material recycling since it is exclusively focused on parts recovery and exchange. This finding was also at least partially corroborated by our ARA survey. As a result, dismantlers have no effective way to know what vehicle parts and models are suitable for recycling; what procedures and costs might be incurred in attempting recycling; or what material delivery specifications must be met. As well, dismantlers lack an information system that tells them what intermediate processor will buy materials; what prices will be paid, and what feedstock applications are the eventual markets.

These issues are not a barrier for ferrous and non-ferrous metals; shredders already target those fractions. It is, however, a major problem for non-metallic material especially due to the large variation in material composition and which vehicle models have which types of materials in which parts.

Opportunities/Challenges

Few simple solutions are available or practiced in the U.S. A super harvester, going after a specific targeted material such as bumpers, provides its network of dismantlers with target part and material information. This system creates a supplier infrastructure to generate material to meet super harvester demand. Information, mostly in written form, is provided about model years that are being targeted, how to remove target parts, and other logistical factors the dismantler must understand to participate. A super harvester takes responsibility for compiling and updating the information. Since a super harvester targets various parts, a dismantler must stay on top of this information and then decide on what operational steps are needed, if any, to respond.

Difficulty of Seat Foam Material Removal

Barriers

Improvement in the efficiency of seat foam recovery can be achieved by addressing the following two areas: 1) rapid removal of seats from vehicles and 2) efficient separation of foam from steel wire frames, or dewiring. The most important need in commercializing seat foam recovery is efficient dewiring, or wire removal. This problem will continue unless and until new seat designs incorporate design for disassembly criteria to facilitate dewiring.

Opportunity/Challenges

Seat removal techniques (as opposed to foam removal) may be more effective in an automotive material recovery facility, or auto MRF, disassembly line approach, or in a field situation where specialized equipment is available for removal. These alternative methods need to be addressed in future projects.

Several different technologies might be considered for cutting seat mounting bolts and/or brackets from inside the car. The technologies most likely to succeed include: 1) plasma torch, 2) abrasive cutoff, 3) pneumatic chisel, and 4) mechanical shear. Additional trials are required to evaluate the effectiveness of these technologies.

Significant challenges in foam recovery exist in disassembly and decontamination. Foam recovery can be accomplished either by cutting the foam off the seats while the seats remain in the vehicle or by various foam removal methods after seats have been removed from vehicles. Five foam dewiring techniques were identified that would address the foam contamination issue.

A large percentage of auto seat cushions are currently manufactured with the foam molded around a wire frame. An increasing number of seats, however incorporate more wire near the middle of the foam. Manual extraction of this foam results in small pieces and requires substantial time and effort. Other methods are required to remove the wire from the foam efficiently. Evaluation of the five dewiring techniques is required to identify the most technically appropriate and cost effective methods.

Material Identification/Decontamination/Processing Field Trials

Barriers

It is clear that some combination of manual and automated methods is required for the accurate and speedy identification of recovered resin types. Three basic methods were identified:

ò Reference lists or "checklists." ARD staff has been researching methods to collect data from the auto companies that indicates what resin the part is likely to be made from based on the manufacturing records. This data may not be completely reliable because the resin types frequently change in manufacturing without changes to the molds or resin labels. However, a collaborative effort to develop this type of reference list with resin manufacturers, compounders, and molders might produce an impressive degree of accuracy and usefulness.

ò Manual Testing for Materials Properties. Some automotive material engineers and plastics reclaimers with knowledge of the properties of individual polymers indicate that the material can be identified by certain design, visual, and audible features: 1) certain resins have a recognizable background color, 2) some resins have distinctive sounds when they are knocked or dropped, 3) certain parts can be made out of only 2 or 3 different resins.

ò Resin Identification Equipment. Instruments that can effectively identify resins are available, but they are not designed for field use. If checklists and manual methods can be used to narrow the range of possible resins to be identified, some existing technologies have potential for successful field application.

Opportunities/Challenges

The development of field ready resin identification equipment, especially at prices affordable to dismantlers, would enhance the technical and economic feasibility of material recovery at dismantling facilities. None of this equipment has been designed for the temperature variability, moisture conditions, and other demands faced in actual field application.

Use of resin ID equipment for line sorting applications remains untested and questionable. However, equipment modifications would affect technical and economic feasibility. Line sorting would certainly be more efficient than field-based material sorting.

As truckload quantities of recovered resins will be required by end markets, central collection sites or intermediary processors are the most likely way to perform plastic identification and sorting. As a result, determining how many pieces need to be identified per hour at a given cost is critical to the demonstration of economic feasibility.

Elastomers represent a high end value material with significant "recovery piggybacking" opportunities. Major material processing and collection infrastructure questions remain before elastomer recycling can be widely practiced. The most significant issue is whether the post-consumer material is consistent enough in quality to meet market specifications.

End Markets

Barriers

The key to successful post consumer vehicle material recycling in the near term is to sell target plastics to processors and compounders who can take wide specification material and use the recycled material in non-visible interior and exterior automotive applications and non-automotive applications. This will require the willingness on the part of the automotive OEMs to require post consumer content specifications for those applications. Tier 1 suppliers then will exert a strong demand for recycled feedstock materials. Processor/compounders should be willing to pay prices that reflect stronger demand for these materials, and such prices will most likely support profitability in the recovery operations.

A key to addressing purity issues is to compile a data base that includes data for specific polymers used in specific applications. The end product of this information is that the disassembler will know, for example, that the polypropylene in the instrument panel of particular auto models and years may be the same as the polypropylene used in the interior door trim of particular auto models and years but may not be the same as the polypropylene used in the fan shroud. Extensive cooperation between resin manufacturers, compounders, molders, and automotive OEMs will be necessary to assemble this type of data base that will simplify and make possible widespread disassembly for material recovery for higher end application end markets.

Current development of the seat foam recovery infrastructure is clearly inadequate for recovery of high volumes of post consumer seat foam. The lack of such an infrastructure prevents the recovery of post consumer seat foam in commercial quantities. Two major tracks that will support development of this infrastructure have been identified and need to be addressed: 1) the lack of market information for disassemblers about automotive materials, including seat foam; and 2) stable prices to support profitable foam recovery operations.

Opportunities/Challenges

Three distinct levels of market development can be delineated from our preliminary findings: 1) strong rebond market demand exists for auto seat foam; 2) a limited number of potential customers exist for polyolefins, TPO, polycarbonate, ABS, and other high end plastics; and 3) elastomer end market customers will require additional research and development prior to the creation of actual market opportunities.

Three very specific end market applications were identified for recycled polyurethane seat foam: 1) carpet underlay, 2) exercise machine padding, and 3) automotive sound barriers. Extensive substitution of rebond for other automotive materials, e.g. shoddy, would dramatically stimulate rebond market expansion.

Current commercial viability of recovery for post consumer seat foam will depend on the ability of end markets to consistently offer pricing of $.25/lb. or higher (for dry, clean, baled material in truckload quantities) so that a steady supply system for foam in sufficient volumes can be developed. Stronger markets could be driven by increased automotive rebond applications which would also result in higher prices for post consumer seat foam.

Economics of Material Recovery from End of Life Vehicles

The collection costs for seat foam, plastics, and elastomers all appeared to be within the range of economic feasibility under the conditions of this study. The analytical results show that if the targeted benchmark costs for removal, decontamination and processing costs can be achieved then material recovery from end of life vehicles can be profitable.

The removal times documented by this project demonstration may not reflect the exact time for removing a particular part/material under different circumstances at another site or environment. The experience gained in the field trials, however, as well as the measured times themselves, provided a strong platform on which to base estimates of actual collection costs for each targeted material under different collection scenarios.

Small Scale Low Volume Recovery - The Gypsy Harvesting Example

Several disadvantages affect the viability of small scale harvesting methods such as gypsy harvesting and, to a lesser degree, super harvesting. Both methods can be characterized as cherry-picking: limited to those parts that can be salvaged easily and quickly without new tools and limited by transportation capacity. Under current circumstances, the range of materials that can be harvested is limited.

The main criteria for material selection will be ease of removal and current market prices of the materials. The analysis shows that a small scale harvesting system will need revenue that equates to $30-40 per hour to create the incentive for dismantling operations, including harvesters, to initiate and sustain material recovery and recycling from vehicles. Over the inventory life of the average vehicle this equates to $25 to $30 in additional revenue. Achieving this level of revenue will require that material be relatively free from contaminants as it is pulled from the vehicle. This further restricts the types and volumes of material that can be recovered.

The total revenue realized by parts removal for material recovery performed by a small scale material recovery infrastructure will need to be split among many parties: dismantlers, harvesters, transporters, sorters, decontaminators, and processors. Double handling of material parts by dismantlers/harvesters and decontamination-identification-sorting operations will increase costs. Intermediate processing capacity will require the development of an extensive collection network of small scale and gypsy harvesters. The number of intermediate processors and their size will be a major determinant in minimizing the additional costs associated with small scale gypsy harvesting.

Small scale harvesting has existed on a very limited basis since the advent of vehicle salvage yards, and will likely continue to occur even as more complete material recovery is accomplished. Additional markets for recycled materials will not greatly impact the way gypsy harvesters and super harvesters conduct their business, but it will create additional sources of income. Additional competition from more systematic, integrated high-tech operations will also determine the types and quantity of materials that are potentially available for harvesting.

Large Scale High Volume Recovery - The Super Processor Example

The prospects for large-scale, high volume super processing operations are uncertain at this time. Such operations might be permanent facilities associated with and integrated into large dismantling operations where discarded automobiles are completely processed down to the hulk. Large-scale operations might gain market advantages by capturing most or all of the value added in the material recovery system and by lowering their cost of goods sold through specialized technologies, worker training, and economies of scale.

Unlike small scale, low volume recovery systems, these large scale operations would have the potential to eliminate splitting the revenue from recovered materials among so many parties. The multiple stages to recover and deliver a material to an end market customer consisting of dismantling, harvesting, transporting, sorting, decontaminating, and processing to meet market specifications would be consolidated, simplified, or streamlined with higher throughput technology.

In a high volume approach, a super processor would take commingled components (dashboards, headlamp units, etc.) as well as individual components made up of multiple materials (PP, PC, etc.). Dismantlers, then, would have lower costs for removing major component systems from end-of-life vehicles. In this scenario dismantlers would operate at a higher profit margin and a lower cost structure when compared to a dismantler using small scale, gypsy harvesting methods.

These higher margins and lower costs would provide opportunities for integrated systems to cover higher capitals costs and to remain commercially viable in the expected up and down cycles of commodity material pricing.

Any of the following three type of large scale, high volume materials recovery systems (as discussed in Chapter 5, Business Development Relationships) may offer economic incentives for market entry.

ò Super Processors: These super processors must be able to cover transportation costs and dismantler costs / profit in prices paid for incoming feedstock. These prices must be sufficiently attractive to guarantee the supply of large volumes of material to satisfy a super processorÆs markets and capacity throughput requirements. At this point, however, a super processor is positioned to realize all the remaining end market revenue in order to cover their costs. The key to the prospective success of a super processor is the capability to deliver high volumes of on-specification materials to end-markets. Since super processor technologies are in the early stages of commercialization, the economic viability of these systems are not yet actually determined or known.

ò Automated Disassembly Line Systems: These automated disassemblers will be able to move material in any of three directions depending on market demand: 1) to used parts inventory / sales; 2) to end-markets for recovered material if the market price is high and the component is easy to remove and clean on-site (e.g. radiator core); or 3) to the super processor if the time and cost for removal of a multi-material component (e.g.: radiator end-caps) is low enough to make the super processor price attractive.

The principal economic advantage an automated disassembler will benefit from is the bundling of all disassembly costs and allocation of those costs to all of the vehicleÆs components including those marketed as used parts as well as those that are marketed as recycled materials. According to European and U.S. based operators of automated vehicle disassembly systems, this 1) increases total revenue per processed vehicle, 2) lowers average removal costs per component and 3) provides some "piggybacking" or ôfree riderö benefits to recycling in the form of lower costs for removal and preparation of material for recycling. Some of these cost reduction benefits are realized through technology and labor specialization, economies of scale, and high volume throughput.

ò Integrated automotive material recovery facility, or ôAuto MRF,ö would combine the best features of a super processor with an automated disassembly line. Such an innovation would complete the vertical integration of a dismantler as a one stop, full service provider for managing end-of-life vehicles for both used parts recovery and material recovery as feedstock for end-markets. Such an operation, conceptual at this time since none are known to exist, would: 1) eliminate transportation costs as well as multiple handling costs for material; 2) capture all of the revenue from material recovery; and 3) achieve the highest level of recovery at the lowest cost.

This type of operation, however, would still have the same challenge facing any automated disassembly operation in that costs for removing and inventorying used parts will be incurred well before market demand for a particular model year peaks. This will create a time lag in cost recovery on the used parts side with the additional risk of having to predict use parts demand well in advance of removal. Most dismantlers in the current economy avoid this by storing the unprocessed hulk until demand for its used parts shows up in the marketplace.

Commercialization Scenarios

A small number of dismantlers and processors currently move limited tonnage of ôpost consumerö non-metal materials from end-of-life vehicles. They are largely small entrepreneurs in some cases working with larger suppliers to the automotive industry. In some cases, ôpost industrialö material is also targeted with the intent to piggyback onto post consumer material for recovery.

An extensive development process is needed to move from current conditions to a future system that can effectively divert an additional 170-200 pounds per car for recycling, or in aggregate over 1,000,000 tons per year, to bring total vehicle recycling up to the 80-85 percent range from current levels. Some of this tonnage will be recovered after shredding but some will also be recovered prior to shredding.

The development of pre-shredding recovery in simple conceptual terms is anticipated to move from simple field based, small scale, and low volume approaches now used (so called gypsy and super harvesting) towards larger scale and high volume approaches that might involve super processors, greater use of automated disassembly at dismantler sites, and the potential emergence of integrated auto material recovery facilities, or ôauto MRFÆsö.

The role of high volume processors may be critical to the long term viability of pre-shredder material recovery from ELVÆs. Yet many unanswered questions remain about this segment that must be addressed including overall profitability, prices of materials sold, optimal facility throughput, distribution and geographical range of facilities, and total size of market (total capacity requirements). These unanswered questions, combined with the risk profile described below, indicate that this segment will likely grow more slowly than the super harvester segment. Answering these questions with favorable results will reduce overall risk and accelerate the rate of the high volume segmentÆs growth.

The future development and evolution of this infrastructure and system will take place in the market place where winners and losers are created as various ventures move through their life cycle of startup, growth, maturation, and eventual termination or absorption by more dominant market players. Getting to this point, however, requires a continuation of public and private collaboration and sponsorship of commercialization that is absolutely critical to successful growth. Indeed, expanding collaboration and sponsorship to include partnering arrangements for long term guarantees of feedstock supply and purchasing end-products is similarly critical to a successful material recovery.

The following discussion highlights key trends that might impact the development of this new material recovery infrastructure.

Near Term Commercialization Market Drivers

The analysis provided earlier in this report shows that the financial returns that can be expected by ventures in this new recovery infrastructure are sufficient to motivate investment but not large enough to encourage speculative market entries. This is demonstrated by the types of players that have emerged:

Gypsy Harvesters

- Small gypsy harvesters can enter the market with minimal investment in technology and businesses that move very small volumes of material at relatively low risk and then only when market prices support the activity. The low level of capital that a typical gypsy harvester might put at risk poses very low barriers to entry as well as exit. Profit margins are relatively thin, commensurate with the level of investment. The net impact in tonnage from any one player is limited but could, in aggregate, provide an opportunity for significant material recovery. With only a few known ventures, this tiny segment is far removed from the scale of operations needed to recover significant tonnage of materials.

Super Harvesters

- A super harvester such as American Commodities, Inc., Flint, MI enters the market with expansion plans and significant monetary investments in technology development and equipment design. The proprietary nature of its processing function currently gives it a competitive edge over any would be rivals. As a super harvester, American Commodities builds on commercially proven material collection and handling techniques. Higher levels of investment in technology by a super harvester have the benefit of also being suitable for processing post-industrial material, thus reducing the risk of the post-consumer portion of the business. The additional capital and longer term business relationships that are required with dismantlers and end markets make entry into this segment more difficult. At the same time the post-industrial aspect removes many barriers to exiting the post consumer side and functions basically as a backup business plan.

  The throughput capacity of a super harvesting facility has the potential to grow to meet market requirements for specific materials in a broad geographical region. There is some evidence that a super harvester could expand with additional technology to grow into and assume the role of a super processor thus expanding the range of materials collected and lowering the preparation requirements for dismantlers that want to supply this super harvester / processor.

Super Processors

- MBA Polymers, Richland, CA is positioned to become the first commercial super processor in the US. This facility is still in the pre-commercialization or early commercialization stages. It is being nurtured with trade association support (e.g.: American Plastics Council) and other funding assistance from both public (e.g. SBIR and state funding) and private sources. Capital and technology requirements are much higher than a super processor and present significant barriers to entry that typically would require higher return on investment (20% to

50%) to justify for potential equity partners. It is not known whether the operating costs of a super processor will allow profitability.

Investors in such projects typically also require that both supply of feedstock and buyers of the output be secured and contractually committed prior to start-up. This poses additional significant barriers to entry for a potential super processor. An added difficulty for this segment is that exit strategies are limited because the technology application is specifically targeted at separation of multi-material mixtures. There are some potential post-industrial applications as well as applications for other industries (appliances, computers, etc.).

Post shredder ASR material streams may also need to be moved through a super processor in order to separate and clean those materials for market. For all these potential users, though, the same cost effectiveness hurdle will have to be met. Under such circumstances barriers to exit are difficult to overcome which is a large risk for investors to work with.

Automated Disassemblers

ò A few new ventures, such as the CARS of Maryland facility in Baltimore and RASF (St. Francis Auto Recycling) facility in Montreal, are entering the automated vehicle disassembly market segment. Expansion plans for additional sites are reportedly under development. Significant multi-million dollar investment requirements are required to capitalize equipment and facility and to set up systems for business tracking, material inventory, dismantling, processing, and marketing. Long term business relationships with large volume buyers of the end products (both used parts as well as recyclable material) are also required.

While these requirements are significant and represent challenges to these new ventures, they are also very similar to the long established business of dismantling without automated disassembly. As such, much is known about the dynamics of both feedstock (hulks) supply as well as end-product demand especially on the used parts and metals recycling side. These ventures view themselves as re-inventing the vehicle dismantling business rather than creating a whole new business. The long track record of the traditional dismantling business segment including historical data on overall profitability helps reduce the risk for entering automated disassembly as a new variation on the traditional approach.

Significant risk is still present, associated primarily with the investment in the automated disassembly equipment. The technology being used to date is not complex and does not represent a true breakthrough in dismantling practices (i.e.: unusual tools that dramatically lower cost of disassembly). Instead, the automated disassembly approach is presented as a comprehensive system that reportedly has lower overall operating costs as well as higher net revenue per processed vehicle. The risk, however, is that the actual automated dismantling equipment doesnÆt contribute significantly to the bottom line of the whole operation and thus may be a drag on the overall business.

Some in the industry maintain that this may, in fact, be the case given the normal business constraints that any dismantler must address which revolve primarily around used parts recovery, inventory, and marketing. At this time it is premature to state whether automated disassemblers have a more profitable business system than the traditional disassembler using more field based practices.

Integrated Auto Material Recovery Facilities (AMRFs)

ò As stated earlier, no known ventures have developed in the integrated automobile material recovery facility or Auto MRF segment. There are reports of those in the automated disassembly business giving some consideration to vertically integrating into super processing functions so that more recycled materials can be prepared for end market specification. However, it is expected that this development is still a few years away given the technology and business barriers identified earlier in this section.

In summary, this initial commercialization phase of an expanded automotive material recovery infrastructure is well underway with ventures emerging in all major business segments except the last. The barriers are significant yet market incentives appear sufficient enough to generate competitive market entry, encouraged in part by the supporting sponsorship of major players such as the individual auto manufacturers and their suppliers; trade associations and business alliances such as the American Plastics Council and the US CAR Vehicle Recycling Partnership and public/quasi public federal, state, and local economic development funding from a variety of sources.

In the near term it is expected that pre-shredder recovery of non-metal recycled materials from ELVs will develop largely through:

ò Significant growth of portions of a network of regional super harvesters motivated by market demand from end-users (polymer processors, parts fabricators, auto suppliers, etc.) to recover specific higher value materials from a super harvesterÆs own regional supply networks of dismantlers. It is expected that more dismantlers will become involved in removal and stockpiling of targeted material in cooperation with a regional super harvester.

ò Gradual growth in the number of automated disassembling facilities and a dispersion of their geographical coverage to the southern, midwestern, southwestern, and western regions of the US. It is expected that over time a number of these new facilities will develop in conjunction with existing larger dismantlers that upgrade their operations. Rapid growth is not expected. It will take time as these facilities sort out ways to operate most efficiently and profitably and as the current consolidation trend continues in the industry. This consolidation trend has already resulted in a decrease of 2,000 dismantlers from the over 12,000 dismantlers operating in the early 1990Æs.

ò The number of and geographic coverage of super processors will increase gradually as the technology develops and commercially viable operations grow. Growth will be slow despite the importance of super processors to high volume recovery of non-metals from ELVÆs. Assuming technology and economic barriers are overcome, many more routine business development barriers must then be addressed that typically get sorted out through trial and error during the first few years of commercial operation. For this reason it is expected that some of these early super processors will end up strategically aligning with either super harvesters, some of the automated disassembly operations, or with end markets. In this way material supply issues will be sorted out more easily while super processors concentrate on what are perceived to be significant technical challenges in material separation and marketing.

ò Gypsy harvesters may grow in serving selected markets and/or selected materials. They might link to super harvesters in extending services to more remote dismantling yards and u-pick sites. During peak market prices, gypsy harvesters will recover material in many markets. The contribution of gypsy harvesters is expected to be limited and not significant in terms of tonnage, but may help overall expansion of the recovery infrastructure as it reaches to serve new market areas.

Mid Term Commercialization Growth Phase

It is expected that after three to five years the near-term commercialization activities just described will establish a strong commercial base. This base will serve as a platform for a growth phase of some five years during which the annual growth rate in capacity increases and is sustained. At the conclusion of this time, much of the necessary infrastructure will be in place to process and supply the volumes of materials that end market customers demand.

Here are some potential growth trends that might occur in this mid-term phase of commercialization:

ò Regional super harvester networks continue expansion of their geographic coverage and add more materials to their targeted parts/materials list.

ò Super harvesters work more closely with super processors so that dismantlers are required to perform less material cleaning at dismantling sites and concentrate on quick low cost removal of major component systems. Super harvesters would continue to cherry pick easy-to-clean and recycle material while passing on increasingly more multi-material component systems to their super processor. Mergers between super harvesters and some of the more aggressive super processors would be expected.

ò Most dismantlers would be serviced by one or more super harvesters and be concentrated more and more on component removal. Dismantlers would benefit from an improved set of destructive dismantling tools and techniques that would lower costs and enable recovery of additional materials and components.

ò Some high volume dismantlers would move towards more automated disassembly systems and develop alliances or joint ventures with super harvester/super processor networks. These facilities may replace the first generation of automated disassemblers should those have failed by now, or merely join the pack if existing trends continue to develop. A few will invest in new jointly operated facilities with super harvester/processors and become the first examples of early generation integrated auto material recovery facilities or ôauto MRFÆsö.

ò Smaller dismantlers will continue to operate but work more and more with super harvesters as well as shredders in moving their inventory of ELVs. U pick yards and gypsy harvesting networks will continue to be important in recovering additional material from these dismantlers.

Long Term Consolidation Phase

In approximately 7 to 12 years but possibly sooner, this emerging material recovery industry can be expected to go through a consolidation phase. More winners and losers will be shaken out by the marketplace as the cost efficiencies of various types of dismantling operations drive long term profitability. This is expected to take place at a stage when most of the emerging technologies now under consideration have had time to demonstrate their viability in the marketplace. Those technologies and approaches that are strong performers in the marketplace will be selected by market leaders and leveraged into stronger market positions for those firms and market segments. Little can be said with any certainty about the specifics at this time. However a number of likely trends can be predicted based on experience with other industries:

ò At some point the overall viability of this new supply system will be demonstrated and its capability in terms of total tonnage of raw manufacturing feedstock more accurately assessed. At this point those end markets that have a strong financial interest in the largest fractions of that material stream can be expected to take more control over the system. It is likely that such firms, whether they be resin manufacturers or producers of specific products like bumpers or automotive interiors will enter into longer term commitments to support this supply chain or take steps to own some stages of it outright.

ò Industry segment consolidation will continue to be a trend especially in processing and material recovery. Participants will be larger in size and fewer in total number. End-markets that want to joint venture will want to contract with market leaders that have control over significant tonnage across North America and globally. High efficiency production will require ongoing expertise and specialization that will effectively drive additional consolidation of the super processor function. These larger entities will be better able to respond to the steady shifting that takes place in material type and quantity as the newer automobiles reach the end of their useful life, dealing with markets for some materials that quickly disappear and new materials that suddenly need new equipment to process and new market arrangements to complete the recycling loop.

Even in this long term scenario, diversity in the dismantling network will remain given the diffuse patterns of population, the need for convenient disposal of ELVs, and local need that will always exist for used parts.

Key Issues in the Commercialization Process

The dynamics of the commercialization process will depend in large part on how the following key questions are answered by the marketplace:

- Will post shredder recovery of non-metals from ASR be commercially developed and start to target some of the 200 pounds of additional material per car which can be economically recovered? ASR-based recovery will only be possible if separation technologies such as froth floatation are technically and economically feasible, and then, only if such techniques produce materials that end-markets can either use as substitutes for virgin feedstock or find lower grade end-markets.

- Will the super processor segment sort out technology and cost issues and prove itself viable in the commercial marketplace? This will require commercial demonstration of a full range of commingled material separation technologies at costs per pound that fit within the target ranges described earlier in this report.

- Will end-markets show the interest in and commitment to purchasing material generated by the post-consumer ELV recycling system? This will include both the auto companies as well as their suppliers in addition to manufacturers in other business segments.

- Will dismantlers prove themselves capable suppliers of high volumes of relatively clean material to super harvesters and more contaminated component parts to super processors?

- Will super harvesters be able to geographically expand their services and demonstrate the ability to organize their dismantler supplier networks around recovery of their targeted materials?

- Will the commercial viability of automated dismantling be demonstrated and expanded into key markets completed?

IX. RECOMMENDATIONS

The Auto Recycling Demonstration (ARD) project focused on vehicle disassembly, target material recovery, and analysis of end markets for those target materials. Based on findings from this project work, 28 action recommendations in six strategic areas are made by project staff to achieve higher volumes of automotive material recycling:

- **Commercial Recycling of High End Target Plastics;**
- **End Market Growth**
- **Field Trials to Demonstrate Tools and Techniques for Commercial Removal and Collection of Auto Seat Foam;**
- **Field Demonstrations of Plastic Resin Identification Tools and Develop a Prototype Heat Probe ID Tool;**
- **Comprehensive Field-Based Dismantling Pilot to Populate Vehicle Dismantling Data Base; and**
- **Commercialization of a Comprehensive Automotive Material Recovery System.**

These recommendations emphasize field-based work strategically designed to benchmark and/or develop tools and techniques for cost effective vehicle disassembly and parts removal for material recovery. Such work would be carried out in close cooperation with an existing dismantler or other similar operation. The intent is to generate useful data on specific vehicles, parts, and removal techniques to enable dismantlers to recover nonmetal materials for sale as recycled feedstock to end market customers.

These recommendations, then, are specifically designed to acquire greater field experience and knowledge of real world nonmetal material recovery from ELVs in the near term. In the longer term looking toward the global economy of the 21st century, these field demonstrations are designed to accelerate development of a commercial automotive nonmetal material recovery system driven by market forces and incentives. Finally, implementation of these recommendations is highly improbable without strong strategic support and commitment from the automotive industry and its suppliers.

Commercial Recycling of High End Target Plastics

Objective

Establish a commercial scale operation to recover and collect target engineering plastics for processing and delivery to end market customers.

Rationale

A major barrier to more effective high end plastics recovery is the lack of resin identification tools that have the capacity for accurate use in field operations. Currently, identification tools are limited by their lack of durability and flexibility for convenient use in field recovery operations.

A key to addressing purity issues is to compile a data base that includes data for specific polymers used in specific applications. The effect of this information will be that disassemblers will know, for example, that the polypropylene in the instrument panel of particular auto models and years may be the same as the polypropylene used in the interior door trim of particular auto models and years but may not be the same as the polypropylene used in the fan shroud. Extensive cooperation between resin manufacturers, molders, and automotive OEMs will be necessary to assemble this type of data base that will simplify and make possible widespread disassembly for material recovery for higher end application end markets.

Other important barriers to material recovery include the need for paint removal from high end plastics and cross contamination of high end plastics with incompatible materials, including adhesives, fillers, and other polymers.

Sufficient material volumes also pose a barrier to commercial scale recycling of post consumer automotive engineering plastics.

Actions

ò Develop a user-driven data base in cooperation with automotive Tier 1 suppliers, OEMs, resin producers, compounders, and molders that provides reliable data on major plastic parts and their specific material composition;

ò Identify target materials and component parts with target materials for disassembly and collection in cooperation with OEMs, molders, compounders, and disassemblers based on sufficient volume, purity of target material in identified component parts, market value, and ease of removal;

ò Identify disassembly operations with the capacity to input data and identify material composition of parts with Tier 1 suppliers to establish this data base, and start with easily removed parts with high target material content;

ò Establish an infrastructure on a commercial pilot basis to move those materials to intermediate processors for regrinding and processing to produce recyclable feedstocks;

- Facilitate contracts between disassemblers and end market customers for purchase of those target material feedstocks;

- Facilitate setting up quality assurance protocols and obtaining certification that materials meet market based specifications in cooperation with auto OEMs for purchase of components with minimum 25% post consumer content; and

- Evaluate use of compatibilizers in commercial polymer processing of selected target materials.

End Market Growth

Objective

Increase end-market demand for post consumer recycled feedstock sourced from ELVs.

Rationale

Supply and demand of recycled feedstocks must grow together with the best results coming from a long term balance between the growth rates of each. Currently markets are reluctant to use recycled based feedstocks due to uncertain supply and concern about material quality assurance issues. A strategy to build demand for recycled feedstocks sourced from ELVs should include the following:

Actions

ò Intensify efforts to integrate design for disassembly (DFD) and design for recycling (DFR) into product design. For example, the effort to reduce the total number of plastic resin types used in automotive applications and to use recycled content and recyclability as a criteria in selecting resin types is critical.

ò Build recycled content goals into markets that are potential targets for ELV recovered materials. For example in the near term, OEM's might influence and leverage greater use of ELV-recovered materials by pallet manufacturers. In the longer term, OEMs might require ELV recovered materials in non-esthetic and non-structural applications, e.g. wheel well mud guards.

ò Build recycled content goals into OEM product lines.

ò Expand investment in technologies and product lines that can use commingled material streams (i.e.: different resin types being extruded into pallets).

ò Increase investment in technologies that allow higher levels of contamination in the feedstock through use of polymer compatibilizers and catalysts.

Field Trial Demonstrations: Tools and Techniques for Commercial Auto Seat Foam Collection and Recovery

Objective

Develop tools and demonstrate techniques for rapid and efficient recovery of auto seat foam

Rationale

Strong market demand by rebonders exists for recycled seat foam (primarily for carpet underlay applications), however, auto seat foam recovery is limited but promising at this time.

A seat foam collection system needs to be designed and implemented to assure sufficient volumes of foam. This system might build on the current dismantler infrastructure or on alternative scenarios as discussed.

The key identified barrier is the lack of tools and technology to remove auto seats and separate auto seat foam from fabric, fasteners, and wire. A quality foam feedstock supply that has been liberated from contaminants can command profitable material prices. Inferior quality drives prices down and undermines the development of this currently underdeveloped collection infrastructure and market.

Current operations and our own field studies suggest that field disassembly techniques need to be improved. Our recent field studies documented that "gypsy harvesting" of foam (cutting foam out of the seats in the scrap yard) requires about 5 minutes per car. The average amount of foam recovered per car is approximately 20 to 25 pounds. It was determined that foam can be removed from seats such as some minivan bench seats very rapidly and that the quantity of foam from these seats was above the average.

Actions

ò Identify and work with an industrial tool manufacturer(s) to assist in the development of tools for rapid seat removal.

ò Identify existing or prototype tools for foam removal (removing foam and separate foam from fabric, fasteners, and wire). If no suitable tools can be identified, prototype tools will need to be designed and built. These tools will be tested in field trials, and data and results documented;

ò Conduct field disassembly trials in the following two environments:

1) Removal of seats and / or foam in a state of the art or prototype disassembly facility; and

2) Removal of seats and / or foam in a clean and efficient and salvage yard operation (D&R or equivalent facility)

- Evaluate two removal methods for method effectiveness and their impact on recovering profitable volumes:

  1) Foam removal cut out (using blades, metal clippers) of cars without removing the seats; and

  2) Whole seat removal for more efficient assembly line foam removal techniques (such as shredding, power washing, and other cutting methods);

- Investigate three existing operations and / or pilot operations, or studies, where seat foam removal is practiced on a commercial scale to compare removal techniques in terms of effectiveness and impact on recovered volumes;

- Develop a data base of seat designs and applications in cooperation with auto seat manufacturers that identifies those seats which facilitate foam removal and those that do not; and

- Compile and evaluate time studies data and methodological data to identify the most technically feasible and economically effective methods of foam removal in field based disassembly and high volume disassembly facilities.

Field Trial Demonstrations: Plastic Resin Identification Tools

Objective

Develop and/or demonstrate resin identification tool appropriate for use by dismantling operations that

- *Clearly define which types of existing equipment provide useful results;*
- *Define the characteristics of field worthiness of existing equipment;*
- *Develop guidelines for field use of the field worthy equipment; and*
- *Identify the need for additional or modified identification tools.*

Rationale

Field worthy resin ID tools are not commercially available. As a result, resin identification in field based disassembly is not currently feasible. However, MBA Polymers of Richmond, CA has tested and evaluated resin ID tools in a super processor environment. Their work will immeasurably assist the field demonstrations that we recommend here.

A basic assumption is that accurate, rapid, and field worthy equipment will significantly assist efforts to expand plastic recycling by either automotive dismantlers and/or automotive/durable goods shredders. Innovative developments in resin identification need to be evaluated for field applications. To our knowledge, these tools have not been adequately tested for use and application in field disassembly operations. The commercial availability of accurate, rapid, affordable, and field-worthy resin identification equipment would significantly enhance greater plastics recovery.

Laboratory work has demonstrated that reliable, hand-held, and field-worthy tools to identify many resins are not available. Existing dielectric and tribopen technologies may be able to fill some of the gaps. Further work is needed to evaluate and/or modify these products. Melting/transition point measurement has the potential to resolve many resin ID issues. The development of a hand-held heat probe/penetration instrument appears to be feasible, and knowledgeable industry operators have expressed strong interest in such development.

Actions

- Conduct field demonstrations of available resin identification tools and perform technical assessments of those trials for comparative analysis of speed, accuracy, ruggedness/durability, and cost-effectiveness of these tools in various field applications(Such field applications include both shredder-based identification as well as dismantler-based identification.).

ò Determine the precise relationship between the size of particles to be identified and the rate at which accurate analysis can be made. This determination will greatly assist in the design and production of the next generation of plastic identification tools and the appropriate environment for their use.

ò Develop and demonstrate a heat probe tool for resin ID in field operations.

Comprehensive Field Based Dismantling Pilot to Populate Vehicle Dismantling Data Base

Objective

Develop a data base that provides information to dismantlers on parts removal for material recovery.

Rationale

An extensive field based dismantling pilot should be conducted focusing on a wide range of vehicles to assist in completing the assembly of data and information by vehicle type and year about techniques and tools to remove parts for materials.

Finally, to better evaluate data from the field trials and nonmetal material recovery demonstrations, the project team will review and evaluate data and information from sources that have experience in material recovery methods and techniques, including European and Japanese disassembly operations.

Actions

Conduct additional dismantling field trials with to focus on three major areas:

ò Continue benchmarking of recovery methods, techniques, tools, and costs;

ò Integrate new data into user friendly database applications for use by dismantlers to facilitate material recovery. This information and data would include vehicle type, part identification, nonmetal material content, and cost effective dismantling techniques into a data base model; and

ò Develop a training component based on field based dismantling demonstrations that can be used by dismantling operations build worker skills in dismantling techniques.

Commercial Demonstration of a Comprehensive Automotive Material Recovery System

Objective

Determine the optimal configuration of a comprehensive automotive material recovery system

Rationale

A comprehensive system approach to automotive material recovery is a practical and necessary option to achieve sufficient volumes of materials essential to effective market development for those recovered materials. Such a system approach would consolidate and streamline recovery operations and reduce double handling of materials.

Actions

ò Design a commercial automotive material recovery system, in cooperation with dismantlers, shredders, and processors;

ò Conduct a feasibility analysis of a comprehensive auto material recovery facility, potentially in cooperation with a specific manufacturer;

ò Develop partnerships and structure deals with end market customers, particularly automotive tier 1 suppliers and OEMs, for recycled feedstocks

APPENDIX A: PLASTIC QUANTITIES AFTER BRUKER-SORTING*

MATERIAL	WEIGHT(lbs) Post-Bruker Weight
PE	
bin #1	270
bin #2	224
bin #3	134
Total PE Weight	628
PP	
bin #1	170
bin #2	122
bin #3	93
bin #4	100
bin #5	95
bin #6	60
Total PP Weight	640
PP(EPDM)	
bin #1	145
bin #2	135
bin #3 (assumed bin not full)	100
Total PP(EPDM) Weight	380
PP(talc-filled)	
bin #1	200
bin #2	70
Total PP(talc-filled) Wt.	270
ABS	
bin #1	70
bin #2	138
bin #3	140
bin #4	122
bin #5	180
Total ABS Weight	650
PA6	
bin #1	57
bag #1 (not yet cleaned)	9
Total P6 Weight	66
PA66 (assumed 68% loss)	
bin #1	395
bag #1 (not yet cleaned)	16
Total PA66 Weight	411

PC	
waste-bask. #1 (not yet cleaned)	17
waste-bask. #2 (not yet cleaned)	20
Total PC Weight	37

PVC	
waste-bask. #1 (not yet cleaned)	20
Total PVC Weight	20
TOTAL WEIGHTS:	3102

* Except where indicated, italicized numbers are calculated based on the assumption of a 33% weight loss.

APPENDIX B: PLASTIC QUANTITIES AFTER DECONTAMINATION*

MATERIAL	Post-Bruker Weight	Post-Cleaning Weight	Weight Lost in Cleaning	% Weight Lost
PE				
bin #1	270	210	60	22%
bin #2	224	150	74	33%
bin #3	134	90	44	33%
Total PE Weight	628	450	178	28%
PP				
bin #1	170	110	60	35%
bin #2	122	58	64	52%
bin #3	93	62	31	33%
bin #4	100	67	33	33%
bin #5	95	68	27	28%
bin #6	60	30	30	50%
Total PP Weight	640	395	245	38%
PP(EPDM)				
bin #1	145	97	48	33%
bin #2	135	80	55	41%
bin #3 (assumed bin not full)	100	67	33	33%
Total PP(EPDM) Weight	380	244	136	38%
PP(talc-filled)				
bin #1	200	110	90	29%
bin #2	70	70	0	0%
Total PP(talc-filled) Wt.	270	180	90	33%
ABS				
bin #1	70	50	20	29%
bin #2	138	90	48	35%
bin #3	140	88	52	37%
bin #4	122	100	22	18%
bin #5	180	98	82	46%

Total ABS Weight	650	426	224	34%
PA6				
bin #1	57	38	19	33%
bag #1 (not yet cleaned)	9	6	3	33%
Total P6 Weight	66	44	22	33%
PA66 (assumed 68% loss)				
bin #1	395	126	269	68%
bag #1 (not yet cleaned)	16	5	11	69%
Total PA66 Weight	411	131	280	68%
PC				
waste-bask. #1 (not yet cleaned)	17	11	6	35%
waste-bask. #2 (not yet cleaned)	20	13	7	35%
Total PC Weight	37	24	13	35%
PVC				
waste-bask. #1 (not yet cleaned)	20	13	7	35%
Total PVC Weight	20	13	7	35%
TOTAL WEIGHTS:	3102	1907	1195	39%

* Except where indicated, italicized numbers are calculated based on the assumption of a 33% weight loss.

APPENDIX C: SAMPLE MARKETS DATABASE ENTRY FORM

APPENDIX D: MARKET CONTACTS EXPRESSING INTEREST IN RECEIVING MATERIAL SAMPLES

Advanced Elastomer Systems	Auburn Hills	MI
Akron Rubber Development Lab	Akron	OH
Appertain, Inc.	Pulaski	TN
Blue Water Plastics	Marysville	MI
Cadillac Div. Rubber & Plastics	Cadillac	MI
Composite Particles	Allentown	PA
Compound Technologies	Troy	MI
Cri-Tech	Hanover	MA
Custom Cryogenics	Ontario, CAN	CAN
D & R Auto Parts Inc.	Belleville	MI
Ecologix	Holland	MI
Empire Molded Plastics, Inc.	Benton Harbor	MI
EnviroTech Plastics		CN
Fairmont, Inc.	Oak Brook	IL
Findlay Foam Recycling	Toledo	OH
Foam Conversions, Inc.	Dalton	GA

Foamex	Fort Wayne	IN
General Foam Corp.	Paramus	NJ
Global Logistics		
Golden Systems	Las Vegas	NV
Industrial Resin Recycling	Brighton	MI
Lubbers Resources	Jennison	MI
Luxaire Cushion Co.	Newton Falls	OH
Michigan Polymer Reclaim	Lansing	MI
Midwest Elastomers Inc.	Wapakanetta	OH
Performance Polymers	Holly	MI
Plastic Separation Specialists	Anderson	SC
Polycytek	Battle Creek	
Rondy and Company, Inc.	Barberton	OH
Scottdel	Swanton	OH
Standard Products Company	Dearborn	MI
STI-K, Inc.	Washington	DC
Strategic Materials		
Structural Polymers		

APPENDIX E: SAMPLE TRACKING FORM

APPENDIX F: MARKET EVALUATION FORM

APPENDIX F: MARKET EVALUATION FORM (CONT'D)

APPENDIX G: END MARKET CUSTOMERS: MATERIAL EVALUATIONS AND REQUIREMENTS

APPENDIX G: END MARKET CUSTOMERS: MATERIAL EVALUATIONS AND REQUIREMENTS (CONT'D)

APPENDIX H: TARGETED MATERIAL BENCHMARKS: ESTIMATED COSTS AND REVENUE

APPENDIX I: VEHICLE DISMANTLER PRO-FORMA