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## PROGRESS IN RECYCLING OF AUTOMOBILE SHREDDER RESIDUE

B.J. Jody, E.J. Daniels, and J.A. Pomykala, Jr.

Argonne National Laboratory  
9700 South Cass Ave  
Argonne, Illinois 60439

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### Abstract

At Argonne National Laboratory, we have been developing a potentially economical process to recycle automobile shredder residue (ASR). We identified three potentially marketable materials that can be recovered from ASR and developed technologies to recover and upgrade these materials. We built and tested a field-demonstration plant for recycling polyurethane foam and produced about 2,000 lb (907 kg) of recycled foam. Several 300-lb (136-kg) samples were sent for evaluation and were found to be of marketable quality. We are also preparing for a large-scale test in which about 200 tons (181 tonnes) of ASR-derived fines (<0.25 in. [ $<0.62$  cm]) will be used as a raw material in cement making. A major cement company has evaluated small samples of fines prepared in the laboratory and found that they meet its requirements as a substitute for iron ore or mill scale. We also produced about 50 lb (23 kg) of recycled acrylonitrile butadiene styrene (ABS) from obsolete automobiles and found that it has properties that could be readily upgraded to meet the specifications of the automotive industry. In this paper, we briefly discuss the process as a whole and summarize the results obtained from the field work on foam and fines recycling.

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## Introduction

Each year, about 10 million vehicles are discarded. On the basis of available data and vehicle statistics [1-4], we estimated that in 1991, the recycling potential from obsolete automobiles was about 10.3 million tons (9.3 tonnes) of ferrous scrap, 0.8 million tons (0.7 tonnes) of nonferrous metals, 0.8 million tons (0.7 tonnes) of plastics/composites, and 2.1 million tons (1.9 tonnes) of other materials. The metals that account for about 75% of the total weight of the discarded vehicles are presently recovered after the automobiles are shredded. The balance of the material (commonly known as automobile shredder residue or ASR), which amounts to over 3 million tons (2.7 tonnes) annually, is currently landfilled.

The cost of landfilling, which has increased over the past few years, combined with more stringent regulations, long-term liability concerns, and shrinking landfill space, dictate that viable disposal alternatives be developed to maintain a healthy metals recycling industry. Moreover, the increasing nonmetal content of vehicles will affect how vehicles are disposed of. For example, the consumption of plastics/composites in domestic automobiles increased from 176 lb (80 kg) in 1978 to 243 lb (110 kg) in 1992 [2,4]. This increase contributed to the decline in the total weight of the average passenger car from 3,494 lb (1,585 kg) in 1978 to 3,136 lb (1,422 kg) in 1992. Of the five main categories of construction materials used in vehicles, only plastics/composites showed increased market penetration over the same period [2,4]. The share of plastics/composites in domestic cars increased from 5.0% in 1978 to 7.7% in 1992 [2].

At Argonne National Laboratory, we have been developing a process to recycle ASR. We have identified a diversity of potentially recyclable materials, including polyurethane foams, iron oxides, and certain thermoplastics that can be recovered from ASR. We have also developed technologies to recover and upgrade these materials. The status of the technology and its economics are discussed below.

## Characterization of ASR

The development of technology for recycling ASR is complicated because ASR is a very heterogeneous waste material; its composition, density, and moisture content change from site to site (and from day to day at the same site) as different types of source materials and different models and years of obsolete automobiles and white goods are shredded [5]. As shown in Table I, ASR contains a large number of intermingled species. Approximately 40-55% of the

Table I Composition of ASR

Recyclables	Energy value	Inerts
Thermoplastics	Paper	Glass
Foams	Brake fluid	Dirt
Fibers	Engine oil	Sand
Metal chunks	Transmission oil	Gravel
Rust	Grease	Moisture
Wires	Wood chips	
	Thermosets	
	Rubber	
	Tar	

ASR is combustible material, and its heating value may vary from approximately 4,000 to 6,000 Btu/lb (9,300–13,960 kJ/kg) and average about 5,400 Btu/lb (12,560 kJ/kg) [6,7]. In many cases, the ASR may contain polychlorinated biphenyl (PCB). ASR also contains heavy metals, such as lead, cadmium, and mercury.

ASR is also heterogeneous with regard to density and shape. For example, the polyurethane foam (PUF), with absorbed moisture and oils, might constitute about 10% of the ASR mass but could account for over 30% of its volume. On the other hand, fines (0.25 in. or <0.62 cm) might constitute about 25% of the mass and only about 5% of the volume. The volume ratios of the large and small PUF pieces could be as high as 250:1.

An expected composition of the plastics portion (based on automotive plastics use in model year 1981) of the ASR is given in Table II [8]. Hock et al. [9] estimated that the “cumulative costs associated with recovery, by selective dismantling, through reclamation of the automotive plastic parts...fall between \$0.36-\$1.08 per lb (\$0.79–\$2.38 per kg) and average \$0.72 per lb (\$1.59 per kg)” [9].

### Recycling

Because ASR has a high hydrocarbon and plastics content, it can, conceptually, be recycled by all four recycling modes: primary, secondary, tertiary, and quaternary. The greatest emphasis on ASR recycling has been on secondary and quaternary recycling, primarily because of the plastics content of the ASR. The applicability of these recycle procedures to ASR is discussed elsewhere [10]. ANL has developed and is conducting large-scale testing of a process for the recycling of most of the ASR constituents, including the thermoplastics [4, 11–17]. This process is summarized below.

Table II Composition of Plastics in Model Year 1981 Cars [5]

Material	Weight %
Polyurethane foam	22.6%
Reinforced polyesters	21.9%
Bulk molding compound/sheet molding compound	
Polypropylene	19.2%
Polyvinyl chloride	15.5%
Acrylonitrile butadiene styrene	7.3%
Nylons	3.7%
Acrylic	2.5%
Phenolic	2.1%
Other	5.2%

## The Argonne Process

The ANL process involves four steps: (1) drying the ASR when required, (2) mechanically separating the foam and the fines, (3) extracting the thermoplastics and regenerating the solvents for reuse, and (4) upgrading the separated products to meet market requirements. These steps are discussed in detail below.

### Drying

The ASR is dried by indirect heating (i.e., steam coil) only, and temperatures in excess of about 220°F (105°C) should be avoided in the presence of air. Because of the potentially high (up to 40 wt%) water content of some ASR material, drying can be an energy-intensive and time-consuming process.

### Mechanical Separation

Mechanical separation of solid mixtures, when technically feasible, is generally simpler and less expensive than other techniques. We employed it in our study to separate the polyurethane foam and the fines (0.25 in. or <0.62 cm in size) from ASR as potential products. Attempts to separate these materials from the shredder fluff by using some commercially available equipment was not successful. The wires in the shredder fluff caused the material to plug the screens in a short period. Small pieces of plastics and nonplastics materials were trapped in the fuzz and in the PUF and could not be shaken loose by the equipment. Therefore, we built a laboratory classification column that also agitated and fluidized the ASR (Figure 1) by air introduced at the bottom of the column [4]. Features of this system were incorporated into the design of a large-scale (over 2.5 tons [2.3 tonnes] of ASR per hour) system to separate the

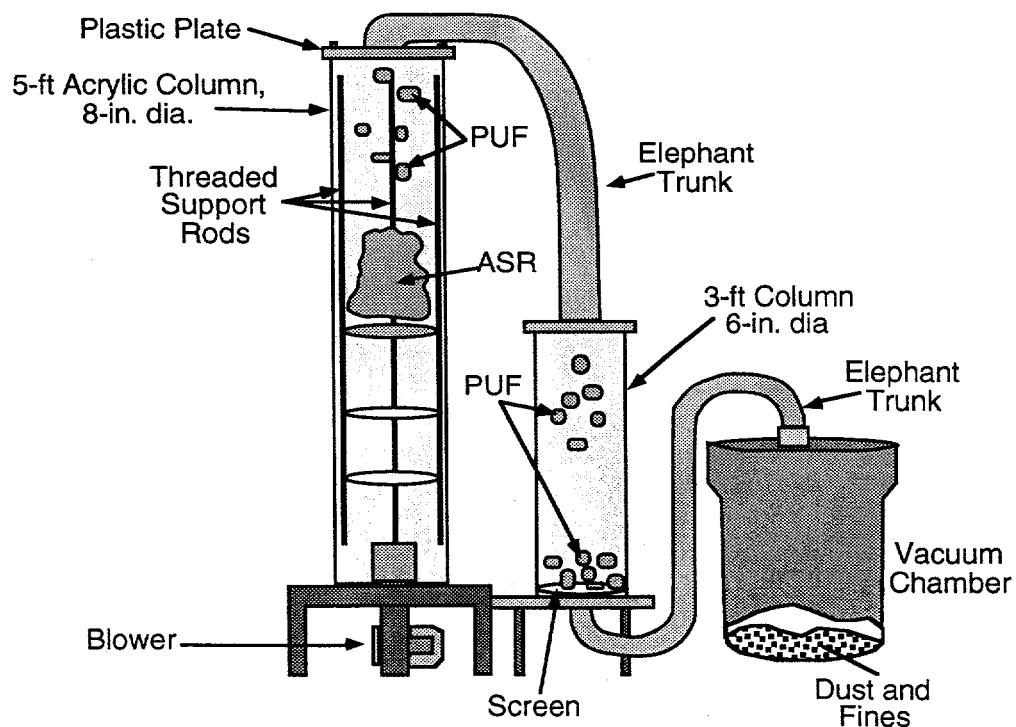


Figure 1 Laboratory Apparatus for Physical Separation of PUF, Fines, and Plastics-Rich Shredder Fluff Fractions

foam and the fines. This system is scheduled for installation at ANL in November 1995. It includes a shredder, a grinder, a multistage trommel, two magnetic separators, an eddy current separator, an air-fluidization subsystem, and over 150 ft (46 m) of various types of conveyors. In addition to separating the foam and the fines from ASR, this system is also capable of recovering the residual ferrous and nonferrous metals. The recovered fines and foam were upgraded by further processing, as discussed below.

#### Extraction of the Thermoplastics

We identified polypropylene (PP), polyvinyl chloride (PVC), and acrylonitrile butadiene styrene (ABS) as potential candidates for recovery from ASR for recycling. These materials are present in relatively large quantities and/or have good market values. Therefore, their recovery can be cost-effective. We evaluated two routes to capture these plastics: after and before shredding.

In the after-shredding approach, the ASR is first subjected to the mechanical separation process, which is described above, to concentrate the plastics in a more manageable stream. The concentrated stream is then treated with organic solvents to selectively dissolve the desired plastics. We found that this technology is technically feasible but only marginally economical, primarily because the extractable material constitutes a small portion of the total waste stream that needs to be processed. We produced ABS material by this approach that is over 98 wt% ABS and over 1 wt% methacrelate derivative additives. The material contained less than 1 wt% PVC. ABS extracted and purified with solvents was mixed with virgin ABS, and the blend was analyzed and compared with the virgin material. The results are given in Table III.

In addition to the solvent-extraction procedure, we conducted mechanical/physical separation on dismantled portions of vehicles to recover desired plastics. For example, mechanically removed dashboards were shredded in a small shredder down to 0.5-in. (1.3 cm) pieces. Metals and metals-containing pieces were then separated from the shredded material by using commercially available systems. The metals-free fraction was then granulated to 0.25 in. (0.62 cm). (This mixture was separated on the basis of density gradients, including surface tension modified density.) Separation yielded four fractions; of the four, one was rich in ABS and another was rich in polycarbonates. The four fractions were sent for detailed chemical analyses to establish their chemical composition. This work is still under way and it is too early to draw concrete conclusions.

Table III Comparison of the Properties of a Blend of Recycled and Virgin ABS (10% recycled/90% virgin) with the Properties of Virgin ABS\*

Sample Type	Izod Impact Strength, ft-lbf/in. (N)	Tensile Strength, psi (kPa)	Breaking Load, lb (kg)	Ultimate Elongation, %
Virgin	6.77 (361)	6,608 (45,562)	—	4.9
Blend	4.24 (226)	6,234 (42,983)	318 (598)	6.2

\* Analyses were conducted by University of Akron.

### Upgrading of the Fines to Meet the Requirements of the Cement Industry

By using a magnet, the fines, which constituted about 30 wt% of the ASR (values as low as 20% and as high as 55% were observed for different samples), were separated further into two different fractions: magnetic and nonmagnetic. The magnetic fraction was about 40% of the total fines. Several cement companies were contacted to explore the possible use of this material as a source of iron oxide units (to replace iron ore and mill scale) in cement making. After extensive discussions with the cement industry and detailed analysis of this product, we had to reprocess the magnetic fraction further to reduce its organic, alkali metal, and zinc contents. The organic content had to be reduced to guard against emitting products of incomplete combustion into the air, because this material has to be fed at the lower temperature end of the kiln. The alkali metals content has to be reduced when low-alkali cement is required. Different levels of zinc affect the curing time of the cement. A magnetic fraction containing as much as 75 wt% iron (elemental analysis) was produced. A one-week test in a cement kiln using about 200 tons (181 tonnes) of fines is planned.

### Upgrading the Polyurethane Foam

The separated foam constituted about 10 wt% of the ASR. About 30–40 wt% of the dirty foam is dirt. This dirt consists of four items: organic “oils” (mostly automotive fluids and, in some cases, low levels of PCBs), inorganic dirt (mostly mud, glass, and residual metal oxide fines), moisture, and metal wires and metal pieces. Processes to clean the foam using organic solvents and water/detergent solutions were tested. The water-based method was rejected because it results in large quantities of wastewater, and the time and cost required to dry the foam were high. There was also concern whether this method can remove the PCBs, since the PCBs are not readily soluble in water. Organic solvent-based methods were very effective in removing the organic “oils” and the PCBs. They were also effective in removing the inorganic dirt. A batch process field demonstration plant was built to demonstrate the technical feasibility of the solvent-based method.

### Residual Material

The residual material from which the foam, the fines, and the thermoplastics had been separated is a dry mixture that could be used as a solid fuel. It is lower in ash and chlorine. A 100-lb sample of this material was used in a low-temperature pyrolysis test that was intended to maximize the production of solid fuel at the expense of liquid and gaseous fuel products. About 83 wt% of this material was converted to a solid fuel having a heating value of about 6,700 Btu/lb (15,580 kJ/kg) and an ash content of about 35–40 wt%.

### Economic Analysis of the Argonne Process

Economic analysis of this process is somewhat complicated because of the many steps involved. Therefore, it is beneficial, at this stage, to discuss the economics of the key steps individually.

### Separating and Upgrading the Fines

Most of the equipment required for this part of the process is commercially available and used in a typical dry shredding scrap yard. The cost of additional equipment for such a facility that produces about 50,000 ton/yr (45,360 tonnes/yr) of ASR is expected to be less than \$50,000, including installation. This equipment is primarily for upgrading the fines to meet an end user's

specifications. In addition, the process is fully automated, so its labor requirements are expected to be negligible. Preliminary discussions with shredders and cement companies indicate that the cement company's tipping fee for this material (if the test is successful) may be less than one-third that charged by a landfill. Given these parameters, a simple payback of a few months can be expected for most shredders in the United States.

#### Separation and Upgrading the Foam

Most required equipment for separating the foam is also commercially available and used in a typical dry shredding scrap yard, especially those facilities that are equipped with an Eddy Current separator. The equipment may have to be modified to enhance separation efficiency. Equipment for cleaning and drying the foam is not commonly used by the shredders (especially for facilities equipped with an Eddy Current separator). Commercially available equipment may be adopted but may not be very efficient in accomplishing this task. Continuous washing and drying equipment (such as that being designed and built at ANL) for a plant that can produce 600 tons (544 tonnes) of clean foam per year is estimated to cost between \$150,000 and \$200,000. This equipment will be fully automated. Therefore, labor requirements associated with the equipment are expected to be small. Preliminary discussions with foam brokers indicate that the value of the recycled foam will be no less than \$0.25/lb (\$0.55/kg). Assuming that this plant will be running 8 h/day and 300 days/yr, the value of the recovered foam will be over \$300,000/yr.

#### Conclusions

Results obtained to date prove that the polyurethane foam, the iron-oxide rich fines, and the thermoplastics that are present in ASR can be recovered and upgraded to marketable products. The energy value of this material can also be tapped. The economics of recovering these different items vary. For some, such as the fines and the polyurethane foam, the economics appear very attractive. For others, such as the thermoplastics and the energy value, more work is required to establish their economic competitiveness. It appears more likely than ever that a combination of technologies will be required to achieve complete and economic recycling of the ASR.

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