White Goods Recycling in the United States: Economic and Technical Issues in Recovering, Reclaiming, and Reusing Nonmetallic Materials

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ABSTRACT

Obsolete white goods (appliances such as refrigerators, freezers, washers, dryers, ranges, dishwashers, water heaters, dehumidifiers, and air conditioners) contain significant quantities of recyclable materials, but because of economic and environmental concerns, only limited quantities of these scrap materials are currently being recycled. Appliances are manufactured from a mix of materials, such as metals, polymers, foam, and fiberglass; metals represent more than 75% of the total weight. Appliance recycling is driven primarily by the value of the steel in the appliances. Over the last 15 years, however, the use of polymers in appliance manufacturing has increased substantially at the expense of metals. The shift in the materials composition of appliances may threaten the economics of the use of obsolete appliances as a source for scrap metals. To increase the recycling of white goods, cost-effective and environmentally acceptable technologies must be developed to separate, recover, reclaim, and reuse polymers from discarded appliances.

Argonne National Laboratory is currently conducting research, with industry support, to develop cost-effective processes and methods for recovering and reclaiming acrylonitrile butadiene-styrene and high-density polystyrene from discarded appliances. This collaborative research focuses on developing a combination of mechanical/physical and chemical separation methods for recovering and reusing these high-value plastics. In addition, cost-effective methods for improving the performance characteristics of the recovered plastics are being investigated with the goal of recycling these plastics to their original application. In this paper, we examine the technical and economic issues that affect the recycling of white goods and present results of Argonne's white goods recycling research and development activities.

INTRODUCTION

It is estimated (EPA 1992) that more than 2.8 million tons of white goods are being discarded annually and become available as obsolete scrap. Discarded appliances, commonly called "white goods," contain significant quantities of recyclable materials; however, not all appliances are recycled for their scrap value. The recycling rate of appliances has risen from 32% in 1990 to 62% in 1993 (*The Recycling Magnet* 1994), partially because of improvements in the infrastructure for collecting and processing old appliances. Environmental regulations implemented recently by as many as 17 states, which provide strict guidelines for managing the disposal of obsolete appliances, have also contributed to the increase in the recycling rate. The scrap value in appliances is primarily in the steel contents. In 1993, more than 1.6 million tons of steel (EPA 1992) were recovered from appliances.

State and federal environmental regulations have substantially increased the cost of proper disposal of old appliances. To comply with these regulations, appliances must be processed to remove hazardous materials. Some environmentally controlled substances that may be present in discarded appliances are polychlorinated biphenyls (PCBs), chlorofluorocarbons, and mercury. Chlorofluorocarbons are used as refrigerants in refrigeration and air conditioning equipment; PCBs have been used in some motor capacitors and fluorescent lighting ballasts; and mercury can be found in electrical switches and in temperature controls for gas stoves and water heaters. Some states have passed regulations that limit the disposal of appliances in landfills before some recyclable materials have been recovered. A typical flow diagram for discarded appliance is shown in Figure 1.

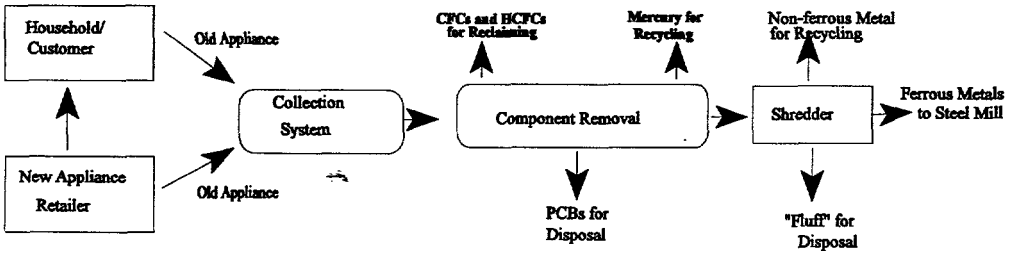

FIGURE 1 Appliance Flow Diagram

The costs of processing appliances to recover environmentally controlled substances and recyclable materials, including the cost for final disposal of the residual fraction in landfills, have increased. To cover their costs, collectors and processors of appliances may charge fees ranging from $10 to $50 to pick up and properly dispose of one appliance. The infrastructure for collecting and processing appliances in the United States is fragmented and under development. Most appliance collection systems are informal arrangements: individuals or companies engaged in collection, transport, processing, and materials recycling of appliances in addition to other services. The costs of collecting, transporting, and processing appliances for materials recovery will continue to be a major barrier to increased recycling.

MATERIALS COMPOSITION OF WHITE GOODS

The home appliance industry is highly competitive. Over the years, technological innovations and improvements in materials have lowered the manufacturing and operational cost of appliances. The use of low-cost, high-performance materials has contributed to the continuing innovation of features and convenience in appliances. The increasing value in appliances has been attributed partly to the versatile and cost-effective plastic materials now used in appliance manufacturing. The changes in materials used in appliance manufacturing as a function of time are shown in Table 1.

TABLE 1 Materials Used in Appliance Manufacturing

	1972[1] (1991)[2]	1980 (1999)	1988 (2007)
Steel	147.6	138.3	129.0
Compressor	30.3	28.2	26.0
Plastics	14.0	21.6	29.0
Fiberglass	17.9	8.9	0.0
Polyurethane Foam	4.0	11.0	18.0
Aluminum	7.9	10.4	13.0
Copper	0.6	0.8	1.0
Miscellaneous	5.7	6.8	8.0
Total	228.0	226.0	224.0

[1] Year of manufacture.
[2] Year of disposal.

Source: American Plastics Council.

CONSUMPTION OF PLASTICS IN APPLIANCES

The use of plastics as a material for parts of major household appliances has followed the same evolutionary path as plastics in other industries. Plastic materials were developed that could cost-effectively replace traditional materials, such as metals and glass, by mimicking their appearance and performance characteristics. Plastics have unique appearance and performance characteristics that can be used in the design of appliance parts and even new appliances.

The use of plastics in large household appliances has grown from less than 1% of material content in the 1960s to as much as 25% (Hagan 1994) by weight today. The amount of plastic used in the appliance manufacturing industry now totals more than 1.2 billion pounds (Mooney undated). In 1991, the largest applications for plastics (Mooney undated) in household appliances were in refrigerators (241 million lb) and washing machines (134 million lb). These two appliances account for more than 45% of all plastics consumed by household appliances. Figure 2 shows the changes in the plastics contents (Baumgartner 1993) of some typical household appliances.

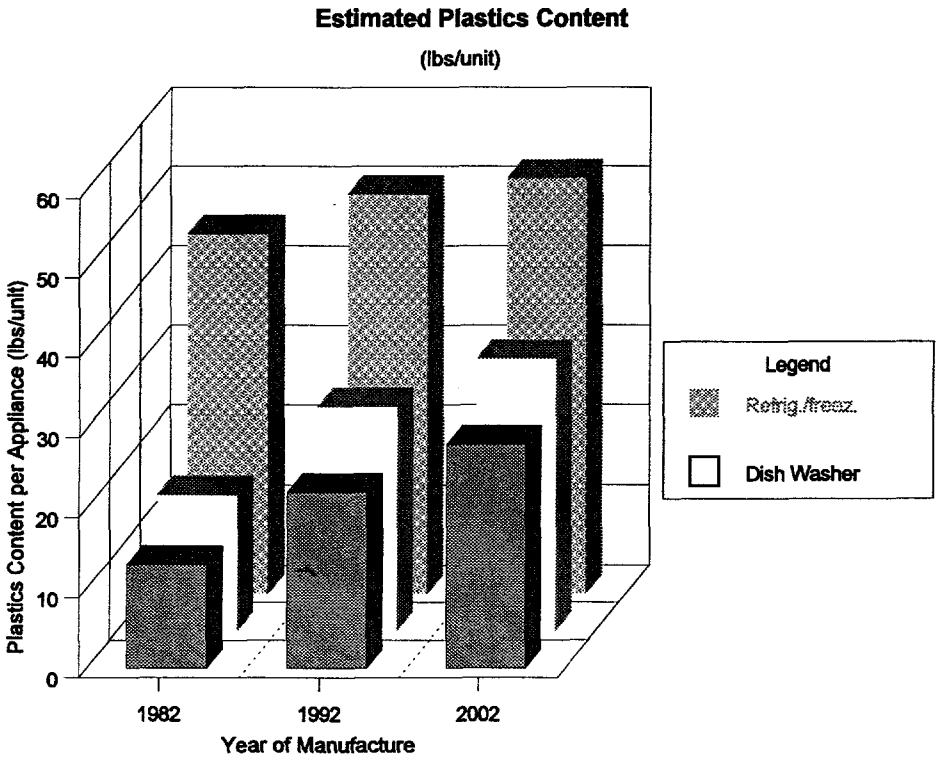

FIGURE 2 Plastic Contents of Typical Appliances

TECHNICAL AND ECONOMIC ISSUES IN RECOVERING AND RECLAIMING PLASTICS

Recycling of postconsumer plastics is primarily confined to nondurable goods, such as packaging media (e.g., film or bottles). A major factor in the increased recycling of these plastics is local regulations that mandate recycling of specific items made of plastics, glass, aluminum, and steel. On the other hand, the recycling of appliances is driven primarily by the value of steel. Before the steel can be recovered, however, hazardous substances such as PCBs, refrigerants, and mercury must be removed from the appliances. The appliances then go through a shredding or disassembly operation so that the metals can be recovered. A by-product of the metal recovery operation is the nonmetallic fraction, which is rich in plastics and is commonly called "fluff." The fluff is currently disposed in landfills at a cost of $10-40 per ton. The plastics fraction generated from an appliance disassembly operation, such as the one employed by the Appliance Recycling Centers of America Inc., is a much cleaner mix of commingled plastics and may be separated into its constituent parts more easily. The plastics most commonly found in the nonmetallic fraction are acrylonitrile butadiene-styrene (ABS), high-density polystyrene (HIPS), polypropylene, and polyurethane.

ARGONNE/INDUSTRY COLLABORATIVE RESEARCH FOR RECOVERING AND RECLAIMING PLASTICS FROM APPLIANCES

Two high-volume, high-value plastic materials used in appliances manufacturing, ABS and HIPS, are currently being targeted by the Argonne/Industry research effort for recovery and recycling to high-value applications. The research effort addresses two important technology and process needs: (a) cost-effective technology for separating ABS and HIPS from commingled plastics and (b) methods for improving the performance characteristics and market value of the recovered plastics.

Argonne research in separating individual plastic materials from commingled appliance plastics has focused on the development of mechanical/physical and chemical processes for recovering high-purity ABS and HIPS materials. A laboratory-scale plastics separation process has been developed and is currently being evaluated to assess its separation efficiency and economic feasibility for recovering ABS and HIPS. The process is based on "sink-float" technology, in which materials float away from each other because of differences in their densities. The commingled plastics are separated into four parts: foam, HIPS-rich fraction, ABS-rich fraction, and heavy materials with densities above 1.15. Through this process, ABS concentrations of up to 80% have been achieved. To further increase the purity of the ABS, a solvent-assisted process is being developed. Preliminary test results indicate this process can increase the purity of the ABS to more than 95%.

A major contaminant on the surface of refrigerator plastic liner materials is the rigid foam insulation that is bonded to the ABS refrigerator liner material. At first, it appeared that a costly process would be needed to remove the foam from the ABS surface. The problem was solved, however, by shredding the commingled plastics into small pieces approximately 1/4 in. in diameter. When the plastics are shredded, the brittle rigid foam breaks away from the ABS liner materials.

As part of the research, the performance qualities of the ABS and HIPS materials from appliances that may have been in use for 15-20 years were determined. A 150-lb ABS sample was produced with the new plastics separation processes, and its properties were evaluated. The preliminary research indicates that the properties of ABS materials used in refrigerator liner materials 15-20 years ago, with the exception of Izod impact strength, are similar to the properties of virgin materials. The Izod impact strength of the recovered material was significantly lower than that of the virgin ABS, probably because of improvements in current materials, degradation of the ABS over the life of the appliance, and possible sample contamination. The use of impact modifiers for improving the Izod impact strength of the recovered ABS materials proved to be successful. More research is needed, however, to assess the economic trade-offs of using costly additives to improve the properties of plastics from discarded appliances. In addition, pigmented plastic materials in recovered ABS that was extruded and pelletized for properties analysis caused inconsistent coloring in the pellets. Researchers from ARCA Inc. have indicated, however, that the colored plastics can be separated at a minimum cost at the appliance processing facilities.

In the future, research activities will focus on improving the efficiency of the separation processes, and plans are under way to scale up the processes to further evaluate their technical and economic performance. Research in the development of cost-effective methods for improving the properties of plastics recovered from discarded appliances will also continue.

ACKNOWLEDGMENT

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