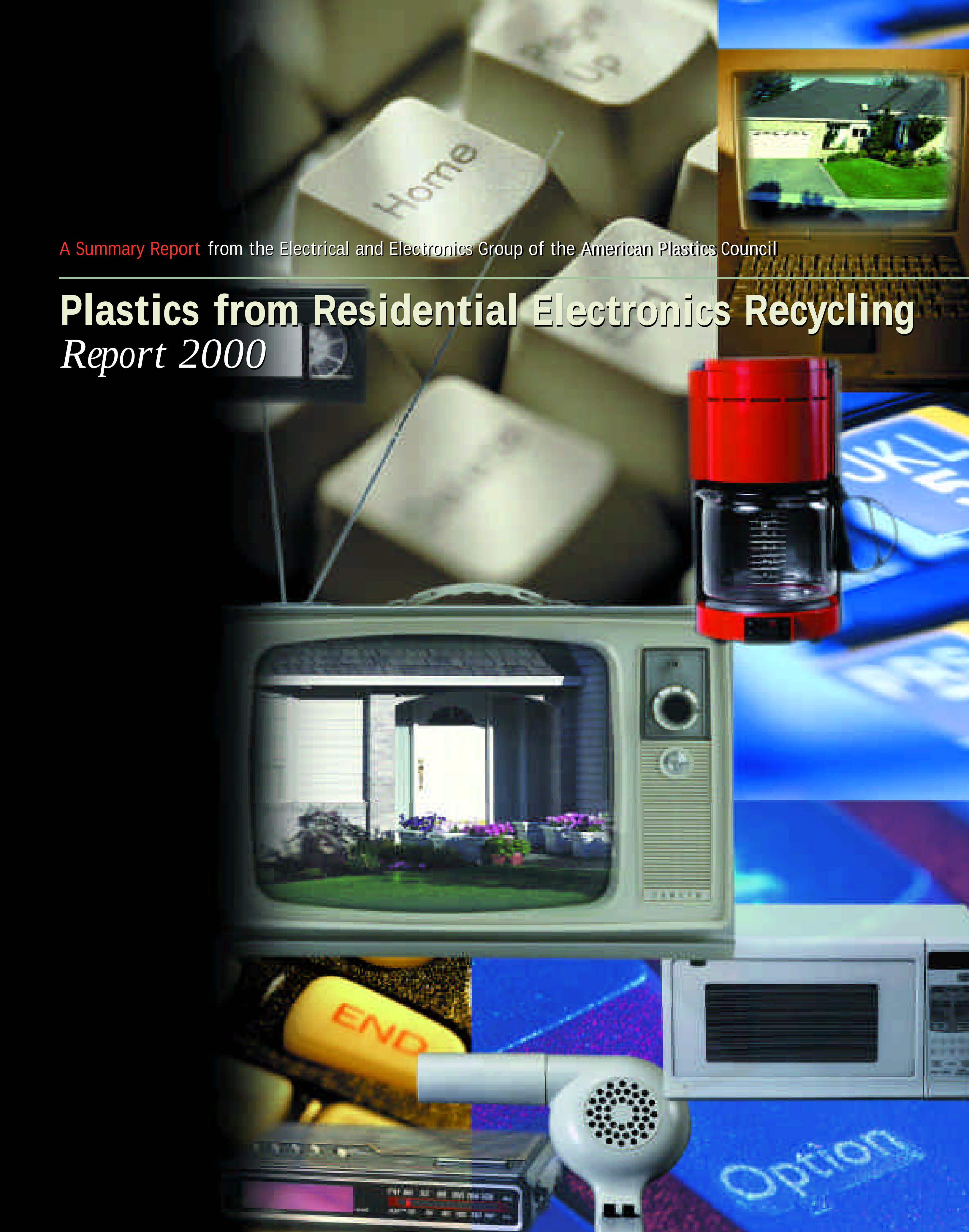
A Summary Report from the Electrical and Electronics Group of the American Plastics Council

Plastics from Residential Electronics Recycling

Report 2000



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Prepared by

Headley Pratt Consulting for the
American Plastics Council

April, 2000

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Plastics from Residential Electronics Recycling: *Report 2000*

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Dear Reader,

The American Plastics Council (APC), in collaboration with Headley Pratt Consulting, is pleased to bring you this groundbreaking report titled *Plastics from Residential Electronics Recycling: Report 2000*. This report provides a comprehensive summary of the role of plastics in consumer electrical and electronic (E&E) equipment from product design through recovery and recycling.

The emphasis in this report is on E&E equipment collected from residential sources. This is the area receiving attention from municipalities and states as they begin to address the expanding volumes of obsolete computers, TVs, and other consumer electronics and small household appliances. The collection, remanufacturing, and recycling infrastructure for the industrial and business sector has evolved significantly over the past ten years compared to the residential sector. Readers involved in all aspects of E&E equipment recovery, however, will find the plastics-related information in *Report 2000* of interest.

Report 2000 provides up-to-date information addressing the following key questions:

1. What are the types of consumer electrical and electronic products in use today?
2. Why are plastics used in the manufacture of these products?
3. What types of products are appearing in collection programs?
4. How much plastic relative to other materials is contained in these products?
5. What are the types of plastics found in these consumer electrical and electronic products?
6. What is the amount of each type of plastic?
7. What is the state-of-the-art with respect to plastics recycling from end-of-life (EOL) electrical and electronic equipment?
8. What is the interplay of technical, economic, environmental, and market factors?
9. What are some of the private and public sector programs actively exploring plastics recovery from EOL E&E equipment?

As noted in the conclusion section of *Report 2000*, developing answers to these questions is an important first step toward understanding the E&E recycling landscape. But it is only a first step. What we know today is based on limited collection programs and a limited analysis of material. As more consumer electronics are collected and processed, and as more research is conducted, our understanding of what can and cannot be done will evolve. Certainly, public-private partnerships—such as those described in this report—will be extremely valuable in ensuring that our knowledge base continues to grow.

We hope you find this report of value, and we welcome your feedback.

Sincerely,
Michael M. Fisher, Ph.D.
Director of Technology

Introduction

In recent years, numerous businesses, states, counties, and municipalities have begun asking a common question: "What is the best way to manage electronics from households and businesses once they are no longer in use?" In the past, nearly all electronic equipment was either landfilled or incinerated, or, in a few cases, a loose network of companies would disassemble a portion of it, extract the precious metals, and dispose of the remaining parts. Today, however, people have begun to question whether that is the best economic and environmental practice. Specifically, they want to know whether used electronic equipment can effectively be recycled, and if so, how.

Unfortunately, that is a difficult question to answer because little information exists on recycling electronic equipment. Few resources document what quantities of equipment are available, what types of equipment are found in which waste streams, what materials the equipment is made with, what technologies exist for material recovery, and what value materials might have upon disassembly and separation. While the body of research in this area is growing, many questions remain.

Another complicating factor is that the information that does exist on electronics recycling is often difficult to interpret. The items generated by sector vary substantially, as do the types of collection programs, program timelines, and data tracking methods. Even the definition of electronic equipment varies significantly from program to program. All of these factors make it difficult to compare existing data and draw meaningful conclusions.

Despite these obstacles, groups like the American Plastics Council[1] (APC)—a national trade association of plastic resin producers—have begun to conduct a number of research projects in an effort to better understand end-of-life electronic equipment and what recycling it might entail. This report is intended to summarize much of what APC has learned to date, particularly about recycling plastics from consumer electronics.

Exhibit 1

Examples of Electrical and Electronic Equipment

Residential	Commercial/Industrial	Both
Brown Goods -Televisions -Audio/stereo equipment -VCRs -Radios -Video cameras -Speakers	**Electrical Equipment Materials** -High power materials or high voltage materials (e.g. large transformers) -Transformers -Small electric engines -Distribution equipment low voltage switches -Low voltage industrial equipment and relays -Electrical materials installations (e.g. circuit breakers)	**Data Processing** -Personal computers -Monitors -Small & intermediate systems -Mainframes -Keyboards
Small Domestic Appliances -Vacuum cleaners -Hair dryers -Coffee makers -Electric knives -Irons -Fryers -Food processors -Toasters/toaster ovens -Fans -Microwaves	**Medical Equipment** -X-ray equipment -Ultasonic equipment -Computer tomographs -Oscilloscopes -Recording and printing measuring instruments	**Telecommunications** -Telephones -Facsimilies -Answering machines -Public telephones -Cellular phones -Pagers -Transmission equipment
Large Domestic Appliances -Refrigerators -Freezers -Washing machines -Clothes dryers -Dishwashers -Ovens	**Office Equipment** -Copiers -Printers	**Other** -Wire and cable

Specifically, the report will use a combination of data from APC, data from other sources, and case studies from Hennepin County, Minnesota, and San Francisco, California, to try to answer such basic questions as:

- What items are included in the definition of electronic equipment?
- What types and quantities of electronics are present in the waste stream?
- What materials are these items made with?
- Why are plastics used in their manufacture?
- What types and quantities of plastics are available upon recovery?
- What contaminants are present?
- What products can be manufactured with plastics recovered from end-of-life electronics?

APC hopes that by answering these questions, businesses, states, counties, and municipalities will have more complete information with which to make decisions about if and when recycling electronic equipment is an effective waste management option. At the very least, the report will highlight what data currently exists and identify where information gaps need to be filled. APC anticipates updating this report periodically as new information becomes available.

What is Electronic Equipment?

In the broadest sense, electronic equipment refers to any product that relies on batteries and/or electricity for operation, as well as equipment—such as wire and cable—that transports electricity to the product. (The latter is often referred to as "electrical" as opposed to "electronic" equipment.) Exhibit 1 provides a list of the items that meet this broad definition.

When looking at recovery options, it is important to keep in mind that not all of these products will show up in every waste stream. For example, electronic equipment diverted from the *commercial* waste stream will not include many large or small domestic appliances or brown goods. Conversely, equipment diverted from the *residential* waste stream will not include many transformers, oscilloscopes, X-rays, or mainframes. And, white goods—such as refrigerators, freezers, and washing machines—should not show up in either waste

WHAT DOES ELECTRONICS RECOVERY INVOLVE?

When recovering any product or package from the waste stream, there are certain steps or phases that the product or package must go through. Following is a description of the five basic steps or phases that recovered electronics typically go through, although they may not always occur in the same order. Note that reuse and remanufacturing should be explored prior to pursuing material recycling options.

- **First**, electronic equipment must be collected. Today, consumer electronics most often are collected at special one-day events, although they may also be collected at the curb, at permanent drop-off locations, and/or at consumer electronic retail outlets. Consumer education on collection programs is important.
- **Second**, electronics are evaluated for their reuse potential. If a product is in good working condition, it usually will be refurbished and resold or donated to an organization, such as a school or local charitable group.
- **Third**, if it does not make economic sense to refurbish a piece of equipment (that is, the labor and upgrade costs outweigh its potential resale value or the product simply is not in demand), it is disassembled into its component parts. Typically, potentially hazardous materials—such as batteries and more frequently CRTs—are removed and disposed of according to state and federal guidelines. If there are any working parts that have value, they are resold intact. Any remaining parts and materials—such as precious metals, other metals, plastics, circuit boards, disk drives, motors, and so forth—are then separated into discrete streams for further processing. If a stream has value—which means that it is present in a quantity and quality sufficient to interest an end market—then the stream is processed for recycling. If not, it is recovered in a waste-to-energy facility or disposed of in a landfill.
- **Fourth**, those streams that are segregated for recycling undergo further processing. That may include shredding, granulating, baling, washing, and/or further identification and separation.
- **Fifth**, once a clean, high-quality stream of material is produced—and it is qualified by the end user for a particular application, which often can take months or even years—it is consolidated and shipped to an end market that will use it to manufacture new products. It is important to keep in mind that, if this fifth and final step is not completed, recycling has not occurred.

Exhibit 2

Types and Number of Items Collected in Hennepin County (1992-1999)

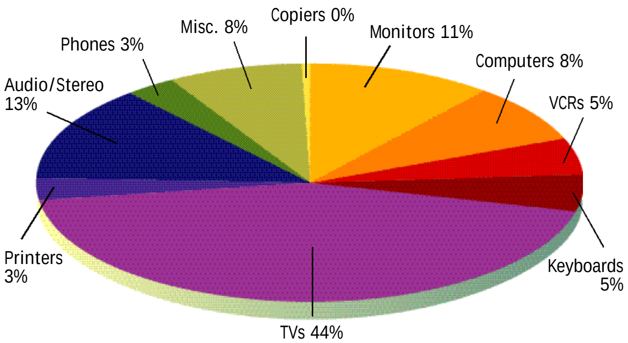
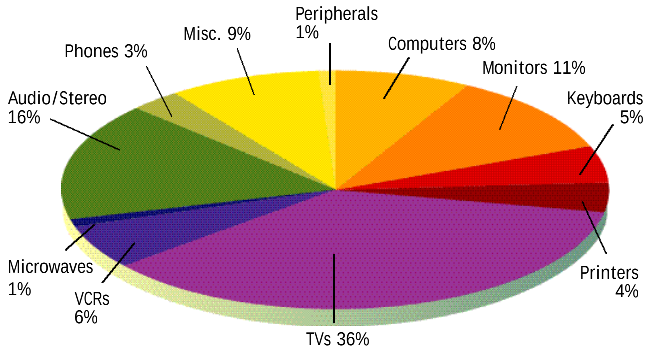


Exhibit 3

Percentage by Type and Number of Items Collected, Weighted Average of Five Collection Events (Source: U.S. EPA)



stream since a separate collection infrastructure exists in most places for managing them. Therefore, how one defines electronic equipment depends, in large part, on the waste stream in which it is found. That definition, in turn, will determine what materials a program needs to collect, process, separate, and market in order to successfully recycle electronics. (See the sidebar entitled "What Does Electronics Recovery Involve?" for more information on the recovery process.)

In this report, APC has chosen to focus on electronics typically found in the *residential* waste stream—or what is commonly referred to as consumer electronics. (This includes brown goods, small domestic appliances, home office, data processing, and telecommunications equipment as shown in Exhibit 1.) This decision was made for a number of reasons. First, the infrastructure for recycling residential electronics is less well established than for commercial electronics. A recent report published by the National Safety Council's Environmental Health Center found that, in 1998, approximately 9.7 million units (or 275 million pounds) of electronic equipment were recycled in the United States.[2] More than 75 percent of those units came from original equipment manufacturers (such as IBM, Hewlett Packard, Xerox, and others) and large-scale users—that is, the commercial sector. Conversely, only a small portion (less than 3 percent) came from individuals.

Second, APC chose to focus on electronics in the residential waste stream because they present greater challenges for recycling. Not only is there a wider range of potential items to recover, but the items found in the residential waste stream tend to be much older. Hennepin County, Minnesota, which has been collecting electronic equipment from the residential sector for a number of years, estimates that its televisions are typically between 20 and 25 years old and its computers are between 10 and 15 years old. That means that (1) the items are not good candidates for reuse, (2) the types of material used to manufacture them are more diverse and less likely to be found in current products, and (3) because of their age and diversity, the materials are more difficult to identify upon disassembly.

Third, electronics from the residential waste stream are collected in many different ways. They are collected at the curb, at permanent drop-off locations, at special one-day collection events, and/or at consumer electronic retail outlets. The absence of a standard collection method means that the types and quantities of electronic equipment recovered vary substantially from program to program, making it difficult for recyclers to determine what materials will be generated, in what quantities, and with what regularity. Since end markets depend on a consistent supply of material, the wide variations that come with different collection methods make recycling more challenging.

Finally, APC chose to focus on consumer electronics because they are more visible to the general public and, therefore, a more likely target for municipal solid waste management programs. The availability of sound data and information will be particularly critical to state and local governments as they debate how to best manage end-of-life electronics.

What Products are Present in the Residential Electronics Waste Stream?

Before you can answer the question of whether it is feasible to recycle electronics from the residential waste stream, you first need to understand the composition of that waste stream. In an effort to do that, APC asked Hennepin County, the focus of one of its case studies, to provide information on the types and numbers of products it had collected over the years. Data from 1992 through 1999 (see Exhibit 2) shows that televisions accounted for 44 percent—or nearly half—of the more than 122,000 products collected by the County over the course of the program. Audio/stereo equipment was the second most prevalent product (at 13 percent) followed by computer monitors (at 11 percent).

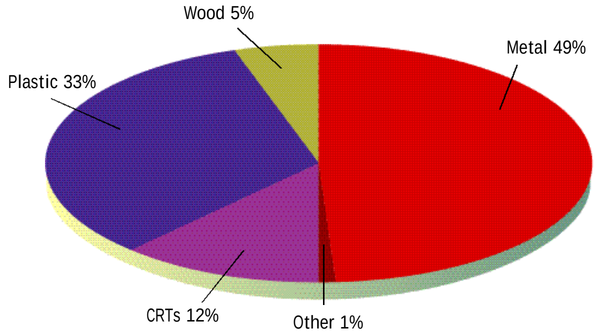
Data compiled by the U.S. EPA supports these findings. (See Exhibit 3.) In its study of five residential electronics collection programs, the EPA found that televisions comprised 36 percent of the total waste stream, followed by audio/stereo equipment (at 16 percent) and monitors (at 11 percent).[3] These numbers, which are similar to those reported by Hennepin County, show what a typical program might expect if it were to collect consumer electronics for recycling.

Interestingly, the mix of electronic products has changed over time. For example, when Hennepin County first started collecting consumer electronics for recycling, televisions accounted for 71 percent of the total electronics waste stream, whereas in 1999, they accounted for only 41 percent. Conversely, in 1992, computers and monitors accounted for only 6 percent of the consumer electronics waste stream, whereas today they account for 25 percent.

Having accurate data on the types and numbers of electronic items found in the residential waste stream is important because it will dictate what types of materials a program will generate for recycling. For example, with televisions and monitors comprising almost half of the products recovered, it is clear that managing the glass from cathode ray tubes (CRTs) will be a high priority. Similarly, the high percentage of televisions—particularly old televisions—means that programs can expect to recover a fair amount of wood. Finally, as the percentage of televisions decreases and the percentage of computers and monitors increases, the types of materials that will be generated in the future will be different than they are today.

Exhibit 4

Materials by Weight of Separated Post-Consumer Electronics (Source: U.S. EPA)



What Materials Are Used to Manufacture Electronic Products Found in the Residential Waste Stream?

Once it is clear what types of electronic products are available for recycling, the next step is to determine what materials those products are made with. In general, electronic equipment is manufactured from steel, aluminum, copper, glass, plastic, precious metals (including gold, palladium, platinum, and silver), and other miscellaneous materials, such as paint, rubber, and wood. While there is little data available on the amounts of these materials that are used to produce electronic equipment, there is at least one study that has shown how much of each material is present after demanufacturing.

In a recent report on residential collection of electronics, the U.S. EPA analyzed data from two residential programs—one in Somerville, Massachusetts, and one in Binghamton, New York.[4] The programs—which were operated during 1997 and 1998—collected a total of 1,862 items during four collection events and generated 15.8 tons of post-consumer electronics. Once the electronics were demanufactured, the EPA found that nearly half of the material recovered by weight from electronic equipment was metal and one-third was plastic. CRTs (primarily glass) comprised another 12 percent of the total, wood comprised 5 percent, and the remaining 1 percent consisted of “other” materials, such as capacitors and batteries. (See Exhibit 4.)

After calculating the amount of each general material category by weight, the EPA then broke the categories down further to determine what specific materials a consumer electronics recovery program could

Exhibit 5

Summary of Types and Weights of Post-Consumer, Residential Electronics

MATERIAL	TOTAL WEIGHT (IN POUNDS)	PERCENT OF TOTAL WEIGHT
Total Wood	**1,545**	**4.90**
Total CRTs (mostly glass)	**3,842**	**12.19**
Total Plastic	**10,424**	**33.09**
Scrap plastic[1]	4,105	13.03
Carcass	3,719	11.80
Clean plastic[2]	2,594	8.23
Phone plastic	7	0.02
Total Metal	**15,362**	**48.76**
Metal	8,281	26.28
Motor	1,273	4.04
Wire	874	2.77
Aluminum	441	1.40
Cast aluminum[3]	23	0.07
Copper	562	1.78
Disk drive[4]	440	1.40
Transformers	1,156	3.67
Yokes[5]	429	1.36
Fans	240	0.76
Radiators	1,203	3.82
Freon tanks	441	1.40
Total Other	**332**	**1.05**
Refine boards[6]	234	0.74
Power supply	21	0.07
Capacitors	38	0.12
Batteries	4	0.01
Toner	35	0.11
TOTALS	**31,505**	**100**

Source: "*Residential Collection of Household End-of-Life Electrical and Electronic Equipment* (February 1998)," U.S. EPA.

1 Scrap plastic refers to plastic pieces that are contaminated with paint, connectors, or foam or have two types of plastic molded together.
2 Clean plastic is plastic that is homogenous and free of all contaminants
3 Cast aluminum is a heavier type of aluminum that is less malleable.
4 A disk drive is a device that computers use to store information. It may be metal or plastic.
5 A yoke is a copper and steel metal assembly at the neck of the CRT.
6 A refine board is a higher grade of board (i.e., mother board, processors) in which the metals have more value.

expect to generate. In that analysis, the EPA identified 23 separate commodities that could potentially be recycled. (See Exhibit 5.)

As this data shows, there are few large, homogenous streams of material that can be targeted for recycling. While half of the material generated is metal, only half of that is what the EPA defines as scrap metal for which there is a well developed recycling infrastructure. The remaining 46 percent is made up of eleven different categories of metal, none of which comprises more than 8 percent of the total. Given the comparatively small volume of each of these eleven materials, it may be difficult to market them.

Plastics face similar challenges. While they comprise about one-third of the material recovered from the programs studied, only 25 percent of that is what the EPA defines as clean plastic—or plastic that is homogenous and free of contaminants. If this material can be identified and separated, and if there is a sufficient quantity, there is a chance it can be marketed. The remaining plastics, however, present greater challenges to recycling.

To better understand those challenges, APC joined forces with MBA Polymers, Inc.—a research center and durables processor located in Richmond, California—to conduct characterization analyses on electronics recovered from residential collection programs. The goal of the analyses was to study real world collection programs to determine

- which plastic resins were present in the residential electronics waste stream and in what quantities,

- what contaminants were present and in what quantities, and
- whether it was feasible to separate plastics into streams that could be marketed to end-users.

As part of that research, though, it is important to first understand why various types of plastics are used in electronic equipment, particularly because their characteristics and properties will determine the products into which they can be recycled.

Why are Plastics Used in the Manufacture of Electronic Equipment?

A variety of materials are used in the manufacture of electronic equipment, including aluminum, copper, steel, glass, plastic, and wood. Each of these materials has properties that enable manufacturers to meet specific cost-performance requirements in specific electronic parts.

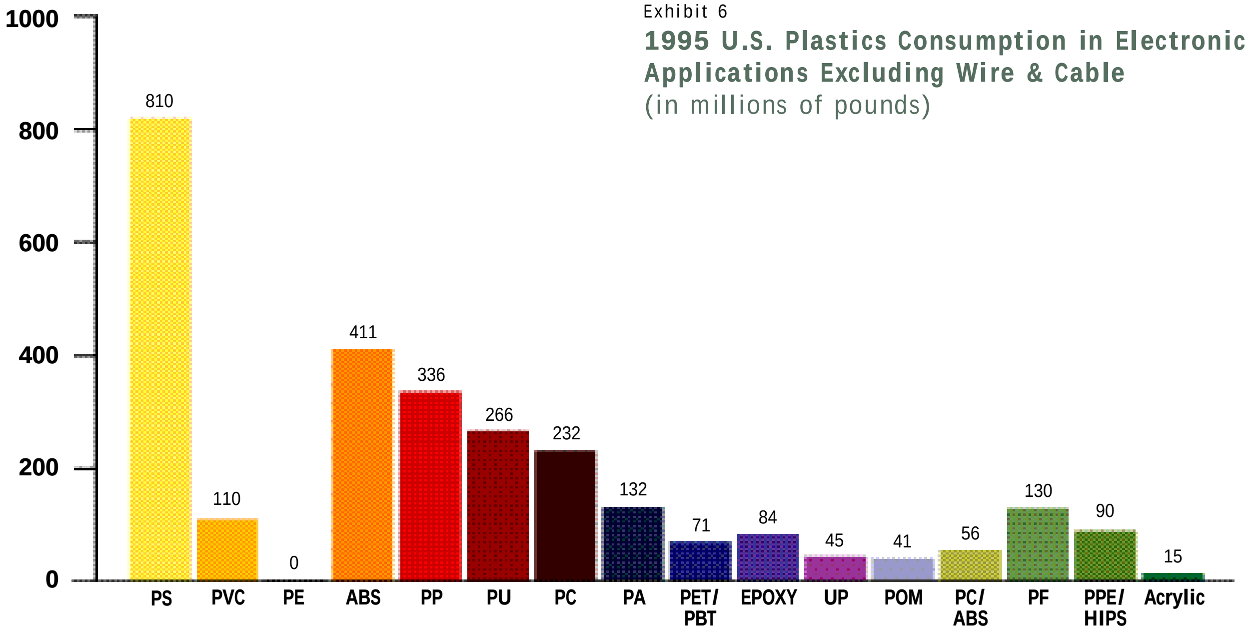
Plastics have an unusually wide range of properties. As the Association of Plastics Manufacturers in Europe (APME) explains in its report, "Plastics: A Material of Choice for the Electrical and Electronic Industry,"[5] manufacturers use plastics because they are durable, lightweight, flexible, cost-effective, corrosion-resistant, and have excellent insulation properties. These properties allow manufacturers to produce highly functioning electronic products while also responding to changing consumer demands.

Following is a more detailed discussion of the properties that plastics have and the role they play in electronic applications.

- **Durability:** Because consumer products often have fairly long lives, they must be made with materials that can withstand wear and tear. It is estimated that consumer electronics (including appliances) are usually in service between 5 and 40 years. Plastics are extremely durable which means they can help manufacturers build equipment that not only performs well but also remains intact over the course of its expected life. Given that consumers make considerable investments in electronic equipment, it is imperative that it reaches its life expectancy.
- **Lightweight:** When consumer electronics were used mainly in homes and businesses, the weight of the product was not much of an issue, except perhaps during transport. Now, however, in the age of mobile phones, laptop computers, and mobile televisions, weight is extremely important. Because plastics are lightweight, they have enabled manufacturers to meet the demand for mobility without sacrificing performance. The weight of plastics also has helped manufacturers achieve efficiencies. Through thin walling, manufacturers can use less plastic (i.e., fewer resources) to make the same amount of equipment, and because the equipment weighs less, it costs less and uses fewer resources to transport. Finally, because of its formability, plastics have allowed for the miniaturization of products—such as micro tape recorders, small cellular phones, and notebook computers—which means that products not only weigh less but also take up less space in shipping, storage, and display, not to mention in the telecommuter's briefcase.
- **Versatility:** Plastics, more than any other material, are extremely versatile. They can be molded and shaped to fit a wide range of design specifications, which enables manufacturers to produce a correspondingly wide range of parts and products. This versatility is important, particularly in the Information Age, as consumer demands are growing and changing at faster rates. In recent years, the versatility of plastics in electronic applications has been increased through such things as molecular design, blending, alloying, and other compounding methods that allow various fillers and reinforcements to be added to plastics to form composite materials. These composites help products perform in new and better ways—ways that could not be achieved by any single material. Plastics also bring an impressive array of colors and levels of clarity to product designs.
- **Cost-Effectiveness:** One of the reasons plastics are cost-effective is because they are easy to process. Easy processing allows manufacturers to simplify the production process and reduce production time, both of which translate into greater production efficiencies and lower costs. Plastics also enable manufacturers to integrate many different component parts within a single product, which helps simplify or streamline the manufacturing process even further. This, in turn, allows mass production of electronics to occur and, when mass production occurs, additional cost reductions usually follow. Plastics also are cost-effective because of reasons mentioned earlier—thin-walling means manufacturers can use less material which lowers raw material expenditures and lighter weights mean lower transportation costs. All of these cost savings help make products, like mobile phones and computers, more affordable for the consumer.

Exhibit 6

1995 U.S. Plastics Consumption in Electronic Applications Excluding Wire & Cable
(in millions of pounds)



- **Heat and Corrosion-Resistance:** Since heat is generated while operating electronic equipment, any materials used in them must be heat resistant. This has become increasingly important in recent years as faster operating speeds have increased thermal stresses. In addition to being heat resistant, material in electronic products also must be resistant to corrosion. Since plastics can be made resistant to heat and are inherently corrosion-resistant, they are ideal for use in electronic applications.
- **Insulation Properties:** Plastics have excellent electrical insulation properties, which, combined with durability, make them ideal for use in such things as wire and cable. If plastics did not have these properties, electricity could not be conveyed safely from outlets to electronic products. Plastics' insulation properties also have value in consumer products where it is necessary to protect the area surrounding electronics from heat generated during operation. Interestingly, when called upon, plastics can be designed to be electrically and thermally conductive, further demonstrating their versatility.

Clearly, plastics—like steel, aluminum, copper, and glass—have an integral role to play in the manufacture of electronic equipment. Their performance characteristics have helped manufacturers achieve their goals, which, in turn, has allowed the electronics industry to meet the needs of consumers. Because plastics will continue to be used in electronic equipment—in fact, their use will increase—it is important to understand which resins are present and what effect their presence has on recycling opportunities.

What Plastic Resins Are Used in Electronic Equipment?

In 1995, approximately sixteen different generic plastic resins were sold into the electrical and electronic sector in any significant amount. They include:

- Acrylic (mostly polymethyl methacrylate or PMMA)
- Acrylonitrile Butadiene Styrene (ABS)
- Epoxy
- Phenol Formaldehyde (PF)
- Polyacetal (POM)
- Polyamide (nylon) (PA)
- Polycarbonate (PC)
- Polycarbonate/Acrylonitrile Butadiene Styrene blend (PC/ABS)
- Polyethylene (PE)
- Polyethylene Terephthalate (PET)
- Polybutylene Terephthalate (PBT)
- Unsaturated Polyester (UP)
- Polyphenylene Ether/High-Impact Polystyrene blend (PPE/HIPS or PPO)
- Polypropylene (PP)
- Polystyrene (including high-impact polystyrene or HIPS) (PS)
- Polyurethane (PU)
- Polyvinyl Chloride (PVC)

To get a sense of the overall prevalence of these resins, APC used data from the Society of the Plastics Industry (SPI) and *Modern Plastics* to determine approximately how much of each resin was sold into the electrical and electronic sector. (See Exhibit 6.) APC backed out resins that were sold primarily into wire and cable, since very little of those products are present in the residential waste stream. The major resins used in wire and cable are PVC, PE, and nylon.

As Exhibit 6 shows, the six most common resins sold into electronic equipment applications are PS (29 percent), ABS (14 percent), PP (12 percent), PU (9 percent), PC (8 percent), and PF (5 percent). These six plastics make up about 77 percent of total resin consumption.

This data, however, should be used with caution for a number of reasons:

(1) The data includes resins that are sold into large household appliances, electrical equipment materials, office equipment, and medical equipment—products that will not be present in large quantities in the residential electronics waste stream.

(2) The resin data is based on 1995 sales figures. Given that most consumer electronics that are collected from the residential sector for recycling were manufactured prior to 1995, it may not be an accurate representation of what will be recovered.

(3) This data relies solely on sales figures, which show what was purchased by processors, but does not necessarily represent what went into the production of actual products or what one can reasonably expect to recover from end-of-life product streams.

(4) The data is not comprehensive. It does not differentiate between flame retardant and non-flame retardant grades, types of fillers and reinforcements, or colors. In addition, it does not include specialty resins that are used in specific applications. Although these resins appear in relatively small quantities—which is why they are not reflected in SPI or *Modern Plastics* data—it is important to know that they are sometimes used in electronic applications.

For these reasons, APC believes that while industry sales data is helpful in getting a sense of the types and quantities of plastics found in electronics, data from real world collection programs is more reliable in assessing current recycling opportunities.

HENNEPIN COUNTY'S CONSUMER ELECTRONICS COLLECTION PROGRAM

In 1992, Hennepin County—which is located in the eastern portion of Minnesota and includes the city of Minneapolis—started collecting electronic equipment from the public. The goal of the program was not only to recycle electronics, but also to reduce waste and remove heavy metals—such as mercury, lead, and cadmium—from the solid waste stream.

Hennepin County uses a variety of methods to collect consumer electronics. Residents are allowed to drop them off at two permanent drop-off sites—one located in Brooklyn Park and the other in Bloomington. The County and cities also have periodic collection events. And, in November 1997, Minneapolis added curbside collection service within the city limits. If residents want to use the curbside service, they simply set the electronic product out on recycling day, and the next working day the city dispatches a vehicle to collect it. Data from 1998 and 1999 shows that 43 percent of the electronics collected in the program come from the city of Minneapolis, 43 percent come from the two permanent drop-off facilities, and 14 percent come from special collection events

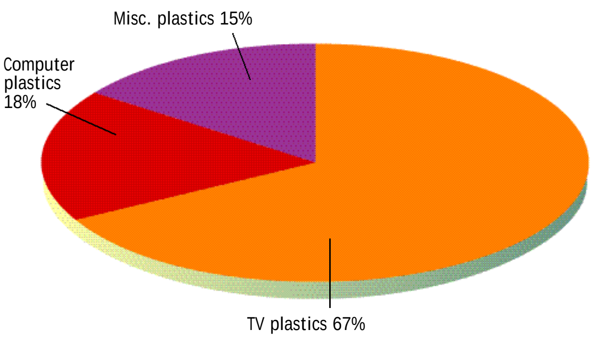
Once electronic products are collected, they are transported to a local train-to-work, not-for-profit organization that is responsible for disassembling them. The scrap metals that are extracted are recycled; the plastics and wood are sent to a waste-to-energy facility; and the CRTs are disposed of via a secondary lead smelter. All other materials, such as circuit boards, batteries, mercury relays, and PCB-containing components, are handled as hazardous or special wastes according to state and federal guidelines.

Since its inception, the County's electronics collection program has grown considerably. In 1992—the year the program began—the County collected a total of 11 tons of consumer electronics. By 1999, that number increased to about 850 tons. Interestingly, the number of units collected increased from 1,241 in 1992-93 to approximately 43,000 in 1999. The County also estimates that the average weight per unit has dropped from 50 pounds per unit to 40 pounds per unit over the course of the program. The County believes that the growth in its electronics recovery program has, in fact, helped it achieve its original goals.

As mentioned above, the plastics generated from Hennepin County's program are currently going to a modern waste-to-energy facility. If it proves, however, that there are viable options for recycling them, then the County is interested in pursuing those options.

Exhibit 7

Breakdown of Hennepin Plastics Sample by Weight



What Types and Amounts of Plastic have been Found in Existing Consumer Electronics Collection Programs?

In order to gather "real world" data, APC partnered with Hennepin County to gather and analyze a sample of its plastics. Hennepin County collects consumer electronics through (1) the city of Minneapolis's curbside collection program, (2) two permanent drop-off sites located within the county's borders, and (3) other periodic collection events. (See the sidebar entitled "Hennepin County's Consumer Electronics Collection Program" for more information.)

The Sample

To gather the sample, Hennepin County asked sorters at its demanufacturing facility to disassemble incoming electronics as usual, but to separate plastics into three categories: television, computer, and miscellaneous plastics. Over the course of two weeks, the County collected 3,084 pounds of municipally derived plastics. Exhibit 7 shows a breakdown of the material by product type on a weight percentage basis.

The plastics were then shipped to MBA Polymers to determine (1) how much of the material was acceptable for further processing, and (2) of the acceptable material, which plastic resins were available in what amounts.

Acceptance or Rejection of Whole Plastic Parts

MBA Polymers started its analysis by accepting or rejecting whole plastic parts. The purpose of this exercise was to determine, prior to characterization, what number of parts had a realistic chance of producing recyclable plastics. (See the sidebar entitled "Acceptance or Rejection: MBA's Criteria" for more information.) MBA rejected parts if they

(1) contained metallized coatings or paint;
(2) were made of highly density-variable structural foam;
(3) obviously contained glass filler;
(4) contained greater than 25 percent metal by weight;
(5) contained composite plastics, such as printed circuit board materials;
(6) had 20 percent of its surface covered by labels or lamination that could not easily be removed; and/or
(7) contained more than three types of plastic.

When applying these criteria to the Hennepin County sample, MBA found that only 35 percent—or about one-third—of the plastics collected were acceptable for further processing (at least by MBA's standards, which are geared toward producing plastics for high-end products). The remaining 65 percent of the plastic parts met one or more of the rejection criterion.

ACCEPTANCE OR REJECTION: MBA'S CRITERIA

As with any material that is recycled, determining which plastics with what level of contamination are "acceptable" depends, in large part, on the markets into which the plastics are being sold. For example, specifications for consumer electronic plastics going into roadbed applications will be fairly wide or accepting, whereas specifications for plastics going into electronic equipment will be fairly stringent or exacting.

For its project work with APC, MBA Polymers developed rejection criteria that are reasonable for most high-end products. It noted that it may be able to produce medium- or lower-quality products by accepting a wider range of plastics, but added that its rejection criteria allows the company to significantly improve quality and, thus, sell plastics into markets of the highest level.

It is important to keep in mind, however, that MBA's criteria were developed for its specific recycling process and its potential markets. Even though a significant number of the plastic parts from consumer electronics were rejected by MBA for its analysis, the plastics still may be able to find a home in other recycled products. They may not, however, bring the highest value.

MBA then looked at the sample by product category to determine whether particular products provided cleaner streams of material. What it found was that plastic parts from computers were much more suitable for further processing than parts from televisions and miscellaneous electronics.

Television parts, in particular, had a high rejection rate—nearly 74 percent were considered unsuitable for further processing. Of the parts that were rejected, 37 percent had multiple combinations of metallized coatings, paint, labels, and lamination; 29 percent had just metallized coatings and paint contamination; 29 percent had just label/lamination contamination; and 4 percent met one of the "other" criterion mentioned above.

Miscellaneous plastic parts also had a fairly high rejection rate—59 percent were considered unacceptable for further processing. The reasons for rejection, however, were different. With miscellaneous plastics, the single largest cause for rejection (at 32 percent) was that parts contained more than 3 types of plastic. Another 27 percent were rejected for label/lamination contamination; 24 percent were rejected for metallized coatings or paint; 10 percent were rejected for containing more than 25 percent metal by weight; and 6 percent were rejected because they contained composite plastics.

Plastic parts from computers had a much lower rejection rate with only 36 percent considered unsuitable for further processing. In this stream, the largest cause for rejection (at 35 percent) was the presence of metallized coatings or paints. Another 28 percent were rejected due to large amounts of labels and lamination, 25 percent were rejected because they contained more than 3 types of plastic, 10 percent were rejected because of large amounts of metal, and 2 percent were rejected due to the presence of structural foam.

Identification of Plastic Resins

Once the rejected parts were removed from the sample, MBA then analyzed the remaining parts to determine which resins were present in what amounts. It used a Bruker FTIR spectrometer—one of the pieces of identification equipment that APC helped develop and test—to accomplish the task. (See the sidebar entitled "APC's Research on Identification and Sorting Equipment" for more information.)

MBA was able to identify nine basic plastic resins in the Hennepin County sample. Exhibit 8 shows the resins as well as the product categories and total percentages in which they were found.

As the exhibit shows, all of the resins are not present in equal amounts. When looking at the total plastic sample from Hennepin County, HIPS is the most prevalent resin, comprising 59 percent of acceptable plastics. ABS (including minor amounts of SAN) is the

Exhibit 8

Resins Found in Hennepin County Plastics Sample (in total and by product category)

Plastic Resin	Television Plastics	Computer Plastics	Miscellaneous Plastics	Percent of Total Sample
HIPS	75%	5%	50%	59%
ABS*	8%	57%	24%	20%
PPO	12%	36%	11%	16%
PP	3%		3%	2%
Other	2%	>1%	2%	2%
PE			6%	1%
PC/ABS		2%		>1%
PC			2%	>1%
PVC			2%	>1%

*This category includes a minor amount of SAN (styrene acrylonitrile).

next most prevalent resin at 20 percent; followed by PPO at 16 percent; PP and "other" at 2 percent; PE at 1 percent; and PVC, PC/ABS, and PC each at less than 1 percent.

Interestingly, these resins are found in widely varying quantities within product categories. For example, television and miscellaneous plastics consist mostly of HIPS (at 75 percent and 50 percent respectively), whereas computer plastics consist mostly of ABS and PPO (at 57 percent and 36 percent respectively).

In another case study of plastics from a consumer electronics collection program in the San Francisco Bay area, MBA generated similar breakdowns for three other electronic products—fans, stereos, and vacuum cleaners. The breakdowns have been included in this report to provide additional information on the types and amounts of plastic found in other household electronics. The Materials for the Future Foundation (MFF) along with APC and MBA organized the collection and evaluation of this sample.[6]

Separation of Plastic Resins

After identifying the plastic resins present in whole plastic parts, the next logical step would be to separate the resins into discrete streams. Doing so is necessary if post consumer/post-industrial processors, want

APC'S RESEARCH ON IDENTIFICATION AND SORTING EQUIPMENT

For a number of years, APC has been involved in a series of projects designed to develop and test identification and sorting equipment to further the recycling of plastics from durable goods, including electronics. To date, they have worked with a number of processors across the country to test more than ten different types of detection equipment in various forms—including hand-held, portable, bench-top, automated parts, and automated flakes. These systems use such things as specular reflection, fiber optic probes, acousto optical tunable filters, and diffuse reflection to differentiate plastic resins from one another as well as to identify contaminants.

APC has also worked with processors to develop and test various forms of separation equipment. A recent APC report, entitled "Development of Hydrocyclones for Use in Plastics Recycling," found that this technology is promising. Compared to other forms of density separation, the hydrocyclone is an economical and effective tool for separating mixed durable plastics and for removing many contaminants from a target plastic. It also offers advantages over other density-based separation techniques, namely lower costs, higher throughput, wider allowable particle size ranges, and fewer space requirements.

Finally, APC has been studying other alternatives for managing plastics from durable goods. This is important because, even as mechanical recycling efforts evolve, some plastics will still have to be managed in other ways. Therefore, APC is examining the roles that feedstock recycling, energy recovery, and landfilling can play in the integrated resource management of durable plastics.

To learn more about APC's studies and reports in these areas, call its toll-free information line at 1-800-2-HELP-90 or visit its website at www.plastics.org.

Exhibit 9
Plastic Resins in Fans
(from Bay Area Sample)

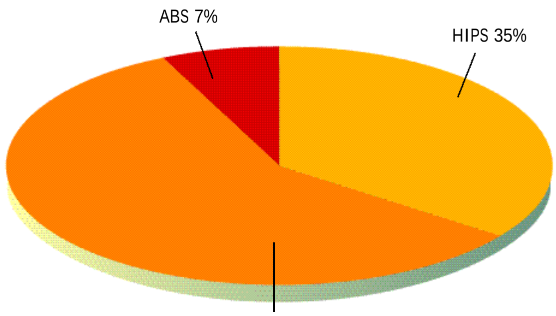
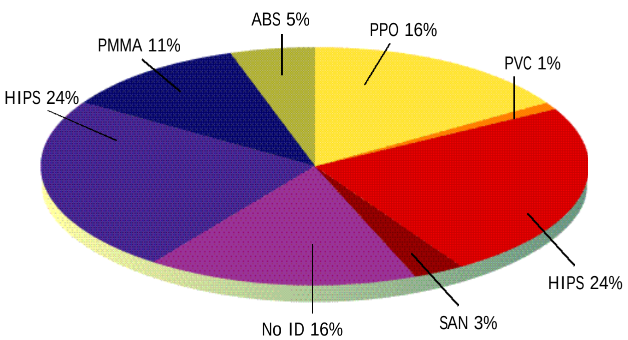


Exhibit 10
Plastic Resins in Stereos
(from Bay Area Sample)



to market pure streams of plastic.

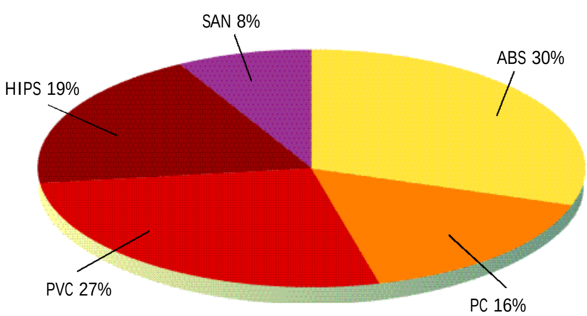
While this analysis was not performed on the sample from Hennepin County (because the volume of material was not sufficient to ensure accurate measurement), it was performed on a sample from the San Francisco Bay Area. In that analysis, MBA found that—through a combination of dry, wet (predominantly hydrocyclone-based), and proprietary developmental separation processing—it was able to produce a 100 percent pure stream of HIPS from television plastics. (See the sidebar entitled "Separating Plastics from the San Francisco Bay Area Electronics Collection Program" for more information.) It required significant processing, though, which raises the question of whether plastics have enough value to warrant the effort necessary to separate them. This is a key question that APC will be studying further as it explores the feasibility of recycling plastics from end-of-life consumer electronics.

What Does the Characterization Analysis Reveal About Recycling Plastics from Electronic Equipment?

Several important lessons can be learned from the characterization analysis of Hennepin County's plastic sample.

- **First**, we now have a better understanding of which resins can be found in consumer electronics and in what amounts. For example, HIPS, ABS, and PPO comprise a significant portion of the plastics found in electronics recovered from the residential waste stream. While the exact quantities of these and other resins will change over time, the information generated in the characterization analysis is an important first step in understanding what plastics might be effectively separated and marketed as part of electronics product recycling. It is interesting to note that, as expected, the resin data generated in the case study varied somewhat from industry sales statistics. As explained earlier, this is due, in large part, to the product mix and the fact that different resins were used to some extent in producing electronics 20 to 25 years ago.
- **Second**, there is a need for better sorting methods at the demanufacturing facility, particularly if recycling programs are going to move toward economic sustainability. Because storage and transportation are significant cost factors for recycling programs, programs cannot afford to store and ship parts that will be rejected. In Hennepin County's case, two-thirds of the plastics it shipped to MBA for the recycling study were not of high enough quality to enter MBA's system. (It should be noted, however, that no special attempts were made to address quality.) Those figures can be improved. In an analysis of consumer electronics from the San Francisco Bay area, MBA met with the demanufacturer prior to shipment and instructed employees on how to properly dismantle and sort plastic parts. As a result, significantly higher portions of the plastics were found acceptable for further processing.
- **Third**, because there are a variety of plastic resins present in consumer electronics, there is a need to develop better identification and separation equipment. APC and MBA have done a great deal of work in this area with a fair amount of technical success. Fast FTIR spectroscopy effectively identified nine basic resins in the Hennepin County sample. Similarly, the dry, wet, and proprietary processing techniques used by MBA on the San Francisco Bay Area sample proved that a pure stream of HIPS could be generated from consumer televisions. What is unclear at this point is (1) whether such efforts can be successful on a commercial scale, and (2) whether the complex level of processing necessary to create discrete streams of plastics makes overall environmental and economic sense.
- **Fourth**, some products contain more valuable plastics than others do. Televisions, for example, account for nearly half of the electronics recovered from the residential waste stream, but they are not a rich source

Exhibit 11
Plastic Resins in Vacuum Cleaners
(from Bay Area Sample)



of high value engineering plastics. Computers, on the other hand, are a rich source of high value plastics and, therefore, have a better chance of being effectively recycled. That means that, in order for consumer electronics recycling to approach feasibility from a plastics perspective, residential programs need to aggressively target computers and other electronic equipment. Again, this lesson proved true in the San Francisco Bay Area analysis. In that case study, APC, MFF, and MBA intentionally targeted a "plastics rich" stream of material, in which plastic parts from computers accounted for 63 percent of the total shipment. In that sample, more than two-thirds of the plastic parts met MBA's criteria for acceptance (compared to Hennepin County's one-third).

- **Fifth**, electronic products that are currently in the residential waste stream were not designed for recycling. The high rejection rate of whole plastic parts as well as the range of plastic resins found in the Hennepin County sample illustrate that consumer electronics—many of which were manufactured 20 to 25 years ago—are not necessarily good targets for recycling. As a result, they require more complex processing systems to derive useable materials.
- **Sixth**, MBA's screening process identified several areas where manufacturers can work to better design electronic products for recycling. In the case of televisions, opportunities exist to reduce the multiple use of metallized coatings, paint, labels, and lamination. With miscellaneous plastics, opportunities exist to reduce the number of plastics used in a single part. In many instances, substitutions may not be possible for cost and/or performance reasons, but the characterization analysis at least identifies places where changes could potentially be made.

What Types and Amounts of Contaminants have been found in Existing Consumer Electronic Collection Programs?

Another area that warrants further investigation is the effect that contamination has on the recyclability of plastics from consumer electronics. As with recycling any product or material, contamination presents both technical and economic challenges that need to be overcome in order for recycling to succeed. Through its case studies, APC was able to identify three critical points in the electronics recycling process where contamination issues tend to surface and, therefore, need to be addressed.

The first point is at the demanufacturing facility where decisions are made about which plastic parts to ship for further processing. In the APC/MFF/MBA study of electronics from the San Francisco Bay Area, four of the pallets of electronic equipment that were shipped from one demanufacturer contained so many non-targeted items that MBA could not perform a characterization analysis. Instead of receiving a "plastics-rich" stream, MBA received such products as

- all metal toasters;
- complete "boom boxes" with circuit boards, speakers, and batteries included;
- Christmas tree lights;
- whole computer keyboards;
- answering machines with cassette tapes and batteries included;
- whole vacuum cleaners with flex hoses and waste bags;
- electrical and telephone cords; and
- a variety of other all-metal parts.

Clearly, if demanufacturers want to recycle plastics from electronics, they need to ensure that they send plastics—not metal or other materials—to plastics processors. Hennepin County made better decisions about what to send to MBA than the demanufacturer mentioned above. And, a second Bay Area demanufacturer, after receiving training from MBA, made even better decisions about what to send. In both cases, good decisions at the demanufacturer level, as well as sound demanufacturing practices, resulted in greater amounts of plastics being accepted for further processing.

The second point where quality control is critical is upon intake at the processor. As mentioned above, prior to processing, MBA removes whole parts that meet its rejection criteria. MBA explains that the criteria were developed to address specific problems. For example, limiting the amount of coatings, paint, and glass filler is necessary to preserve the unique properties of plastic—the properties that manufacturers need to produce high-quality recycled products. Limiting the amount of metal is necessary because it lowers the feed quality of plastics which makes the production process less efficient and, hence, more costly. In addition, limiting labels, lamination, structural foam, and multiple and composite plastics is necessary because they are difficult to separate. MBA explains that even small

SEPARATING PLASTICS FROM THE SAN FRANCISCO BAY AREA ELECTRONICS COLLECTION PROGRAM

In a joint project with APC and MFF, MBA not only identified the resins present in a sample of plastics collected in the San Francisco Bay Area, but also tried to separate them to determine whether it could produce a pure stream of HIPS. HIPS was selected because it appears in large quantities in television plastics. MBA started the process by mixing all of the plastic resins from television housings together, including ABS, HIPS, PPO, PMMA (polymethyl methacrylate), PVC, and PP. These resins totaled 270 pounds.

MBA then put the resins through a dry processing system where they were granulated and magnetic metals and lights (such as paper, foam, labels, and dust) were removed. This process yielded 251 pounds of recovered usable plastic. MBA's analysis shows that 6 percent of the material was removed as lights and 1 percent as metals.

Next, MBA put the usable plastic resins through a wet processing system (primarily hydro-cyclone based) to separate dissimilar plastics from one another as well as unknown contaminants from the target plastic. The wet separation process yielded 138 pounds (or 55 percent of the stream) as concentrated HIPS. MBA determined that the HIPS stream, at this point, was 86 percent pure.

As a final step, MBA put the remaining HIPS through a proprietary process to determine whether it could produce a pure stream of plastic. The third process yielded 40 pounds of material that was 100 percent pure HIPS.

What this case study demonstrates is that pure plastic resins can be successfully recovered from municipally derived electronic equipment. It did, however, raise some additional questions.

- Can a sufficient volume of material be collected to make the recovery process economically sustainable? If only 40 pounds of pure HIPS can be derived from 270 pounds of television housing plastics, it may be difficult to generate enough recycled material to interest a market and/or achieve recycling efficiencies.
- Can the proper level of dismantling be sustained in order to make plastic recovery possible? The second San Francisco sample was shipped from a demanufacturer that had received direct training from MBA on how to properly dismantle and sort plastics. Other demanufacturers that are not trained may not be able to produce the same level of quality. That means it may take even more material from other programs to generate this amount of pure plastics.
- Can the system used by MBA be duplicated in a large-scale production facility, and will such a facility be able to address highly complex technical issues while maintaining efficient operations? Being able to produce a pure stream of plastics in a test situation is different than producing it for three shifts every day in a commercial production facility. At this point, it is unclear whether MBA's results for television housings can be duplicated on a large scale.

Answering the questions above is critical to determining whether recycling plastics from consumer electronics is not only technically feasible, but also commercially feasible.

amounts of these incompatible materials can cause serious problems in subsequent extrusion and molding processes; therefore, they must be removed prior to processing.

The final point where contamination is a concern is in processing the plastics to obtain the purest stream possible. APC has been working extensively with MBA and other facilities to develop and test resin identification and separation equipment so processors can cull plastics down to the highest quality stream possible. This is important because it will broaden the markets into which recycled plastics can be sold.

APC and MBA also have been testing equipment that can identify the presence of heavy metals and fire-retardant additives in plastics. For example, when analyzing the Hennepin County sample, MBA used a hand-held X-ray fluorescence spectrometer to identify the presence of fire retardants in two resins that are present in television plastics: HIPS and ABS. In its preliminary analysis, MBA found that 87 percent of the

HIPS derived from televisions contained fire retardants, as did 67 percent of the ABS.

This information is important for at least two reasons. First, some consumer electronics will continue to contain fire retardants to prevent combustion during use. Plastics processors must know if and how those retardants affect the performance of recycled plastic because it will determine the markets into which they can sell their flake and/or resin. For example, plastics containing older fire retardant formulations probably cannot be sold to manufactures of new computer parts, but they may be sold to producers of other medium- to lower-end products.

Second, end-markets—primarily compounders and molders—must understand which fire retardants are used in consumer electronics and in what quantities. Such information is critical because it could impact the final composition and performance of the product they manufacture.

Recently, there have also been some health issues raised surrounding the presence of brominated fire retardants in plastics. While the data at this point is inconclusive, concerns have been voiced about the health effects that fire retardants—particularly older formulations—may have on employees as well as on the performance of products. This is another issue that could influence the recycling of plastics from electronics in the future.

Clearly, the presence of additives or contaminants—fire retardants or otherwise—and their effects on the performance of recycled plastics is an area that requires further study. Fortunately, the characterization analyses have helped in identifying the potential contaminants in recycled plastics that are of greatest concern and in recognizing the appropriate points at which they can be removed, whether that be during manufacturing, disassembly, and/or processing.

Where Do We Go From Here?

While APC's studies, as well as those sponsored by other organizations, have provided a wealth of new information on electronics recycling, many questions remain. We have yet to determine what markets can use the plastics found in consumer electronics, what value plastics have to those markets, and the level and complexity of separation that is necessary to get plastics into a form in which they can be used. Until we have answers to those questions, it is difficult to determine whether recycling plastics from consumer electronics is an effective resource management tool.

Markets

While compiling its baseline report, the National Safety Council's Environmental Health Center identified 79 firms that were directly involved in recycling electronic equipment. A survey of those firms indicates that plastics from end-of-life electronics are currently being sold into such applications as lumber, outdoor furniture, and roadbed materials.[7] In addition, the survey found that a limited amount of closed-loop recycling of plastic parts is taking place. It is generally believed that some plastics from end-of-life electronics are also going overseas for recycling. This information, while helpful, is not sufficient to answer the question of whether larger quantities of plastics recovered from consumer electronics will have a home in the future once they are collected, identified, and processed.

In an effort to extend the body of research on markets, APC has begun identifying and testing potential uses for consumer electronic plastics. One project—conducted in conjunction with Conigliaro Industries (Framingham, Massachusetts) and the Massachusetts Department of Environmental Protection (Boston, Massachusetts)—included the development of a high-capacity processing system to recycle mixed computer and electronic plastic equipment housings from both the commercial and residential sectors. The plastics generated by the newly designed system are used in two applications: (1) an aggregate that is integrated into an asphalt matrix product and used as a base course in road beds and parking lots, and (2) a consumer cold patch used for filling potholes. Conigliaro's system has the potential to use 12 million pounds of recycled plastics each year.

The good news about this market is that the material requires very little handling. The computer and television housings move directly from the demanufacturing facility to Conigliaro without requiring further identification, separation, or processing. The bad news is, because it is a fairly low-end application replacing a fairly low priced commodity, it does not have tremendous economic value in terms of supporting wide-scale electronic collection efforts.

Another product in which recovered plastics from consumer electronics has reportedly been used is laminated flooring. At least one company has used recycled engineered plastics from electronics in the synthetic core of its laminated flooring product. The product has a 25-year residential wear, stain, fade, and water damage warranty, making it one of the highest performing products on the market. It is estimated that this application could use as much as one million pounds per month of recycled plastics. Unlike the Conigliaro product, the use of recycled electronic plastics in laminated flooring takes better advantage of engineering plastics' unique characteristics, including its durability, stability, and waterproof nature.

There also appears to be some potential for marketing mixed plastics into other medium-level applications. At present, some computer manufacturers grind whole electronic parts, separate out some of the metals, and send the plastics along with residual metals to a smelter. This process captures the energy content of the plastics and reduces fossil fuel use. As technology evolves, however, it may be possible to separate the ground mixed plastics from the residual metals and route them into a recycled plastic product. APC is exploring this alternative.

Clearly, markets for plastics from consumer electronics have been evolving slowly. That makes sense given the fact that, until recently, little was known about the types and quantities of plastics available from the residential electronics stream. APC hopes that with the research it and other organizations are doing, markets will begin to emerge in close step with collection efforts.

Economics

The final—and perhaps most important—question is whether recycling plastics from consumer electronics makes economic sense. Again, because this is a new, quickly evolving area, it is too early to answer that question with any confidence.

One study prepared by the U.S. EPA, which analyzed the economics of five different residential electronics collection programs, concluded that most current programs run at a net cost. It found that the cost to collect consumer electronics ranged from 3- to 35-cents per pound for one-day collection events and from 7- to 28-cents per pound for programs using other collection methods.[8] These figures include collection, demanufacturing, and disposal costs minus any revenue received from the sale of equipment and materials (such as glass, metals, plastics, and so forth).

In addition to high collection and demanufacturing costs, preliminary results of an economic-based project on which APC is currently working indicates that there also are significant costs at the processing level. Working with MBA Polymers, APC determined that costs to the recycler—from sourcing feedstock through the packaging and storage of the final product—range from 23- to 52-cents per pound depending on the sorting method used.[9] Given the relatively high costs of collecting, demanufacturing, and recycling plastics in these two examples, it is unclear whether and under what circumstances recycling plastics from electronics makes economic sense. As new markets develop, however, and as identification and sorting equipment are perfected, the economics may improve. It should be noted that manufacturers are beginning to make design changes in their products to facilitate plastics recovery in the future.

With regard to developing innovative recycling technology, the commercial sector will most likely take the lead. As more commercial programs come on line and generate more plastics for recycling, the technology to identify and separate them will continue to emerge, thus boosting residential efforts. It makes sense that development will start in the commercial sector because its waste stream typically contains newer and more homogenous materials in larger and more consistent quantities. That means it does not have as many recycling challenges to overcome as the residential sector. In addition, the economics of recycling electronics—in both sectors—may improve as other countries develop recycling technologies that can be applied here.

It is important to keep in mind that recycling plastics from consumer electronics may make economic sense at different levels. If creating pure streams of plastic is not economically feasible, then other avenues should be explored, such as the use of recycled plastics in medium- and lower-end products—products that do not require such high levels of purity. As the recycling community learned with packaging, there are a variety of products that place varying demands on the quality of recovered materials. The key with recycling plastics from consumer electronics will be matching what is technologically feasible with what makes economic sense in the marketplace.

Additional Research Efforts

The U.S. EPA, the National Safety Council, APC, and MBA Polymers are just a few of the organizations that are currently conducting research on electronics recycling. There are a number of other organizations that have projects underway—some of which are described below—that should help significantly increase our understanding of the opportunities and challenges of recovering electronic equipment from all sectors. APC is participating in each of the following efforts.

- **The Electronics Industries Alliance** (EIA) established its Environmental Issues Council (EIC) so industry executives from all sectors of the electronics industry could examine international, federal, and state initiatives. One of its working groups is looking specifically at issues related to cathode ray tube and lead recycling—areas that are of primary concern in managing end-of-life electronics.
- **The Gordon Institute at Tufts University**, with funding from the U.S. EPA, is holding a series of stakeholder dialogues on recycling engineering thermoplastics from end-of-life electrical and electronic equipment. The entire electrical and electronics supply chain is involved in the project.
- **The Institute of Electrical and Electronics Engineers, Inc.** (IEEE) is a professional association for engineers. It facilitates technology transfer by providing opportunities for engineers to share information and build alliances. IEEE is one of the avenues through which electronics manufacturers are currently addressing the environmental benefits and impacts of their products.
- **The International Association of Electronics Recyclers** (IAER) is a trade association created specifically for the electronics recycling industry. Its primary goal is to help develop an effective and efficient infrastructure for managing the life cycle of electronic products. IAER brings together all elements of the supply chain—from original equipment manufacturers and material suppliers to demanufacturers and recyclers—to examine issues related to electronics recovery.
- **The Minnesota Office of Environmental Assistance** (OEA) has created a public/private partnership with Sony, Panasonic, Waste Management, and the American Plastics Council. The goal of the partnership is to explore issues related to the health, safety, and recycling of electrical and electronic equipment. Project partners hope to determine how best to collect electronic products from the residential waste stream as well as how to handle hazardous, potentially hazardous, and non-hazardous materials in a safe and efficient manner.
- **The U.S. Department of Defense** initiated a project called DEER2, which stands for Demanufacturing of Electronic Equipment for Reuse and Recycling. The goal of the project is to research, test, and deploy technology that will aid in the management of end-of-life electronic equipment. While the focus is primarily on electronics generated by the Department's own agencies, it will also provide information to a much broader audience.

The work of these and other groups will go a long way toward helping businesses and government agencies deal with remaining questions about the feasibility of recycling end-of-life electronics.

Conclusion

While making any judgment as to the feasibility of recycling plastics from consumer electronics is premature, several key pieces of information are starting to fall into place. Because of the research that has been done over the past few years, we now know:

- what electronics are likely to be found in the residential waste stream;
- what materials can be derived from those products upon disassembly;
- what plastics are likely to be present (in total as well as in specific products);
- what level of processing is needed to separate plastics into pure streams;
- what contaminants present obstacles to recycling plastics; and
- what markets may be available to absorb some of the electronic plastics once they are collected, separated, and processed.

Having this information is an important first step in determining whether recycling consumer electronics—and the plastics contained in them—is a viable resource recovery option. The preliminary information seems to indicate that mechanical recycling of consumer electronic plastics has potential—if not in putting these plastics back into electronic parts in the short term, then at least in putting them back into medium- and lower-end applications.

It is imperative, however, that organizations that are conducting research in this area continue to encourage public/private partnerships in an effort to answer remaining questions. At least one thing is certain—the recycling landscape for electronics will change. What we know today is based on limited collection programs and a limited analysis of material. As more consumer electronics are collected and processed, and as more research is conducted, our understanding of what can and cannot be done will evolve. As a result, our assumptions about whether recycling plastics from consumer electronics makes sense must evolve as well.

Endnotes

[1] The American Plastics Council is a national trade association comprised of 26 of the leading plastics manufacturers in the United States. APC's mission is to ensure that plastics are a preferred material by actively demonstrating they are a responsible choice in a more environmentally conscious world.

[2,7] "Electronic Product Recovery and Recycling Baseline Report: Recycling of Selected Electronic Products in the United States," National Safety Council's Environmental Health Center, May 1999.

[3,8] "Analysis of Five Community Consumer/Residential Collections: End-of-Life Electronic and Electrical Equipment," U.S. Environmental Protection Agency, April 1999.

[4] "Residential Collection of Household End-of-Life Electrical and Electronic Equipment: Pilot Collection Project," U.S. Environmental Protection Agency, February 1998.

[5] "Plastics: A Material of Choice for the Electrical and Electronic Industry--Plastics Consumption and Recovery in Western Europe, 1995," Association of Plastics Manufacturers in Europe.

[6] "Recovery of Plastics from Municipally Collected Electrical and Electronics Goods," American Plastics Council and The Materials for the Future Foundation, March 1999.

[9] "Plastics Recovery from Electrical and Electronic Durable Goods: An Applied Technology and Economic Case Study," MBA Polymers and the American Plastics Council, November 1999.

Acknowledgement

We would like to express our sincere appreciation to the many organizations and individuals who have contributed to this expanding database on the recovery and recycling of plastics from end-of-life residential electrical and electronic equipment. Our special thanks to Cheryl Lafrano Zaske with Hennepin County, Minnesota, the Materials for the Future Foundation, the Association of Plastics Manufacturers in Europe (APME), the Canadian Plastics Industry Association (CPIA), wTe Corporation, and the entire technical team at MBA Polymers for their pioneering contributions to this field.

A Summary Report from the Electrical and Electronics Group of the American Plastics Council

Plastics from Residential Electronics Recycling

Report 2000