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Electronic Product Recovery and Recycling Baseline Report

Recycling of Selected Electronic Products in the United States

May 1999

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Preface

In recent years, many recyclers, manufacturers, large-scale users of electronic equipment, and government agencies have been faced with managing ever-increasing quantities of end-of-life or used electronic equipment—in the absence of useful data about how much equipment there is, where it is, and what is being done with it.

The *Electronic Product Recovery and Recycling Baseline Report: Recycling of Selected Electronic Products in the United States* presents the results of the first major effort to gather quantitative information directly from firms involved in the electronics recycling industry about the nature of the industry and the equipment it handles. It is also the first report to use such information to project the volume of equipment that will require management in the future. The results of this research are intended to help inform policy decisions about and to encourage responsible management of the growing quantities of end-of-life and used electronic equipment.

The need for this report was identified by the Electronic Product Recovery and Recycling Roundtable, a multistakeholder body that consists of representatives from electronic equipment manufacturers, recyclers, nongovernmental organizations, academic institutions, and federal, state, and local government agencies. The roundtable members also identified the key electronic products to be covered in the report.

We are very grateful for the generous financial support provided for this report by the following organizations:

- American Plastics Council
- Hewlett-Packard
- IBM
- Commonwealth of Massachusetts
- Matsushita/Panasonic
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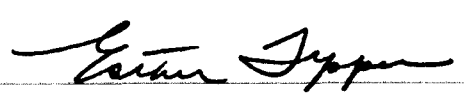
- U.S. Environmental Protection Agency

We are also indebted to the many organizations that provided data for the study (see appendices A and B). Without their cooperation, this report would not have been possible.

Stanford Resources, Inc., a management and market research firm that specializes in electronic display and related industries, conducted the research for this study.



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Executive Summary

Background

This study presents the results of the first large-scale survey and analysis of end-of-life electronic product recycling and reuse in the United States. The survey, which covered the years 1997 and 1998, addressed the following electronic products:

- Desktop personal computer (PC) CPUs
- Mainframe computer CPUs
- Workstation computer CPUs
- Notebook (portable) computers
- Cathode ray tube (CRT) computer monitors
- Computer peripherals (printers, plotters, and scanners only)
- Telecommunications equipment (routers and switches only)
- CRT consumer television (TV) sets

The database of potential survey respondents was drawn from several existing compilations of firms active in electronics recycling. Efforts were made to contact all such firms and to ask those verified as industry participants to participate in the survey.

Data were collected from 123 firms. Information on 114 of the firms came directly from surveys, and information on 9 of the firms was collected from secondary sources. Of the total number of firms covered, 79 were recycling firms (data on 73 came from direct surveys, and data on 6 came from secondary sources). Data from 38 third-party organizations (which accept end-of-life electronic equipment with the intent of refurbishing it for resale or donation) were also collected. Of that number, 20 were nonprofit organizations (information about 3 of the nonprofits came from secondary sources) and 18 were for-profit resellers. Six original equipment manufacturers (OEMs) and large corporate users were also surveyed.

The U.S. Electronics Recycling Industry

The study's key finding about the U.S. electronics recycling industry is that activity is concentrated among large firms, including subsidiaries of computer OEMs. In both 1997 and 1998, the top five firms processed 50 percent of the electronic equipment recycled in the United States, and the top ten firms processed 75 percent.

The survey also found that despite broad geographic distribution of electronics recycling firms in the United States, firms based in the Mid-Atlantic and Midwest regions accounted for half of all recycling of electronic equipment. Most recycling firms employed few workers; 75 percent of the firms surveyed had fewer than 40 employees. More than half of the firms surveyed began processing electronic equipment in 1990 or later.

U.S. Electronics Recycling Activity

The study estimates that the total volume of electronic equipment recycled in the United States exceeded 268 million pounds (equivalent to 9.4 million units) in 1997 and 275 million pounds (9.7 million units) in 1998. (These figures do not include equipment handled by third-party organizations.) For specific types of equipment, the study found the following:

- Recycling of desktop PC CPUs declined from 59 million pounds in 1997 to 58 million pounds in 1998 (2.4 and 2.3 million units, respectively).
- Mainframe computer recycling declined from 56 to 54 million pounds (56,000 and 54,000 units, respectively).
- Workstation CPU recycling increased from 10 to 12 million pounds (342,000 and 413,000 units, respectively).
- Notebook PC recycling was level at 3 million pounds a year (300,000 units).
- CRT computer monitor recycling increased from 46 to 51 million pounds (1.3 and 1.5 million units, respectively).
- Computer peripheral recycling was level at approximately 73 million pounds a year (2.9 million units).
- Telecommunications equipment recycling increased from 21 to 22 million pounds (2.1 to 2.2 million units, respectively).
- TV recycling increased from 700,000 to 950,000 pounds (14,000 and 19,000 units, respectively).

Third-party organizations handled fewer than 1 million units of equipment in 1997 and fewer than 1.3 million units in 1998. Desktop PC CPUs accounted for 45 percent of equipment handled by third-party organizations in 1998.

In 1998 alone, more than 20 million PC CPUs became obsolete. (This figure refers only to PCs shipped in 1992 or later that became obsolete in 1998 and does not include older PCs still in storage or use.) Thus, only about 11 percent of units that became obsolete in 1998 were recycled. Adding in the number of PCs refurbished and resold or donated by third-party organizations raises this percentage slightly, to about 14 percent.

The ratio of PC CPUs recycled in 1998 to new PC CPUs shipped from manufacturers to retailers and other customers in 1998 was even lower—about 6 percent. (This figure does not include units handled by third-party organizations.) In contrast, for major appliances (washing machines, water heaters, air conditioners, refrigerators, dryers, dishwashers, ranges, and freezers), the proportion recycled in 1998 was about 70 percent of the number shipped that year.

The study found that more than 75 percent of end-of-life electronic products received by electronics recyclers and third-party organizations come from electronics OEMs and large-scale users of electronic equipment (those with more than 500 employees). Individual users and small businesses contribute only a small fraction of the electronic equipment that is recycled. However, with TV penetration approaching 100 percent of U.S. households and PC penetration exceeding 50 percent, the need for consumer participation in electronics recycling will become increasingly important.

Forecasts

In the near term, the study estimates that the most rapid area of electronics recycling growth will be notebook PCs, which will become obsolete in large numbers early in the next decade. Growth in desktop PC recycling will also be significant, as more units in storage are sent to recyclers.

The study also estimates that the number of PC CPUs that become obsolete in 2002 will exceed the number of PC CPUs shipped that same year by 3.4 million units.

If current trends continue, the study estimates that the volume of equipment processed by the U.S. electronics recycling industry will grow by 18 percent annually over the period 1998 to 2007, reaching about 40 million units in 2007.

I. INTRODUCTION

A. Background

This report summarizes the results of a study carried out for the National Safety Council's Environmental Health Center. The study is a component of the Electronic Product Recovery and Recycling (EPR2) Project. The goal of the project is to promote environmentally and economically sound management of electronic equipment that no longer meets the needs of its original owner.

The study addressed the following electronic products:

- Desktop personal computer (PC) CPUs
- Mainframe computer CPUs
- Workstation computer CPUs
- Notebook (portable) computers
- Cathode ray tube (CRT) computer monitors
- Computer peripherals (printers, plotters, and scanners only)
- Telecommunications equipment (routers and switches only)
- CRT consumer television (TV) sets

In this study, recycled electronic equipment and products refer only to the above-mentioned items. For the purposes of this report, the term CPU includes the following: computer unit containing printed circuit boards with microprocessors and other components, disk drives (fixed, floppy, CD, removable), power supply, and metal or plastic chassis and cabinet.

B. Report Structure

This report, which documents the research efforts and presents an analysis of the data collected, is organized into the following chapters:

Chapter II presents an overview of the electronics recycling industry in the United States. Roles played by the key organizations that collect, test, refurbish, dismantle, and sell or donate systems, parts, or raw materials are reviewed and defined.

Chapter III presents data on the sources and destinations of end-of-life electronic products and of parts and materials recovered from electronic products.

Chapter IV describes the methodology and sources used in this study. The survey approach is summarized, and key assumptions, uncertainties, and gaps in data are discussed.

Chapter V is an analysis of the data collected through the industry survey and from other sources. First, an analysis of the characteristics of the electronics recycling industry is presented, including information on changes in the industry structure. Second, estimates of the volume of equipment recycled are compared to historical shipment data and estimates of the volume of obsolete equipment.

Chapter VI contains information on other aspects of the recycling industry, including government/school supply-and-demand drivers for PCs and markets for raw materials. A recycling forecast is then presented for each of the electronic products covered, using the estimates for 1997 and 1998 and taking into account market and technology changes.

Chapter VII presents findings and recommendations.

II. OVERVIEW OF ELECTRONICS RECYCLING INDUSTRY

The electronic equipment recycling industry consists of several levels of activities. The terms original equipment manufacturer, primary recycler, secondary recycler, third-party organization, and smelter are used in this report to describe these levels.

A. Recycling Organizations

1. Primary Recyclers

Primary recyclers typically specialize in particular products or industries, such as electronic equipment, furniture, clothing, or automobiles. They prefer to refurbish (that is, repair or upgrade) and resell whole products, because they can receive higher returns on investment than if they sell raw materials. Primary recyclers do not normally recycle two unrelated products, such as computers and cars.

Primary recyclers use equipment that is only moderately automated, and they rely heavily on manual labor for disassembly or remanufacturing. In the case of electronics recycling, a primary recycler will often accept computer equipment whole or broken down. The primary recycler may then either repair and resell the product or break it down further into its component parts, such as plastic housings, wires, metals, and circuit boards. These components are then sent to smelters or secondary recyclers who have the equipment and facilities to process the components further.

2. Secondary Recyclers

Secondary recyclers demanufacture various products in order to recover raw materials, such as metals, plastics, and glass. Most secondary recyclers do not limit their processing to one type of industry, but instead process any products that contain relatively high levels of the raw materials they seek. For instance, a secondary recycler might process anything that contains certain metals, such as containers, appliances, automobiles, and electronic equipment, although typically not at the same time or in the same manner. A secondary recycler is often referred to as a "recycler's recycler" because it has the ability and facilities to break down products that other recyclers cannot.

Secondary recyclers have highly automated processing equipment and minimize manual disassembly, thereby decreasing labor costs. The lower labor costs are offset by lower revenues obtained from selling raw materials rather than whole products and by the high level of capital investment required. For secondary recycling facilities to be economically viable, they must run at volumes very close to their designed capacity.

Secondary recyclers receive most of their goods from other recyclers, large corporate users, and manufacturers. If secondary recyclers receive working systems or parts, they typically resell them to primary recyclers or computer resellers. Hence, secondary recyclers can also function as primary recyclers or resellers. The secondary recycling phase is the last stage of recycling before final disposition; anything that secondary recyclers cannot process is usually smelted, incinerated, or landfilled.

3. Smelters

Smelters are large industrial facilities that use mined ores or secondary materials as inputs to produce raw metals. Smelting is a pyrometallurgical process of melting or fusing ores to separate metallic constituents such as lead and copper. Smelters can use CRT glass as a fluxing agent, which promotes the fusing process. The leaded glass in CRTs is used to convert lead compounds to raw lead.

Smelters charge for accepting CRTs. One study estimated that processing costs, excluding transportation, are $0.10/lb. for intact CRTs and $0.07/lb. for crushed CRTs (or $2 to $3 for a 30-pound CRT).[1]

4. Third-Party (Resellers and Nonprofit) Organizations

The term third-party organization in this study refers to organizations that refurbish and then resell or donate used computer products, but that do not break down the equipment into components or raw materials. Third-party organizations focus on rapidly sorting products to identify those with the greatest market value and refurbishing (restoring to working condition) systems that are not fully operational. In the process of accepting computer donations, third-party organizations invariably acquire computers that cannot be repaired. In such cases, working parts that are easily removed are used to restore other computers to working condition. The remainder of the nonrepairable computer is then sent to a primary or secondary recycler.

There are two main types of third-party organizations: resellers, which are typically privately held for-profit corporations, and nonprofit organizations, typically charitable groups. Besides the presence or absence of an economic profit motive, there are other differences between resellers and nonprofit organizations.

Resellers tend to accept a larger volume of equipment from auctions and large corporate users, and in the process they receive equipment they cannot resell. Since resellers do not rely on a cyclical (volunteer) workforce, as nonprofit organizations often do, they tend to have a larger, more experienced employee base and can test, disassemble, and reassemble more quickly than nonprofits. This results in a higher turnover rate for equipment received. Also, resellers normally have larger facilities in which to process and repair equipment.

Nonprofit organizations do not generally have large facilities and must be selective in the equipment they accept (it should be in, or close to, good working condition). To avoid or minimize processing and transportation costs associated with sending products to a recycler, nonprofit organizations attempt to resell or donate systems locally whenever possible.

5. Differences between Recyclers and Third-Party Organizations

In the course of surveying industry participants, significant confusion emerged about which organizations should be classified as recyclers and which as resellers. In the above definitions, the primary distinction is that recyclers concentrate on demanufacturing, whereas resellers focus on refurbishment, followed by either resale or donation. The factors distinguishing primary from secondary recyclers are that primary recyclers focus on particular products or industries and tend not to have major processing equipment investments, whereas secondary recyclers concentrate on recycling a specific material and have large investments in recycling equipment and facilities.

Some companies perform both demanufacturing and refurbishment for resale or donation; this study considers such organizations to be recyclers that also resell. The approach taken is that companies should be classified by the level of recycling they can perform. For instance, breaking a product down to its raw materials or smelting a product is the lowest level of recycling; therefore, any company with these capabilities is classified as a secondary recycler. While a secondary recycler may also resell products, it would not be categorized as a reseller because (unlike a reseller) it has the capability to break down products further if it chooses.

[1] *Potential Markets for CRTs and Plastics from Electronics Demanufacturing: An Initial Scoping Report*, University of Massachusetts-Amherst, Chelsea Center for Recycling and Economic Development, August 1998. The authors estimated that processing costs for CRT recycling by disassembly vary from $3 to $10 per CRT.

III. ELECTRONICS RECYCLING FLOW MODELS

This chapter summarizes the recycling process and flow of products through the electronics recycling industry, first by presenting a generic flow model and then by summarizing data collected about the sources and destinations of end-of-life electronic equipment.

A. Electronics Recycling Process

Figure 1 is a generic flow diagram for the electronics recycling process. It is most applicable to PC recycling but can also be used to illustrate the recycling process for other electronic equipment. Not all the steps shown are taken by all recyclers, nor are the steps necessarily taken in the order shown. In general, however, the four stages described below represent the major decision/action points in the process.

1. Determination of Potential for System Reuse

The first stage (step ①) consists of testing the computer to determine its usability and can be carried out by primary recyclers, secondary recyclers, or third-party organizations. Two primary factors determine usability.

The first determinant of usability is age. For PCs in particular, the age at which a computer becomes "old" has decreased over time. However, particular developments in processor and operating system technology have at times decreased the importance of age. For example, relatively soon after the generation of PCs based on Pentium microprocessors was introduced, PCs using previous microprocessor generations (80486 and 80386) became outdated. This coincided with the release of the Windows 95 operating system and other demanding software. On the other hand, many analysts have concluded that there is not a great deal of difference between the Pentium III processors now on the market and the prior Pentium II generation, especially because many applications have become more dependent on the Internet than on the desktop computer.

The second determinant of usability is the mechanical condition of the system. If a system is not outdated and is in working condition or requires only minor upgrades such as added memory, a CD-ROM drive, or current software, it will most likely be refurbished and then resold or donated.

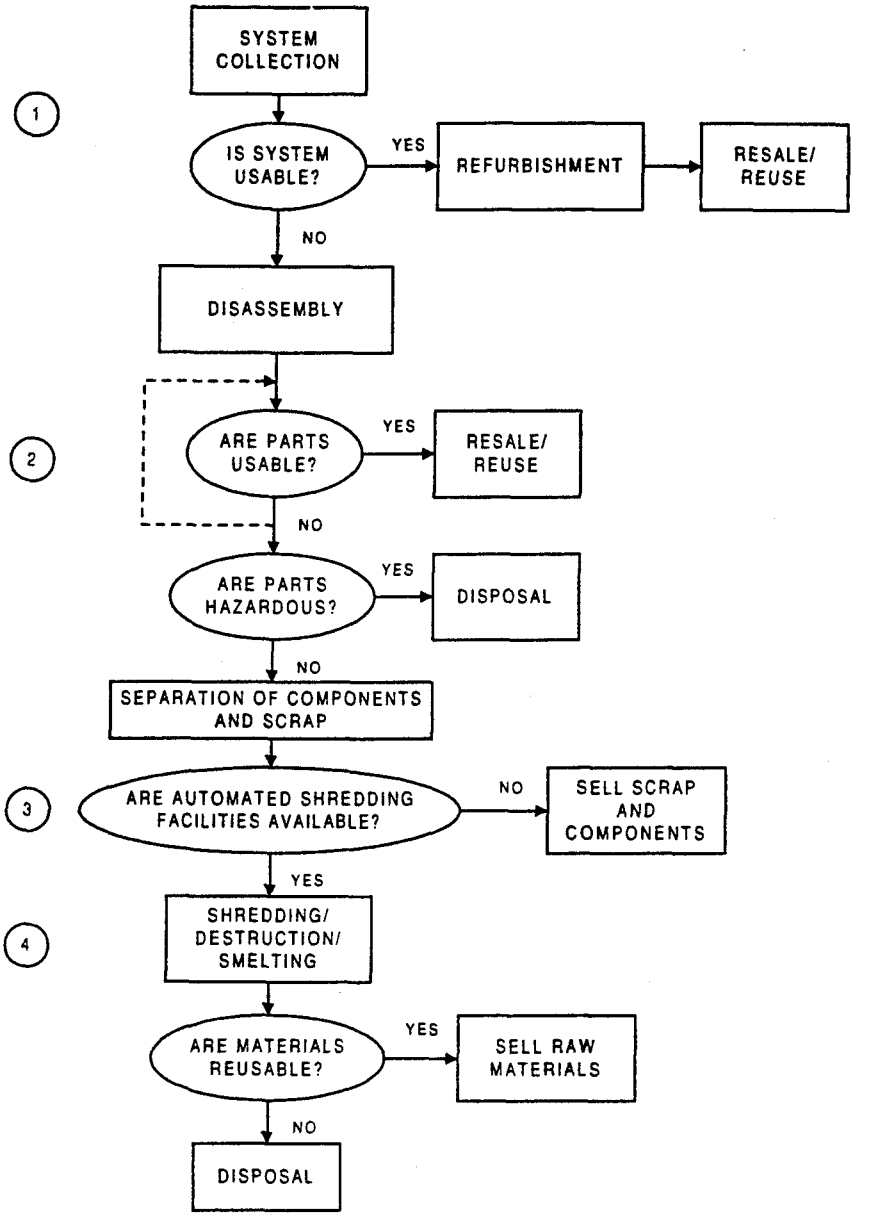
2. Manual Disassembly

If the labor and upgrade costs to refurbish a system outweigh the expected selling price of an intact system, the product will then be manually disassembled (step ②). Such parts as floppy disks, hard disks, and CD-ROM drives that can be resold or reused are removed. Hazardous components, such as batteries, are also removed and disposed of properly.

3. Separation of Components and Scrap

Once the useful and hazardous parts are removed from the computer, it can be broken down further into components (step ③), such as plastic housings, wires, metals, and circuit boards. Primary or secondary recyclers can perform this process. Recyclable components are separated from scrap according to their raw materials composition. At this point, primary recyclers distribute the separated components to secondary recyclers for further processing. An important category of recyclable components is the CRT, which can either be disassembled and sorted by glass type for resale to a CRT manufacturer or sent to a smelter.

Figure 1: Generic Flow Diagram for the Electronics Recycling Process



Source: Stanford Resources, Inc., 1999

4. Final Disposition

After the computer is separated into the various components, the parts not sold or disposed of are sent to a secondary recycler, where they are shredded, destroyed, or smelted (step ④). The resulting materials are sold to manufacturers, disposed of in a landfill, or incinerated (sometimes in a waste-to-energy facility).

B. Product Flow

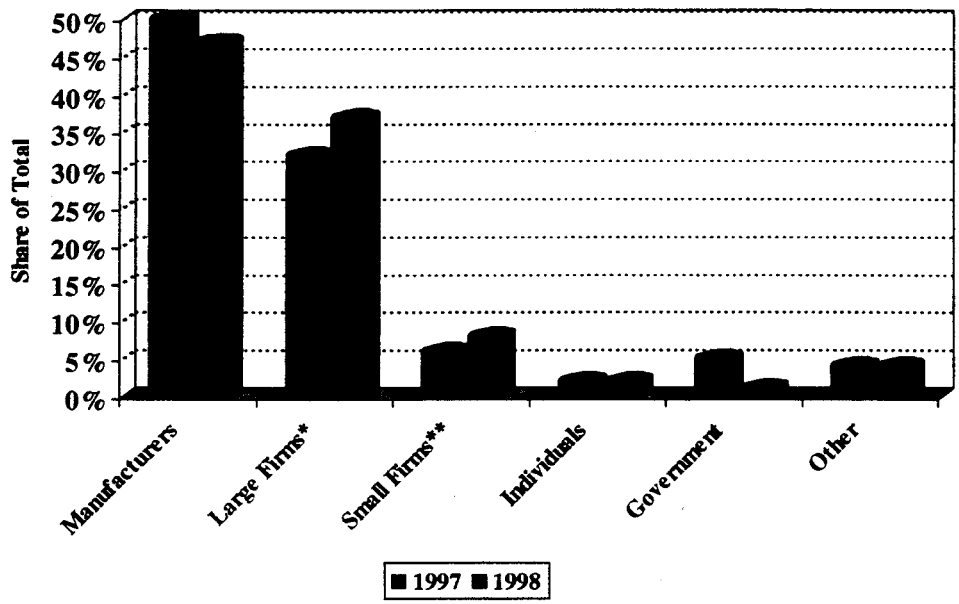
The recycling industry flow outlined in the previous section does not include the sources of end-of-life electronic equipment, nor does it address eventual disposition of refurbished systems, parts, or raw materials. This section characterizes these input and output flows.

1. Sources of End-of-Life Electronic Equipment

Figure 2 and **figure 3** show the distribution of sources of end-of-life electronic products received by recyclers and third-party organizations, respectively.[2] The sources of electronic products for recycling are predominantly original equipment manufacturers (OEMs) and large corporations (those with more than 500 employees). For recyclers, the share of equipment received from manufacturers and large corporate users exceeds 80 percent; for third-party organizations, the share is 75 percent.

Survey questions were also posed to third-party organizations about the use status of equipment immediately before they received it. While there was not sufficient response to these questions to draw any firm conclusions, the answers suggest that most PCs, monitors, and peripherals come from active use, whereas mainframe computers come largely from storage.

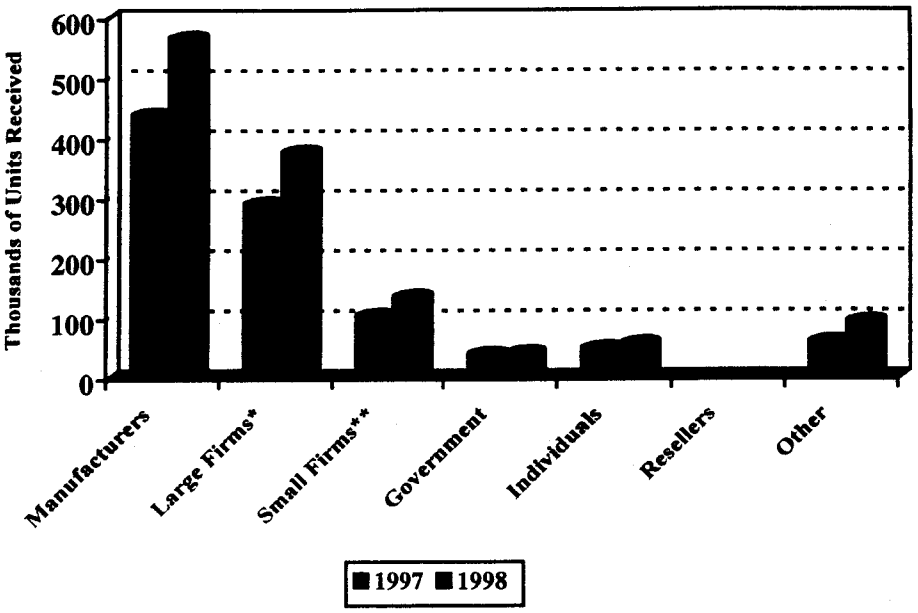
Figure 2: Sources of Electronic Products Handled by Recyclers, 1997–1998



Source: Stanford Resources, Inc., 1999
Notes:
*Large firm > 500 employees
**Small firm < 500 employees

[2] Recyclers tend to track the amount processed by weight, so the data in figure 2 are presented as a share of the total weight processed. Third-party organizations track by units of equipment, so figure 3 uses that metric.

Figure 3: Sources of Electronic Products Handled by Third-Party Organizations, 1997–1998



Source: Stanford Resources, Inc., 1999
Notes:
*Large firm > 500 employees
**Small firm < 500 employees

2. Destination of Refurbished Equipment

Third-party organizations were surveyed about the purchasers or recipients of resold or donated systems. While there was not sufficient response to these questions to draw firm conclusions, the answers suggest that the organizations most likely to receive or purchase refurbished computers are schools, nonprofit organizations, small firms, and, increasingly, other resellers or brokers.

3. Destination of Parts and Raw Materials

Study results provided little detail about the destination of parts and raw materials after processing by primary and secondary recyclers. In general, numerous brokers are willing to purchase bulk containers of electronic parts and scrap. Much of this material is believed to be exported, but very little information was available on this issue. A well-developed market exists for such raw materials as precious metals and glass, and to a lesser extent for plastics, which pose unique challenges (see next section). Chapter VI discusses markets for raw materials from recycled electronic products.

4. Plastics

Plastics are the most challenging materials to recycle from electronic equipment. They consist of numerous resin types and additive combinations. And—unlike food packaging, plastic housings, and other items—plastic parts recovered from electronic equipment are not marked according to type of plastic, which makes distinctions by visual inspection very difficult. The market value of mixed (unsorted) plastics is very low because of the difficulty of working with materials of unknown composition.

Plastic parts recovered from end-of-life electronic equipment can be recycled in several ways. The simplest is direct reuse of the part; for example, a standard plastic casing for a family of electronic products could allow for substitution of electronic parts inside a reused casing. Plastic materials can also be incinerated, producing energy in the form of heat. According to one estimate, one ton of plastics can replace 1.4 tons of coal in cement kilns.[3]

An alternative approach is to separate plastic parts by resin type and chemically reprocess the parts into basic chemicals, monomers for plastics, and hydrocarbon feedstock. This requires detailed knowledge of the plastic's composition. One of the most difficult aspects of recycling plastics used in electronic equipment is that many different types of plastics are used, and they generally bear no markings or visible properties that allow recyclers to identify and separate them easily. Processing different types of plastics or resins together greatly decreases the value of the end product as a reusable material. For plastics recovered from electronic products to have value in the raw materials market, recyclers must ensure accurate separation of resin types.

One example of the changes in plastics composition over time is the addition of flame-retardant chemicals to plastics used for equipment housings. Efforts are under way in Europe and the United States to reevaluate the use of brominated compounds because of their potential link to toxic dioxins; production of computer monitor housings without flame-retardant additives has recently begun.[4] Changes in regulations or common practice may result in changes in materials being recycled and perhaps the ability to process end-of-life materials containing such additives.

Supported by Ford Motor Co.'s Visteon Automotive Systems, SpectraCode Inc. has developed a Polymer Identification System to rapidly identify plastic materials during collection. The system uses a hand-held probe that illuminates materials with a laser and analyzes the molecular properties through a technique called Raman spectroscopy. The results are available within one second and can be read on a mobile console. The developers estimate that the system, used in conjunction with an automated transport system, could analyze 100 pieces per second. This system is still under development and is not yet available for commercial use.

In contrast to the recycling of postconsumer plastic packaging, which in the United States exceeded 1.6 billion pounds in 1996,[5] no widely adopted framework exists for recycling plastics used in electronic equipment. Individual initiatives have resulted in the use of plastics recovered from electronic equipment for such products as lumber, outdoor furniture, and roadbed materials. Some closed-loop recycling of parts, such as computer printer housings, has also occurred.

No estimates have been located for the plastics content in electronic equipment sold in the United States, nor for the amount of plastics waste resulting from end-of-life electronic equipment in the United States. The Association of Plastics Manufacturers in Europe (APME) has estimated the amount of plastics waste generated by electronic equipment in Western Europe. **Table 1** shows estimates for 1995 and projections for 2000.

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[3] *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.

[4] Peter Mapleston, "Variability of FR Grades Becomes a Hot Issue," *Modern Plastics*, November 1998.

[5] *Modern Plastics Encyclopedia*, 1998.

Table 1: Plastics Waste in Western Europe, 1995 and 2000, Millions of Pounds

	1995	2000
Office equipment (printers, copiers)	40	68
Data processing (computers, monitors)	106	214
Brown products (TVs, VCRs, audio)	130	224

Source: *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.

The 1997 consumption of all plastic resins in North America is estimated at more than 70 billion pounds.[6] According to the APME, the five most widely used plastics in electrical and electronic product manufacturing are polyvinyl chloride (PVC), polyethylene, acrylonitrile-butadiene-styrene (ABS), polystyrene, and polypropylene. These and other thermoplastics, including engineered resins, are used in housings, cable insulation and connectors, and such mechanical components as knobs, buttons, and keys. Also used are thermosets, such as epoxy and phenolic materials.

It has been estimated that total consumption of plastic resins by the electrical and electronic industries was over 3.1 billion pounds in the United States in 1996 and nearly 4.3 billion pounds in Western Europe in 1995.[7] One product-specific estimate is that the worldwide consumption of thermoplastics for monitor housings is over 240 million pounds per year.[8]

[6] *Modern Plastics Encyclopedia*, 1998.

[7] Data published on the web site of the Society of the Plastics Industry; *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.

[8] Peter Mapleston, "Variability of FR Grades Becomes a Hot Issue," *Modern Plastics*, November, 1998.

IV. METHODOLOGY AND SOURCES

The electronics recycling estimates and forecasts developed for this report are based on both primary and secondary research. More than 120 interviews were conducted during late 1998 and early 1999 with knowledgeable sources at selected organizations, including firms involved in electronics recycling and/or reselling, nonprofit organizations, large corporate users, Internet-based equipment exchanges, and electronics, glass, and plastic manufacturers. Lists of the companies contacted are in **appendix A** and **appendix B**. Separate surveys or questionnaires were developed for recyclers, resellers, and manufacturers.

A. Research Approach

1. Database Construction

Efforts were made to construct a database with as many computer recyclers, resellers, nonprofit organizations, original equipment manufacturers (OEMs), and large corporate users as resources would permit. The database of companies contacted was compiled from the following sources:

- *Electronics Reuse and Recycling Directory*, U.S. Environmental Protection Agency (EPA), EPA530-B-97-001, March 1997
- 1998 IEEE International Symposium on Electronics & Environment (attendance list)
- 1998 Electronic Product Recovery and Recycling Conference (participant list), Environmental Health Center, National Safety Council
- Interviews with personnel from U.S. EPA regional offices
- U.S. EPA Jobs Through Recycling project (www.epa.gov/jtr)
- Interviews with personnel from state environmental agencies
- State publications (e.g., *Wisconsin Recycling Markets Directory*)
- Interviews with personnel from recycling organizations (e.g., California Integrated Waste Management Board)
- Internet sites (e.g., www.p2pays.org, www.libertynet.org)
- Recycling equipment suppliers
- Other recycling consultants

Each company identified in the search was investigated in an attempt to identify all firms involved in recycling electronic equipment. Each company that was identified as appropriate for the survey was contacted and asked to participate. Several contact methods were used, including personal interviews, telephone, facsimile, and email.

In addition to the primary research sources listed above, this study drew on market and recycling industry data from the following sources:

- Stanford Resources market research data
- Market surveys from the Consumer Electronics Manufacturers Association (CEMA)
- Data compiled by state and federal government agencies, including the U.S. EPA, state environmental agencies, and nonprofit organizations
- *Plug Into Electronics Reuse*, Brenda Platt and Jennifer Hyde, Institute for Local Self-Reliance, Washington, DC, 1997.
- *Scrap Electronics Processing and Marketing Research Project*, University of Massachusetts-Amherst, Office of Waste Management, 1998.

- *End-of-Life Computer and Electronics Recovery Policy Options for the Mid-Atlantic States*, David Biddle, Mid-Atlantic Consortium of Recycling and Economic Development Officials, September 14, 1998.
- *The San Jose Computer Collection and Recycling Pilot*, Leah B. Jung, Vista Environmental, U.S. EPA Contract No. 7W-3901-TASA.
- *Residential Collection of Household End-of-Life Electrical & Electronic Equipment: Pilot Collection Project*, EPA-901-R-98-002, U.S. EPA, February 1998.
- *Potential Markets for CRTs and Plastics from Electronics Demanufacturing: An Initial Scoping Report*, University of Massachusetts-Amherst, Chelsea Center for Recycling and Economic Development, August 1998.
- *Surplus Federal Computers for Schools: An Assessment of the Early Implementation of E.O. 12999*, Thomas K. Glennan et al., Critical Technologies Institute, Rand Corporation, 1997.
- *Extended Product Responsibility: A New Principle for Product-Oriented Pollution Prevention*, Gary A. Davis et al., University of Tennessee Center for Clean Products and Clean Technologies, and U.S. EPA, June 1997.

2. Interview Summary

In total, 375 companies believed to be in the computer recycling industry were contacted for this study. Of these original companies, 38 no longer had working telephone numbers. Another 39 of the companies contacted either did not recycle the products covered in this report or could only provide qualitative data, such as information on recycling programs or industry contacts. Of the remaining 298 companies, 20 ceased electronic product recycling in 1998 or 1999; only 3 computer recycling companies and 2 major resellers entered the market during that span.

3. Interview Distribution

Of the 298 companies successfully contacted, 140 (47 percent) were recyclers, 80 (27 percent) were resellers, 51 (17 percent) were nonprofit organizations, and 27 (9 percent) were OEMs or large corporate users. Of the 114 surveys conducted, recyclers completed 73 (59 percent), nonprofit organizations completed 17 (14 percent), resellers completed 18 (15 percent), and OEMs and large corporate users completed 6 (5 percent). Qualitative information on 6 recyclers (5 percent) and 3 nonprofits (2 percent) was obtained from two published studies.[9]

B. Assumptions, Uncertainties, and Data Gaps

This study used assumptions for estimates, forecasts, and extrapolations regarding product lifespan, storage inventory, units currently installed, and product weight. These assumptions are explained in the sections that follow.

1. Lifespan

The lifespan estimates used in this study were developed through interviews with more than 30 major manufacturers and resellers. Major computer manufacturers were consulted to determine the lifespan of electronic equipment. Because manufacturers know when their products were fabricated and many also have recycling facilities, these firms are qualified to make an educated lifespan estimate. Resellers and nonprofit organizations were asked to estimate the reusable life or "second life" by product

[9] *Plug Into Electronics Reuse*, Brenda Platt and Jennifer Hyde, Institute for Local Self-Reliance, Washington, DC, 1997; "Scrap Electronics Processing and Marketing Research Project," University of Massachusetts-Amherst, Office of Waste Management, 1998.

and processor type. These inputs were used to develop estimates of the first life (the amount of time a product is useful to its original owner) and the *total* lifespan (period from manufacture to disposal) for each electronic product.

Lifespan assumptions for first life and total life are shown in **table 2**. The increasing rate of technology development is the primary reason for the shortened lifespans of recent desktop PC products. Notebook PCs now have an equivalent or slightly longer lifespan than Pentium II desktop PCs because their higher price encourages maximum use, and their smaller size makes them attractive to keep as a backup system.

Table 2: Average Product Lifespans (in years)

	First Life	Total Lifespan
Desktop PC - 386	4	4-6
Desktop PC - 486	3-4	4-6
Desktop PC - Pentium I	3	4-5
Desktop PC - Pentium II	2-3	3-4
Mainframe computer	7	7
Workstation computer	4-5	4-5
CRT computer monitor	4	6-7
CRT TV	5	6-7
Notebook PC	2-3	4
Computer peripherals	3	5
Telecommunications equipment	not available	not available

Source: Stanford Resources, Inc., 1999

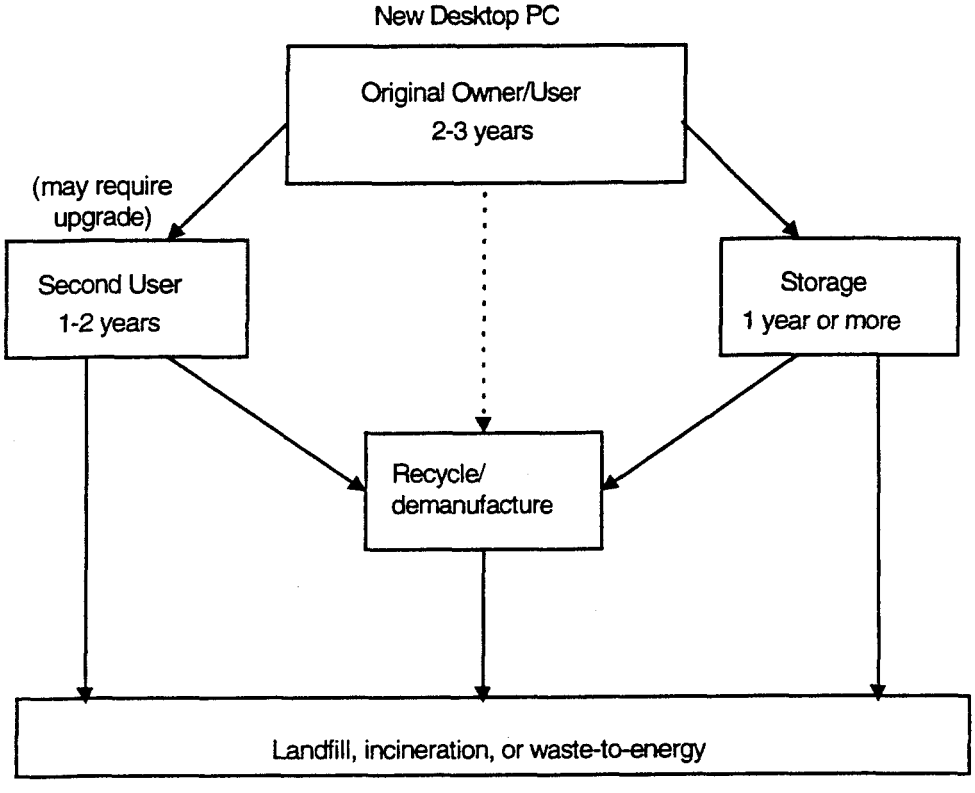
Due to the large number of PCs sold and their decreasing lifespan, it is important to pay attention to this class of electronic equipment. **Figure 4** is a simplified schematic of the lifespan of a desktop PC. It shows the typical life of a Pentium-class desktop PC, beginning with what is considered the first life. In this model, once a PC is no longer capable of performing the tasks for which it was purchased, there are two main disposition options.

The first option is reuse. The "second user" category of **figure 4** includes cascading (that is, passing a computer within an organization), resale, donation, and any other reuse of the intact computer. (Any of these reuse categories could require that the equipment be refurbished.) From the perspective of new computer sales, once a computer passes from the first life to the second, it has been replaced. From the end-of-life perspective, however, the computer is still in use. The end of a computer's second life is the point at which it can no longer be resold intact and its only monetary value is the worth of its parts or raw materials. At the end of the second life, the product can either be sent to a recycler, where most (estimated to be 95 percent) of the components and materials are reused, or to a landfill, in which case none of the components are reused. Desktop PCs occasionally go from "second life" to storage; once removed from storage, the PC essentially has only raw material value or a negative value if the cost of processing the PC or any of its components (for example, CRTs) is higher than the value derived from the parts.

The second option is to place the computer in storage. In this model, equipment is assumed to be in storage if it is out of use for a minimum of one year. PCs that enter storage typically stay in storage for 12 to 18 months. When an original user puts a computer in storage, the computer's total lifespan drops from a range of three to five years (for Pentium-class PCs) to a range of two to three years. Storage

consumes one to two years of the computer's second life. In general, once a used computer is in storage for at least a year, it no longer retains any reuse value. After a PC is removed from storage, the options are essentially to recycle it or send it to a landfill.

Figure 4: Model of PC Lifespan and End-of-Use Disposition



Source: Stanford Resources, Inc., 1999

A third, but little-used, option is for the original owner to have the computer recycled or demanufactured for parts recovery at the end of its first life. While this option may be a good way for the original owner to receive a return on the original investment, it is very rarely used. Two key factors limit use of this option. First, original owners general believe that the computer retains more value as a system then as a source of parts and materials. Second, original owners, especially individuals, generally lack awareness of recycling options.

2. Storage

To substantiate secondary information gathered about storage, resellers and nonprofit organizations were asked about the status of the equipment they receive (that is, whether it had been in storage, in active use, or returned to a manufacturer or retailer). OEMs and large corporate users were also questioned about the amount of electronic equipment they have in storage. However, most of the information about equipment in storage obtained from interviews is purely qualitative. In general, the lifespan assumptions outlined in **table 2** were used to estimate the number of PCs that become obsolete each year, and this estimation process invites significant uncertainty.

3. Units Shipped

The unit shipment information in this study is based on ongoing Stanford Resources' research on monitors, televisions, and notebook computers and other published sources. Unit shipment information was combined with lifespan estimates to estimate the number of obsolete products. No reliable installed-base estimates for the electronic equipment of interest were located. (Shipments refer to units shipped from manufacturers to retailers or other sales outlets. They also include direct sales from manufacturers to consumers.)

4. Market Assumptions

Attempts were made to contact all known electronics recyclers, resellers, and nonprofit organizations in the industry. Some companies contacted did not respond, and not every company that is in the business was known or reachable for this study. For some companies that did not respond, previously published data were used to estimate electronics recycling. The estimates reported in this study for all electronic equipment recycled are believed to account for at least 80 percent of all electronics recycling in the United States.

5. Measurement Inconsistencies

Many companies do not track the amount of material they process. Therefore, many of the answers supplied were estimates rather than definitive amounts. Also, recycling operations—even within the same company—use no single standard of measurement. Survey respondents indicated that equipment is sometimes measured in pounds and other times in units. Often, all equipment is weighed together as it arrives at the facility, and parts are taken out and counted as they leave the facility. In some operations, equipment is not weighed at all.

The organizations surveyed for this study were asked to give data in either units or pounds. Depending on which type of measurement was provided, the data were converted from units to pounds or from pounds to units by multiplying or dividing (as appropriate) by a standard conversion ratio. The conversion ratios, listed below in **table 3**, were developed in consultation with equipment manufacturers.

Table 3: Conversion Ratios

Equipment Type	Conversion Ratio (lbs./unit)
Desktop CPU	30
Mainframe computer	1,000
Workstation computer	35
CRT computer monitor	30
CRT TV	50
Notebook PC	10
Computer peripherals	25
Telecommunications equipment	10

Source: Stanford Resources, Inc., 1999

6. Limitations on Export Data

U.S. organizations appear to export end-of-life electronic equipment to China for three primary reasons. First, CRT processing is less regulated in some other countries, particularly China. Second, exporting CRTs can be less costly than processing them in the United States. Costs are lower not only because compliance with U.S. hazardous waste regulations is not necessary, but also because manual labor costs in countries such as China are low. As a result, CRT disassembly and scrap can yield significant profits. Third, China also has a larger market for used or recycled materials extracted from CRTs and for scrap because of its proximity to companies that use these materials in manufacturing.

Negative publicity associated with exporting end-of-life-equipment and scrap to China has made it extremely difficult to quantify the volume of end-of-life electronic products sent outside the United States. Few recyclers surveyed reported exporting CRTs or scrap electronics to China. However, several recyclers indicated that, in general, a greater volume of these products is exported to China than companies will discuss. Export data are also limited because many recyclers sell materials to brokers. While recyclers believe that many of these brokers export the materials in bulk to China and other less-developed nations, they do not know with certainty what brokers do with the materials.

V. ANALYSIS OF ELECTRONICS RECYCLING

A. Characteristics of Recycling Firms Surveyed

1. Location

The recyclers sample, which includes both primary and secondary recyclers, consists of 79 companies (see **appendix A**). The firms are headquartered in 22 states (see **table 4**). Seven states (California, Massachusetts, New Jersey, New Hampshire, Minnesota, Texas, and Wisconsin) account for 62 percent of the respondent recyclers; the top 12 states account for 81 percent of the respondent recyclers.

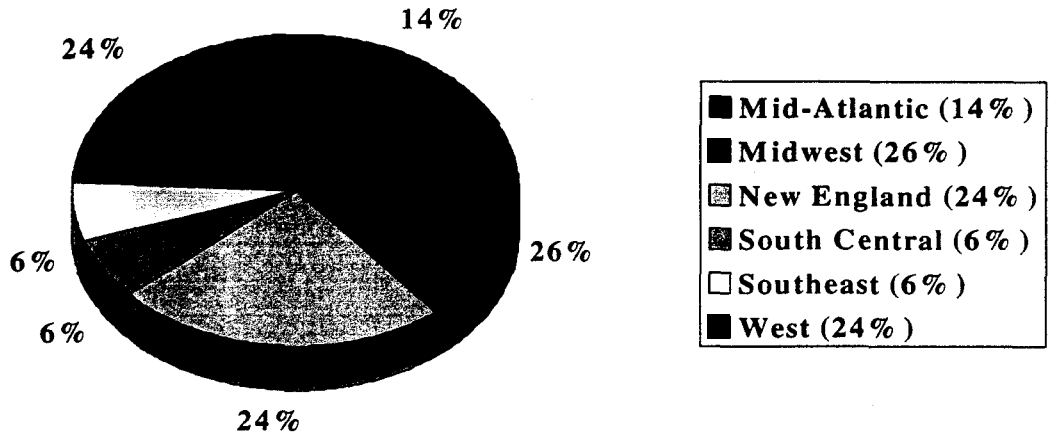
Table 4: Distribution of Recyclers Sampled, by State

State	Number of Recyclers with Primary Location in State	State's Share of Total Recycler Sample
CA	14	17.7%
MA	7	8.9%
NJ	7	8.9%
NH	6	7.6%
MN	5	6.3%
TX	5	6.3%
WI	5	6.3%
AZ	3	3.8%
FL	3	3.8%
IA	3	3.8%
IL	3	3.8%
VT	3	3.8%
CT	2	2.5%
MI	2	2.5%
NY	2	2.5%
PA	2	2.5%
WA	2	2.5%
GA	1	1.3%
IN	1	1.3%
NC	1	1.3%
OH	1	1.3%
RI	1	1.3%

Source: Stanford Resources, Inc., 1999

The 79 companies are concentrated in the Midwest, New England, and the West, each of which accounts for approximately one-quarter of the firms sampled (see **figure 5**).[10] **Figure 5** refers to the number of firms, not the amount processed, and therefore reflects the presence of recycling operations in each region, rather than the total amount of recycling activity. For example, only two firms reported a primary location in New York. Both, however, are large OEMs with several recycling facilities in the state and are among the largest recyclers in the United States.

Figure 5: Distribution of Recyclers Sampled, by Region

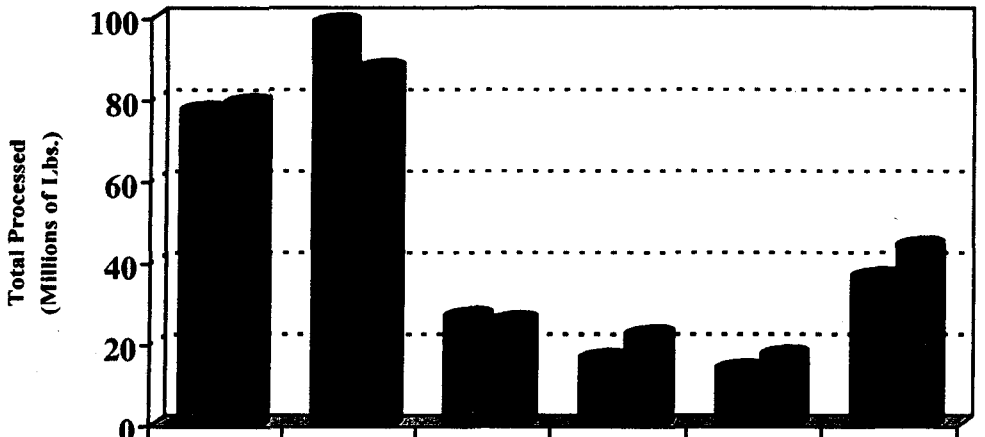


Source: Stanford Resources, Inc., 1999

An analysis of the regional distribution of total recycling activity indicates that the Midwest and Mid-Atlantic regions have the highest level of recycling activity. **Figure 6** shows regional electronic product recycling activity, in terms of pounds of equipment processed.

[10] Surveyed recyclers were in the following states: (Mid-Atlantic) New York, New Jersey, Pennsylvania; (Midwest) Iowa, Illinois, Indiana, Minnesota, Ohio, Wisconsin; (New England) Connecticut, Massachusetts, New Hampshire, Rhode Island, Vermont; (South Central) Texas; (Southeast) Florida, Georgia, North Carolina; and (West) Arizona, California, Washington.

Figure 6: Amount of Electronic Equipment Recycled, by Region

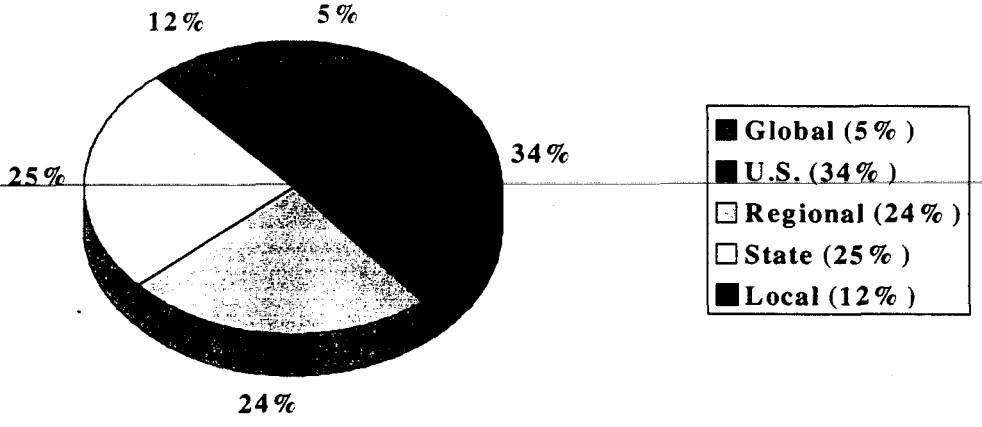


	Mid-Atlantic	Midwest	New England	South Central	Southeast	West
1997	77	99	27	16	14	36
1998	79	87	26	22	17	44

Source: Stanford Resources, Inc., 1999

Participating firms differed in their geographic coverage—the areas from which they accept equipment (**figure 7**). Only 4 (5 percent) of the firms reported global coverage; 27 (34 percent) reported that they covered all of the United States; and 45 (61 percent) reported that they covered only their local, state, or regional area.

Figure 7: Distribution of Recyclers Sampled, by Geographic Coverage

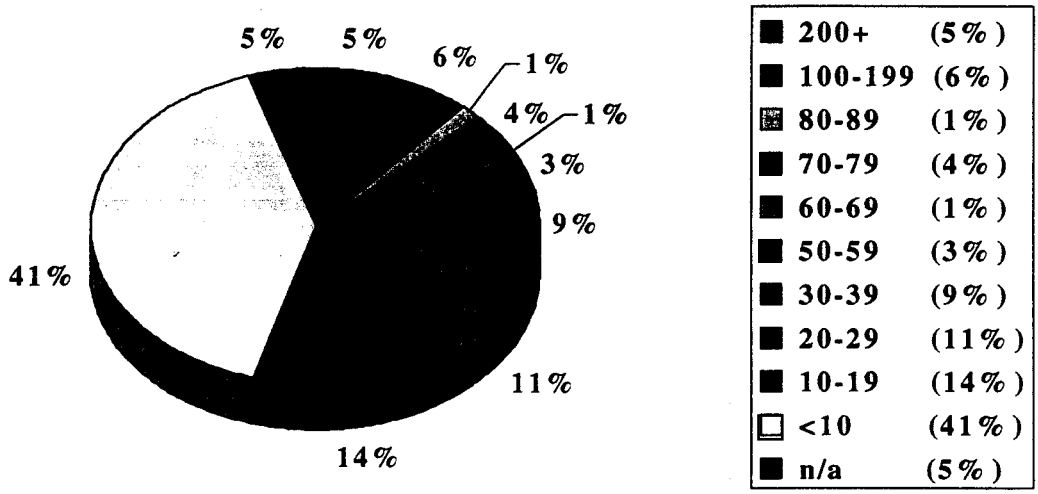


Source: Stanford Resources, Inc., 1999

2. Number of Employees

The total number of employees directly involved in electronics recycling at the firms sampled is approximately 3,000. Most of the responding firms employ very few workers; 59 (75 percent) have fewer than 40 employees, and 32 (41 percent) have fewer than 10 employees (see **figure 8**).[11] These counts do not include volunteers or inmate laborers.

Figure 8: Distribution of Recyclers Sampled, by Number of Employees



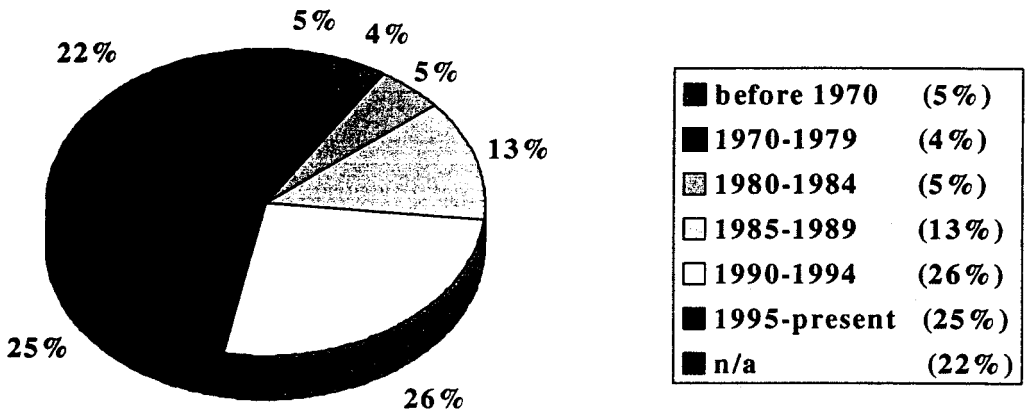
Source: Stanford Resources, Inc., 1999

[11] None of the firms surveyed had employee totals in the ranges of 40-49 or 90-99.

3. Years in Recycling Business

In general, the firms interviewed are relatively new to electronics recycling; 41 (51 percent) began processing electronic equipment in 1990 or later, as shown in **figure 9**.

Figure 9: Distribution of Recyclers Sampled, by Year Recycling Began



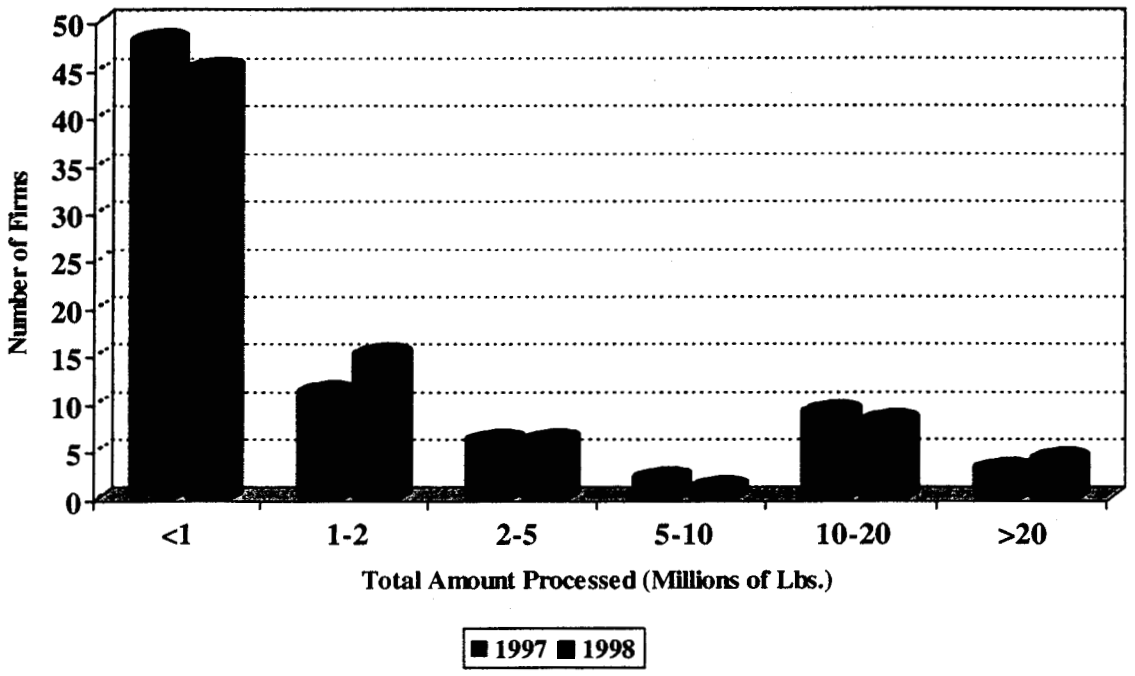
Source: Stanford Resources, Inc., 1999

4. Industry Trends

The U.S. electronics recycling industry has a concentrated structure. A few firms account for the majority of electronic products processed. In 1998, as shown in **figure 10**, 8 firms processed 10 to 20 million pounds, and 4 firms processed in excess of 20 million pounds.

The majority of firms (48 in 1997 and 45 in 1998) processed less than 1 million pounds per year. In 1997, 11 firms processed 1 to 2 million pounds, and 15 firms processed that amount in 1998. Only 8 firms processed 2 to 10 million pounds in 1997 and 7 processed that amount in 1998.

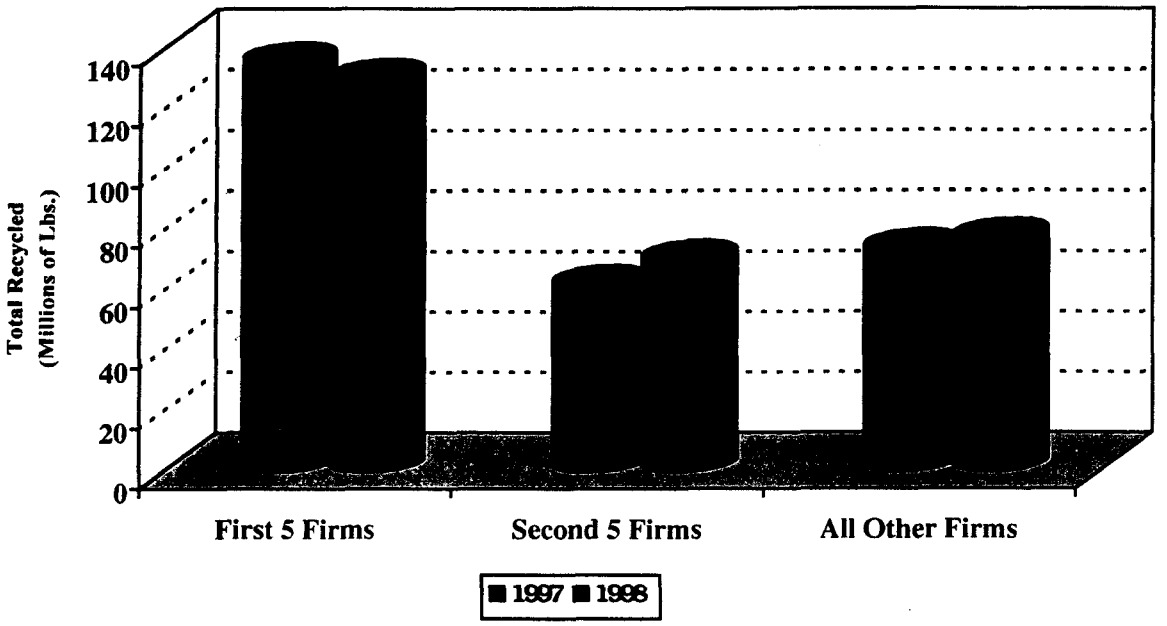
Figure 10: Distribution of Recyclers Sampled, by Amount Processed, 1997–1998



Source: Stanford Resources, Inc., 1999

Figure 11 illustrates another aspect of industry concentration—volume processed. In 1997 and 1998, the top 5 firms processed 50 percent of all electronics equipment recycled by the sampled firms. The next 5 largest firms processed 25 percent.

Figure 11: Electronics Recycling Industry Concentration, by Amount Processed, 1997–1998



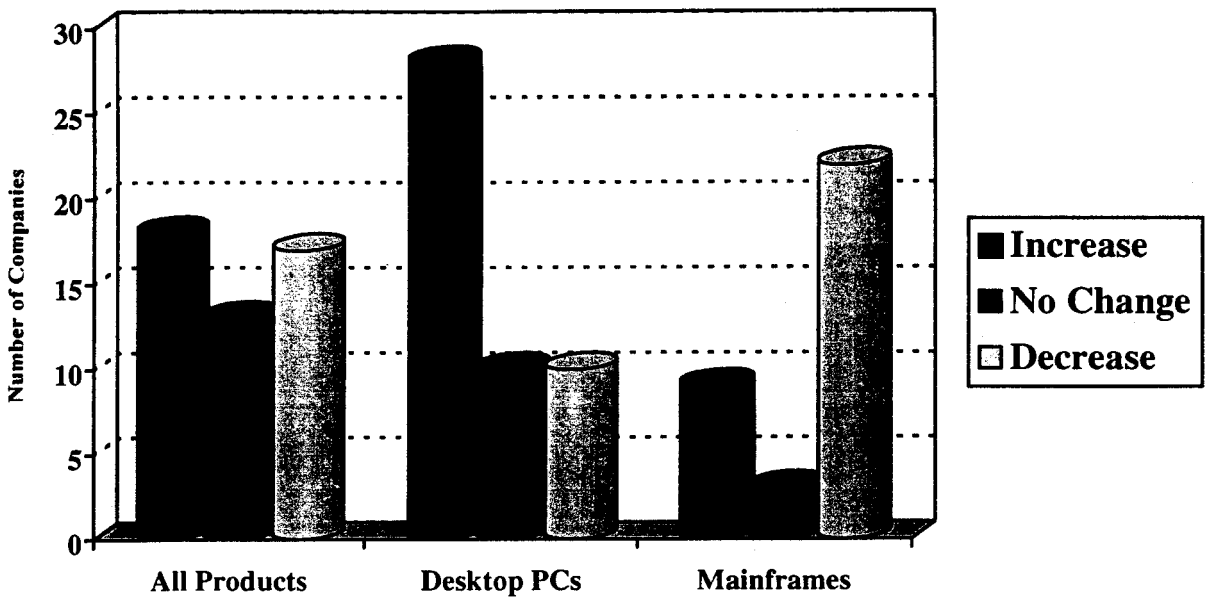
Source: Stanford Resources, Inc., 1999

Finally, among the primary and secondary recycling firms surveyed, 5 had just entered the business in 1998, 20 went out of business in 1997 or 1998, and 6 recycle only parts, plastic housings, and circuit boards. Among the remaining firms, several trends in recycling volume emerged (see **figure 12**):

- For total volume processed, roughly the same number of firms reported an increase (18) as reported a decrease (17).
- For desktop PC recycling only, many firms (28) reported an increase in amount processed, while only 10 reported a decrease.
- For mainframe recycling only, of the 34 firms that handled mainframes, the majority (22) reported a decrease in amount processed, while only 9 reported an increase.

These findings indicate that there is a shift in recycling activity toward PC recycling and away from mainframes, driven by the diminishing stock of end-of-life mainframe computers and the increasing stock of end-of-life PCs. At the same time, there is concentration in volume processed by large companies, along with increasing numbers of companies processing small amounts of volume.

Figure 12: Firm-Level Changes in Recycling Volume, 1997–1998



Source: Stanford Resources, Inc., 1999

B. Estimates of Total Volume of Electronics Recycling

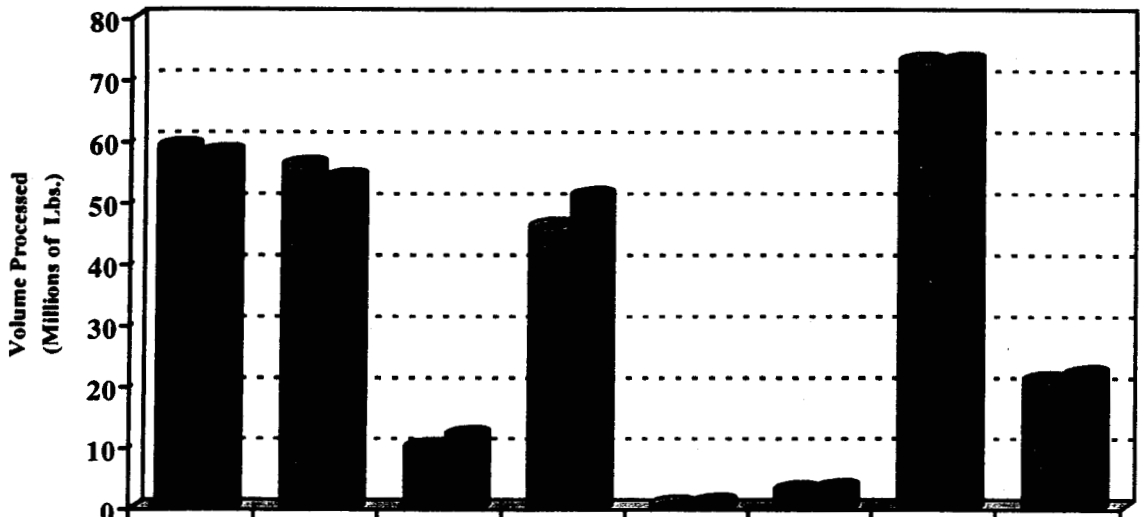
The total volume of electronic products recycled in 1997 identified by this study exceeded 268 million pounds, equivalent to approximately 9.4 million units of equipment. In 1998, the totals are estimated to be 275 million pounds and 9.7 million units. **Figure 13** compares volume recycled by product for 1997 and 1998. Among the firms surveyed, the leading electronic products recycled in 1997 and 1998, by weight, were the following:

- computer peripherals, at a constant level of approximately 73 million pounds;
- desktop PCs, which declined from 59 to 58 million pounds;
- mainframe computers, which declined from 56 to 54 million pounds; and
- CRT computer monitors, which increased from 46 to 51 million pounds.

In terms of units of equipment (**figure 14**), the leading electronic products recycled in 1997 and 1998 by the firms surveyed were the following:

- computer peripherals, unchanged at 2.9 million units;
- desktop PCs, which declined from 2.4 to 2.3 million units;
- telecommunications equipment, which increased from 2.1 to 2.2 million units; and
- CRT computer monitors, which increased from 1.3 to 1.5 million units.

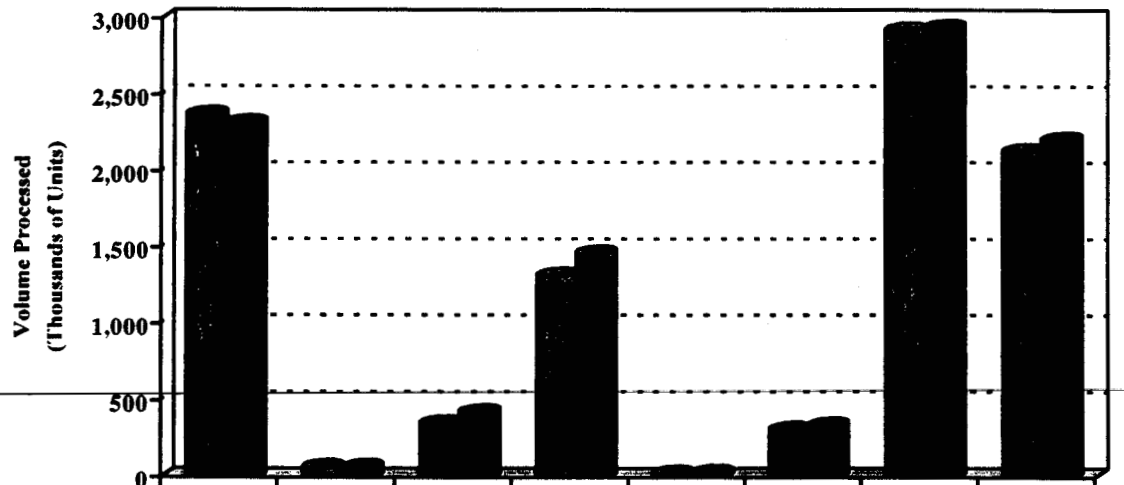
Figure 13: U.S. Electronic Product Recycling, by Weight, 1997–1998



	Desktop PCs	Mainframes	Workstations	CRT Monitors	CRT TVs	Notebook PCs	Peripherals	Telecom
1997	59	56	10	46	0.7	3	73	21
1998	58	54	12	51	1	3.3	73	22

Source: Stanford Resources, Inc., 1999

Figure 14: U.S. Electronic Product Recycling, by Units, 1997–1998

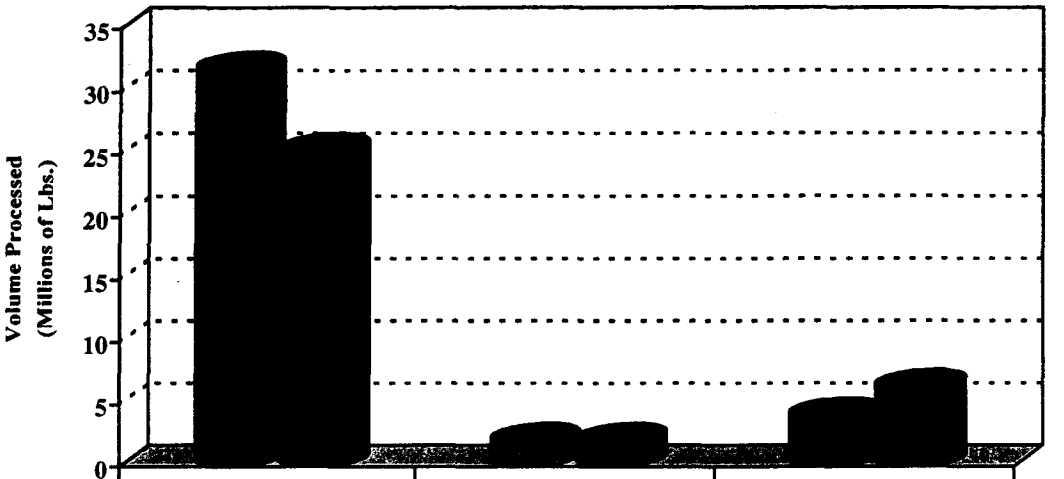


	Desktop PCs	Mainframes	Workstations	CRT Monitors	CRT TVs	Notebook PCs	Peripherals	Telecom
1997	2,362	56	342	1,307	14	301	2,915	2,122
1998	2,308	54	413	1,453	19	327	2,933	2,197

Source: Stanford Resources, Inc., 1999

Recyclers also reported receiving a significant volume of electronic equipment in the form of disassembled parts not traceable to any particular product, typically from service organizations within OEMs. As shown in **figure 15**, recyclers received 37 million pounds of assorted parts, circuit boards, and plastic housings in 1997, falling to 33 million pounds in 1998. The only part recyclers received in greater volume in 1998 than in 1997 was plastic housings, increasing from 4 million pounds to 6 million pounds.

Figure 15: Disassembled Parts Recycled, 1997–1998



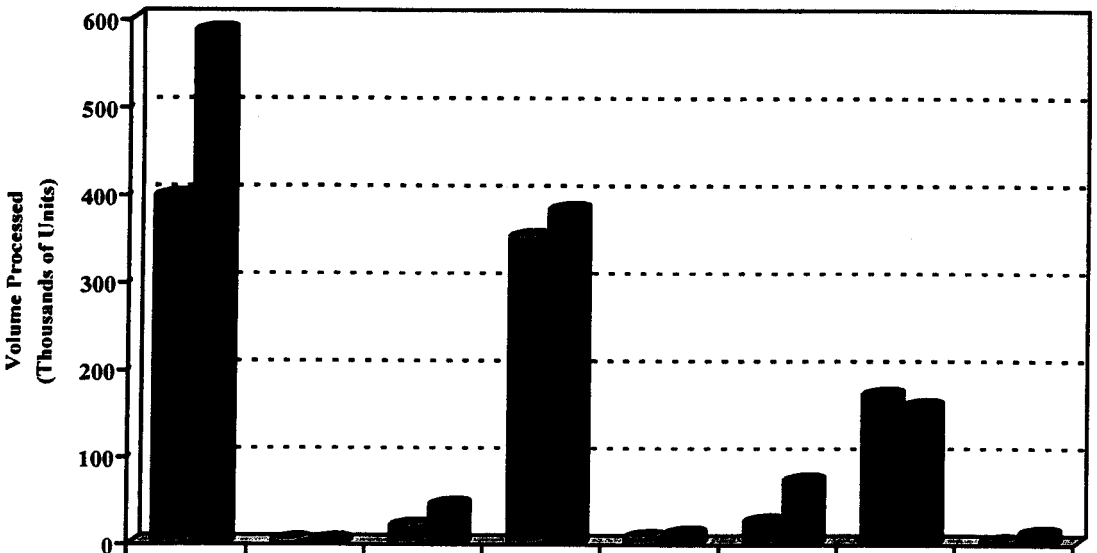
	Parts	Circuit Boards	Plastic Housings
1997	31.5	1.8	3.8
1998	25.0	1.8	6.1

Source: Stanford Resources, Inc., 1999

The third-party resellers and nonprofit organizations surveyed for this study reported receiving nearly 1 million units of electronic equipment in 1997, increasing to 1.3 million units in 1998. **Figure 16** shows that PC-related products were the primary types handled by third-party organizations in 1997 and 1998: desktop PC CPUs, which increased from 400,000 to 585,000 units; CRT computer monitors, which increased from 350,000 to 380,000 units; and peripherals, which declined from 170,000 to 160,000 units. **Table 5** shows the volume of equipment handled by recyclers and by third-party organizations in 1997 and 1998.

The data collected from third-party organizations for this survey are in general less detailed, and rely on a smaller sample, than the data collected from primary and secondary recyclers. While it is possible to survey and estimate the vast majority of recycling activity, the same is not true for third-party activities. Third-party organizations are usually small operations, and many are difficult to locate. The organizations surveyed for this study did not keep records detailed enough to accurately answer questions about demand for specific types of electronic equipment or the destinations of the equipment they processed.

Figure 16: Electronic Products Handled by Third-Party Organizations, 1997–1998



	Desktop PCs	Mainframes	Workstations	CRT Monitors	CRT TVs	Notebook PCs	Peripherals	Telecom
1997	396	2	19	350	6	24	170	1
1998	585	2	43	381	10	71	157	10

Source: Stanford Resources, Inc., 1999

Table 5: Electronic Products Handled by Recyclers and Third-Party Organizations, Thousands of Units, 1997–1998

	Recycler 1997	Third-Party 1997	Total 1997	Recycled 1998	Third-Party 1998	Total 1998
Desktop PC CPUs	2,362	396	2,758	2,308	585	2,893
Mainframe CPUs	56	2	58	54	2	56
Workstation CPUs	342	19	361	413	43	456
CRT monitors	1,307	350	1,657	1,453	381	1,834
CRT TVs	14	6	20	19	10	29
Notebook PCs	301	24	325	327	71	398
Peripherals	2,915	170	3,085	2,933	157	3,090
Telecom. Equip.	2,122	1	2,123	2,197	10	2,207
Total	**9,419**	**968**	**10,387**	**9,704**	**1,259**	**10,963**

Source: Stanford Resources, Inc., 1999

C. Estimates of Electronics Recycling by Product

The following sections compare, for each product, the estimates of total amounts recycled (combining recycler and third-party organization estimates) to historical shipment data. Forecasts of future recycling opportunities for each product are presented in **chapter VI**.

1. Desktop Personal Computer CPUs

The number of desktop PC CPUs processed by recyclers or handled by third-party organizations is estimated to have increased from 2.8 million in 1997 to 2.9 million in 1998. This estimate is considerably lower than the widely cited Carnegie Mellon PC recycling forecast of 6.6 million in 1997 and 7.3 million in 1998. This discrepancy most likely results from differences in methodology.[12]

Two factors make personal computers the product of greatest consequence to the level of electronics recycling in the United States. First, PC shipments to the United States market have been growing at a rapid rate over the past several years and are expected to exceed 42 million units in 1999, making PCs the electronic product with the highest volume of shipments of all the products considered in this study. Second, as described in **chapter IV**, PCs exhibit a short and declining useful life.

To estimate the number of PC CPUs that become obsolete each year, the study used a lifespan model that relies on a finer set of assumptions than those described in **chapter IV**. In the model, shown in **table 6**, annual U.S. PC shipment estimates are assigned to become obsolete in a future year through the use of a varying lifespan model. The model assumes a range of lifespans for each year's shipments, based on variations in usage patterns. For each year from 1992 to 2007, the table lists an average lifespan and a distribution of lifespans (from two to five years) for the PCs shipped. The final column of the table totals the number of PC CPUs estimated to become obsolete each year from 1997 through 2007. It is important to note that this model does not attempt to account for the stockpile of computers in attics, basements, and warehouses that has been created over the past two decades; it only estimates the lifespan of computers shipped from 1992 forward.

In 1998 alone, more than 20 million PC CPUs became obsolete. (This figure refers only to PCs shipped in 1992 or later that became obsolete in 1998 and does not include older PCs still in storage or use.) Thus, only about 11 percent of units that became obsolete in 1998 were recycled. Adding in the number of PCs refurbished and resold or donated by third-party organizations raises this percentage slightly, to about 14 percent.

The ratio of PC CPUs recycled in 1998 to new PC CPUs shipped from manufacturers to retailers and other customers in 1998 was even lower—about 6 percent. (This figure does not include units handled by third-party organizations.) In contrast, for major appliances (washing machines, water heaters, air conditioners, refrigerators, dryers, dishwashers, ranges, and freezers), the proportion recycled in 1998 was about 70 percent of the number shipped that year.

[12] *Disposition and End-of-Life Options for Personal Computers*, H. Scott Matthews et al., Green Design Initiative Technical Report #97-10, Carnegie Mellon University, July 7, 1997. This study reported the results of a simulation that used historical and forecast PC shipments to the United States as inputs. The initial lifespan of a PC was assumed to be five years, after which the PC could be reused, recycled, landfilled, or stored. For reused PCs, the second life was assumed to be three years, after which it could be recycled, landfilled, or stored. Storage was also assumed to be a three-year period. The estimates of numbers of PCs recycled produced by this model are thus heavily reliant upon the lifespan and product flow assumptions, rather than on primary research on recycling activity.

Table 6: Obsolete Personal Computers in the United States, 1997–2007, Millions of Units

Year	Unit Shipments [M]	Average Lifespan [Years]	Share of PCs Lasting				Number Obsolete [M]
			5 Years	4 Years	3 Years	2 Years	
1992	11.5	4.5	50%	50%			-
1993	14.6	4.2	20%	80%			-
1994	15.8	4.1	10%	90%			-
1995	17.1	3.8		80%	20%		-
1996	21.4	3.6		60%	40%		-
1997	31.4	3.4		40%	60%		17.5
1998	36.7	3.2		20%	80%		20.6
1999	42.6	3.1		10%	90%		23.8
2000	48.9	2.8			80%	20%	31.6
2001	49.9	2.6			60%	40%	41.9
2002	52.0	2.4			40%	60%	55.4
2003	53.3	2.2			20%	80%	63.3
2004	54.6	2.1			10%	90%	61.1
2005	55.8	2.0				100%	63.4
2006		2.0				100%	59.8
2007		2.0				100%	61.3
Total, 1997–2007							**499.8**

Source: *Appliance Magazine*, 1998; Stanford Resources, Inc., estimates based on numerous sources

2. Workstation Computer CPUs

Workstation CPUs have been processed by recyclers or handled by third-party organizations at a high level in the past two years, increasing from just over 360,000 units in 1997 to nearly 456,000 units in 1998. **Table 7** shows U.S. workstation CPU shipments of 470,000 in 1993 and 540,000 in 1994. Assuming a four-year lifespan for workstation CPUs, these numbers indicate a very high level of product recovery, most likely due to the high relative value and close control of workstations by corporate users and OEMs. **Table 7** shows U.S. workstation CPU shipments from 1993 to 2003; these computers are likely to be available for recycling in the coming years.

Table 7: U.S. Workstation CPU Shipments, Millions of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
0.47	0.54	0.55	0.61	0.70	0.81	0.89	0.91	0.93	0.93	1.05

Source: Stanford Resources, Inc., 1999 (figures for 1999-2003 are forecasts)

A higher percentage of workstation CPUs than desktop PC CPUs are being recycled, mainly because fewer workstations are resold; hence, workstations directly enter the recycling stream. Workstations are more difficult to resell than desktop PCs for two primary reasons. First, many large organizations prohibit the resale of their products—especially workstations. Since they are often used for critical applications, workstations are often shredded to ensure that proprietary information does not fall into the wrong hands. Donations of workstations are thus less likely than donations of desktop PCs. Second, workstations are not in high demand among purchasers of used computer equipment because

they are more specialized and tend to be used for very specific, information-sensitive purposes. As a result, workstations are less attractive to customers looking for inexpensive, all-purpose computers.

3. Mainframe Computer CPUs

The number of mainframe computers processed by recyclers or handled by third-party organizations in the United States is estimated to have been approximately 58,000 in 1997 and 56,000 in 1998. Since U.S. mainframe shipments have remained at approximately 12,000 a year over the period 1988–1997, this represents a high level of recycling. Asset management firms interviewed for this study estimate that 90 to 100 percent of mainframes being recycled were in storage prior to being recycled. This suggests that there is a backlog of old systems currently being recycled and that the high level of mainframe recycling in 1997–1998 will decline as the stockpile of mainframes is eliminated. The mainframe recycling market is expected to remain stable for only one to two more years and is likely to fall steadily after 2000.

Today, there are almost no first-time mainframe buyers. The movement from mainframe-based systems using terminals to networked PCs linked to servers has resulted in less reliance on mainframe technology. Nevertheless, mainframes continue to excel in environments in which high security, reliability, and immense processing capacity are needed. The strengths of the mainframe remain attractive to large corporations, especially those dealing with electronic commerce, for whom security is particularly important.

Demand is high for mainframes for recycling because their materials and parts are larger and more valuable (containing more precious metals) than those of present-day PCs. Replacement parts for mainframes are difficult to find. Therefore, many mainframes are stripped for parts, which are kept on hand to fix existing mainframes. This trend will decrease as more mainframes are recycled and replaced by servers.

Because the recycling of mainframes drove early (mid-1990s) electronics recycling activity, most established electronics recyclers began as mainframe recyclers. However, the decline in supply of stockpiled mainframes and the large capital investment required to recycle such machines have led many recyclers to focus on smaller, less-valuable products such as PCs, peripherals, and monitors over the past two to three years. Mainframe manufacturers and a few large-volume recycling companies now dominate mainframe recycling. Manufacturers and large recyclers have facilities that can handle the enormous size of mainframes, and both have relationships (through sales, leasing, and asset-management agreements) with the companies that possess the mainframes.

As shown in **table 8**, U.S. mainframe shipments are forecast to decline over the next several years, serving only specialized applications. Many of the remaining mainframes are likely to be replaced by servers connected to networks of PCs or workstations.

Table 8: U.S. Mainframe Computer Shipments, Thousands of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
12.0	11.7	11.4	11.7	11.7	11.5	11.0	11.0	10.0	9.0	8.0

Source: *Appliance Magazine*, April 1998 (figures for 1999-2003 are forecasts)

4. Notebook (Portable) Computers

The number of notebook computers processed by recyclers or handled by third-party organizations grew from approximately 325,000 units in 1997 to about 398,000 units in 1998. Because notebook computers are a relatively new product category, and expensive systems tend to be handed down within organizations or families, notebooks have only recently entered the recycling system. U.S. sales of notebook computers first reached 2 million units in 1993; growth has been rapid since then, however, with 1998 sales reaching 6 million units (see **table 9**). Thus, recycling of these computers is expected to increase over the next few years. However, compared to desktop systems, notebook computers are assembled in a dense and complex fashion. As a result, demanufacturing and parts extraction are more difficult and, consequently, more costly, which could limit interest in recycling such systems.

Table 9: U.S. Notebook Computer Shipments, Millions of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
2.0	3.0	3.4	4.5	5.4	6.0	6.7	7.5	8.4	9.3	10.5

Source: Stanford Resources, Inc., 1999 (figures for 1999-2003 are forecasts)

5. CRT Computer Display Monitors

The number of CRT monitors processed by recyclers or handled by third-party organizations grew from 1.7 million units in 1997 to 1.8 million units in 1998. CRT monitor sales in the United States exceeded 10 million units per year in the 1980s and reached 19.5 million units in 1994 (see **table 10**). Thus, there is a large installed base that recycling has barely tapped. Shipments of computer monitors based on cathode ray tubes have grown rapidly over the past several years but are forecast to peak in 2001, as liquid crystal and other flat panel displays increasingly penetrate the market.

Table 10: U.S. CRT Monitor Shipments, Millions of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
18.1	19.5	22.1	24.2	26.1	27.3	27.3	28.4	27.6	26.8	26.1

Source: Stanford Resources, Inc., *Monitor Market Trends*, 1999 (figures for 1999-2003 are forecasts)
Includes terminals, workstations, and desktop PC monitors, color and monochrome.

Table 11 indicates that fewer than 620,000 CRTs were recovered by U.S. smelters and CRT recyclers in 1997, and just over 100,000 were exported. These totals can be compared to the amount that primary and secondary electronics recyclers and third-party organizations (which accept monitors and televisions but ship the CRTs elsewhere for recycling) reported receiving: 1.7 million units. For 1998, 723,000 CRTs were recovered (through smelting or disassembly) and 150,000 exported, compared to a total of 1.8 million accepted by recyclers and third-party organizations. Therefore, after accounting for U.S. smelting, U.S. CRT recycling, and exports, nearly 1 million CRTs each year remain unaccounted for. It is likely that many of these CRTs are transferred to brokers, who often export CRTs in bulk shipments. Obtaining any type of accurate accounting for this flow proved impossible, however.

Table 11: Recovery of CRTs in the United States

	1997		1998	
	Units	Weight (lbs.)	Units	Weight (lbs.)
CRT monitors received by U.S. smelters	**100,000**	**2,200,000**	**100,000**	**2,200,000**
CRTs received by U.S. glass recovery firms				
CRT monitors	477,714	16,720,000	576,571	20,180,000
CRT TVs	41,600	2,080,000	46,400	2,320,000
Total received by U.S. glass recovery firms	**519,314**	**18,800,000**	**622,971**	**22,500,000**
Total CRTs recovered in the United States	**619,314**	**21,000,000**	**722,971**	**24,700,000**
CRTs exported	**100,543**	-	**149,303**	-

Source: Stanford Resources, Inc., 1999

6. Computer Peripherals

Approximately 3.1 million peripheral devices were processed by recyclers or handled by third-party organizations in the United States in 1997 and 1998. The majority of these devices were printers. **Table 12** and **table 13** show shipment estimates for printers and scanners (the two most prevalent peripherals), indicating that only a small fraction of such devices are being recycled.

Table 12: U.S. Computer Printer Shipments, Millions of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
10.7	11.6	13.0	12.1	14.3	16.2	16.1	17.0	17.9	18.4	18.3

Source: *Appliance Magazine*, 1998 (figures for 1999-2003 are forecasts)
Includes inkjet, laser, and dot matrix.

Table 13: U.S. Scanner Shipments, Millions of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
0.6	0.6	0.9	1.7	2.1	2.8	3.50	4.3	5.3	5.4	5.5

Source: *Appliance Magazine*, 1998 (figures for 1999-2003 are forecasts)

7. Telecommunications Equipment

Telecommunications equipment processed by recyclers or handled by third-party organizations exceeded 2 million units in both 1997 and 1998. Recyclers of AT&T, Lucent, Nortel, and Cisco equipment handle the majority of telecommunications products that are recycled.

8. Consumer Television Sets

The number of CRT TV sets processed by recyclers or handled by third-party organizations is very low, although it is increasing, rising from 20,000 units in 1997 to 29,000 in 1998. Approximately 25 million sets are purchased in the United States each year (see **table 14** and **table 15**); thus, televisions represent the product category with the largest discrepancy between shipments and recycling. This discrepancy likely results from the long lifespan of televisions, the lack of information available to consumers about recycling televisions, and the very low value of materials from recycled CRT TVs.

Table 14: U.S. Direct View CRT TV Shipments, Millions of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
23.0	24.1	24.5	24.6	23.6	23.7	24.7	25.9	26.4	25.9	26.3

Source: Stanford Resources, Inc., *Television Systems*, 1998 (figures for 1999-2003 are forecasts)

Table 15: U.S. Projection CRT TV Shipments, Millions of Units

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
0.5	0.6	0.6	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5

Source: Stanford Resources, Inc., *Television Systems*, 1998 (figures for 1999-2003 are forecasts)
Note: Each TV system uses 3 CRTs.

VI. SUPPLY, DEMAND, AND FORECASTS FOR ELECTRONICS RECYCLING

A. Supply from the Federal Government

The analysis of sources of end-of-life electronic products in **chapter III** of this study indicates that government agencies account for less than 5 percent of the total amount of electronic equipment received. There have been efforts to spur donations of government computers to schools, including an executive order.[13] One study of government computer donations estimates that the federal government has an installed base of 2.1 million computers, 500,000 of which are replaced each year. Most (65 to 90 percent) of those replaced are not operable or are obsolete, leaving perhaps 100,000 working systems available for reuse annually.

The process for transferring ownership of used federal computers to schools is very complex, however. It requires coordination with the General Services Administration and state bodies; in fact, a federal regulation prohibits agencies from packing and shipping surplus equipment to schools. These hurdles limited the number of computers donated to fewer than 50,000 in 1996 (the General Services Administration estimates the number for 1997 to be 70,000). Many more systems could be donated with some repair or refurbishment, but the study found that federal agencies are reluctant to use nonprofit third-party organizations because of concerns about fraud or other improprieties.

B. Demand by Public Schools

The limited data collected in this study regarding final disposition of refurbished electronic equipment indicate that public schools are a significant source of demand, particularly for PCs. An educational research firm estimates that the installed base (see **table 16**) of computers in the nearly 87,200 public schools and more than 16,400 school districts in the United States reached 6 million in the 1996–1997 school year.[14] From 1990 to 1996, increases in the installed base were below 1 million units per year, but the increase in 1996 was 1.6 million.

Table 16: Installed Base of Computers in U.S. Public Schools

School Year	Computer Installed Base (millions)
1990–91	2.1
1991–92	2.3
1992–93	2.8
1993–94	3.2
1994–95	4.1
1995–96	4.4
1996–97	6.0

Source: Quality Education Data. Inc., 1999 (data from www.qualityeducationdata.com)

[13] "Surplus Federal Computers for Schools: An Assessment of the Early Implementation of E.O. 12999," Thomas K. Glennan et al., Critical Technologies Institute, RAND Corporation, 1997.

[14] Quality Education Data. Inc., 1999 (data from www.qualityeducationdata.com).

In the 1997–1998 school year, Apple/Macintosh computers represented 47 percent of the installed base in U.S. schools, with DOS/Windows computers accounting for 38 percent. The share of Apple/Macintosh systems in schools has been declining, and Quality Education Data, Inc., forecasts that school computer purchases for the 1998–1999 school year will include 1.53 million Windows computers and 0.76 million Macintosh systems. Regardless of operating system, great demand exists in schools for multimedia computers that are suitable for Internet access and running programs with demanding graphics and sound requirements. As a result, computers with anything less than a Pentium or PowerPC chip will not be useful to most schools.

C. Raw Materials Markets

The demand for raw materials is created by thousands of manufacturing plants worldwide, which produce automobiles and other vehicles, appliances, construction materials, and consumer products. This demand is met by a worldwide system of mining and smelting operations to supply metals, glass factories using silica to produce raw glass, and processing plants to produce plastics. Recycled raw materials represent a small part of this material flow, and post-consumer packaging is the primary source of recycled materials.

The surveys undertaken for this study identified raw material flows from recycled electronic equipment in excess of 91 million pounds in 1997 and 112 million pounds in 1998 (see **table 17**). However, more than 25 percent of this total is accounted for by glass, which recyclers must pay to ship to and have processed by a CRT recycler or smelter.

Table 17: Raw Material Outputs from U.S. Electronics Recyclers, Millions of Pounds

	1997	1998
Glass	25.6	29.2
Plastic	8.2	14.4
Aluminum	8.7	9.9
Steel	31.9	43.9
Copper	6.9	7.9
Precious metals*	2.5	2.2
Other	7.8	5.4
Total	**91.6**	**112.9**

Source: Stanford Resources, Inc., 1999
*Precious metals include gold, palladium, platinum, and silver.

Other than gold, most recovered raw materials sell at prices below $1 per pound. **Table 18** lists some recent prices for recovered raw materials. Using the 1998 figures from **table 17** and the prices in **table 18** as guidelines, the following market values can be estimated:

- aluminum: $2 million
- copper: $5.5 million
- steel: $0.9 million to $1.3 million

Table 18: Prices for Recycled Materials

Material	Price ($/lb)
Commodities	
Gold	5,015.50
Copper	0.69
Steel scrap*	0.02-0.03
Recycled Materials	
Nonferrous metals	0.55
ABS, flaked	0.29
ABS pellets	0.41
Polypropylene, flaked	0.12
Polypropylene, pellets	0.19
Polystyrene, flaked	0.30
Polystyrene, pellets	0.40
PVC	0.21
Gold chips/fingers	20.00
Aluminum	0.20
Wire	0.15
Disk drives	0.14
Iron/aluminum	0.09
Transformers	0.07
Fans	0.06
Power supplies	0.04
Circuit boards	0.10
Scrap metal	0.02

Sources: *Plastics News*; *Recycling Manager*; *Business Week*; *Scrap Electronics Processing and Marketing Research Project*, University of Massachusetts-Amherst, Office of Waste Management, 1998.
*Steel scrap price range is based on April 1999 quotes from the following sources: *American Metal Market*, *Business Week*, and *Recycling Manager*.

D. Forecasts for Electronics Recycling

Based on the primary and secondary research performed for this study, a growth model for electronic equipment recycling was developed. Industry dynamics, technology changes, and economic value were evaluated for each product to develop a set of estimated annual growth figures for the period 1999 to 2007. These growth figures are shown in **table 19**.

In the near term, the most rapid growth in recycling opportunity is expected to be for notebook computers. These products will begin to become obsolete in large numbers in the early part of the next decade. Growth in desktop PC recycling will be significant, as more stored units are sent to recyclers. The only products forecast to decline are mainframe computers, which are currently being recycled much faster than historical shipments.

Table 19: Volume Growth Assumptions for Electronics Recycling Industry, by Product

	1999	2000	2001	2002	2003	2004	2005	2006	2007
Desktop PC CPUs	15%	20%	20%	25%	25%	27%	30%	30%	30%
Mainframe CPUs	-10%	-15%	-30%	-40%	-50%	-	-	-	-
Workstation CPUs	5%	10%	10%	12%	14%	14%	15%	15%	15%
CRT monitors	19%	21%	24%	25%	25%	25%	20%	20%	20%
CRT TVs	10%	10%	12%	12%	15%	15%	17%	18%	18%
Notebook PCs	35%	35%	36%	28%	25%	22%	15%	10%	10%
Peripherals	5%	5%	10%	10%	14%	15%	10%	9%	8%
Telecom. Equip.	4%	4%	6%	7%	8%	10%	11%	14%	16%

Source: Stanford Resources, Inc., 1999

Using the 1998 figures for amount of products recycled by weight, a forecast of total products recycled was developed. This forecast, shown in **table 20**, estimates that electronic product recycling will exceed 40 million units in 2007.

Table 20: Electronics Recycling Forecasts, Millions of Units

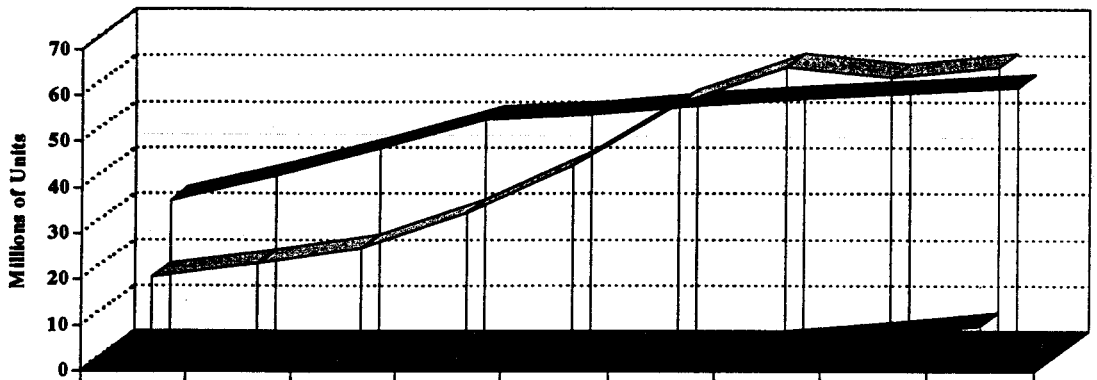
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	CAGR
Desktop PC CPUs	2.36	2.31	2.65	3.19	3.82	4.78	5.97	7.58	9.86	12.82	16.66	26%
Mainframe CPUs	0.06	0.05	0.05	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00	-40%
Workstation CPUs	0.34	0.41	0.43	0.48	0.53	0.59	0.67	0.76	0.88	1.01	1.16	13%
CRT monitors	1.31	1.45	1.73	2.09	2.59	3.24	4.05	5.07	6.08	7.30	8.76	22%
CRT TVs	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.06	15%
Notebook PCs	0.30	0.33	0.44	0.60	0.81	1.04	1.30	1.58	1.82	2.00	2.20	22%
Peripherals	2.91	2.93	3.08	3.23	3.56	3.91	4.46	5.13	5.64	6.15	6.64	10%
Telecom. Equip.	2.12	2.20	2.28	2.38	2.52	2.69	2.91	3.20	3.55	4.05	4.70	9%
TOTAL	**9.42**	**9.70**	**10.69**	**12.02**	**13.88**	**16.30**	**19.41**	**23.37**	**27.88**	**33.38**	**40.19**	**18%**

Source: Stanford Resources, Inc., 1999

Note: CAGR = compound annual growth rate, over the period 1998-2007.

The following graphs put the forecasts shown in **table 20** into perspective, comparing them with forecasts of new product shipments shown in **chapter V**, section C. **Figure 17** compares PC CPU shipment forecasts with the recycling trends predicted above and the obsolescence trends in **table 6**, indicating that the number of PCs recycled could exceed 11 percent of PCs shipped in 2003 and reach 18 percent in 2005. **Figure 17** also shows that in 2002, the number of obsolete PCs will exceed the number shipped by 3.4 million units. **Figure 18** compares recycling, shipment, and obsolescence forecasts for CRT monitors, indicating that a higher ratio of recycling to shipments (16 percent in 2003) is possible. For notebook computers (**figure 19**), the projections indicate that recycling will reach 12 percent of shipments in 2003.

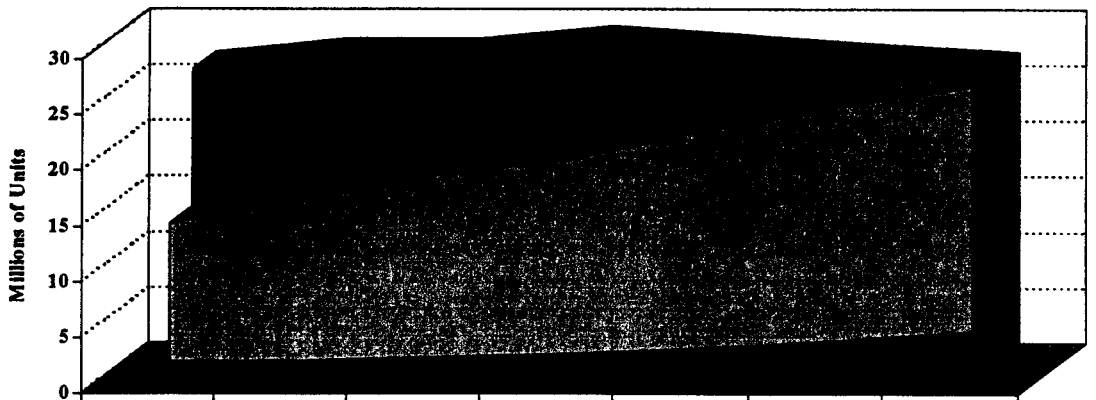
Figure 17: Forecast of U.S. PC CPU Shipments, Obsolescence, and Recycling, 1997–2005



	1997	1998	1999	2000	2001	2002	2003	2004	2005
Recycled	2.4	2.3	2.7	3.2	3.8	4.8	6.0	7.6	9.9
Obsolete	17.5	20.6	23.8	31.6	41.9	55.4	63.3	61.1	63.4
Shipped	31.4	36.7	42.6	48.9	49.9	52.0	53.3	54.6	55.8

Source: Stanford Resources, Inc., 1999
Note: See table 6 for detailed obsolescence data. Obsolescence data in this figure refer to units becoming obsolete during the referenced year; they are not cumulative.

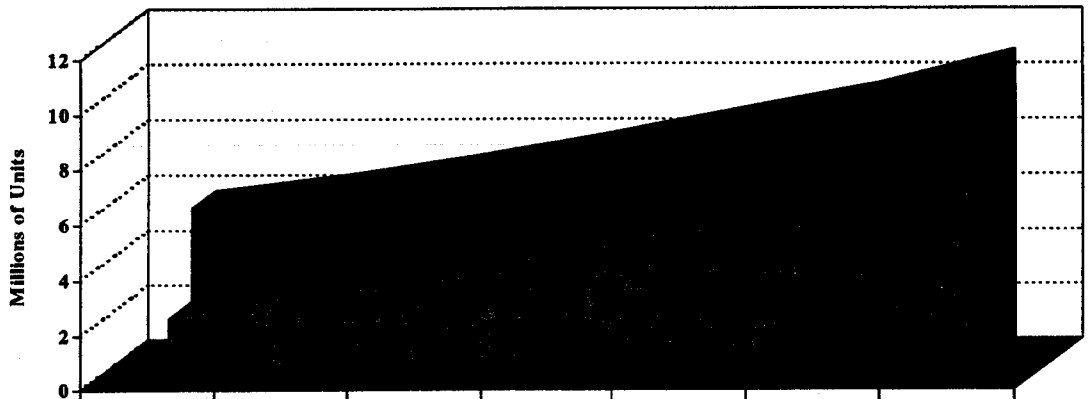
Figure 18: Forecast of U.S. CRT Monitor Shipments, Obsolescence, and Recycling, 1997–2003



	1997	1998	1999	2000	2001	2002	2003
Recycled	1.3	1.5	1.7	2.1	2.6	3.2	4.1
Obsolete	13.7	15.8	18.1	19.5	22.1	24.2	26.1
Shipped	26.1	27.3	27.3	28.4	27.6	26.8	26.1

Source: Stanford Resources, Inc., 1999
Note: Obsolescence estimates are based on a six-year lifespan. Obsolescence data in this figure refer to units becoming obsolete during the referenced year; they are not cumulative.

Figure 19: Forecast of U.S. Notebook Computer Shipments and Recycling, 1997–2003



	1997	1998	1999	2000	2001	2002	2003
Recycled	0.3	0.3	0.4	0.6	0.8	1.0	1.3
Obsolete	2.0	3.0	3.4	4.5	5.4	6.0	6.7
Shipped	5.4	6.0	6.7	7.5	8.4	9.3	10.5

Source: Stanford Resources, Inc., 1999
Note: Obsolescence estimates are based on a four-year lifespan. Obsolescence data in this figure refer to units becoming obsolete during the referenced year; they are not cumulative.

VII. FINDINGS AND RECOMMENDATIONS

This report documents the results of a study on recycling of electronic equipment in the United States. The study drew from numerous primary data sources, including direct interviews with representatives of approximately 120 recyclers, third-party organizations, and OEMs. Representatives of state and federal environmental agencies and industry associations were also interviewed. In addition, a large number of secondary data sources were consulted.

The findings document an electronics recycling industry still in a nascent stage in which roles continue to be defined. Considerable definitional confusion exists within the industry, with such terms as recycler and reseller used interchangeably in different contexts. There are no fixed boundaries within the chain of activities involving collection, refurbishment, disassembly, and redistribution of electronic equipment. Finally, there is little standardization in methods of accounting for product flows through the electronics recycling industry.

In general, large companies and facilities dominate the electronic equipment recycling industry. These organizations have the ability to make significant capital investments in equipment for automated sorting and destruction of electronic equipment. They also have relationships with manufacturers and users of electronic products required for a high level of capacity utilization in their facilities.

Several trends emerged in the course of this study that suggest a decline in electronics recycling activities: a decrease in the volume of products processed from 1997 to 1998, the withdrawal of 20 companies from the electronics recycling business in 1998 and 1999, and the entry of only 3 recycling companies and resellers during the same period.

Although the volume of electronic products recycled decreased from 1997 to 1998, the electronics recycling industry is expected to grow by 18 percent annually over the period 1998 to 2007. The decrease during the two years surveyed is attributed mainly to a decrease in mainframe recycling and the transition to PC recycling. Predicted growth in the industry is expected to result from the entry of new firms to the business and to increased volume handled by large-capacity facilities.

The possibility of government takeback regulations for electronic equipment is not a primary concern for large OEMs; most do not believe the government will intervene in this area. Market forces, however, have spurred companies to become more environmentally responsible. When recyclers were asked which factors influenced OEMs and large corporations to decrease the amount of electronic products in storage and to increase recycling, the most common responses were implementation of leasing programs and requirements placed on OEMs by large corporate customers to take back used equipment. The least common responses were government legislation and development of new modular designs to alleviate disposal issues. Increased concern among large corporations and consumers about the potential for improper disposal of large volumes of electronic equipment has helped drive the computer leasing, reselling, and recycling markets.

Many OEMs and asset management firms handle disposition of obsolete electronic equipment as a service to large corporate accounts. The user organization is relieved of the burden of removing data and disposing of the equipment. Decreases in the cost of computers and in the value derived from recycling them have increased the importance of such arrangements to large-scale users of electronic equipment. These arrangements also account for a significant portion of the electronic equipment recycled in the United States.

Individual users (including families) and small businesses contribute only a small fraction of the electronic equipment that is recycled. There appears to be no concerted effort by OEMs or recyclers to educate individuals about recycling electronic equipment. However, with TV penetration approaching 100 percent of U.S. households (and more than two televisions per household, on average) and PC penetration exceeding 50 percent, the need for consumer participation in electronics recycling will become increasingly important. It would seem reasonable for OEMs to provide information about electronics recycling to purchasers of new computers or televisions. A campaign of trade-in credits for old equipment could perhaps spur new product sales.

Recycling CRTs from computer monitors and televisions remains problematic. Federal regulations designating end-of-life CRTs as hazardous waste have created barriers to handling and shipping CRTs and have likely hindered further development of CRT recycling. Recyclers report having processed many more CRTs (more than twice as many in 1997 and 1998) than the number reported as having been received by smelters or glass recovery firms or exported. The most likely explanation for this disparity is that a significant number of CRTs are transferred to brokers who then export the tubes. Another finding in this area is that much of the volume handled by CRT recyclers is actually scrap glass and failed tubes from CRT plants; these materials are sorted and broken down into different glass types by CRT recyclers and transferred back to CRT manufacturers. This flow can in no way be classified as end-of-life.

Transportation costs are another hindrance to electronics recycling. If the cost to ship a PC exceeds the amount obtained from resale of the whole computer or the useable parts, there is little motivation to recycle. Thus far, local bans on landfilling equipment (or bad publicity associated with it) and laws prohibiting landfilling of CRTs have been the incentives for recycling, even when it is not profitable.

Research for this study indicates that electronic products are not the most promising uses for plastics recovered from end-of-life electronic products; other products, such as outdoor furniture or automobile parts, have consumed most recycled plastics. Generally, the share of recycled content in such applications is less than 25 percent. The major obstacle to overcome is the inability to recycle mixed plastics; once a solution to this problem is discovered, more plastics will be recycled.

In summary, this study found an electronics recycling industry in its formative stages—an industry requiring further definition and infrastructure to become fully effective. The industry (including not only primary and secondary recyclers, but also third-party remanufacturing, resale, and reuse organizations) has the potential to provide a critical service not only to manufacturers, but also to municipalities and large- and small-scale end users of electronic equipment. In the future, equipment manufacturers are likely to take a more aggressive approach to product stewardship in response to customers' needs and other market forces. In addition, the volume of obsolete equipment will continue to grow along with the rapid pace of technological change; this growth will help provide the critical mass of material needed to support an advanced recycling industry. More than a sufficient volume of material will be necessary to support effective electronics recycling, however. An efficient, workable electronics recycling system will depend on partnerships and collaborations among manufacturers, transportation providers, recyclers, third-party organizations, and other stakeholders.

APPENDIX A: Recyclers, Manufacturers, and Corporate Users Interviewed

This appendix lists 80 firms that contributed data to this study, either through direct interviews or secondary sources. Six firms asked not to be named and do not appear on the following list. Two firms submitted a joint survey; they are listed separately.

5R Processors
A & B Recycling, Inc.
A & G Electronics, Inc.
Absolute Recycling
Advanced Recovery, Inc.
AERC
America II Electronics
Asset Recovery Corp.
Axcess Technology
Blue Fin Technology
Butler-MacDonald, Inc.
Carolina Environmental Associates, Inc.
Cerplex
City Industries, Inc.
Colt Refining Group
Compaq (formerly Digital Equipment Corp.)
Complex Metals
Computer Recyclers
Computer Recycling Services
Conigilaro Industries
DMC
Dynamic Technologies
Electronic Disposal & Recycling, Inc.
Electronic Environmental Recycling
Electronic Recovery, Inc.
Electronic Recyclers Group
Encore
Envirochem
Envirocycle
EnviroLight & Disposal
Fox Electronics
Hess Technology
HOBI International
Hewlett-Packard
IBM
Ingenuity Corp.
Marion Iron
Markovitz and Fox
Martin Metals
Materials Processing
Metech International
Micro Mechanics
Midwest Recycling
Newtech Recycling
Noranda, Inc., Micro Metallics Corporation
North American Micro Corporation
Oxford Metals
Polymer Recovery Service
Recyclights
Recycling Separation Technology
Reliable Recycling
RST Computer
Rustec
Salesco
San Jose Metals
Scientific Recycling
Secure Environmental Electronic Recycling (SEER)
Shapiro and Sons
Sipi Metals
Southern Recycling
Stateline Recycling
Stephen Anderson
System Service International
Tecnotes
Texas Metal Recyclers
Tryonics
UNICOR Federal Prison Industries
United Datatech
University of Massachusetts, Amherst
Vetco
Visteon Exterior Systems
Wade Environmental
Waste Management, Phoenix
Waste Management, Wisconsin
Welsco Recycling
West Pacific Industries
Westech Recyclers
Winfield Alloy
Xerox
Youth for Service

APPENDIX B: Third-Party Organizations Interviewed

This appendix lists 35 firms that contributed data to this study, either through direct interviews or secondary sources. One firm asked not to be named and does not appear in the following list. Two firms completed interviews as both third-party organizations and as recyclers; these firms are listed in appendix A.

Action Computers
Community Resource Bank/United Way of Central Maryland
Computer Inventory Liquidation Systems (CILS)
Computer Reclamation
Computer Recycling Project
Computers 4 Kids
Davis Memorial Goodwill Industries
Detwiler Foundation
DRAGnet
East-West Foundation
Electronic Materials Recovery, Inc.
Gifts In Kind
Long Island City Business Development
Mid America Housing Partnership
MKR Data Resources
Motor City Computer Services
National Association for the Exchange of Industrial Resources (NAEIR)
National Christina Foundation
Patterson Education Fund
Public Service Electric & Gas (PSE&G)
R. Frazier
Recycle North Work Program
Recycle Town
Resource Area for Teachers (RAFT)
Resources Concepts
Ribbon Recyclers
Rumarson Technology, Inc.
Scanlan, Dairy, Swine Consulting
Seattle Computer Exchange
Silver Tree
Spring Lake Computer Exchange
TecsChange
U.S. Micro Corporation
Urban Ore
USA City Link

APPENDIX C: Stanford Resources, Inc.

Stanford Resources, located in San Jose, California, and established in 1978, is a management consulting and market research firm. The company, which has a worldwide clientele, covers the electronic display and related industries. Stanford Resources' personnel have experience in the display field in such areas as product development, market research, manufacturing, technology assessment, operations management, and business development. Below are brief biographies of the analyst group that conducted research for this study.

Paul Semenza, Director of Market Analysis. Paul Semenza is responsible for market research and strategic analysis for the firm's publications and studies, and directs the activities of all of the company's market research analysts for both multiclient and custom market research studies. Before joining Stanford Resources, Mr. Semenza was a program officer at the Computer Science and Telecommunications Board of the National Research Council, where he directed studies on software engineering, wireless communication technologies, and the economic and social impacts of computing and communications technologies. Mr. Semenza was an analyst at the Office of Technology Assessment from 1993 to 1995, and he was a member of the technical staff at The Analytic Sciences Corporation from 1985 to 1992. He has a bachelor's degree in electrical engineering and a master's degree in electro-optics from Tufts University, and a master's degree in public policy from the John F. Kennedy School of Government at Harvard University.

Adria Ferguson, Market Analyst. Adria Ferguson is responsible for gathering data and performing research for Stanford Resources' multiclient reports and custom studies. Previously she conducted market research and analysis for Izahi, Inc., a video-imaging firm. Ms. Ferguson has conducted market research in both the digital enhancement and retail industries. She graduated from the University of Pennsylvania with a bachelor's degree in psychology and economics in 1997.

Donald Johnson, Senior Industry Analyst. Donald Johnson is involved in research for various custom studies and coordinates Stanford Resources' *Global LCD Supply and Demand Quarterly*. He has 16 years of experience researching the Japanese semiconductor and semiconductor production equipment industries. He has been a correspondent for *Semiconductor World*, a Japanese trade magazine, and participated in the launch of *FPD Intelligence*, the first Japanese magazine dedicated to flat panel displays. Mr. Johnson holds a bachelor's degree in Japanese Studies from San Jose State University.

George Aboud, International Database Manager. George Aboud is responsible for Stanford Resources' comprehensive databases on display technology. Mr. Aboud is involved in research for many of the firm's annual multiclient surveys and market forecast reports. He is a graduate of San Jose State University with a bachelor's degree in economics.

National Safety Council's Environmental Health Center

The Environmental Health Center is a division of the National Safety Council, a leader in accident prevention and home, workplace, auto, and highway safety. The National Safety Council established the Environmental Health Center in 1988 to help society and individuals better understand and act responsibly in the face of environmental health risks.

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