

**GENERAL BACKGROUND DOCUMENT ON
CATHODE RAY TUBE
GLASS-TO-GLASS RECYCLING**

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CATHODE RAY TUBE GLASS-TO-GLASS RECYCLING

1. BACKGROUND

This report provides general background information on cathode ray tubes (CRTs) and the process of recycling used CRT glass as a raw material input in new CRT glass manufacturing (a.k.a. "glass-to-glass recycling"). This information is intended to be used in conjunction with other background materials to support a rulemaking revising the Resource Conservation & Recovery Act (RCRA) hazardous waste management regulations to remove regulatory barriers to CRT glass-to-glass recycling. This rulemaking implements a recommendation made to EPA by the Common Sense Initiative (CSI) Council designed to facilitate the recycling and reuse of CRTs. The recommendation was developed by the CSI Computer & Electronics Subcommittee (CES) through its work group on CRT glass-to-glass recycling.

The report consists of four sections. The remainder of Section 1 presents a general description of what is a CRT, the management options for post-use CRTs, and the advantages of CRT glass-to-glass recycling. Section 2 provides an overview of CRT manufacturers, generation, collection, transportation, as well as recyclers of end-of-life CRTs. Section 3 describes general CRT glass-to-glass recycling processes and technologies, as well as waste generation and management issues related to the processes. Section 4 assesses the implications of CRT glass-to-glass recycling on the environment, occupational health and safety, and environmental justice.

The information provided in this report was compiled based on documents produced by EPA, consultations with industry experts and CSI Computer & Electronics Subcommittee members, and a literature search. It should be noted that this report is a generalized document which provides basic information for the discussion of CRT management. The CRT glass-to-glass recycling industry is an emerging industry still in its infancy. It is undergoing constant changes and new developments, therefore, it should be noted that this document is not intended to serve as a technical reference for CRT glass-to-glass recycling.

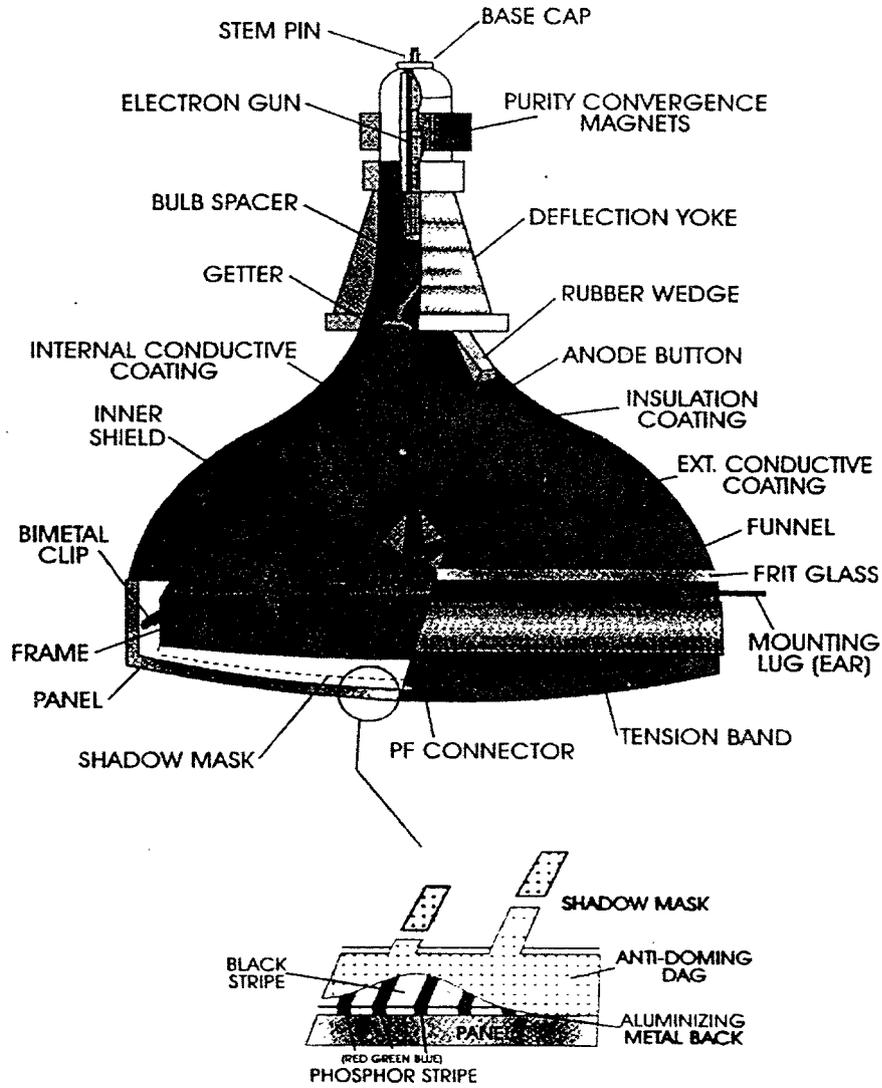
1.1 What is a CRT?

Cathode ray tubes (CRTs) are the video display components of televisions and computer monitors (EPA, 1995). CRT products represented by Standard Industrial Classification (SIC) code 3671, include tube glass, color picture tubes, monochrome picture tubes, and rebuilt tubes.

Components of a Typical CRT

A CRT is composed of four major parts: the *glass panel* (or faceplate), a *shadow mask*, a *glass funnel*, and an *electron gun*. Figure 1 illustrates the structure of a typical color CRT. Figure 2 is the diagram of a typical monochrome CRT. The glass panel is the front of the CRT that is seen when viewing a TV or monitor. The shadow mask is a thin metal sheet with apertures, positioned immediately behind the glass panel. The glass funnel is shaped like a funnel and is attached to the back of the glass panel. The glass panel and glass funnel are connected using a glass *frit* solder. The glass funnel holds the electron gun and forms the back end (neck) of the CRT. The electron gun produces the electrons that strike the glass panel and produce images that are seen on the TVs or monitors.

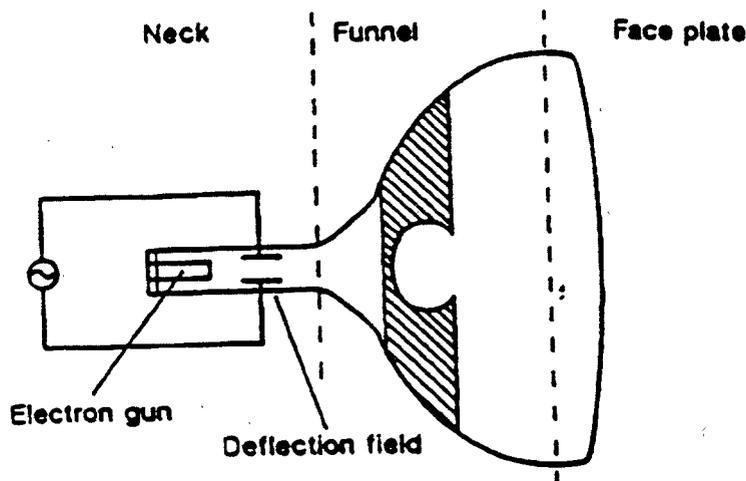
Figure 1
Structure of a Typical Color CRT



Source: Diagram of a color picture tube from Toshiba Display Devices Inc.

Compared to monochrome CRTs, color CRTs have slightly more complicated construction with additional components, such as internal magnetic shield.

Figure 2
Diagram of a Typical Monochrome CRT



Source: Per Hedemalm, Per Carlsson, and Viveka Palm, *A Survey of the Contents of Materials and Hazardous Substances in Electric and Electronic Products*, Swedish Institute of Production Engineering Research (IVF), no date.

A CRT is assembled into a display that includes several other parts, including a plastic cabinet, electromagnetic shields, circuit boards, connectors, cabling, and other discrete components. This report focuses primarily on CRTs themselves, not the other parts of the overall display.

The image on a CRT is created by exciting phosphors with electrons. The process of exciting the phosphors which coat the inside of the glass panel, produces incidental X-rays. To shield the viewer from the radiation generated inside the CRT, X-ray absorbing materials such as lead, barium, strontium, and zirconium oxides are added to the CRT glass.

The primary materials in each of the components of a typical 20-inch color CRT are shown in Table 1.

Table 1
Primary Materials in a Typical 20-Inch Color CRT

Component	Material
Panel	2 % lead glass
Funnel	28 % lead glass
Grille	Aquadag (these are suspensions of electrically conductive carbon materials with silicate binders in a water suspension)
Phosphors	ZnS, YOS
Aluminizing	aluminum

Conductive coating	Aquadag, iron oxide powder
Shadow mask	steel
Shadow mask frame	steel
Spring clips	spring steel
Washer	steel
Magnetic shield	steel
Electron gun	300/400 series steels, borosilicate glass, nickel, cathode coat
Base	plastic
Implosion band	steel
External coating	Aquadag

Source: U.S. DOE and MCC, 1993.

CRTs are composed largely of specialized glass. Each glass manufacturer uses slightly different input materials and processes, which result in CRTs with different compositions. In addition, CRTs have changed over time due to technological advances in CRT glass manufacturing and environmental concerns. In the past 25 years, greater than one hundred different panel compositions with several different transmissions for each composition were manufactured. The different components and compositions of CRT glass are discussed in detail in Section 3.1

Distinct Types of CRTs

There are two general categories of CRTs: (1) monochrome (single color) CRTs, and (2) color CRTs. There are two different designs of monochrome CRTs, including low voltage CRTs for direct view and high voltage CRTs for the projection of images onto large screens. Color CRTs, including direct view and projection, all require high voltages.

High voltage monochrome CRTs operate at the same power as large direct view color CRTs, which require a higher voltage than low voltage CRTs for improved resolution. Higher voltage results in an increase in X-ray generation. To absorb the increased level of X-rays, high voltage CRTs contain higher levels of lead or other heavy metals than direct view monochrome CRTs. High voltage monochrome CRTs do not contain lead in the faceplate, but require high concentrations of barium, strontium, and zirconium for X-ray absorption.¹

CRTs are mainly used in households, businesses, schools, and government and non-government organizations. In general, CRTs manufactured for households are the same as those manufactured for businesses.² Available data indicate that the composition of CRTs in televisions is not significantly different from that of computer monitors (McKenna et al., 1996). In addition, some CRTs are manufactured for specialized commercial uses, such as military, marine, aerospace, and commercial radar displays. Many medical (e.g., remote image displays for X-ray equipment and CAT scan imagery), automotive, oscilloscope, and appliance displays also use CRTs.

¹ Source: David Isaacs, December 13, 1996; personal communication with Jeff Lowry, November 5, 1996

² Personal communication, Jeff Lowry, November 5, 1996.

1.2 CRT Life Cycle

Figure 3 shows the life cycle flow of a typical CRT. The lead that is used for CRT glass manufacturing is converted to lead oxide and shipped largely by rail to CRT glass manufacturers. In the CRT glass manufacturing facilities, lead oxide is combined with sand, limestone, and other raw minerals including potassium, barium, and strontium compounds. In addition to such raw materials, broken glass (or "cullet") from previous batches of CRT glass and recycled CRTs are used, both to preserve the value of the raw materials in the cullet and to lower the melting point of the new mixture. These materials are melted in a glass furnace to make new CRT glass. The molten glass is formed into glass parts, panels, funnels, or necks depending on the composition of the mixture. These parts are subject to multiple quality control checks and final polishing prior to shipment to tube manufacturers.

Tube manufacturers receive finished glass parts from CRT glass manufacturers. In the tube manufacturing process, coating is applied to the glass parts which are then assembled to form the CRT. The glass parts are sealed together by using glass frit as a solder. A vacuum is created inside the tube prior to a final sealing. Electronic components are then added and the assembled CRT is shipped to a display manufacturer.

Display manufacturers produce TVs or computer monitors by setting the CRT into the appropriate casing. Electronic components such as wiring, switches, and other circuits are attached to the CRT during displaying assembly. Most manufacturers buy imported tubes to go with their own hardware. A few buy CRTs and discrete components to assemble displays.

CRT monitors or displays are widely sold to households, businesses, governments, and other entities. In general, the computer monitors have an average lifetime of 5 to 7 years and the TVs have an average lifetime of 15 to 20 years before they are discarded.³ Some data indicate that many post-use CRTs generated by households may be in storage. According to a 1995 report from Tufts University, 75 percent of end-of-life CRT products are in storage. Some industry representatives have suggested that large number of stored CRTs is due to a lack of infrastructure to collect and transport retired products to a viable recovery facility. Although households and some businesses can dispose of their CRTs along with other trash, a 1996 MCC report suggests that many municipalities would prefer not to pick up large volumes of electronic equipment at curbside given their current inability to handle them. Therefore, the majority of post-use CRTs remain in storage, while a small fraction is taken to disposal facilities.

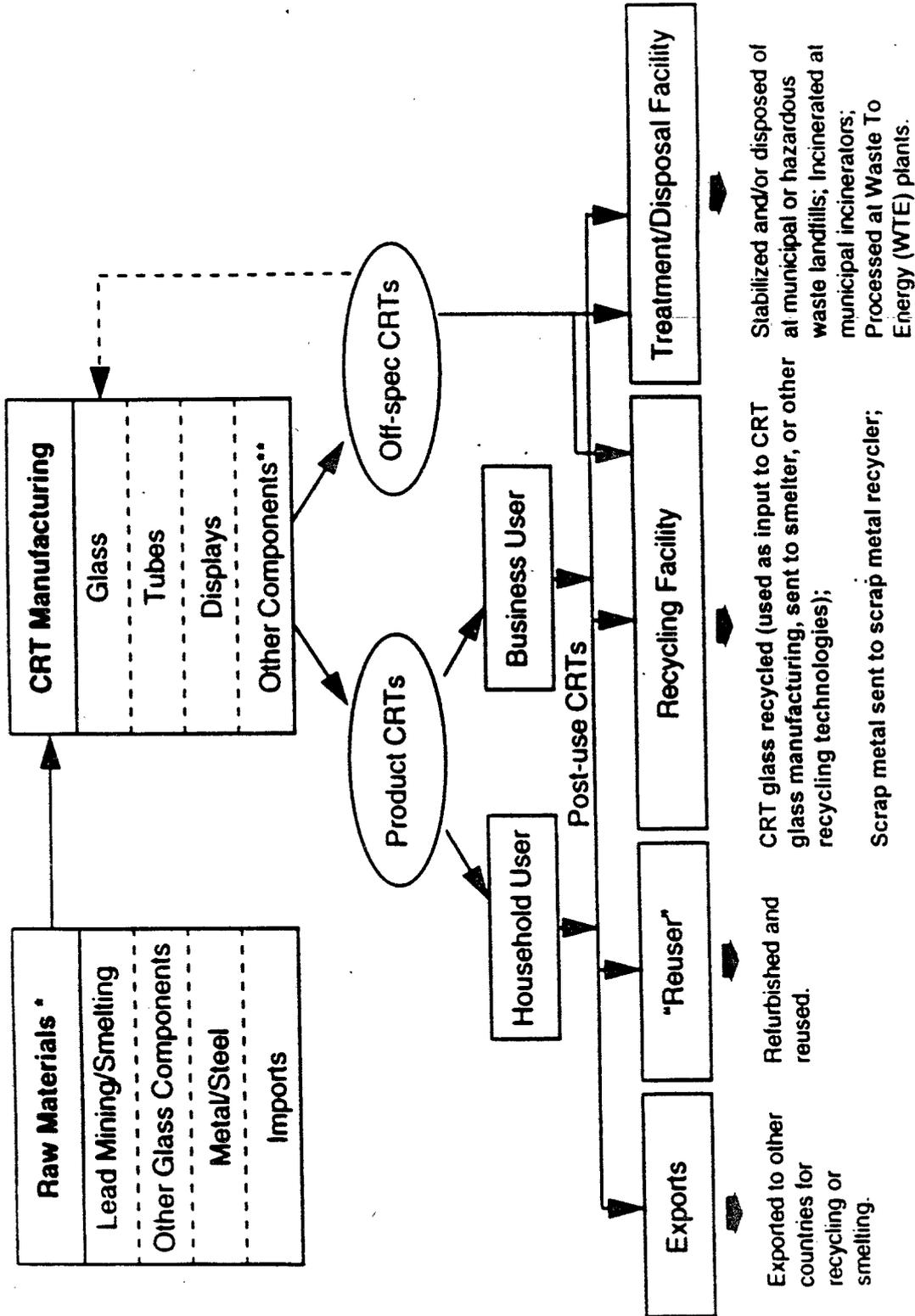
For the household computers and televisions that are disposed of in the U.S., approximately 78 percent are disposed of in municipal landfills, 21 percent are disposed of at municipal waste-to-energy (WTE) facilities, and 1 percent are recycled (McKenna et al., 1996). Some non-household CRTs are disposed of in municipal landfills as well. It should be noted, however, that some municipal landfills are banning disposal of CRT products.⁴ In Seattle, for example, intact monitors and displays from both commercial and household users are disposed of in municipal landfills. However, King County landfill managers, who accept wastes from Seattle and its suburbs, are considering not accepting CRTs, including whole monitors, because of their hazardous constituents and the associated liability.⁵ Some companies dispose of CRTs in hazardous waste landfills after stabilization. Stabilization involves

³ Source: MCC, 1997; personal communication, Grèg Voorhees, Envirocycle, May 25, 1999.

⁴ J. Matthews, Envirocycle Inc., Letter to C. Mooney, OSW, EPA, February 19, 1996.

⁵ Personal communication, Nancy Helm, EPA Region X, November 6, 1996.

Figure 3
Life Cycle Flow of Cathode Ray Tubes



* Recycling also occurs prior to CRT manufacturing.

** For example, lead is recycled as it is being made into frit

•• Such as phosphors and shadow masks.

crushing the CRT glass into small pieces and mixing it with concrete to reduce the mobility of metals and other constituents from the landfill.⁶

1.3 CRT Recycling

Due to the potential hazardous waste status and associated liability of CRT disposal and because of the inherent value in some components of CRTs and CRT products, non-disposal management options have been developed. The predominant non-disposal option is recycling including both the reclamation of discrete materials from the CRT and reuse of the intact CRT. Reclamation processes CRTs or their component back into the CRT manufacturing process or into other processes, such as lead smelting. Lead smelting reclaims the lead, and possibly other metals, from the CRT for general use, and uses the glass as a fluxing agent in the smelting process itself. In some cases, however, used products containing CRTs are sold or donated for reuse by entities that require the newest products (e.g., schools, lower technology companies). Similarly, products may be collected from end-user sites and reconditioned or refurbished to be sold as functioning systems from factory outlets and other channels (MCC, 1996). Unfortunately, due to the fast pace of technological change and rapid obsolescence of products, most discarded CRTs are not suitable for incorporation into current technology products.⁷ Therefore, reclamation may often be a more viable option than reuse.

All materials from CRTs are potentially recoverable, including leaded glass, optical quality glass face plates, conductive coatings, low carbon steel shadow masks, and luminescent materials. There are two main categories of CRT glass recycling. The first uses CRT glass in materials or processes other than CRT manufacturing. For the most part, these recyclers send their glass to primary or secondary lead smelters to be used as a substitute for raw materials or fluxing agents. There is also a growing trend of using CRT glass in other products, such as lighting and reflective beads used in roads. The second category is referred to as "glass-to-glass recycling," in which CRT glass is used as a raw material input in new CRT glass manufacturing.

CRT glass-to-glass recycling has been identified as an environmentally and economically sound approach by offering significant potential to reduce lead in landfills and combustors without increasing the risk for significant lead releases to the environment. In addition glass-to-glass recycling recovers the resource value of specialty glasses and lead, reduces waste management costs, diminishes the demand for new lead in CRT glass manufacturing, and lowers the energy consumption of CRT glass manufacturers (CSI/CES, 1998).

The remainder of this report focuses on CRT glass-to-glass recycling to support a rulemaking to facilitate CRT glass-to-glass recycling practices and overcome the regulatory barriers to CRT management under RCRA.

2. INDUSTRY OVERVIEW

This section provides an overview of the entities involved with CRT recycling. Section 2.1 presents available information on companies that manufacture CRTs. Section 2.2 discusses sources of discarded CRTs. Section 2.3 describes mechanisms for collecting and transporting CRTs to recycling; and Section 2.4 profiles existing CRT recycling companies.

⁶ J. Matthews, Envirocycle Inc., Letter to C. Mooney, OSW, EPA, February 19, 1996.

⁷ Source: letter from Robert Dodds, Sony, to Nancy Helm, EPA Region X, July 8, 1996.

2.1 CRT Manufacturers

Most CRT glass manufacturers and almost all projection television and computer display manufacturers are located outside of the U.S. However CRT glass, color picture tubes, single phosphor tubes, and rebuilt tubes are manufactured in the U.S. (EPA, 1995).

There are three stages of CRT manufacturing in the U.S. that together make up the CRT manufacturing industry: CRT glass manufacturers, tube manufacturers, and display assemblers. Table 2 lists the domestic and international companies involved in the manufacture of CRT glass, tubes, and displays in the U.S. in 1994. A 1995 EPA report indicates that there were 189 CRT glass and tube manufacturers in the U.S. in 1992.

Table 2
CRT Glass, Tube, and Display Manufacturers

CRT Glass Manufacturers	Cathode Ray Tube Manufacturers		Display Manufacturers	
	TV Tubes	Monochrome Tubes	TV Sets	Computer Monitors
Corning Techneglas Thomson American Video Glass*	Hitachi Matshushita Toshiba Philips Thomson Sony Zenith	Clinton CRT Scientific Tektronix Hughes Raytheon Thomas Video Display	AKEI Daewoo Gold Star Games Manufacturing Hitachi JVC MCEA MTC (P&Q) NAP (MAG/SYL/PHI) Sanyo (Fisher) Sharp Sony Wells Gardner Zenith	Aydin Compaq IBM Display Tech DEC Modicon NCR Unisys

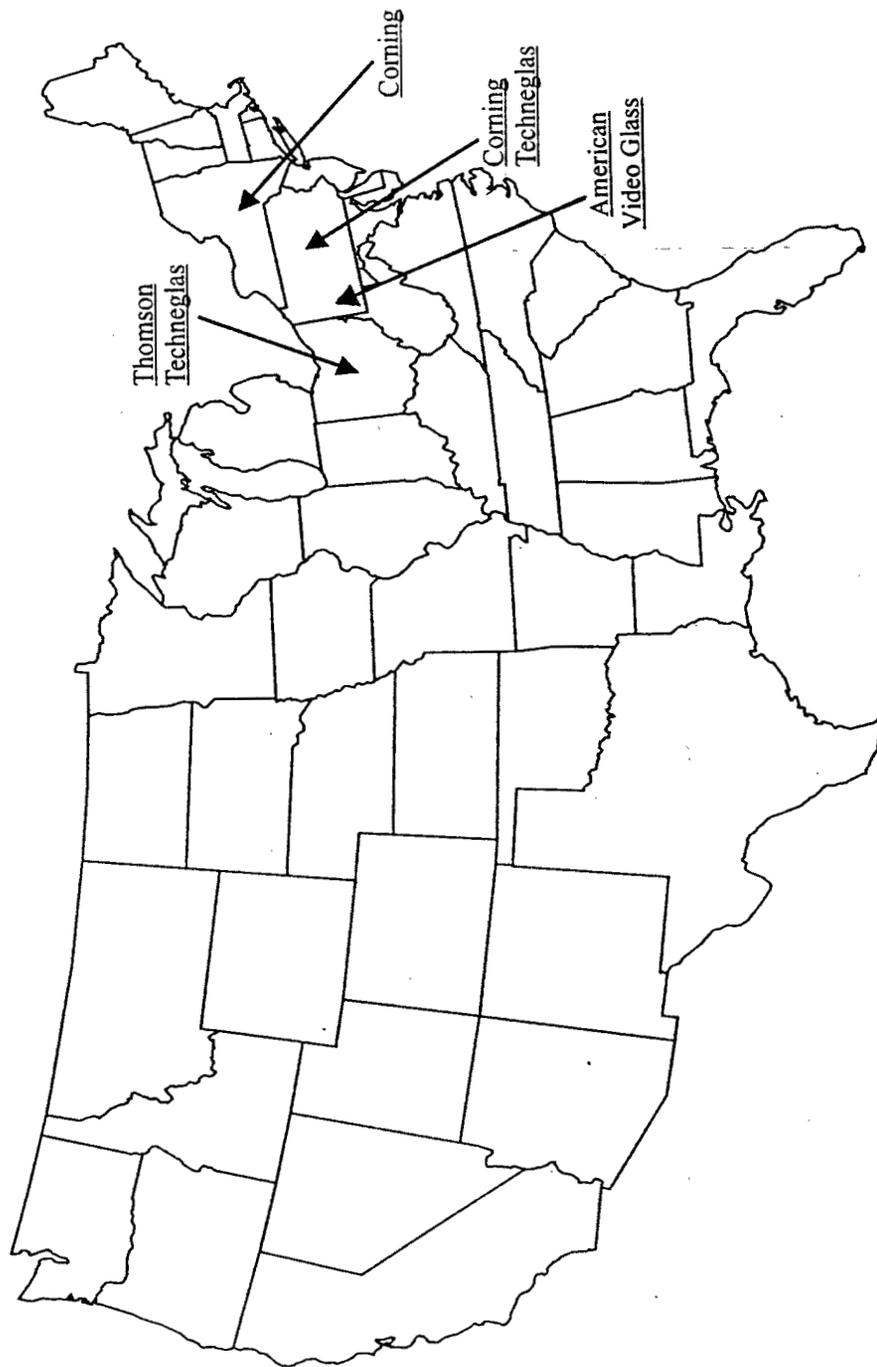
Source: Burriss G., Cathode Ray Tube Industry Subsector Presentation, September 26-28, 1994.

*American Video Glass, Pittsburgh, Pennsylvania, is a new facility started operation in 1998 (Personal communication, Greg Voorhees, Envirocycle, May 25, 1999).

CRT manufacturing facilities are located in California, Georgia, Illinois, Indiana, Kentucky, New York, Ohio, Massachusetts, New Jersey, Pennsylvania, South Carolina, and Washington (Burriss, 1994). Figure 4 shows the location of U.S. CRT glass manufacturers.

The majority of CRTs are produced for televisions and computer monitors for both household and commercial uses. Other types of CRTs are produced in much smaller quantities. It is estimated that each year, 12-15 million new monochrome monitors and TVs, 18 million color monitors, 5 million small color television sets (less than 19 inch), 20 million large color television sets (19 inch or greater), and 1 million projection CRTs are sold in the U.S. (MCC, 1997). Approximately 85 percent of 25-inch or larger CRTs consumed in North America are manufactured domestically and the remaining 15 percent are imported. Approximately 45 percent of smaller displays and all computer monitors are

Figure 4
CRT Glass Manufacturers in the U.S.



Source: George Burris, Thomson Electronics, CTR Industry Subsector Meeting Presentation, September 26-28, 1994

imported (EIS, 1995). According to an industry expert, approximately 10 percent of the computer monitors have been manufactured domestically and the largest portion is still imported from the Asian region.⁸

CRT displays produced in the U.S. generally range in size from one inch diagonal to 36 inches diagonal. Medical, automotive, oscilloscope, and appliance displays are typically 12 inches diagonal or smaller, whereas military and aircraft control tower displays may be much larger.⁹

2.2 Generation of End-of-Life CRTs

There are essentially three sources of end-of-life CRTs and products containing CRTs: households, businesses, and tube and display manufacturers. Discarded CRTs from households and businesses are post-consumer CRTs and CRTs from tube and display manufacturers are off-spec CRTs. Actual data on the quantities of CRTs discarded by households and tube and display manufacturers are not identified. However, several sources contain estimates of the number of CRTs discarded by these entities. The economic impact analysis for the CRT glass-to-glass recycling rulemaking contains an estimate for the number of CRTs generated by all businesses. The numbers of medical, automotive, and appliance displays reaching the end of their useful lives each year are unknown, although these displays are thought to be of less environmental consequence due to their smaller size and because they are usually monochrome (Electronics Industry Sector - CRT Industries, 1995). Some industry experts have indicated that there are no good U.S. data on the numbers of CRTs and CRT-containing products reaching end-of-life.¹⁰ The following paragraphs discuss the three sources of discarded CRTs and the approximate quantity of CRTs discarded by each.

Households

The number of CRTs discarded by households is highly uncertain for two reasons. First, many households do not discard old televisions or computer monitors when they buy new televisions or computers. The old TVs and monitors are frequently stored by households. Experts have estimated that the average household has between two and three old CRTs in storage. Thus only using sales figures to estimate the number of discarded CRTs will yield unreliable results. Second, there is no tracking of the discarded CRTs. Most households are believed to dispose of CRTs with their household trash. Thus the CRTs from households are sent to landfills and municipal waste combustors (MWC), unless they are sorted out for metals recovery or other reasons before reaching the landfill or MWC. This background document has not attempted to independently estimate the number of CRTs discarded by households.

Several sources have estimated the number of CRTs discarded by households. According to a 1996 MCC report, a total of 12 million computers are disposed of annually, amounting to more than 300,000 tons per year. As discussed below the number of computers discarded by businesses is approximately 8 to 10 million. This suggests that households may discard between 2 and 4 million computers each year. EIA estimated that approximately 10 million television sets are discarded each

⁸ Source: personal communication, Greg Voorhees, May 25, 1999.

⁹ Source: personal communication, Jeff Lowry, November 5, 1996; personal communication, Richard King, November 6, 1996.

¹⁰ comments received from EIA member company, December 17, 1996.

year.¹¹ Essentially all of the TVs discarded each year are assumed to come from households. To put these numbers into perspective there are 94.2 million households with at least one TV. The estimates on the number of CRTs discarded from households does not account for the potentially large stockpile of additional CRTs in storage and eligible for immediate disposal. The Consumer Electronics Manufacturers Association (CEMA) estimated that an average household owned two TV sets in 1997.¹² One industry expert also estimated that two televisions in storage per household is a reasonable estimate.¹³

Businesses

Businesses are estimated to generate between 8 and 10 million CRTs per year.¹⁴ The estimate only includes CRTs from computer monitors because of the relatively small proportion of TVs used in businesses compared to computer use. The range in the estimate is due to the uncertainty in the average life of a monitor in a business application. The average lifetime is assumed to be between four and five years. An estimate for the number of TVs generated by businesses was not developed. However, the number of TVs generated by businesses is likely to be significantly less than the number of CRTs from computer monitors. Businesses are also assumed to store monitors beyond their initial use. No estimates of the number of monitors stored by businesses were identified.

Tube and Display Manufacturers

Tube and display manufacturers generate pre-consumer CRTs because a portion of units manufactured do not meet product specifications. Approximately one to two percent of CRT production results in off-spec units. The glass in off-spec units has the same composition as glass currently being manufactured. Thus recycling off-spec CRTs into new CRTs is easier than recycling older CRTs that may have a different or unknown glass composition. Off-spec CRTs also may be sent to a third party recycler that separates the components and sends the parts to non-CRT glass manufacturers (e.g., automobile glass manufacturers, fiberglass manufacturers) or to lead smelters. The manufacturer may send off-spec CRTs to lead smelters directly as well.¹⁵ MCC reports that CRT manufacturing plants in North America generated between 30 and 50 million pounds of manufacturing waste in 1991 including damaged glass (MCC, 1993). In Envirocycle, 80 to 85 percent of the CRT glass they recycle is obtained from original equipment manufacturers.

2.3 Collection and Transportation of End-of-Life CRTs

Based on information from CRT recyclers, recycling facilities generally do not collect post-use CRTs. Instead, the generators deliver CRTs to the recycler. The majority of CRTs are delivered to recycling facilities by freight services, such as UPS, Roadway, or Response. They may be delivered as

¹¹ Electronics Industry Sector - CRT Industries, Green Paper on the Environmental Issues and Needed Research in Color Displays, September 27-28, 1995.

¹² Source: <http://www.cemacity.org/cemacity/gazette/files/forecast.htm>.

¹³ Source: personal communication, David Isaacs, December 13, 1996.

¹⁴ ICF Inc., Draft Assessment of the Cost and Economic Impacts of the CSI Regulatory Option for Glass-to-Glass Recycling of CRTs, prepared for OSW, U.S. EPA, February 24, 1999.

¹⁵ Source: personal communication, Jeff Lowry, November 5, 1996; personal communication, Richard King, November 6, 1996.

single units or by the truckload. The CRTs may or may not be packaged for shipment. If packaged, the CRTs may be contained in a single shipment box or in gaylords (4 foot by 4 foot boxes) which are placed on pallets and stacked three or four on top of each other with a shrinkwrap coating. An unknown fraction of CRTs are broken in transit.

Generators are typically responsible for paying freight charges; however, customers may be able to use the recycler's discount with transporters. For a fee, recyclers will pick up CRTs and electronic equipment within a certain radius (e.g., 200 miles) or a specified area (e.g., Massachusetts and New Jersey), using a company-owned truck. In addition, some recycling facilities accept drop-offs from the local community or electronic equipment from municipal collection systems, usually at a cost to the recycling facility. At one recycler Envirocycle, however, only about two household units are received per month.¹⁶ The States of New York and Massachusetts, Tufts University, Panasonic, Lucent Technology, EPA, and others are participating in a household and small business electronics collection and recycling project. As part of this project, pilot community collection days were sponsored in Somerville, Massachusetts and Binghamton, New York in November 1996. The results from this first phase of collection and subsequent phases of the project are being used to determine (1) the types and volume of electronic equipment (including CRTs) to be collected, (2) the economic viability of residential collection, and (3) the willingness of residents to pay for this disposal option (Bonica, 1996).

2.4 CRT Recyclers

The majority of CRTs currently received at recycling facilities are post-use CRTs in computer monitors from large businesses and pre-use CRTs from tube and display manufacturers. The CRTs may be received as whole monitors, which require disassembly, or as bare CRTs that have already been removed from the monitors. The post-use CRTs in computer monitors are mainly from large businesses. Computer monitors are also received from small businesses and consumers in lesser quantities. A very small fraction (i.e., less than a fraction of a percent) of the CRTs received are household television sets. Off-spec CRTs, including those not meeting manufacturer's specifications or not operating correctly, are received from tube manufacturers, electronics manufacturers and recyclers, and repair shops. At Envirocycle, approximately 85 percent of CRTs are received from electronics manufacturers and 15 percent are from small business entities.¹⁷ At Electronics Processing Associates, Inc., another recycler, approximately 99 percent of CRTs are from electronics manufacturers.¹⁸

Received CRT shipments are typically stored on site in enclosed buildings. The capacity for on-site storage of incoming CRTs ranges from 10,000 units to 100,000 units.¹⁹ Occasionally, recyclers will accumulate inventory when there is a large customer demand. Units may or may not be stored in boxes and are placed on pallets or set on concrete pads in a warehouse area. CRTs broken in transit are typically stored in gaylords in warehouse areas²⁰.

¹⁶ Personal communication, Harvey Goldman, November 15, 1996; personal communication, Greg Voorhees, November 15, 1996; personal communication, Jim Maher, November 15 and 26, 1996.

¹⁷ Personal communication, Greg Voorhees, November 15, 1996.

¹⁸ Personal communication, Jim Maher, November 15 & 26, 1996.

¹⁹ A unit may be a whole computer monitor or a bare or off-spec tube. A typical monitor weighs 25 to 30 pounds, while a 35-inch monitor might weigh 140 pounds.

²⁰ Personal communication, Harvey Goldman, November 15, 1996; personal communication, Greg Voorhees, (continued...)

The CRT glass-to-glass recycling industry is an emerging industry and is still in its infancy. Most CRT glass recycling involves lead smelting. According to industry experts, there is a large number of small CRT glass recyclers in the U.S. However, minimal information is available on these recyclers. The following profiles summarize available information on one large CRT glass recycler (Envirocycle Inc.), and some recyclers who process CRTs as a sideline:

Envirocycle Inc., New York, has been recycling CRT glass since 1991. Their process includes dismantling units containing CRTs, separating glass types, removing coatings from glass, and sending the glass to CRT glass manufacturers to use as a feedstock. Envirocycle Inc. also reclaims scrap metal from the shadow mask and electron gun. In 1995, it recycled over 12 million pounds of CRT glass to be used for new CRT glass manufacturing.²¹

Federal Prison Industries, Ohio, processes approximately 4,000 monitors per year. It receives discarded computers from GE, Motorola, computer manufacturers, and schools. Discarded computer monitors are picked up, sorted and sent to Envirocycle Inc.²²

DMC Recycling, New Hampshire, processes approximately 500 tons of monitors per year. It receives monitors from a government agency (NSA), businesses, and computer monitor manufacturers. All of the CRT glass recycled at DMC is sent to a lead smelter to be used as a fluxing agent. Typically they ship the glass by rail in quantities of about 50 tons.²³

I.G. Inc., Ohio, processes approximately 5,000 monitors annually. It receives used CRTs mainly from leasing companies, and a few from households. CRTs are separated and processed and the CRT glass is sent to glass manufacturers.²⁴

Doe Run, Missouri, processes 100-125 tons of CRT glass every year. It receives CRT glass from recovery services that scavenge used computers. The CRT glass is introduced as a fluxing agent at the lead smelter.²⁵

²⁰(...continued)

November 15, 1996; personal communication, Greg Voorhees, November 25, 1996; personal communication, Jim Maher, November 15 and 26, 1996

²¹ Source: <https://www2.epix.net/~enviro/env.html>, September 1996; Envirocycle Inc. Web site: <http://www.enviroinc.com>, May 1999.

²²Source: Jim Weber, Federal Prison Industries, interview made by Chotikajan S. ICF Inc. November 6, 1998.

²³ Source: Gary DiRusso, DMC Recycling, interview made by Chotikajan S., ICF Inc., October 30, 1998.

²⁴ Source: Tony Catareno, I.G. Inc, interview made by Chotikajan S., ICF Inc., November 6, 1998.

²⁵ Source: Cliff Asbury, Doe Run, interview made by Uden T., ICF Inc., November 10, 1998.

3. CRT GLASS-TO-GLASS RECYCLING PROCESS

This section provides an overview on the CRT glass, the CRT glass-to-glass recycling process and the relevant waste management issues. Section 3.1 illustrates different types of CRT glass, the compositions, major constituents of concern, as well as the recyclability. Section 3.2 describes the general process of CRT glass-to-glass recycling. Section 3.3 discusses the waste generation and management issues related to the CRT glass-to-glass recycling process.

3.1 CRT Glass Types

Compositions of CRT Glasses

There are four types of glass in a CRT: panel glass, funnel glass, neck glass and frit glass. Panel glass is an optical quality glass. In a typical 27-inch TV tube, panel glass represents approximately 66 percent of the weight of the CRT. Funnel, stem and neck glass accounts for 26.0, 7.4 and 0.5 percent of the total weight, respectively (Dillion, 1998). The compositions of the four glass types vary in order to meet performance requirements. Table 2 lists constituents found in different types of color TV panels, and in different types of color CRT neck funnel glass, as a percentage by weight.

Table 2 Composition of CRT Panel, Funnel, and Neck Glass (Percent by Weight)²⁶

Constituent	Color TV Panel Glass ^a	General Panel Glass ^{b,c}	Neck and Funnel Glass ^{b,d}
Na ₂ O	7.00-7.88	7.0-10.0	5.3-8.3
K ₂ O	7.92-8.88	6.0-10.0	6.8-8.2
Li ₂ O	≤ 0.098	--	--
SrO	9.14-10.30	8.0-12.0	0.1-0.6
BaO	2.09-2.34	2.0-10.0	0.1-3.7
PbO	2.09-3.08	0.0-3.6	11.0-23.5
ZrO ₂	--	0.0-1.8	0
Al ₂ O ₃	1.36-2.11	2.8-4.0	1.6-5.2
CaO	1.81-2.85	0.8-3.0	0.9-3.8
MgO	0.09-1.47	0	0.5-0.9
As ₂ O ₃	0.15-0.29	trace	0
Sb ₂ O ₃	0.41-0.51	trace	0.3
TiO ₂	0.45-0.54	trace	0
CeO ₂	0.20-0.25	trace	0
SiO ₂	61.8-64.3	60.0-65.0	50.3-63.8
CeO	--	0.0-2.5	0
Fe ₂ O ₃	0.03-0.057	trace	trace

²⁶ The data were based on color TV panel glass from seven manufacturing plants between 1979 and 1983. Source: Mixuki, C., G. Pitts, T. Aanstoos, S. Nichols (MCC), CRT disposition: an assessment of limitations and opportunities in reuse, refurbishment, and recycling in the U.S., Proceedings of the 1997 5th IEEE International Symposium on Electronics and the Environment, ISEE, 1997.

^b Per Hedemalm, Per Carlsson, and Viveka Palm, A Survey of the Contents of Materials and Hazardous Substances in Electric and Electronic Products, Swedish Institute of Production Engineering Research (IVF), no date.

^c Not clear if data are for monochrome or color CRTs. Data represent minimums and maximums from three suppliers.

^dData are for color CRTs. Data represent minimums and maximums from two sources.

A principal constituent of concern in CRT glass is lead, which absorbs the X-rays generated inside the tube. Lead is found in the glass panel, glass funnel, neck, and glass frit of color CRTs. Table 3 presents the lead content in the components of color monitors CRTs. As shown in Table 3, the different components of CRTs contain varying lead compositions. Leaded glass panels typically produced in the U.S. contain approximately two percent lead. Since the funnel and neck are much thinner, they require higher lead content to meet shielding performance requirements. The glass funnel contains approximately 22 to 28 percent lead and the neck contains approximately 30 percent lead. The glass frit, contains 70 to 85 percent lead oxide. Although the concentration of lead in the glass frit is high, each tube only contains from 60 to 145 grams of glass frit.²⁷

Table 3
Lead Content in Different Components of Color Monitor CRTs

Component	Composition
Panel	0-4% lead oxide alkali/alkaline earth aluminosilicate
Funnel	22-28% lead oxide alkali/alkaline earth aluminosilicate
Neck	30% lead oxide alkali/alkaline earth aluminosilicate
Stem	29% lead oxide alkali aluminosilicate
Frit	70-85% lead oxide zinc borate

Source: Dillion, 1997; CSI/CES, 1995.

A study conducted by researchers at University of Florida tested the toxicity of CRTs by simulating leaching conditions under landfill operations.²⁸ Results from toxicity Characteristic Leaching Procedure (TCLP) tests showed that concentration of lead in leachate of CRT glass averaged 18.5 ppm, which exceeding the toxicity characteristic TC regulatory level of 5 ppm. Therefore, disposal of CRT glass in landfills may pose potential risks to human health and the environment.

The amount of lead used in CRT glass is decreasing. In imported monitors and some domestic monitors, the lead in panels is replaced with barium, strontium, and/or zirconium oxides. In addition to the reduction in lead, other examples of changes include the elimination of the use of cadmium-containing phosphor materials in color CRTs in 1988, conversion from chlorofluorocarbons to alternative materials in the late 1980s, and a decrease in arsenic levels in CRTs produced after the early 1980s (MCC, 1993).

²⁷ Source: Electronics Industry Sector - CRT Industries, September 1995; David Isaacs, December 13, 1996

²⁸ Source: "Don't landfill TVs and monitors, study warns", December 10, 1998, from website: <http://cnn.com/TECH/science/98/12/10tv.landfill.enn/index.html>

Recyclability of CRT Glasses

The recyclability of CRT glass is determined by whether the composition of the glass is compatible with the new CRT glass that is manufactured. The composition CRTs has changed over time due to technological advances and environmental concerns. Changes in chemistry of CRT glass cause different recyclability profiles for each type of CRT glass.²⁹

Overall, the composition of color CRT funnel glass from the last two years is similar enough across the industry that any glass manufacturer can recycle any other glass manufacturer's funnel glass. However, more than one hundred different panel compositions have been manufactured over the past 25 years. This poses a barrier to mixing panel glasses from different manufacturers and recycling them together since it may jeopardize the X-ray protection of the glass or the optical qualities. For example, the panel glass of imported monitors and panel glass produced by Techneglas contains no lead. Televisions and other U.S.-produced computer monitors have varying levels of lead and other constituents in the panel glass. As a result, U.S. CRT glass manufacturers are reluctant to use panel glass from imported CRTs. To avoid possibly altering the quality of the panel glass, many CRT glass manufacturers only use recycled panel glass from their own products.³⁰

The different components of CRTs from monochrome displays have a uniform composition, and a lower lead content than color displays. By contrast, the later-developed higher resolution color displays have higher lead contents in order to absorb the increased level of X-rays generated. The color CRTs account for approximately two-thirds of the TV and monitor market (MCC, 1997).

3.2 CRT Glass-to-Glass Recycling Process

In the CRT glass-to-glass recycling process, CRT glass is used as a raw material input in CRT glass manufacturing. Both household and commercial televisions, computer monitors, and other CRT products are disassembled by a CRT recyclers. Glass-to-glass recycling involves collecting TVs and monitors, separating the glass from other components, removing the coatings from the glass, sorting the glass to meet composition specifications, and returning the glass to a CRT glass manufacturing melting furnace. This general process is depicted in Figure 5. This general process is typical for CRT glass-to-glass recycling. However, it is important to note that variations of this process may be used at different facilities. Moreover, since CRT glass-to-glass recycling is a quickly evolving industry, it undergoes constant changes. Companies are working on the development of new technologies and approaches to improve the efficiency of the process as they get more experience. Therefore, it should be noted that current glass-to-glass recycling processes may not be fully described in this report.

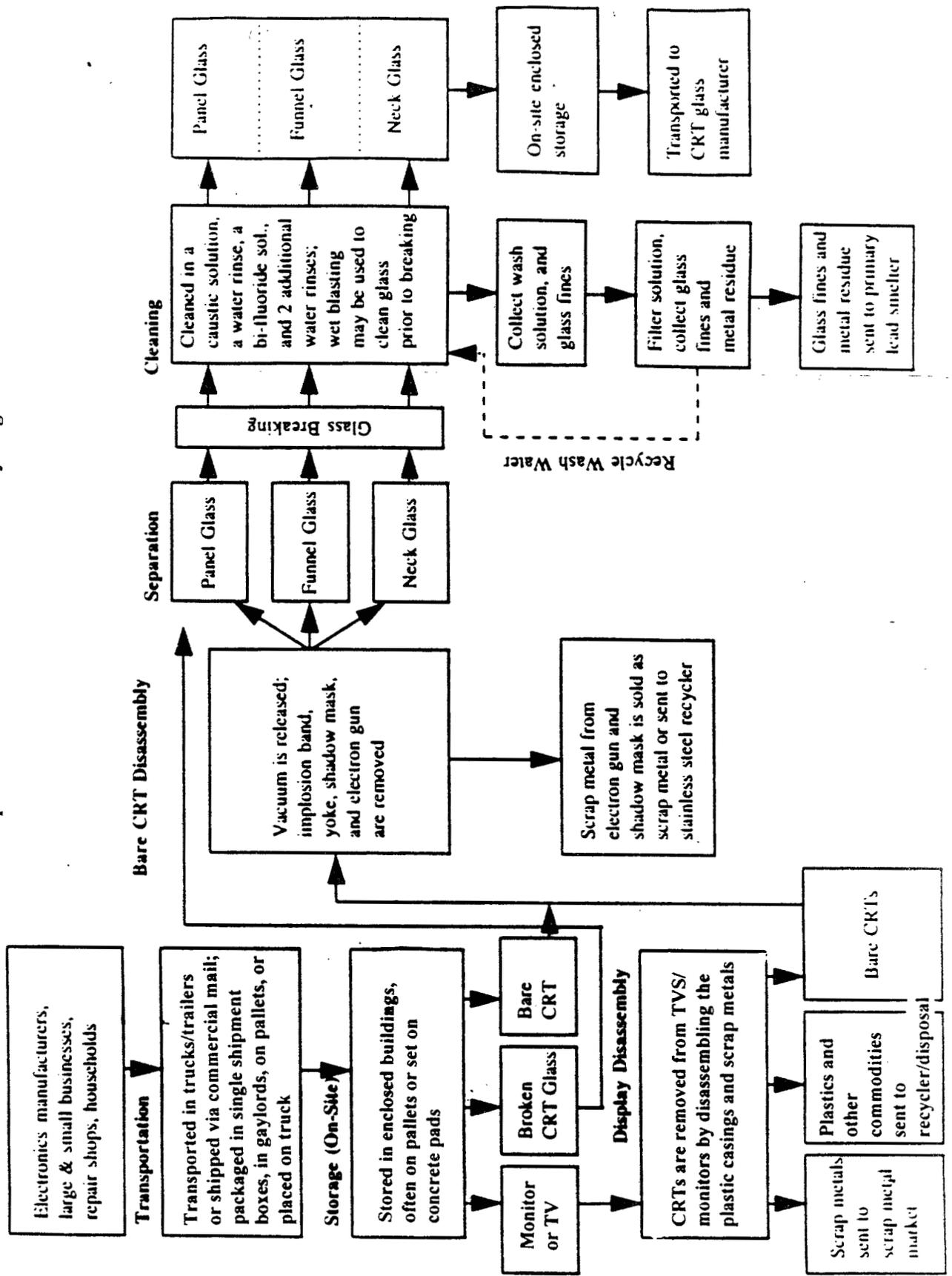
Disassembly

Whole CRT displays are first dismantled in a manual "reverse assembly line." The plastic components, printed wiring boards, shadow mask, electron gun, and other scrap metals in the CRT display are manually removed, leaving the bare CRTs. Off-spec CRTs from repair shops and tube manufacturers may be tested at facility to determine if they are repairable. If so, they are sent to manufacturers for use in CRT-containing products. If not, they enter the recycling process with other bare CRTs. The first step in the process for bare CRTs is to release the vacuum and remove the deflection yoke. One way the vacuum may be released is by drilling through the anode, a small metal

²⁹ Source: personal communication, Richard King, November 6, 1996.

³⁰ Source: personal communication, Jeff Lowry, November 5, 1996.

Figure 5
Representative CRT Glass-to-Glass Recycling Process*



* Based on information provided by Envirocycle and Conversion Technologies. Note: No waste is generated or disposed of from this process, according to facility personnel.

button imbedded in the glass funnel. The implosion band is then removed, and any adhesives from the band attachment are removed using a solvent.

Glass Separation

Monochrome CRTs are made of only one glass composition (i.e., the panel, funnel, and neck are all the same kind of glass). However, different manufacturers use different compositions of glass in their monochrome CRTs. The manufacturers' markings are used to manually separate the glass into the different compositions.

For color CRTs, the different components are separated. The panel is separated from the funnel and the neck glass is broken off. Currently, the panel and funnel are separated by etching or scribing, and thermally shocking the tube (MCC, 1997). The neck glass constitutes one category of glass. The panel and funnel glass are further separated by manufacturer and glass chemistry using manufacturers' markings.

Once different components are separated, the glasses are classified according to composition. X-ray fluorescence used to identify different types of glasses.³¹ Another option is to use an ultra-violet (UV) light sorting process to separate the glass by composition. The different types of glass are manually placed in separate bins for subsequent processing as separate batches.

Any broken CRTs that are received by recycling facilities are sorted into miscellaneous funnel and panel glass categories. These batches go through an automated sorting process using short-wave UV light (to avoid hand contact and the risk of cuts), and are added to cullet (broken glass) with similar characteristics at the end of the process.

Glass Breaking

CRT glass may be broken into large pieces. At one recycler, Envirocycle, the separated glass is broken when it is dropped into a 4 by 4 foot gaylord for storage. The glass is not crushed or ground into fine pieces, which are more likely to be sources of airborne particulates. Once the glass is broken, the process is fully automated to avoid direct hand contact and reduce the risk of cuts. At some recyclers, the glass may be broken into small pieces (i.e. ¼ inch in size) before the cleaning process.³²

Glass Cleaning

After the glass is broken, it must be cleaned to remove any coatings. To begin the cleaning process, the broken glass is placed in baskets. At one facility, the cleaning process consists of two lines of 4 foot by 4 foot tanks operating simultaneously. The first step of the cleaning process is to dip the glass in a water tank to inhibit lead and glass dust formation. The basket of broken glass is then sequentially submerged in a warm caustic solution, a water rinse, a bi-fluoride solution, and two additional water rinses. Fume hoods are used to capture and release any evaporated caustic to the outside air. At one recycler, Envirocycle, solvent is no longer used in the cleaning process and pure water is used as solution.

³¹ Information based on practices at Envirocycle Inc. and Conversion Technologies (MCC, 1997).

³²Source: personal communication, Greg Voorhees, Envirocycle, May 25, 1999.

An alternate cleaning process uses wet blasting of the glass prior to breakage and sorting.³³ In each process, the resulting product is clean cullet of uniform, known compositions that can be sold to CRT glass manufacturers.

Reclaimed Material Storage, Processing, and Transport

The sorted and cleaned cullet is typically stored in enclosed buildings at the site where the CRTs are disassembled and separated. At two facilities,³⁴ the storage capacity is 7 million pounds each. The glass is transported in dump trailers to CRT glass manufacturers on demand. The trucks have a capacity of 40,000 pounds and require the use of a tarp cover to prevent contamination with other materials and loss of materials to the environment during transport.

Glass fines are small leaded glass particles produced during glass breaking and processing. They are collected by filtering wash water and used cleaning solutions. At Envirocycle, approximately 80,000 pounds of glass fines were generated during 1996 from the processing of about 20 million pounds of CRT glass.³⁵ The glass fines may be used with sand as a filter media to collect metals in the solutions from the cleaning process. The fines and other filter media are collected and sold to lead smelters to be used as a fluxing agent. Glass fines are typically transported in a tarp-covered dump trailer.

3.3 Waste Generation and Management

Water used to prevent dust formation or to rinse the glass is typically filtered, chemically adjusted, and recycled back into the process. It is never discharged according to industry representatives. The caustic and bi-fluoride solutions used in glass-to-glass recycling also are filtered and recycled. The collected residues, including glass fines and metals, are collected and sent to lead smelters. Approximately 88 to 90 percent of all materials, including packaging, are recycled. According to the recyclers, the largest solid waste issue is the pallets and packaging materials used to transport the CRTs.³⁶

As discussed above, the glass breaking and subsequent handling activities could, in theory, be a source of particulate emission. At one large recycler, Envirocycle, such emissions are controlled by breaking the glass only into large pieces and/or by keeping the broken glass wet. If the glass is crushed into smaller and dispersible particles, the particulate emissions could be a potential concern if not captured properly. According to a representative at Envirocycle, local air quality authorities and regulations do not require these emissions to be permitted or controlled.³⁷

³³ Details on this process are not available as they are considered company proprietary information.

³⁴ Envirocycle Inc. and Techneglas Inc.

³⁵ Source: personal communication, Greg Voorhees, November 25, 1996.

³⁶ Source: personal communication, Harvey Goldman, November 15, 1996; personal communication, Greg Voorhees, November 15, 1996; personal communication, Greg Voorhees, November 25, 1996; personal communication, Jim Maher, November 15 and 26, 1996.

³⁷ Source: personal communication, Greg Voorhees, November 25, 1996.

4. IMPACTS OF CRT GLASS-TO-GLASS RECYCLING

This section assesses the potential impacts of CRT glass-to-glass recycling. Section 4.1 evaluates the environmental impacts; Section 4.2 addresses the occupational health and safety issues. Section 4.3 briefly discusses the environmental justice issues.

4.1 Environmental Impacts

Reducing Virgin Lead Consumption

CRT glass-to-glass recycling reduces the need to mine and process raw lead from ore by reducing the use of raw lead in CRT glass manufacturing. For example, the recycling of one ton of funnel glass could avoid mining and processing 0.2 tons of virgin lead. CRT glass recycling may also reduce waste generated from lead mining and smelting, such as tailings, mine water, fugitive dust, and lead slag.

Reducing Environmental Lead Load

Of all the constituents in CRT glass, lead is of greatest concern from a human health and environmental protection standpoint. Not only is it present in large amounts in CRT glass -- the neck and funnel contain up to 29 percent lead oxide by weight -- it also is the only constituent found to leach above the federal Toxicity Characteristic regulatory level (5 ppm). Lead poisoning is a serious environmental health risk for all humans. Children under the age of six are especially vulnerable because their nervous systems are still being developed. At high levels, lead poisoning can cause coma, convulsions, and death. At lower levels, lead poisoning in young children can reduce intelligence, impair hearing, and decrease stature, vitamin D metabolism, and blood production.³⁸ The potential for CRT glass disposal at Subtitle D sites to result in releases of and exposures to lead and other constituents is discussed below, first for Municipal Solid Waste (MSW) landfills and then for municipal waste combustors (MWCs). By reusing rather than releasing lead, CRT glass-to-glass recycling may reduce the total lead load on the environment.

Reducing Lead in Municipal Solid Waste Landfills

It is useful to compare CRTs with other municipal solid wastes being disposed in MSW landfills in terms of lead concentrations and potential total lead loadings. Available data indicate the lead concentration in CRT panel glass ranges from 0 to 34,000 ppm, while the lead content of neck and funnel glass ranges from 102,000 to 270,000 ppm. In comparison, extensive data collected in support of the EPA's Hazardous Waste Identification Rule for contaminated media indicate that other MSW being disposed in Subtitle D landfills averages about 2,200 ppm of lead. Similarly, EPA estimates the total loading of lead to MSW landfills from other wastes to be approximately 19,500 tons per year. The lead load due to discarded CRTs can be estimated by assuming that 20 million TVs and monitors are discarded each year with an average weight of 40 pounds each and the percent of glass is 60 percent, and the percent of lead in the glass and frit is 15 percent by weight. The calculation yields an estimate of 36,000 tons of lead per year. This large incremental loading of lead is corroborated by a Tufts University estimate, which suggests that 940,000 tons of lead could be added to MSW landfills

³⁸ U.S. Department of Housing and Urban Development, *Regulatory Impact Analysis of the Proposed Rule on Lead-Based Paint*, p. ES-1, June 7, 1996.

over the next 20 years through the disposal of home computers and televisions.³⁹ This translates into 47,000 tons of lead being added to MSW landfills each year, not even counting CRTs from businesses that might be disposed in MSW landfills.

In summary, shifting CRTs away from MSW landfills and toward recycling would have the environmental benefit of saving a potentially large amount of landfill capacity. In addition, such a shift would avoid the placement of a waste in MSW landfills that (1) has up to 100 times higher lead content than other municipal solid wastes on average, and (2) could result in a total loading of lead that is about two times higher than otherwise expected.

Reducing Lead from Municipal Waste Combustors

The primary environmental concerns associated with the management of CRTs at MWCs are (1) the potential transfer of CRT contaminants to ash, with subsequent releases and exposures from ash handling and disposal; and (2) the potential release of CRT contaminants from combustor stack to the air.

Although combustion of CRTs probably adds to the volume and lead content of MSW ash, existing regulatory controls limit the risks associated with the ash management. In particular, a supreme court decision in the case of *The City of Chicago v. The Environmental Defense Fund*, issued on May 2, 1994, ruled that ash generated from the incineration of household waste is not eligible for the household waste exemption under RCRA. This means that the ash must be tested with the TCLP and, if it proves to be toxic, must be handled and disposed in accordance with Subtitle C standards. If the ash does not fail the TCLP test, it may be disposed of at MSW landfills in accordance with the criteria in 40 CFR Part 258, or at other sites under other Subtitle D restrictions.

The new source performance standards and emission guidelines for MWC plants apply more directly to stack emissions from MWCs. These standards limit airborne emissions of lead from MWCs to less than 0.20 milligrams per dry standard cubic meter. Similar standards are imposed on emissions of particulate matter, acid gases, organics, and NOx. Compliance with these standards will substantially reduce stack emissions and risks associated with the combustion of MSW, including CRTs.

Overall, greater CRT recycling will decrease the amount of CRTs sent to MWCs. Therefore, the contribution of lead releases from MWCs that is due to CRTs, either via stack emissions or ash disposal practices, will be decreased. CRT management at MWCs is believed to be substantially less prevalent than disposal at MSW landfills. On the national level, therefore, an increase in CRT recycling should have less of an impact on MWCs than MSW landfills.

Increased Activities at CRT Recycling Facilities

The CSI alternative is designed to stimulate an increase in glass-to-glass CRT recycling in the regulated entities. If the initiative is successful the glass-to-glass recycling industry will develop and expand its operations. As CRT recycling infrastructure develops it will become a more attractive option for the non-regulated community. Thus, some non-regulated entities may shift the management of their

³⁹ Tufts University, *Life Cycle Assessment of the Disposal of Household Electronics*, A Capstone Thesis Project submitted by D. McKenna, K. Powers, and S. Reagan, in partial fulfillment of the requirements for the degree of Master of Science in Civil and Environmental Engineering, p. 5-9, August 1, 1996.

waste from Subtitle D landfills to glass-to-glass recyclers. The result is that the CRT glass-to-glass recycling industry may expand significantly due to the proposed CRT recycling regulations.

The activities at CRT recyclers generally pose a low risk to public health and the environment because virtually no wastes are generated and discharged to the environment. Increasing the volume at existing recyclers, or starting new recycling facilities that use existing processes, should not significantly increase these risks. One concern that might arise, however, is the potential to generate substantially larger volumes of dirty mixed cullet in the event recyclers become flooded with large volumes of CRT glass from mixed and/or unlimited sources. If the composition of such cullet cannot be determined or is not suitable for recycling back into CRT glass, it would have to be used in other ways or discarded as a solid waste.

The increase in recycling could potentially pose the problem of an oversupply of recycled CRT glass, with insufficient glass manufacturing capacity to use all of it, thus resulting in some CRT glass being disposed of in landfills. Techneglas, a CRT glass manufacturer, has stated that they could use up to 40 percent post-consumer cullet in each melt (or batch of glass produced).⁴⁰ Techneglas estimates that, on an annual basis, it could use up to 100,000 tons of post-consumer cullet per year.⁴¹ Based on the numbers used above to estimate the lead load at landfills the total glass that could enter the recycling stream is 240,000 tons. Because much of the CRT glass from household CRTs is unlikely to be recycled and assuming that the other two CRT glass manufacturers could use some post-consumer cullet, the total amount of CRT glass bound for recycling is unlikely to be greater than the demand for post-consumer cullet.

As discussed in Section 3.1, only selected glass that provides the necessary optical and overall product quality can be recycled back into CRTs. Therefore, glass acceptance criteria based on product quality standards should ensure that glass that is re-manufactured into CRT glass matches other materials already being used to make new glass. In this sense, re-use of waste glass should not have a significant effect on current glass manufacturing processes and associated risks. Nor should recycling affect final product quality or the risks associated with the use of those products.

Changes in Energy Demand and Air Emissions in the CRT Life Cycle

The predominant environmental impacts associated with changes in energy demand are likely to be twofold: (1) an energy savings from the reduced energy use in CRT glass manufacturing as well as the reduced energy use in producing cement for CRT stabilization that would be required if CRTs are disposed; and (2) a change in transportation energy requirements for shipments between sites (MCC, 1993). Both of these changes would impact airborne emissions of NO_x and SO₂, among other pollutants (e.g., CO₂). Both NO_x and SO₂ are precursors to airborne particulates and acid rain. NO_x also is a precursor to the formation of ozone.

Using a ton of recycled CRT glass instead of virgin materials in the production of new CRT glass saves three MMBtus worth of natural gas because the cullet melts more easily than other CRT glass raw materials such as sand and lime. Recognizing that natural gas furnaces emit approximately 0.2 pounds of NO_x per MMBtu, this translates into a NO_x emission reduction of 0.6 pounds per ton of CRT glass recycled. In addition to this savings, diverting a ton of CRT glass from the stabilization step

⁴⁰ "Closed-Loop CRT Recycling: Why Europe and the U.S. Differ?" Cutter Information Corporation, Product Stewardship Advisor, www.cutter.com/psa/fulltext/1997/09, Volume I, No. 4: September 1997.

⁴¹ Ibid.

required for Subtitle C disposal saves 5.7 MMBtu. If NOx emission rates from burning coal to fire cement kilns are like those from burning coal at industrial boilers, cement manufacturing emits approximately 0.6 pounds of NOx per MMBtu. This translates into an added NOx emission reduction of 3.4 pounds per ton of CRT glass recycled. In total, therefore, recycling a ton of CRT glass would reduce NOx emissions by about 4 pounds.

The energy savings for cement manufacturing can also be translated into a SO₂ emission reduction. Again, assuming coal used as fuel at cement plants has an average sulfur content like that burned in industrial boilers, cement manufacturing emits two to three pounds of SO₂ per MMBtu. Multiplying this figure by the energy savings of 5.7 MMBtu per ton of CRT glass diverted from stabilization, we estimate that recycling a ton of CRT glass reduces SO₂ emissions by about 11 to 17 pounds. The energy savings in CRT glass manufacturing would not reduce SO₂ emissions because existing glass furnaces burn natural gas, which is not a source of SO₂.

These emissions reductions might be offset somewhat by increased emissions from vehicles (cars, trucks, and rail) needed to transport CRTs to recyclers and ultimate use destinations. It is virtually impossible to predict at this time how many CRTs will be transported by different modes and for different distances if there were a robust CRT recycling industry. However, it seems reasonable to assume that, even under the most optimistic projections, CRT recyclers are likely to be fewer and more dispersed than the current inventory of Subtitle C and Subtitle D disposal sites. Therefore, getting the CRTs to these new destinations will likely involve more transportation than the current scenario.

4.2 Occupational Health and Safety⁴²

The activities undertaken in the CRT glass-to-glass recycling process are typical of small manufacturing operations with many conventional safety and health issues. The initial assembly line process involves separation of the various electronic components and materials and sending the CRTs on a separate assembly line. Workers use various power and hand tools in the dismantling. They are exposed to various moving machinery, electrical equipment, grinders, crushers, and cutters. There is not much difference in the process of dismantling CRTs and other components.

Workers may be exposed to lead as components of the CRT is recycled. The activities, however, do not appear to involve high levels of lead exposure or very high levels of exposure to other toxics (Donald Elisburg, 1998). According to industry experts, lead exposure during the glass-to-glass recycling process is insignificant and workers would be protected with routine precautions and monitoring, as required under the OSHA lead standard. Even if particles are ingested, the likelihood of lead leaching from particles is minimal and the worker exposure would not be high. The likelihood of exposure from lead pellets or glass cullet to workers engaged in the glass manufacturing process is small (Donald Elisburg, Dr. Phil Watson, 1998).

Another area of potential exposure is the phosphors used for tube-coating. The phosphors are removed during the recycling process through a washing process. Workers are potentially exposed to the phosphors as well as solvents that may be used in the removal process. A review of the material safety data sheets for these compounds finds that the treating or removal of coatings using chemical washes is a fairly standard process subject to OSHA control, as in many similar manufacturing processes. A similar process was observed during site visits at both Envirocycle and Toshiba. The standard protection

⁴² This section is based on consultation and a memo addressed to Workgroup on Overcoming Barriers to Pollution Prevention, Product Stewardship and Recycling of the CSI Computers and Electronics Sector prepared by Donald Elisburg: *OSHA Issues and CRT Glass-to-glass De-manufacturing*, May 28, 1998.

includes rubber gloves, boots, and aprons. The actual washing is done in an enclosed tub or bath with ventilation to prevent indoor fumes (Donald Elisburg, 1998).

4.3 Environmental Justice⁴³

The production activities involved in CRT glass-to-glass recycling have minimal potential community exposure to lead or chemical coatings. However the process involves some potential for lead exposure as well as the use of various chemical coatings. Other environmental justice issues might include increased truck traffic, noise, or the potential for new jobs.

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⁴³ This section is based on consultation and a memo addressed to Workgroup on Overcoming Barriers to Pollution Prevention, Product Stewardship and Recycling of the CSI Computers and Electronics Sector prepared by Donald Elisburg: *Environmental Justice Issues and CRT Glass-to-glass De-manufacturing*, May 28, 1998.

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