An Analysis of the Demand for CRT Glass Processing in the U.S.

1. INTRODUCTION

Electronic waste (e-waste) recovery and recycling in the U.S. has grown as an industry over the past decade, spurred by the development of e-waste recovery programs in half the states in the nation and the implementation of landfill and incinerator disposal bans for certain types of e-waste in many states. Some electronic devices contain components with hazardous characteristics which, if improperly handled, may pose a risk to public health or the environment. By recovering e-wastes, these hazardous components can be properly managed through recycling and disposal methods, and valuable components can be reclaimed, including precious metals such as gold and silver and other metals such as copper and steel.

Recycling markets have developed for many of the components of the e-waste stream, enabling recyclers to disassemble e-wastes and distribute the parts to a number of downstream processors or end users. However, the U.S. is currently facing a challenge in managing a large component of the e-waste stream, providing the focus for this paper: cathode ray tubes (CRTs). CRTs, the “picture tubes” from older televisions and computer monitors, contain high levels of lead which necessitate special handling during processing and recycling.

The CRTs collected for recycling were recycled into new CRTs through glass-to-glass recycling, or else sent to secondary lead smelters to recover the lead. Glass-to-glass recycling has been the most common management method, but with the shift from CRT technology to flat panel technologies for video displays, the market for new CRTs is dwindling. There are only a few operations in which recovered CRT glass may be used to produce new CRT glass -- none of these operations are located in the U.S.

Various reports within the past year have indicated some processors are stockpiling CRTs due to a lack of market capacity or affordable access to market capacity. Other processors are reporting concerns about the ability to continue securing markets for CRT glass. These market constraints are a concern given the high levels of lead in CRT glass and the continued interest in ensuring the viability of the e-waste recycling industry.

As a result of current and developing market conditions, Kuusakoski Recycling, a leading international metals and electronics recycler, commissioned Shaw Environmental, Inc. (Shaw), a CB&I company, to evaluate the CRT glass market in the U.S. Based on the research conducted for this study, the following trends and conditions were identified:

Included in this study:

- Review of CRT components
- Summary of e-waste laws
- Analysis of CRT quantities
- Review of existing and proposed CRT glass processing capacity
- Costs of managing CRT glass
- Assessment of beneficial use of treated CRT glass as an additional management option
- Discussion of environmental impacts of CRT glass processing options

- CRTs comprise the largest portion (estimated by U.S. EPA at 43 percent) of the current e-waste stream.
- Significant quantities (6.9 million tons or 232 million units) of CRTs remain to be recovered from homes and businesses in the U.S. The vast majority of these CRTs (85 percent) are projected to be collected and require management over the next 10 years. An additional 330,000 tons (or 12,000,000 units) is reported to be currently stockpiled by processors.
- There are only four CRT glass processing facilities[1] operating in North America. Of these, only one is operating in the U.S.
- Existing processing facilities do not provide sufficient capacity to manage the quantity of CRTs that may be recovered currently and over the next 10 years. This may explain the stockpiling of CRTs that has recently been reported within the electronics recycling industry.
- Four new CRT glass processing facilities have been proposed to be developed in the U.S. None of these facilities are currently operational, and only one facility has commenced construction. Even with these additional facilities, more CRT glass may be collected than can be managed.
- Alternate approaches to CRT management, including beneficial use of CRT glass, will help the e-waste industry to meet the near-term demand for CRT glass processing, allowing the e-waste industry to focus greater efforts on developing necessary infrastructure to process flat panel devices and other electronics that will require management for many more years in the future.

[1] CRT glass processing facilities are end-users of CRT glass. These facilities do not include intermediate processors that handle CRT glass prior to final disposition.

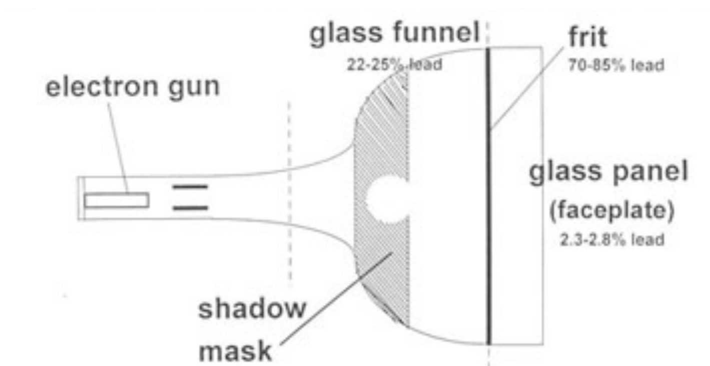
Components of a CRT

Cathode ray tubes (CRTs) are the largest component of older computer monitors and televisions, responsible for generating and displaying video images. The CRT is comprised mostly of glass, with some metals; Figure 1 below describes the functional components of a typical CRT.

What is in a CRT?

Cathode ray tubes (CRTs) contribute approximately 60-70 percent of the weight of an older monitor or television, with the remaining weight contained in the outer plastic or wood housing, circuit board, and cabling and wires. The CRT itself is comprised of the following components:

1. Screen (panel glass)
2. Conical glass behind the screen (funnel glass)
3. Electron gun
4. Narrow glass tube enclosing the electron gun (neck glass)
5. Glass solder, or frit, connecting and sealing the sections of glass
6. Copper deflection yoke to direct electrons



Source: Florida Department of Environmental Protection, Bureau of Solid and Hazardous Waste

FIGURE 1. CRT COMPONENTS

During the recycling process, whole monitors and televisions are disassembled by e-waste recyclers to separate the components and direct them to appropriate recycling and disposal markets. CRTs require special handling during the recycling process, because a significant fraction of the CRT glass contains high levels of lead. Approximately 70 percent of the weight of CRT glass is non-leaded panel glass, and the remaining 30 percent is leaded funnel glass.

Funnel glass contains approximately 22-25 percent lead by weight; the lead was used to shield the user of the CRT from the radiation emitted by the electron gun. The frit, a solder used to attach the panel glass and funnel glass, contains 70-85 percent lead by weight (see Figure 1).

Although the leaded glass components provided a protective feature during the use of the CRT, they may pose risks to public health and the environment when the CRT is dismantled for recycling or disposal if not properly handled. The lead content of broken funnel glass will typically exceed federal regulatory threshold limits of 5 mg/L for lead, resulting in the material being characterized as a hazardous waste as determined by the Toxicity Characteristic Leaching Procedure (TCLP)[2]. Mixed broken CRT glass (which would include both panel glass and funnel glass) can also exhibit a lead content in excess of federal limits.

Historically, panel glass also contained lead, though in much lower levels than in funnel glass (generally less than 3 percent). During the last years of CRT production, most panel glass produced and sold in the U.S. did not contain lead and was instead treated with barium oxide. The concentration of these metals is generally below hazardous levels, enabling separated panel glass to typically be handled as a non-hazardous waste without any further treatment.

CRT Recycling

The electronics recycling process involves a complex network of recyclers, processors and end use markets[3]. E-wastes are first received by recyclers, inventoried, and may begin to be disassembled. As e-wastes are broken down to component parts at the recycler, parts may be sent to intermediate downstream processors for further disassembly and processing or they may be sent to end use markets for final disposition or production into new products.

Specifically for CRTs, electronics recyclers typically dismantle computer monitors or televisions and recover the portions of the device outside the CRT (including the plastic or wood cabinet, circuit boards, wiring, and metals). The CRT portion is then shipped for recycling by an intermediate processor (who may or may not separate and/or crush the glass, but does not serve as a final processor of CRT glass) or a CRT glass processor that is an end use market. This process flow is depicted in Figure 2.

The commodity components within a computer monitor or television are shown in Figure 3. Glass represents approximately 63 percent of the total weight of the electronic device. The non-leaded panel glass accounts for 44 percent of total weight, while the leaded funnel glass contributes 19 percent. Metals contained within the CRT (steel and copper) comprise 7 percent of the overall device. The remaining 30 percent consists of wood or plastic materials from the cabinet housing the CRT, and circuit boards and wiring.

2 A limited exemption from the hazardous waste characterization is provided for broken CRT glass stored for less than one year and used in a glass-to-glass recycling process, secondary lead smelting process, or other recycling process approved by U.S. EPA on a case-by-case basis, as discussed in the next section.

3 U.S. International Trade Commission, *Used Electronics Products: An Examination of U.S. Exports*, (USITC Publication 4379), February, 2013, p. 1-4

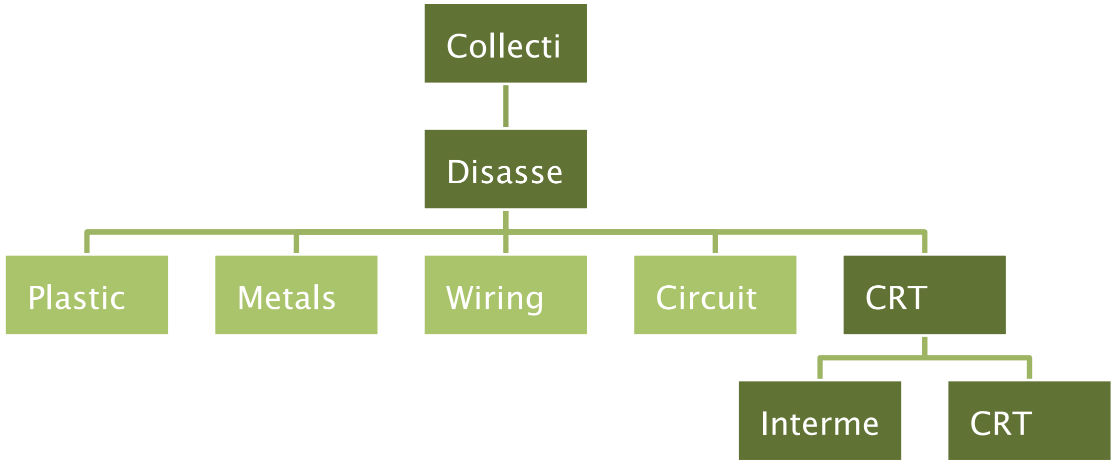
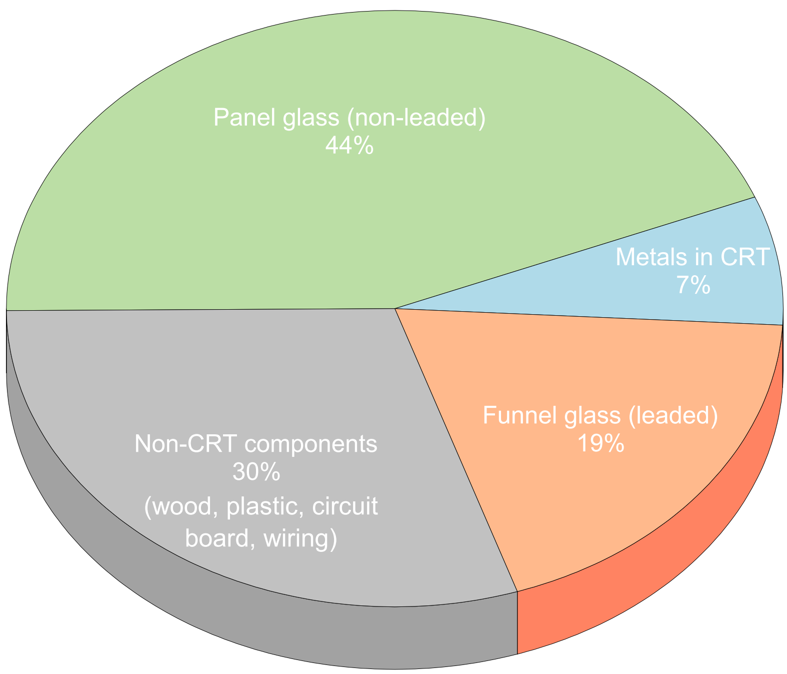


FIGURE 2. CRT RECYCLING PROCESS FLOW



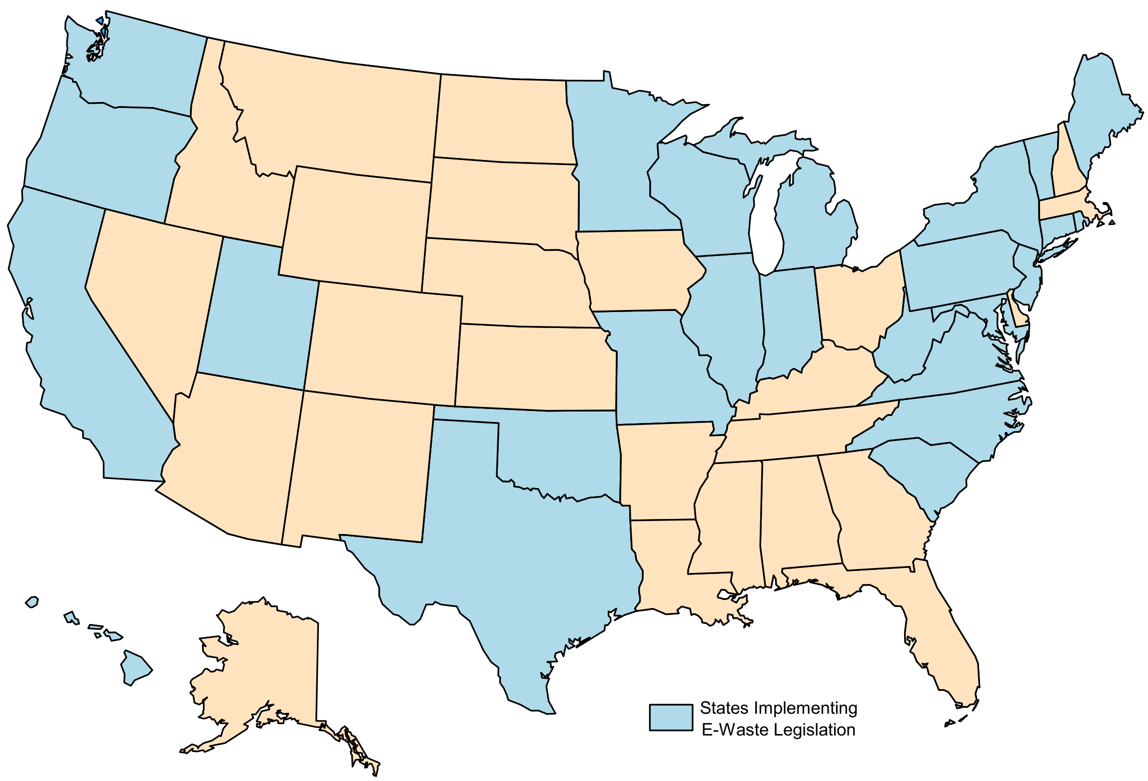
Source: Kuusakoski Recycling, personal communication, May 2013

FIGURE 3. MATERIALS WITHIN A CRT DEVICE

Electronic Waste Laws

State E-Waste Laws

A national discussion on the development of federal legislation to provide for the recycling of electronic wastes (e-wastes) such as televisions, computer monitors, computers, printers, and other devices, began in the late 1990s. After several years of discussion, federal legislation did not materialize, and individual states instead pursued their own legislation. In 2003, California became the first state in the U.S. to pass and implement legislation directed at the recovery and recycling of e-wastes. Within a decade, a total of 25 states passed e-waste laws (see Figure 4). The last state to pass e-waste program legislation was Utah in 2011; no additional states were added in 2012 or are expected to be added in 2013[4].



Source: Adapted from National Center for Electronics Recycling

FIGURE 4. STATES IMPLEMENTING E-WASTE LEGISTLATION

The e-waste program laws vary from state to state but generally are intended to provide access to recycling opportunities for e-waste generated from residents, often with no direct cost to residents delivering material. Some programs also incorporate units of government, schools, and small businesses, but larger commercial operations are typically excluded.

4 Jason Linnell, Executive Director, National Center for Electronics Recycling, 2013 Illinois Electronics Summit, April 2013.

Although there is no direct cost to residents in many states, there remain real costs to collect, process, and manage e-wastes. The costs are paid for through a variety of funding mechanisms for the state programs. E-waste program laws are largely established as extended producer responsibility (EPR) laws. Therefore, recycling costs for materials collected under state-legislated e-waste programs are generally paid by electronics manufacturers. California is an exception, in that retailers collect a fee from consumers when new electronics are purchased, remit the fees to the state, and the state reimburses recyclers for the processing of e-waste from these fees.

Many state e-waste laws also require that manufacturers pay for the recycling of a certain goal weight of material annually, and if the goals are not met they may be prohibited from selling their products in that state. This provides an incentive to manufacturers to secure contracts with e-waste recyclers and support collection and recycling efforts to meet the annual program goals.

While the e-waste legislation in each state differs in the devices that are covered, all laws include CRT devices. Therefore, in at least the 25 states that have e-waste recycling laws in effect, a significant fraction of e-waste collected consists of CRT devices that must be managed by e-waste recyclers.

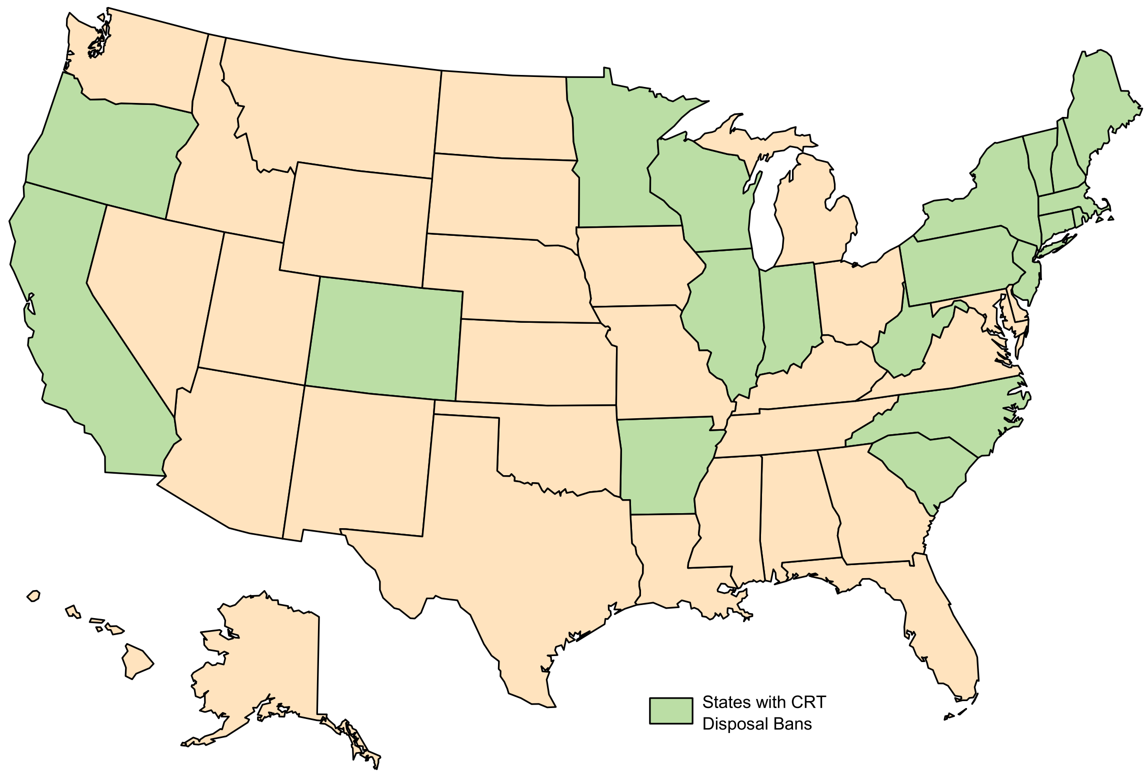
CRT devices are included in e-waste program legislation in 25 states in the U.S.

CRT Disposal Bans

Many states have taken their e-waste recovery efforts a step further and banned the disposal of certain e-wastes in landfills and incinerators. A total of 20 states have passed disposal bans prohibiting the disposal of CRTs in municipal waste landfills[5] (see Figure 5). Though the majority of states with a disposal ban have also implemented e-waste legislation, four states (Arkansas, Colorado, Massachusetts and New Hampshire) have banned the disposal of CRTs without implementing e-waste program legislation. The 19 states with active disposal bans represent about 50 percent of the population of the U.S.

CRT devices cannot be landfilled or incinerated in 19 states, representing half of the U.S. population.

[5] Disposal bans have been implemented in 19 of the 20 states; Arkansas passed its disposal ban in 2010 but has not established a date on which it will be implemented.



Source: Adapted from National Center for Electronics Recycling

FIGURE 5. STATES WITH CRT DISPOSAL BANS

In addition to the e-waste program laws and disposal bans implemented at the state level, there are federal regulations governing the management of CRTs. To enable easier collection and recycling of CRTs, U.S. EPA has conditionally excluded CRTs from management as a hazardous waste if certain conditions are met[6]:

- Unbroken CRTs can be accumulated by collectors or recyclers for up to one year without being regulated as hazardous waste. Collectors or recyclers may also accumulate broken CRTs up to one year provided they are in clearly labeled containers, transported safely, and stored indoors to minimize risk to the public and the environment.
- Once delivered to a glass processor, CRTs must be processed in a building at temperatures below that at which lead may be volatilized from the glass.
- Only two markets are specified for CRT glass which exempts the material from regulation as hazardous waste: 1) glass-to-glass recycling to produce new CRTs, or 2) secondary lead smelters to recover lead.
- CRT glass delivered to a CRT glass manufacturer or lead smelter is not regulated as hazardous unless it is stored for more than one year or used in a manner

6 U.S. EPA, 40 CFR 261, and U.S. EPA, *Fact Sheet: Easier Recycling of Cathode Ray Tubes*, November 2012.

constituting disposal (applied to the land, such as being used in road construction material).

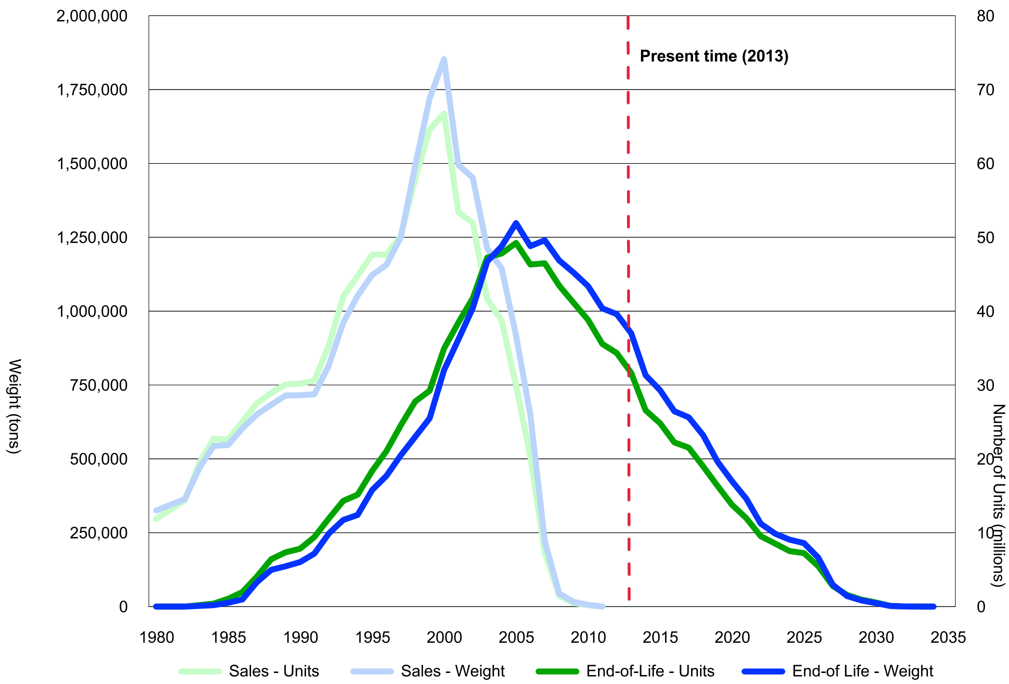
- CRT glass recycled by any other process may request an exemption from hazardous waste characterization; such requests are evaluated by U.S. EPA on a case-by-case basis.

The implementation of CRT disposal bans in 19 states and e-waste program laws in 25 states have resulted in significant quantities of CRTs being collected. Future implementation of disposal bans and/or e-waste program laws in other states would further increase the amount of CRTs collected, by as much as 100 percent. The following sections evaluate the size of the CRT market and availability of processing capacity.

CRT Management by the Numbers

CRTs: From Purchase to End-of-Life

The implementation of e-waste legislation and disposal bans has coincided with the phasing out of CRT technology for televisions and computer monitors. U.S. EPA estimates that more than 979 million CRT televisions and monitors were sold[7] between 1980 and 2010 (see Figure 6). Beginning around the year 2000, sales of CRTs decreased dramatically, replaced by increased sales of flat panel devices including liquid crystal display (LCD) and plasma screens. For purposes of this paper, CRT sales are assumed to have largely ceased after 2010[8].



Note: End-of-life projections are based on sales between 1980 and 2010. CRT devices sold prior to 1980 are not included in the projection of end-of-life management. Based on U.S. EPA's method of forecasting end-of-life *and* the maximum lifespan of CRT devices, CRTs sold prior to 1980 would have reached end-of-life by 2003 and would therefore not impact projections analyzed in this report.

Source: U.S. EPA, *Electronics Waste Management in the United States Through 2009*, May 2011.

FIGURE 6. CRT DEVICES: ANNUAL SALES AND END-OF-LIFE MANAGEMENT PROJECTIONS (1980-2033)

Using the historical sales data for CRT devices, U.S. EPA developed a model to estimate annual quantities of CRT devices (and other components of the e-waste stream) reaching their "end-of-life", at which point the CRTs would be collected for recycling or

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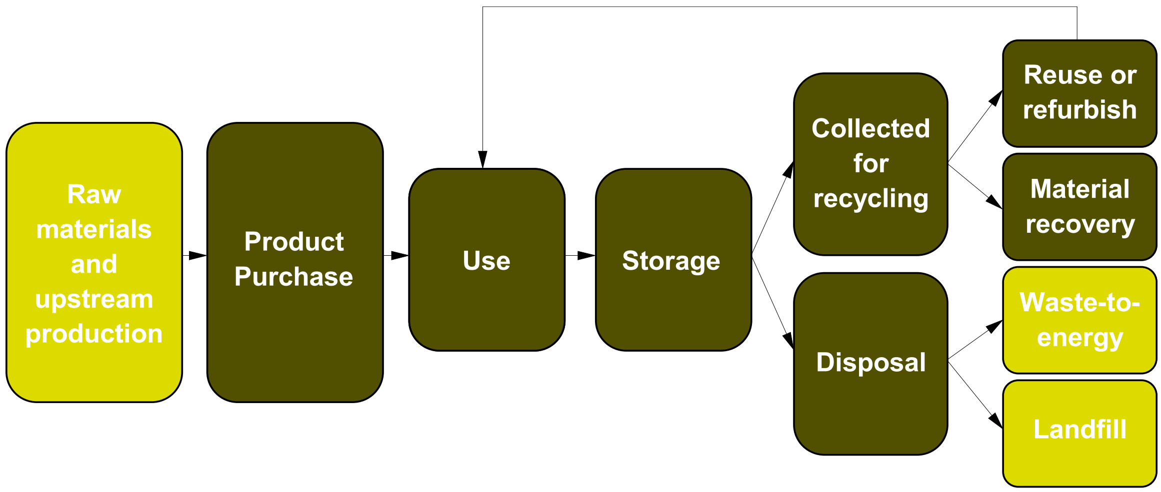
7 U.S. EPA used manufacturer shipment data as a proxy for sales.

8 U.S. EPA estimated sales of CRT units of 194,000 in 2010, a minimal amount compared to sales of flat-panel screens (computer and TV) of 61,391,000 units.

disposal. The time period between purchase and end-of-life management includes initial use of the CRT, potentially a second use (if the CRT is sold or given to another person), and a period of storage by the final user before the device is collected for final disposition (e.g., a CRT may be stored in a household for a period of time after it is no longer used and before it is finally taken to a recycling facility or set out for disposal). Figure 7 shows the life-cycle stages of a CRT device used in the model.



Upstream production
Not modeled

Use
Electronic products sales data, weights, and lifespans

Storage
Lifespans and storage estimates

End-of-life management
Share of electronic products at end of life that are recycled versus disposed

End use or disposal
Survey of electronics recyclers' practices

Life cycle stages included in U.S. EPA model

Not included in model.

Source: Adapted from U.S. EPA, *Electronics Waste Management in the United States Through 2009*, May 2011.

FIGURE 7. U.S. EPA LIFECYCLE MODEL FOR ELECTRONIC PRODUCTS

There is thus a lag time between the point when a CRT is purchased and when it would be collected for recycling or disposal -- the lag time (or, alternatively, "average life") represents the period that the CRT was used/reused and some period of storage by the final user. The U.S. EPA model estimates that residential computer CRTs have an average life of 9 years, and a maximum life of 13 years[9]. The average life of commercial computer CRTs is 4 years, with a maximum life of 5 years (U.S. EPA estimated a shorter life span for commercial CRTs). CRT televisions have a comparatively longer average life of 14-15 years, with a maximum life of 20-23 years (depending on size).

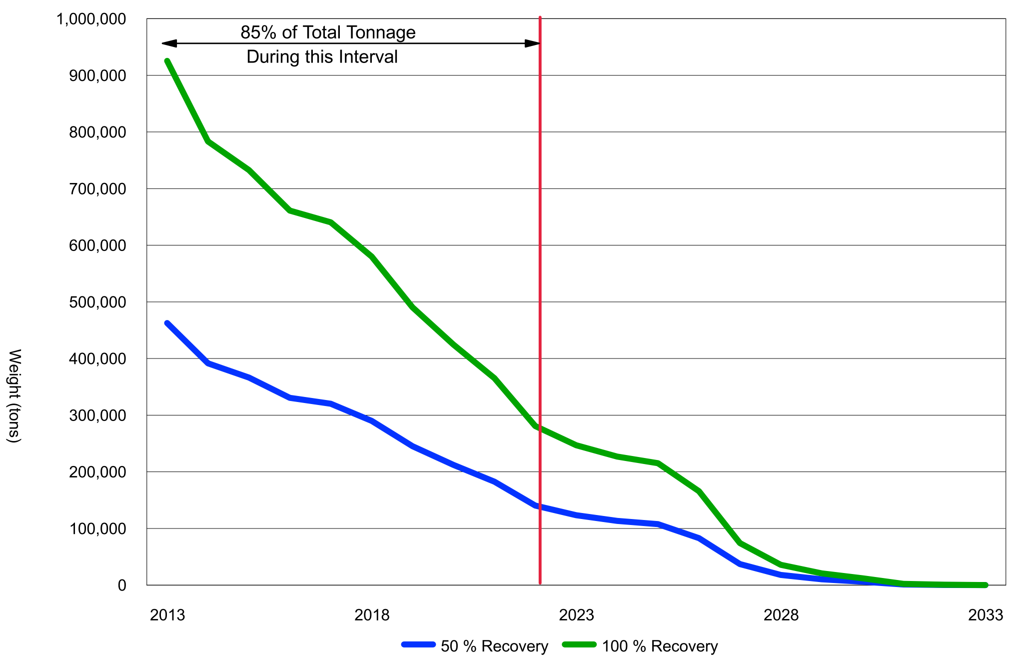
[9] U.S. EPA, *Electronics Waste Management in the United States Through 2009*, May, 2011, Table 4, p. 16.

Figure 6 shows projections of the number of CRTs reaching end-of-life of management based on these average life assumptions[10]. The lag time between initial purchase and the end-of-life management is apparent.

More than 6,900,000 tons of CRT devices must be managed in the future. 85 % will reach end-of-life by 2022. On average, 590,000 tons per year of CRTs will need to be managed in the U.S. over the next 10 years.

Quantities of CRTs Projected to Reach End-of-Life in the Future

With the transition to flat-panel monitor and television technologies and declining use of CRT devices, the annual quantity of CRTs ready for recycling or disposal is expected to decrease over time. Based on end-of-life calculations contained in the U.S. EPA model, all computer monitors containing CRTs are projected to reach end-of-life by 2023, while all televisions are projected to reach end-of-life by 2033 (see Figure 8). Projections are shown for two scenarios: 1) assuming 50 percent of CRTs reaching end-of-life are recovered for recycling; and, 2) assuming 100 percent of CRTs are recovered for recycling. The two scenarios were developed to provide a lower and upper bound estimate of the number and tonnage of CRTs that may be recovered for recycling as discussed further in this section.



Source: Shaw projections based on U.S. EPA end-of-life spreadsheet model.

FIGURE 8. CRT DEVICES REACHING END-OF-LIFE (2013-2033)

[10] The U.S. EPA report included projections through 2010. The spreadsheet model is available on the U.S. EPA website (http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm), and Shaw continued the projections in the spreadsheet forward to 2033.

In total, an estimated 6.9 million tons (232.2 million units) of CRT devices will require management from 2013 to 2033. If all CRTs projected to reach end-of-life are recovered for recycling (100 percent recovery), the annual quantity of CRTs recovered would range from 925,000 tons in 2013 to 280,000 tons in 2022, ultimately dropping to 0 in 2033.

Approximately 85 percent (5.9 million tons, 197.5 million units) of remaining CRT devices are projected to reach end-of-life by 2022. During the 10-year period ending 2022, an average of 590,000 tons (19.5 million units) will require management each year. After 2022, annual averages will drop to 91,000 tons (3.2 million units) per year.

As previously discussed, 19 states have implemented CRT disposal bans; these states represent approximately 50 percent of the population of the U.S. Assuming that the distribution of CRT devices is correlated with population, approximately half of the CRTs to be managed in the future are from states in which a CRT disposal ban is in place. Thus, at a corresponding lower-bound recovery rate of 50 percent, an estimated 3.5 million tons (116.1 million units) of CRT-containing devices would be diverted to recycling over the next 20 years.

Between 2013 and 2022, when the majority of remaining CRT devices are projected to reach end-of-life, a recovery rate of 50 percent will result in the need to process more than 450,000 tons of CRT devices in 2013, dropping to 140,000 tons in 2022. On average, 295,000 tons (9.8 million units) per year of CRT devices may be recovered from states with CRT disposal bans currently in place over the next 10 years.

A recovery rate of 50 percent is conservatively low for a number of reasons:

- Devices from states without disposal bans have not been included. Several states (such as Michigan, Texas, Virginia, and Washington) have e-waste recovery laws but no disposal ban, and CRT devices are recovered in these states.
- Some recycling and recovery of CRTs is also occurring in states without e-waste program laws or disposal bans as well.

In States with disposal bans, CRTs will average 295,000 tons per year over the next 10 years.

- If additional states implement e-waste program laws or ban CRT disposal, the recovery rate may increase further.

Further, the U.S. EPA end-of-life model assumes some period (often lengthy) of temporary storage of CRTs (in homes or businesses) after they stop being used. As more residents and businesses become aware of growing e-waste collection and recycling opportunities in their area and CRT devices grow more obsolete, devices may move rapidly from storage to final disposition at recyclers or disposal facilities, further increasing the near-term demand for processing capacity.

Quantities of Stockpiled CRTs

Some CRTs that have previously reached end-of-life and have been collected for recycling are reportedly being stockpiled by electronics recyclers and CRT processors, as discussed in a number of recent reports and articles. Stockpiling refers to the accumulation of materials at one or more stages of processing. Stockpiling may occur for a number of legitimate business reasons, for instance:

- To accumulate sufficient volume to transport to a processor; or
- To accumulate sufficient volume to operate a processing technology.

However, stockpiling may also occur due to market problems, such as:

- A lack of capacity or markets; or
- Existing markets are not cost-effective.

As discussed previously, federal law allows CRTs intended to be recycled to be accumulated for up to one year without being regulated as a hazardous waste. Stockpiling CRTs becomes a concern if the material is being accumulated speculatively without a market for the material defined; this may occur when capacity is not available or is too costly for a recycler or intermediate processor.

U.S. EPA hosted a listening webinar on May 30, 2013 regarding CRT management in the U.S. and questioned participants regarding their knowledge of stockpiling activities; state inspectors and regulators participating on the call from Connecticut, Illinois, and Wisconsin each indicated that they have encountered some sites that have accumulated material but have not pursued enforcement action. In addition, some state regulators have indicated that they are generally not made aware of facilities accumulating CRTs until a facility is abandoned or reported because the facilities are often intermediate processors and are not inspected or tracked by the state regulatory programs[11]. The State of Wisconsin indicated this in its 2012 annual report on it E-Cycle program:

> *As discussed earlier, monitoring recycling activities that occur outside of the E-Cycle Wisconsin program has been extremely challenging and often these activities <u>only come to the DNR's attention when a problem occurs</u>. More than 25 complaints have been addressed by DNR Waste and Materials Management Program staff since January 2010. These complaints include illegal dumping of whole or dismantled electronics, businesses stockpiling material because they don't have a market or can't afford to pay the cost of proper recycling, and illegal processing of electronics, such as by smashing cathode ray tubes (CRTs)*[12]. (emphasis added)

Stockpiled CRTs are a small fraction of the total remaining CRTs in the U.S., but they are an immediate concern.

Stockpiling concerns have been raised by others as well. The U.S. International Trade Commission indicated, in a February 2013 study of the export of used electronic products from the U.S., that U.S. operations handling CRTs either export them for

[11] Jeff Hunts, Covered Electronic Wastes Program Manager, CalRecycle, personal communication, May 2013. Dave Walters, E-Scrap Program Manager, Illinois EPA, personal communication, April 2013.

[12] Wisconsin DNR, E-Cycle Wisconsin 2012 Report, December, 2012, p. 18.

production of new CRTs or stockpile them because processing is not cost-effective[13]. A March 18, 2013 article in the New York Times cited examples of a known stockpile being investigated in Fresno, California and a prior stockpiling issue at a glass processor in Yuma, Arizona[14]. Muskingnum County, Ohio reported in July 2013 that “overwhelming” quantities of CRTs have been dumped illegally at County recycling sites, and the illegal dumping activities are now under investigation by Ohio EPA and the County Sherriff’s Office[15]. In August 2013, Resource Recycling, an industry trade publication, reported the discovery of more than 10,000 tons of CRT glass in abandoned stockpiles at two former e-waste processing facilities in Arizona and Colorado, and stated that reports of other potential stockpiles in Maryland and Pennsylvania were being investigated[16]. A subsequent report one week later from Resource Recycling identified that approximately 3,000 gaylord containers of CRTs had been found at an abandoned warehouse in Maryland[17]. The owner of that company cited an inability to secure agreements with end-use markets as the reason for the accumulation of material.

Transparent Planet, a consultant to the electronics recycling industry, worked with a group of CRT processors in 2012 to address CRT management issues in the U.S. In its report, Transparent Planet estimates that 330,000 tons of CRTs are stockpiled across the U.S.[18]; this is the only quantified, aggregate estimate of stockpile quantities that was identified in conducting the research for this paper.

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13 U.S. International Trade Commission, *Used Electronic Products: An Examination of U.S. Exports*, February 2013, page xix.

14 Ian Urbina, “Unwanted Electronic Gear Rising in Toxic Piles”, *New York Times*, March 18, 2013.

15 Waste and Recycling News, “Overwhelming Numbers of CRTs Illegally Dumped in Ohio”, July 18, 2013.

16 Resource Recycling, “BREAKING: Abandoned warehouses full of CRTs found in several states”, August 2013.

17 Resource Recycling, “Abandoned Baltimore warehouse is full of CRTs”, August 2013.

18 Transparent Planet, *U.S. CRT Glass Management: A Bellwether for Sustainability of Electronics Recycling in the United States*, December 2012, page 31.

Summary of CRT Quantities

Based on the foregoing, Table 1 summarizes the estimates of CRT devices that may require management now and in the future.

TABLE 1. ESTIMATE OF CRT DEVICES REQUIRING MANAGEMENT

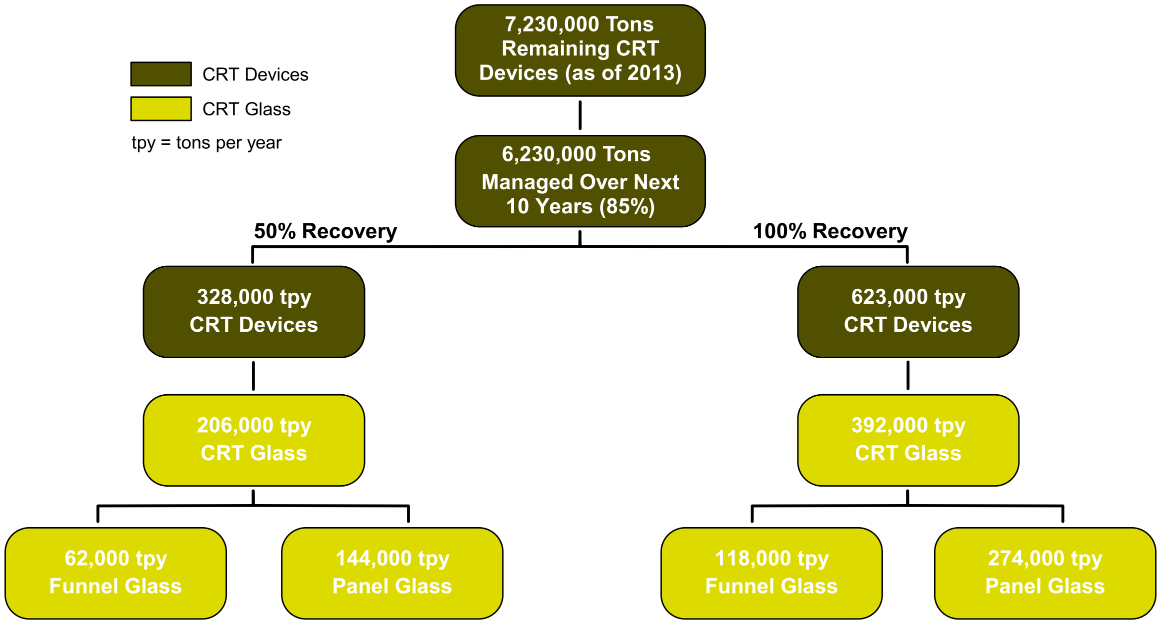
Category	Units	Tons
Reaching end-of-life, 2013-2022	197,500,000	5,900,000
Reaching end-of-life, 2023-2033	34,800,000	1,000,000
Previously collected and stockpiled (2012 estimate)	12,000,000	330,000
Total	244,300,000	7,230,000

Sources:
1. U.S. EPA, *Electronics Waste Management in the United States Through 2009*, May 2011.
2. U.S. EPA, *Electronics Waste Management in the United States: Approach 1*, July 2008. Spreadsheet model (http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm), updated by Shaw.
3. Transparent Planet, *U.S. CRT Glass Management: A Bellwether for Sustainability of Electronics Recycling in the United States*, December 2012. (stockpile estimates)

CRT Glass Estimates

The tonnage noted in Table 1 is whole device tonnage, representing the weight of intact monitors and televisions (including the exterior cabinet of wood and/or plastic). As was noted in Section 2, approximately 63 percent of the weight of an intact CRT-containing device is glass; the funnel glass has a high lead content, while the panel glass (e.g., the screen) has a much smaller lead content. The markets for CRT glass have declined, and ultimately it is the amount of CRT glass collected that presents the largest challenge for recovery and recycling of CRTs.

Projections of future CRT glass quantities are summarized in Figure 9, again assuming recovery rates of 50 percent and 100 percent to provide a lower-bound and upper-bound estimate of the amount of glass to be managed through recycling. At the lower-bound rate of 50 percent, 206,000 tons per year of CRT-glass will be recovered over the next 10 years. At the upper-bound rate of 100 percent, 392,000 tons per year of CRT-glass will be recovered.



Source: Shaw projections based on U.S. EPA end-of-life spreadsheet model and composition of CRTs.
Note: The 6,230,000 tons to be managed over the next 10 years includes estimated stockpiled CRTs (330,000 tons) which are assumed to be 100% recovered under both scenarios.

FIGURE 9. PROJECTED FUTURE QUANTITIES OF CRT DEVICES AND CRT GLASS (2013-2022)

Estimates of CRT Recycling and Disposal

Electronic waste comprises a relatively small (but fast-growing) fraction of the overall municipal solid waste stream. U.S. EPA estimates that approximately 1.3 percent of the municipal waste stream in 2010 was comprised of electronic wastes, with an estimated 3.32 million tons of e-waste generated and requiring management. Of the e-waste collected, about 650,000 tons was recovered for recycling[19].

U.S. EPA further estimates that 194,000 tons of computer monitors and 181,000 tons of televisions were recycled in 2010[20], corresponding to recycling rates of 33 percent and

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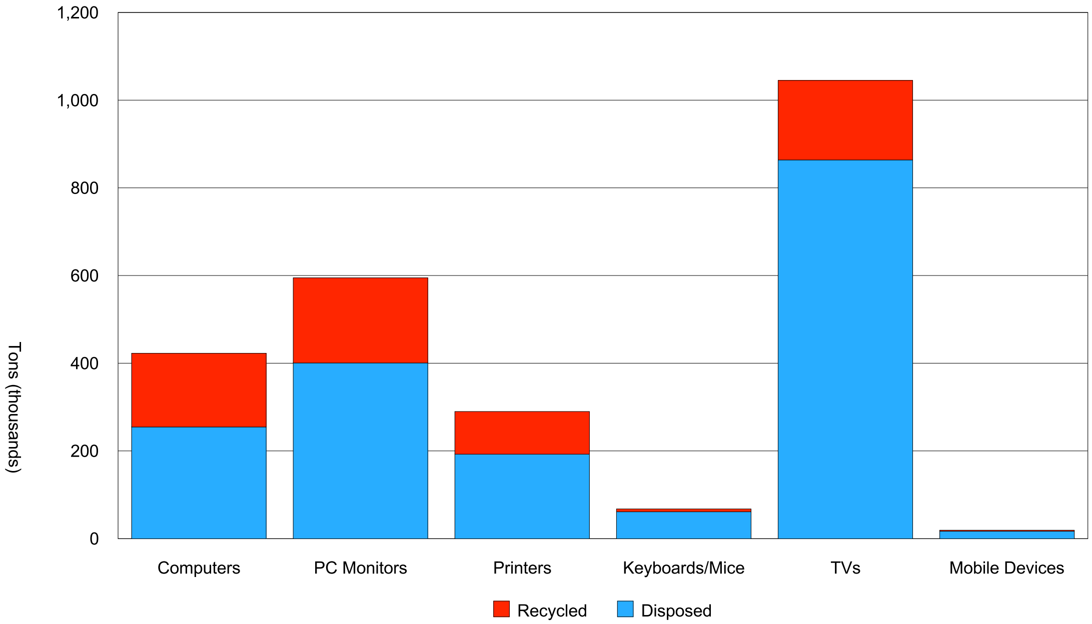
[19] U.S. EPA, *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2010*, December, 2011, Tables 12 and 13. Note that the 3,320,000 total tons of electronics reported in the 2010 *MSW Generation* report is higher than 2,440,000 tons of electronic products reaching end-of-life in 2010 as reported in the EPA's 2011 *Electronics Waste Management* report. The reason for this difference is that a more limited subset of electronics devices was analyzed in the 2011 *Electronics Waste Management* report (electronic devices included computers, computer monitors and other peripherals, televisions and cell phones). EPA did not list the additional electronic devices that were included in the 2010 *MSW Generation* report, although it would appear to include other consumer electronics (e.g., video players/recorders, games, stereo equipment, cameras, fax machines, etc.) that were not included in the 2011 *Electronics Waste Management* report.

[20] U.S. EPA Office of Resource Conservation and Recovery, *Electronics Waste Management in the United States Through 2009*, May 2011, Table 11, page 26.

17 percent, respectively, for those types of devices (see Figure 10). Note that those recycling tonnages and rates include both CRT devices *and* flat-panel devices.



Source: U.S. EPA, *Electronics Waste Management in the United States Through 2009*, May 2011.

FIGURE 10. RECYCLING TONNAGES FOR ELECTRONIC DEVICES (2010)

Computer monitors and televisions are therefore a large share of recovered e-waste, constituting approximately 375,000 tons or 58 percent of the 650,000 total tons of e-waste recycled in 2010 (see Figure 11). This is consistent with the amounts and types of recovered electronic devices reported by State e-waste programs as well as e-waste processors.

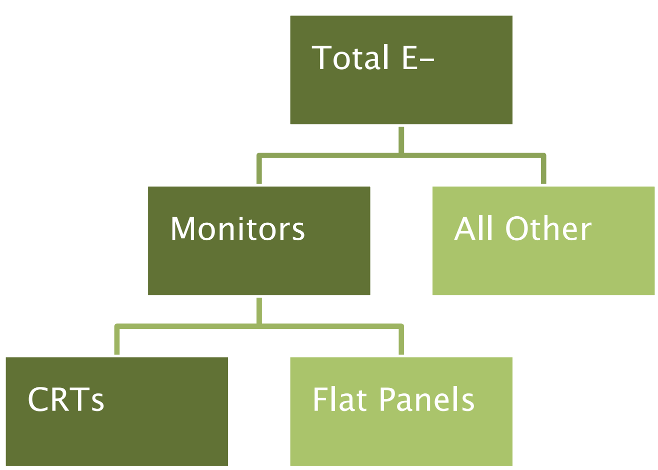


FIGURE 11. CONTRIBUTION OF MONITORS/TVs TO OVERALL E-WASTE RECYCLING (2010)

Although U.S. EPA did not report the specific tonnages of CRT-containing devices that were recycled in 2010, the U.S. EPA's end-of-life model predicts that CRTs constituted

66 percent of the total weight of computer monitors and televisions reaching end-of-life in 2010. Assuming that CRT devices also constituted 66 percent of the 375,000 tons of monitors/televisions recovered for recycling in 2010, then an estimated 247,500 tons of CRT devices were recycled in that year (see Figure 11).

This seems a reasonable estimate. In 2010, U.S. EPA estimated that 1,085,000 tons of CRT-containing devices reached end-of-life; the 247,500 tons of recovered CRTs therefore represents a 23 percent recycling rate. As of 2010, 9 states representing approximately 21 percent of U.S. population had implemented CRT disposal bans[21].

[21] An industry representative also put the amount of CRTs recovered for recycling at 250,000 tons per year. David Cauchi, Closed Loop Refining and Recovery, cited in *Scrap* Magazine (published by the Institute for Scrap Recycling Industries), November/December 2012, p. 53.

CRT Processing Capacity

In performing the research for this paper, known existing and proposed CRT glass processing facilities were contacted to obtain information on their process technology, an estimate of capacity to receive CRTs for processing, and the cost for processing. Available information on processing facilities is presented in this section.

Existing CRT Glass Processing Facilities

There are currently two primary methods by which CRTs are recycled: 1) glass-to-glass recycling processes, in which new CRT glass is produced from recovered CRT glass, and 2) secondary lead smelting operations, in which lead is recovered from CRT glass and the glass is used as a flux agent in the smelting process. Glass-to-glass recycling is the larger market for CRT glass currently. However, changes in the market demand for CRT glass, the limited availability of processing facilities, and the increasing cost to manage CRT glass are presenting challenges to e-waste recyclers, and some recyclers are concerned that the challenge will only increase in the future.

The location of existing facilities managing CRT glass are shown in Figure 12. Only four facilities in North America have been identified as receiving CRT glass for processing from the U.S.; this is consistent with information published by a number of entities regarding CRT glass processing outlets[22]. Note that the four facilities represent end-use markets for recovered CRT glass[23], and therefore do not include all upstream intermediate processors that may handle and disassemble CRT devices or facilities that accept CRT glass for disposal (such as hazardous waste landfills).

Three of the facilities are located outside the U.S. -- one in Mexico and two in Canada. Notably, these facilities are located in the far northeast, far northwest and far southwest relative to the continental U.S., which means that CRT glass must be transported long distances to a glass processing facility. Only the Doe Run facility in Missouri is centrally-located within the U.S.

Three of the facilities are secondary lead smelters: Doe Run, Teck Resources and Xstrata Zinc. The Cali Resources/TDM facility is a glass-to-glass processor that cleans and crushes recovered glass and subsequently transports it to Samtel/Videocon in India.

Four facilities process CRT glass in North America. Of these, only one is located in the U.S.

[22] CalRecycle, California's Covered Electronic Waste (CEW) Recycling System, presentation to CalCUPA, February 4, 2013, page 12.
Transparent Planet, *U.S. CRT Glass Management: A Bellwether for Sustainability of Electronics Recycling in the United States*, December 2012, page 37.
U.S. International Trade Commission, *Used Electronic Products: An Examination of U.S. Exports*, February 2013, page 3-10.

[23] As discussed below, one of these facilities (Cali Resources/TDM) is a glass-to-glass processor that ships recovered glass to India for processing into new CRTs and therefore represents an end-use market in conjunction with the India facility.

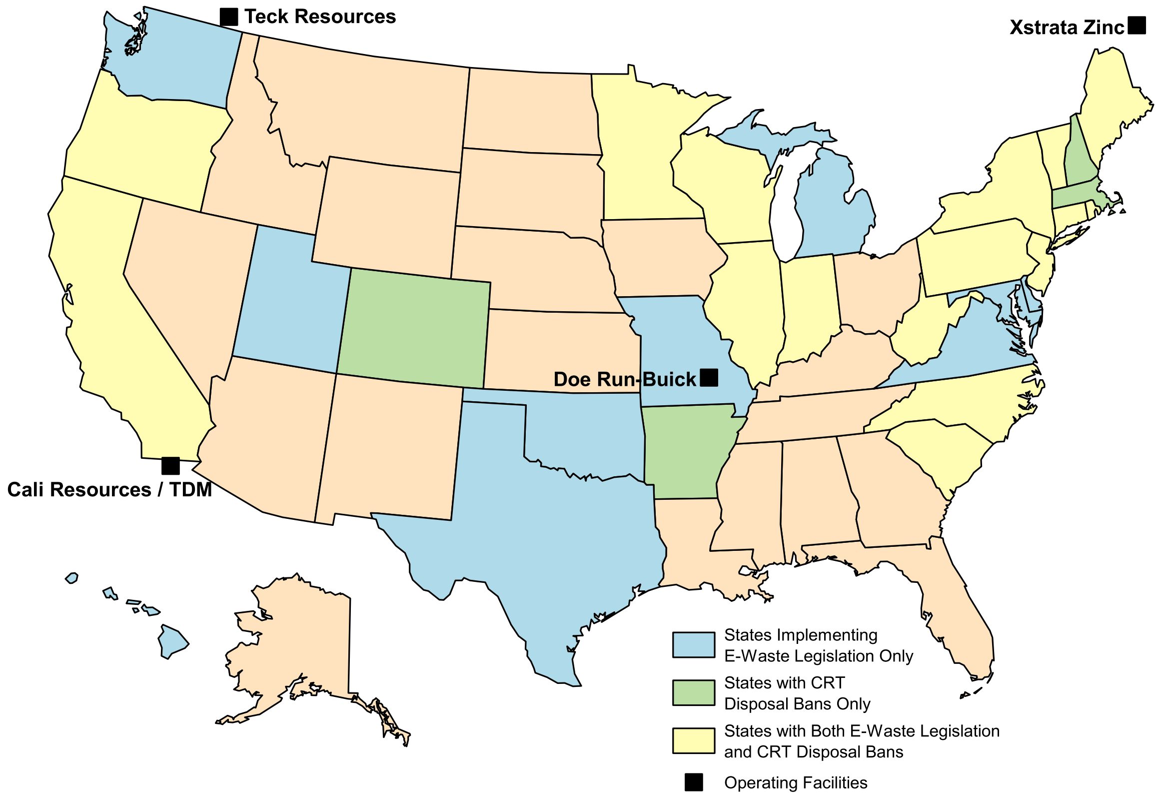


FIGURE 12. LOCATION OF EXISTING CRT GLASS PROCESSING FACILITIES

Additional information on the glass processors operations and capacity is provided in Table 2. This information was collected through a telephone survey of representatives of the facilities and company websites. Note that the Xstrata facility accepts leaded glass cullet only; the other facilities accept whole CRTs (i.e., panel glass and/or funnel glass).

The four existing facilities have an estimated annual CRT glass capacity of 128,000 tons. However, not all of this capacity is available to U.S. customers. The lead smelting facilities in Canada both indicated that they receive approximately half of their incoming CRT glass from U.S. customers and the other half from Canadian customers. Cali Resources/TDM may also receive material from Mexico and Canada, in addition to the U.S., decreasing the capacity available to U.S. e-waste recyclers.

TABLE 2. EXISTING CRT PROCESSING CAPACITY (END USE MARKETS)

Facility	Location	Status	Technology	Annual Capacity
Cali Resources / TDM	Mexicali, Mexico	Operating	Glass separation and cleaning, transport to India for glass-to-glass recycling	102,000 tons

Doe Run Co. - Buick Resource Recycling Division	Boss, Missouri	Operating	Secondary lead smelter	Did not report; estimate 8,000 tons
Xstrata Zinc	Belledune, New Brunswick, Canada	Operating	Secondary lead smelter	At capacity, and capacity is declining; estimate 3,000 tons
Teck Resources	Trail, British Columbia, Canada	Operating	Secondary lead smelter	At capacity; estimate 15,000 tons
Total				128,000 tons

Sources:
1. Cali Resources / TDM: http://www.caliresources.com/US/GlasstoGlass.htm, May 2013.
2. Doe Run Company: PRWeb, "Doe Run Recycling Division Earns Recertification for Environmental, Management Standards", February 20, 2008.
3. Xstrata Zinc: Personal communication with vendor representative, May 2013.
4. Teck Resources: Personal communication with vendor representative, May 2013.

In Section 4, it was estimated that over the next 10 years (2013-2022), an average of 206,000 tons per year of CRT glass would be recycled assuming a 50 percent overall CRT recovery rate. Compared to the estimated capacity of the four processors, there is an apparent shortfall in capacity of 78,000 tons per year, even assuming that all of the capacity was made available to U.S. recyclers. This capacity shortfall may explain recent reports of CRTs being stockpiled.

Assuming 50 % Recovery Rate for CRTs:

Estimated CRT Glass Recovery	=	206,000 tons/year
Existing Processing Capacity	=	128,000 tons/year
Estimated Shortfall	=	78,000 tons/year

If there was a national goal of recovering 100 percent of CRTs, the capacity shortfall would be even greater, estimated at 264,000 tons per year.

Assuming 100 % Recovery Rate for CRTs:

Estimated CRT Glass Recovery	=	392,000 tons/year
Existing Processing Capacity	=	128,000 tons/year
Estimated Shortfall	=	264,000 tons/year

The two Canadian lead smelters (Xstrata and Teck Resources) indicated that they are operating at capacity[24]. Xstrata further indicated that its handling of CRT glass is declining due to the need to preserve smelting capacity for other leaded materials that provide greater lead recovery; as noted previously, Xstrata will accept only leaded CRT cullet.

Based on throughput data provided on its corporate website, the Cali Resources/TDM facility is also operating near its capacity. The facility reportedly handles 240 tons per day and has a capacity for 280 tons per day, and therefore operates at 86 percent of capacity[25].

The capacity provided by Cali Resources/TDM represents nearly 80 percent of the existing CRT glass processing capacity shown in Table 2. The CRT glass that is processed by Cali Resources/TDM is sent to an end use market in India for the manufacture of new CRTs. The facility in India is the last remaining CRT manufacturing facility available to handle CRT glass exported from the U.S. and may not be a long-term market; according to recycling industry representatives, the facility may cease production of CRTs by 2014 or 2016[26]. Other industry representatives have indicated that the future operating status of Cali Resources/TDM represents an industry-wide concern[27]:

> *"Everybody in the whole market place is worried about it [TDM]."*

Doe Run did not provide throughput or capacity information during the phone survey, although the representative indicated the facility has capacity for additional CRTs. Information on the company's website indicated the facility processed 275,000 CRTs in 2007[28]; assuming an average CRT weight of 35 pounds (glass only), this would correspond to an estimated total weight of 4,800 tons. An earlier study of CRT markets that also surveyed end use markets, including Doe Run, indicated a capacity of 8,000 tons per year[29].

The capacity analysis presented above indicates that additional end-use outlets are needed to support continued recovery and processing of CRTs. This need, and the market challenges of CRT recycling, have been recognized by a number of agencies in various reports and/or studies:

- CalRecycle (California), Update on Electronic Waste Recycling Program.[30]

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24 Teck Resources and Xstrata Zinc, personal communications with vendor representatives, May 2013.

25 Corporate website (http://www.caliresources.com/US/GlasstoGlass.htm), accessed May, 2013.

26 Institute of Scrap Recycling Industries, *Scrap* Magazine, November/December 2012, p. 53.

27 Resource Recycling, "A Look Through the Leaded Glass", June 2013, page 36.

28 Doe Run Company: PRWeb, "Doe Run Recycling Division Earns Recertification for Environmental, Management Standards", February 20, 2008.

29 Chelsea Center for Recycling and Economic Development, University of Massachusetts, *Potential Markets for CRTs and Plastics from Electronics Demanufacturing: An Initial Scoping Report*, August, 1998.

30 Department of Resources Recycling and Recovery (CalRecycle), *Update on California's Covered Electronic Waste Recycling Program, Implementation of the Electronic Waste Recycling Act of 2003*, June, 2012.

Future CRT Glass Markets Uncertain:

- *"Glass-to-glass" recycling has limitations since CRT technology is being replaced by flat screens.*
- *Smelter flux continues to be option; limited domestic destinations, higher cost.*
- *New options for CRT glass management are needed, possibly non-traditional recycling applications, but also including the possibility of proper disposal.*

- Wisconsin Department of Natural Resources, E-Cycle Program Report.[31]

  The CRT glass is one of the most problematic materials for all recyclers, but especially for the backyard or small-scale recyclers, to responsibly handle. Markets for CRT glass are dwindling, and the smelters and glass-to-glass processors will not work with small-scale operations. In addition, the weight of CRT glass makes transportation costs high and if the CRTs are not recycled and need to be disposed of in a landfill, they are considered a hazardous waste.

- United Nations Environment Programme, Electronic Waste Recycling Study.[32]

  Another factor determining the opportunities for glass-to-glass recycling is the demand for CRT glass. This demand has been steadily declining over the past years, as plasma and LCD screens are becoming more and more pervasive instead. As a consequence it can become more and more difficult to do glass-to-glass recycling in the future.

- U.S. International Trade Commission, Study of U.S. Exports of Used Electronic Products.[33]

  The widespread popularity of flat screen TVs and monitors has curtailed global demand for CRT glass. As a result, most used CRTs are reportedly recycled, rather than reused. Furnaces to manufacture CRT glass are scarce; reportedly, there are no remaining facilities in developed countries. Industry sources indicated that several processors for recycling of used CRT glass exist in the United States. Still, the limited domestic capacity for recycling CRTs, compounded by firms' stockpiling in order to avoid paying disposal costs, has ensured continued U.S. exports of CRTs for recycling.

- Institute of Scrap Recycling Industries, Journal Article in *Scrap* Magazine.[34]

  It's nearly impossible to buy a new consumer electronic product containing a cathode-ray tube in North America or Europe these days, and the production of such devices in the rest of the world is slowing significantly as well. Industry

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31 Wisconsin *DNR*, *E-Cycle Wisconsin 2012 Report*, December, 2012, p. 18.

32 United Nations Environment Programme, *Recycling - From E-Waste to Resources*, July 2009, page 37.

33 U.S. International Trade Commission, *Used Electronic Products: An Examination of U.S. Exports*, February 2013, page 3-9.

34 Institute of Scrap Recycling Industries, *Scrap* Magazine, November/December, 2012, p. 53.

insiders expect CRT production will halt altogether within the next decade, perhaps much sooner. This might be good news for electronics recyclers, who receive such devices at their end of life and have struggled to find markets for CRT glass. But it's bad news as well: Until now, one of the most valuable markets for recycled CRT glass has been the production of new CRTs.

- Waste Management World, Industry Publication, Journal Article.[35]

  At the same time that recycling programs are collecting more old cathode ray tubes (CRTs) from old TVs and computer monitors, solutions for recycling CRT glass are disappearing fast in the U.S.

  According to E-World Online, which administers e-waste take-back and producer responsibility programs across the U.S., without updated regulations and new recycling models, old CRT glass - which contains lead and requires responsible recycling - will become harder and potentially more costly to recycle.

  Currently, CRT glass is separated into leaded and non-leaded glass and processed for recycling into other glass products. CRTs used to be recycled into new CRT displays, however E-World says that due to the rise of flat screen technologies the demand for CRT glass has collapsed worldwide.

  Many state regulations require CRT glass to be recycled rather than disposed. According to E-World the recycler's dilemma is that currently there are too few domestic end-markets for this material.

- Waste & Recycling News, Industry Publication, Journal Article.[36]

  The market for cathode ray tube (CRT) glass is shrinking and it's only getting smaller, as more and more old televisions and monitors are being recycled instead of being landfilled, said Steve Skurnac, president of Sims Recycling Solutions.

  "I think we're already [at the saturation point] in the market." he said. "There's a lot of glass in California that is having a hard time finding a home. Easily within the next year, a similar issue is going to crop up in other jurisdictions."

Proposed CRT Glass Processing Facilities

In response to the decline in historical markets for CRT glass, several new processing options are currently being proposed. Three companies are seeking to develop new glass processing furnaces to separate lead from the glass and provide feedstock for production of new glass products. Closed Loop Refining and Recycling has proposed two glass furnaces in Arizona and Ohio. Regenesys Glass Processing has proposed a glass furnace in Texas, and NuLife Glass has proposed a glass furnace in New York. The location of these proposed facilities is shown in Figure 13, and additional

[35] Waste Management World, *Market for Recycled CRT Glass Drying Up as Volumes Rise*, September, 2011.

[36] Waste & Recycling News, *Facilities Overwhelmed by CRT Glass*, November 8, 2012.

information about the facilities is provided in Table 3. This information was again collected through a telephone survey of representatives of the companies.

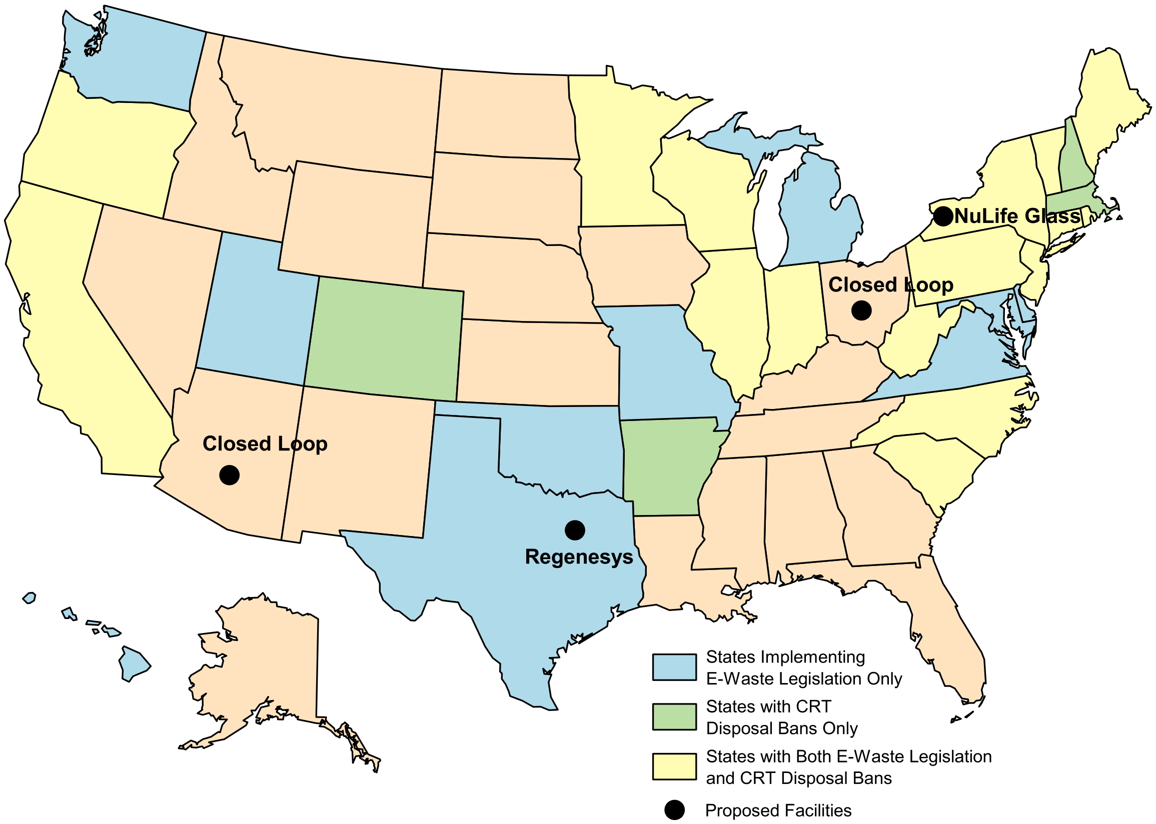

FIGURE 13. LOCATION OF PROPOSED CRT GLASS PROCESSING FACILITIES

TABLE 3. PROPOSED CRT PROCESSING CAPACITY

Facility	Location	Status	Technology	Annual Capacity
Closed Loop Refining & Recycling	Phoenix, Arizona and Columbus, Ohio	Accepting material, in permitting - not yet processing	Glass furnace	29,000 tons (Arizona) 36,000 tons (Ohio)
NuLife Glass	Buffalo, New York	In permitting - not yet processing	Glass furnace	13,000 tons
Regenesys Glass Processing	Terrell, Texas	Under construction - not yet processing	Glass furnace	120,000 tons
Total				198,000 tons

Sources:
1. Closed Loop Refining & Recycling: Personal communication with vendor representative, May 2013.
2. NuLife Glass: Personal communication with vendor partner, May 2013.
3. Regenesys: Personal communication with vendor representative, May 2013.

The four new facilities proposed for development may ultimately provide an additional 198,000 tons of domestic CRT glass processing capacity. Three of the facilities are in the permitting phase, and one facility is under construction (Regenesys).

- The two facilities proposed by Closed Loop Refining & Recycling are awaiting permits prior to moving forward with development. Company representatives expect permits to be received during summer or fall of 2013. The company estimates that, upon receipt of permits, the facilities may be operational within 12 to 15 months.

  Closed Loop has started accepting CRT glass and accumulating it for feedstock for the furnaces once they are operational. The facilities will separate panel glass and funnel glass using an automated process before breaking the glass. Panel glass is planned to be marketed to domestic glass manufacturers. Funnel glass will be processed in the furnace to separate lead from the glass, and the lead and glass are planned to be sold to end markets for use in production processes[37].

- The NuLife Glass facility must secure permits prior to proceeding with furnace development and operation. CRT glass is expected to begin being collected in summer 2013 and accumulated until the furnace commences operation.

  Whole CRTs will be accepted for separation, and leaded funnel glass will be processed in the furnace to recover lead and produce glass for use by glass manufacturers. NuLife previously supplied a furnace for a similar facility in the UK owned and operated by a Kuusakoski joint venture[38].

- The Regenesys Glass Processing facility is currently under development, with furnace construction expected to be complete in summer 2013. Testing will commence upon completion of construction, and full operation is projected to be achieved by the end of 2013.

  The facility will separate whole CRTs onsite, and panel glass will be marketed to glass manufacturers. Funnel glass will be smelted to recover lead, and the glass will be renourished prior to being marketed to glass manufacturers[39].

> Development of new furnace technologies requires extensive lead time to identify sites, obtain permits and construct the facility.

Development of new processing capacity requires significant lead time to identify a suitable site location, secure necessary permits, and construct facilities. Regenesys noted that the permitting process is lengthy, and that permitting of its proposed facility required approximately two years to complete, notwithstanding that the facility is being developed at the site of a former permitted lead smelting operation.

The proposed facilities each are designed to separate lead from glass and produce a glass feedstock that can be used by manufacturers to produce new glass products. The separation process may not provide complete recovery of the lead however, leaving some lead remaining in the final glass feedstock.

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37 Closed Loop Refining & Recycling, personal communication, May 2013.

38 Kuusakoski Recycling, personal communication, May 2013. Kuusakoski operates the NuLife facility in the UK.

39 Regenesys Glass Processing, personal communication, May 2013.

Test data documenting the concentration of residual lead remaining in the glass after processing by the proposed furnaces has not been published. Material testing will be required to confirm that the processed glass from proposed facilities meets standards for use in glass manufacturing processes. The processed glass must also be of acceptable quality and performance to the glass market and, ultimately, be acceptable to consumers. This concern was recently noted by Sims Recycling Solutions, a large global e-waste processor, in reference to proposed CRT glass processing facilities:

> *"Both of them have promise, but the difficulty with both of the technologies, based on the research we've seen and done, is that they don't quite get all the lead out of the leaded glass," he says. "So it's really going to boil down to how much it costs and what kind of capacity does it have and how good a job does it do at taking the lead out, and is the glass of a quality that's OK for regulators and the secondary uses in the market place."*[40]

Ability of Existing and Proposed CRT Glass Processing Capacity to Meet Demand

Existing CRT glass processing facilities provide an estimated 128,000 tons of capacity annually. Proposed facilities, if developed and operated at the capacities they have planned, would ultimately provide an additional 198,000 tons of capacity per year. In total, approximately 326,000 tons of capacity may become available to process CRT glass from the U.S.

This assumes that all of the existing and proposed facilities are operating at the same time. As noted before, three of the proposed facilities are still in the permitting process, and the fourth (as of the date of this report) is under construction and not yet processing material. There will therefore be some lag time before all four facilities are up and running.

Further, the Cali Resources/TDM facility currently exports processed CRT glass to a CRT manufacturing facility in India. As noted before, industry experts believe the manufacturing facility in India may cease production of CRTs as early as 2014, or perhaps will operate until 2016. At that stage, Cali Resources/TDM may continue to process CRTs, but might function more as an intermediate processor of CRTs, not in its current function as an end-use market (in conjunction with the CRT manufacturing facility in India). In that event, the Cali Resources/TDM facility would require another end-use outlet for the processed glass, presumably one of the new facilities proposed for the U.S. The Cali Resources/TDM facility has a reported capacity of 102,000 tons per year as discussed previously.

Thus, it seems more likely that the development of the four proposed facilities will ultimately result in end-use processing capacity of 224,000 tons per year (= 326,000 tons per year less 102,000 tons per year).

Performing the capacity analysis as before, and assuming a 50 percent CRT recovery rate, indicates that even with the timely development of all four proposed facilities (doubling the number of existing facilities), only a relatively small "buffer" capacity of 18,000 tons would exist. Combined, the existing and proposed facilities would be at 92 percent capacity under the 50 percent CRT recovery scenario.

Assuming 50 % Recovery Rate for CRTs:

Existing + Proposed Processing Capacity	=	224,000 tons/year
Estimated CRT Glass Recovery	=	206,000 tons/year
Buffer Capacity - Best Case	=	18,000 tons/year

Such a situation would still represent tight market conditions for electronics recyclers and intermediate processors in finding end-use markets for CRT glass. Further, the estimated buffer capacity is a conservative, "best-case" estimate (in terms of capacity being available) for a number of reasons:

- It assumes that all existing and proposed facilities are available and operating at the same time. A delay in the development of one of the proposed facilities, or (worse) the loss of a single facility, could result in a capacity shortfall.
- The estimated demand of 206,000 tons per year is an average projected value over the next 10 years. Projected demand would be higher than 206,000 tons per year over the first 5 years, lower over the subsequent 5 years. By way of example, the projected demand for 2014 is estimated at 267,000 tons of CRT glass, and thus there exists a near-term capacity shortfall even if all proposed facilities were available today.
- The estimated demand of 206,000 tons per year is based on recycling of CRTs by the 50 percent of the U.S. population residing in states that have implemented CRT disposal bans. Electronic waste recycling and recovery of CRTs also occurs in states that have not implemented bans (and therefore are not included in the 50 percent estimate), resulting in demand exceeding 206,000 tons per year.
- The estimated demand of 206,000 tons per year assumes no additional states adopt disposal bans in the future.

If there was a national goal of recovering 100 percent of CRTs, a considerable capacity shortfall would exist, estimated at 168,000 tons per year:

Assuming 100 % Recovery Rate for CRTs:		
Estimated CRT Glass Recovery	=	392,000 tons/year
Existing + Proposed Capacity	=	206,000 tons/year
Estimated Shortfall	=	168,000 tons/year

For these reasons, existing and proposed facilities do not appear to provide sufficient capacity to meet annual processing needs over the next several years.

CRT Processing Costs

In addition to the limited capacity currently available at existing CRT glass processors, the cost of processing is a growing concern. Processing costs have been cited by a number of agencies as a reason for collected CRTs being stockpiled:

- U.S. International Trade Commission, Study of U.S. Exports of Used Electronic Products.[41]

  The world has few CRT processing facilities; most are in Mexico and India. U.S. entities that handle CRT glass either export it or, reportedly, stockpile it in the United States because U.S. processing is cost prohibitive…the limited domestic capacity for recycling CRTs, compounded by firms' stockpiling in order to avoid paying disposal costs, has ensured continued U.S. exports of CRTs for recycling.

- Transparent Planet, Study of CRT Stockpiling. [42]

  …stockpiling of CRT glass is the result of a number of factors, not the least of which is that glass that once produced revenue for recyclers now costs money to recycle…Recyclers 'setting aside' the cost of managing CRT glass while enjoying revenue from commodities is the single largest contributor to stockpiling CRT glass.

- Wisconsin Department of Natural Resources, E-Cycle Program Report. [43]

  The rising cost of recycling leaded glass from cathode ray tubes and diversion of the more valuable electronic components from the program are posing economic challenges to recyclers and manufacturers.

CRTs are generally more costly to process than other components of the e-waste stream because of the cost incurred to process CRT glass[44]. CRT processing costs are recovered through a number of methods:

- Revenue from charges to generators delivering devices to the processor, charged on a per unit or weight basis;

- Revenue from electronics manufacturers (original equipment manufacturers, or OEMs), paid on a weight basis to enable OEMs to fulfill recycling goal weights established by state e-waste laws; and/or

- Revenue from the sale of recovered materials that have a marketable value, such as precious metals, copper, steel, and plastic.

6. CRT PROCESSING COSTS

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41 U.S. International Trade Commission, *Used Electronic Products: An Examination of U.S. Exports*, February 2013, page xix and page 3-9. "Exports" reference the processing of CRT glass at the Cali Resources/TDM facility in Mexico, where glass is separated, cleaned, and shipped to Samtel/Videocon in India for the production of new CRT glass.

42 Transparent Planet, *U.S. CRT Glass Management: A Bellwether for Sustainability of Electronics Recycling in the United States*, December 2012, page 6 and page 22.

43 Wisconsin DNR, *E-Cycle Wisconsin 2012 Report*, December 2012, page 2.

44 Vintage Tech, LLC, personal communication, May 2013.

Funding from OEMs is reportedly declining and may not be sufficient to cover the costs of CRT recycling. In states where OEMs are responsible for funding a portion of recycling efforts through EPR e-waste program laws and meeting an annual recycling goal, more e-waste may be collected than the OEMs are required to fund. The State of Wisconsin has indicated that this is happening in its program, and that because the weight of material collected is exceeding the goals manufacturers must meet and manufacturers are able to readily secure enough credit for recycling, OEMs are pushing to reduce the price they are willing to pay recyclers[45]:

> *Because of increased costs for recycling/proper disposal of CRT glass, several recyclers report rising costs, while manufacturers continue to press for a lower cost per recycled pound to meet their recycling targets.*
>
> *During program years 2 and 3, the weight of electronics actually collected and recycled was several million pounds higher than the total manufacturer obligation. This increased supply contributes pressure to lower rates manufacturers pay to recyclers, as manufacturers are generally having no trouble meeting their targets.*

This market condition is further compounded because recyclers are reportedly eager to secure contracts from the OEMs, and they may therefore bid contracts with aggressively low pricing:

> *Attracted by revenue from OEMs, some recyclers bid below-market prices to recycle CRT products, sell all the valuable commodities and then stockpile the glass in hopes that large volumes will command affordable prices. To their chagrin, however, they find that as markets for CRT glass continue to decline, the cost for CRT recycling continues to rise.*[46]

CRT Glass Processing Costs

Current and proposed prices quoted by the existing and planned CRT glass processors identified previously are presented in Table 4. Processing costs (excluding transportation costs) generally range from \$0.07 to \$0.12 per pound, or \$140 to \$240 per ton[47].

TABLE 4. CRT PROCESSING COSTS

Facility	Location	Cost ($/pound)	Cost ($/ton)	Material Type
Cali Resources / TDM	Mexicali, Mexico	$0.08	$160	Bare CRTs
Doe Run Company - Buick Resource Recycling Division	Boss, Missouri	$0.11	$220	Bare CRTs

45 Wisconsin DNR, *E-Cycle Wisconsin 2012 Report*, December 2012, pages 22-23.

46 Transparent Planet, *U.S. CRT Glass Management: A Bellwether for Sustainability of Electronics Recycling in the United States*, December 2012, page 16.

47 As indicated by a representative from Teck Resources in May 2013, whole, bare CRTs delivered to its facility are charged a much higher rate of \$0.16 per pound or \$320 per ton to discourage the delivery of this material, because silica demand at the facility is low.

Xstrata Zinc	Belledune, New Brunswick, Canada	$0.10 (see note 1), +$0.025 crushing charge, if cullet >1/4"	$200 (see note 1), +$50 crushing charge if cullet >1/4"	Leaded CRT cullet
Teck Resources	Trail, British Columbia, Canada	$0.07 (leaded cullet) $0.16 (bare CRTs)	$140 (leaded cullet) $320 (bare CRTs)	Leaded cullet or bare CRTs
Closed Loop Refining & Recycling	Phoenix, Arizona and Columbus, Ohio	$0.075 (Arizona) $0.0875 (Ohio)	$150 (Arizona) $175 (Ohio)	Bare CRTs
NuLife Glass	Buffalo, New York	$0.12 (projected)	$240 (projected)	Bare CRTs
Regenesys Glass Processing	Terrell, Texas	$0.11-0.12 (projected)	$220-240 (projected)	Bare CRTs

Source:
1. Personal communication with vendor representatives, May 2013.

Notes:
1. Xstrata Zinc charges $400/ton ($0.20/pound) for leaded cullet crushed to less than ¼" in size and pays a rebate of 85% of the value of lead recovered. Xstrata Zinc representative indicated an effective price after the rebate of $200/ton ($0.10/pound) based on typical lead recovery and typical lead pricing.

Treatment and disposal of crushed leaded glass at hazardous waste facilities is estimated to range from $0.04 to $0.05 per pound ($80 to $100 per ton)[48]. The cost to crush CRT glass is estimated at $0.02 to $0.05 per pound ($40 to $100 per ton), resulting in an effective processing and disposal cost of $0.06 to $0.10 per pound ($120 to $200 per ton). Whole CRTs delivered to hazardous waste disposal sites requiring crushing and treatment prior to disposal incur higher costs, estimated at $90 to $120 per cubic yard[49]. Costs to dispose of crushed CRT glass as a hazardous waste are therefore comparable to the cost to recycle the material, though whole CRTs may be more expensive.

By comparison, in states without a CRT disposal ban where CRT devices may be disposed in municipal waste landfills with no processing or treatment, landfill disposal costs generally range from $18 to $105 per ton, or $0.01 to $0.05 per pound, significantly less than the processing cost for CRT glass[50].

CRT Glass Transportation Costs

In addition to the costs charged by the processing or disposal facilities accepting CRTs, transportation costs also impact the cost of CRT glass management. Transportation costs are generally $0.03 to $0.04 per pound ($60 to $80 per ton) for transport of full trailers to facilities within 300 to 400 miles. At greater distances, transportation costs increase to $0.05 to $0.06 per pound ($100 to $120 per ton) or more[51].

As was discussed previously, the majority of existing CRT processing capacity is located at three facilities in Mexico and Canada, and those facilities are located in the far

48 Peoria Disposal Company, personal communication, May 2013.

49 *Ibid.*

50 Waste and Recycling News, "Tipping Fees Vary Across the U.S.", July 20, 2012.

51 Vintage Tech LLC, personal communication, May 2013.

northeast, far northwest, and far southwest relative to the continental U.S. Only one facility is centrally-located within the U.S. Transportation costs are therefore increased for recyclers in many regions of the U.S., including the Midwest and east coast, who lack local outlets for CRT glass.

Of the proposed CRT glass processing facilities, two will be located in the southwest U.S., one will be located in the Midwest, and one will be located in the northeast. The proposed facilities, though not currently operating, may provide relief from the long transportation distances currently required to access end-use markets. However, even with these proposed facilities, there will still be a relatively small number of end-use markets in the U.S. and transportation costs will remain a challenge.

CRT Processing Costs Summary

Recyclers and regulators have stated that the high cost of CRT glass recycling relative to other components of the e-waste stream is a challenge to the e-waste recycling industry. When considering the full cost to recover and process CRT devices (including disassembly, transportation, and glass processing), CRT costs are approximately double the costs to process other components of the e-waste stream. As manufacturers continue to reduce processing costs they pay through state e-waste programs, recyclers will be increasingly challenged to manage CRT glass cost-effectively.

Processing costs at existing and proposed CRT glass processors generally range from $0.07 to $0.12 per pound, with most proposed facilities having costs at the higher end of this range, indicating that the cost to process CRT glass in the future will be at least as high as it is currently. Additionally, though development of new facilities may reduce transportation distances, the limited number of CRT glass end-use markets will still present challenges for recyclers.

Beneficial Use of Treated CRT Glass

A process to treat crushed CRT glass, stabilize the lead to prevent leaching of lead from the glass, and beneficially use the treated material as alternative daily cover (ADC) to support operation of a municipal waste landfill has been developed and permitted by Peoria Disposal Company (PDC)[52], an environmental services company.

The treatment and beneficial use of CRT glass by PDC provides access to an additional, domestic CRT glass processing facility and end-use market. Beneficial use of many materials, including as ADC, is recognized as recycling or diversion by a number of states. Beneficial use of treated CRT glass, in conjunction with other existing and proposed processing facilities discussed previously, will help to address the immediate and long-term demand for CRT glass processing.

Description of Treatment Technology

Based on information provided by PDC[53], the treatment process begins with delivery of crushed leaded or mixed CRT glass to PDC's Waste Stabilization Facility (WSF) in Peoria, Illinois. The WSF is an existing, operating hazardous waste treatment facility. It is permitted to receive and treat CRT glass, and the CRT glass treatment process is operating currently. PDC filed a provisional patent application for the CRT glass treatment technology and a service mark application for the CRT glass treatment process, KleanKover (the treated CRT glass product), in July 2013.

At the WSF, untreated CRT glass (crushed to a maximum size of 6" prior to delivery) is placed in a mixing unit until the size is further reduced to 2" or less in any dimension, at which time a proprietary chemical treatment reagent blend is added to the CRT glass in the mixing unit. Water is added to the mixing unit as needed to facilitate the rapid and thorough blending of all ingredients, as well as initiate the chemical reaction that results in treatment of the heavy metals present in the CRT glass.

When complete, the treated CRT glass is removed from the mixing unit, and samples are collected for Toxicity Characteristic Leaching Procedure (TCLP) analyses to verify compliance with the EPA Universal Treatment Standards (UTS). When compliance is confirmed, the treated CRT glass is removed from storage and shipped to a permitted municipal solid waste landfill owned by PDC in neighboring Tazewell County for beneficial use as ADC. Crushed panel glass may also be beneficially used as ADC if other markets for the non-leaded glass are not available. Panel glass will be tested to confirm that it is non-hazardous and treatment at the WSF is not required prior to being beneficially used as ADC.

Kuusakoski Recycling is currently developing a CRT recycling facility in Peoria to accept whole CRTs or CRT glass. The CRT recycling facility will crush and segregate leaded and non-leaded glass in preparation for transport to the WSF. The WSF can currently accommodate approximately 50,000 tons of CRT glass for treatment annually, and has the option of increasing capacity to 100,000 tons per year. At this treatment capacity,

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52 PDC has been in business for over 80 years and provides a range of waste management services including collection, recycling, transfer, transport, consulting, analysis, and treatment and disposal of municipal solid waste, non-hazardous special waste, certified non-special waste and hazardous waste.

53 Peoria Disposal Company, personal communication, May 2013.

Kuusakoski Recycling and PDC can provide a combined CRT glass processing capacity of 167,000 tons to 333,000 tons per year.

Kuusakoski indicates that the cost to crush and segregate CRT glass, transport the crushed glass to the WSF, treat it at the WSF, and beneficially use the treated glass as ADC will be $0.075 per pound or $150 per ton. This is at the lower end of the range of costs for other current and proposed CRT end-use markets.

PDC and Kuusakoski Recycling indicate the following environmental safeguards are incorporated into the treatment and beneficial use process:[54]

- Airborne particulates generated from the crushing of CRT glass will be collected and managed through air filtration processes.
- The treatment process uses a chemical reagent blend to fix lead in the glass, rendering it relatively non-leachable.
- PDC has been treating CRT glass in this manner since 1989 and received permit approval to use treated CRT glass for ADC in 2012. PDC has also utilized similar treatment technologies to treat other hazardous materials to non-hazardous standards, including steel mill dusts, demonstrating that the process is both technically feasible and commercially viable.
- Treated CRT glass will be tested daily using the TCLP to confirm that regulated metals concentrations are below the EPA UTS.
- To qualify for use as ADC, treated CRT glass must meet the EPA UTS of 0.75 mg/L lead concentration. The treated CRT glass is found to be relatively inert, typically testing at TCLP metals concentrations below the detection limit of laboratory instrumentation, easily satisfying the UTS limit. The UTS limit of 0.75 mg/l for lead is significantly lower than the TCLP standard of 5.0 mg/L; waste material from a generator testing below the TCLP threshold for hazardous waste can normally be disposed as non-hazardous waste without treatment.
- Treated CRT glass must be placed as ADC on the day it is delivered.
- Treated CRT glass has a density of approximately 3,000 pounds per cubic yard, and generally behaves like a stiff to hard soil.
- Treatment and beneficial use of CRT glass as ADC reduces the use of virgin soil to meet daily cover requirements and provides the same important environmental purpose of controlling disease vectors, fires, odors, blowing litter, and scavenging that virgin soil provides[55].
- Treated CRT glass is essentially odorless, with possible detection of a slight musty smell (like wet lime or cement) if held directly beneath the nose.
- PDC has established a Perpetual Care Fund for the facility that will beneficially use treated CRT glass. The Perpetual Care Fund is intended to be used to monitor and maintain the facility into perpetuity, and is in addition to the

[54] Peoria Disposal Company, personal communication, May 2013.

[55] 40 CFR 258.21.

applicable federal and state requirements for the post-closure management of municipal solid waste landfill facilities.

- The availability of a CRT glass processing facility in the Midwest will reduce transportation distances and, therefore, transportation-related emissions associated with the movement of CRT glass from e-waste recyclers to CRT glass processing facilities.

Beneficial Use as a Diversion Method

The use of treated CRT glass as ADC to support landfill operations is a beneficial use of CRT glass. Application of treated CRT glass as ADC provides value by preserving clean soil excavated during landfill construction to be used for other commercial purposes. PDC is currently selling clean soil for use in a number of environmental projects, and there is a market for clean soil for local and regional construction projects.

> Alternative daily cover is a recognized and accepted beneficial use in many states, and not a waste.

A number of states have formally recognized ADC as a beneficial use and a recognized form of recycling or diversion. Some states formally include beneficial use of materials when calculating recycling or diversion rates:

- California's environmental regulations state that beneficial use of materials that are approved as ADC constitutes diversion: "The use of solid waste for beneficial reuse in the construction and operation of a solid waste landfill, including use of alternative daily cover, which reduces or eliminates the amount of solid waste being disposed pursuant to Section 40124, shall constitute diversion through recycling and shall not be considered disposal for the purposes of this division"[56]

- Colorado counts beneficial use as recycling. Operations that process materials for beneficial use file annual recycling reports documenting the quantities of material managed[57].

- Florida has a 75 percent recycling goal, and awards recycling credits for yard trash placed in a landfill that recovers landfill gas for the production of energy. Yard trash that is used as ADC receives full credit for every ton applied, and other yard trash that is placed in the landfill receives a partial credit[58].

- Iowa recognizes the use of many materials for ADC, including glass, to be a universally approved beneficial use. The use of such materials in a landfill as ADC is considered utilization of a resource rather than disposal[59].

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56 California Public Resources Code, Section 41781.3(a).

57 Code of Colorado Regulations, 6 CCR 1007-2, Part 1, Section 8.

58 Florida Statute, Chapter 403.708(12)(c).

59 Iowa Administrative Code, Section 567-108: Beneficial Use Determinations: Solid By-Products as Resources and Alternative Cover Material.

- Maine classifies the use of residues from solid waste processing facilities as ADC as recycling[60].

- Massachusetts Department of Environmental Protection has issued a beneficial use determination for the application of crushed and processed fluorescent bulbs as ADC at select landfills within the state[61]. Massachusetts considers the use of a waste to substitute for a commercial product or commodity to be beneficial use.

- New Mexico classifies beneficial use as diversion and includes beneficially used materials in the calculation of diversion rates[62].

Regulatory Developments in California

Similar alternative management options are being considered in the State of California. The California Department of Toxic Substance Control (DTSC) implemented emergency regulations on October 15, 2012 which temporarily allow CRT glass to be managed by alternative methods, including disposal in hazardous waste landfills, if recycling outlets are unavailable; such action is being considered in West Virginia as well[63]. California's electronic waste program manager indicated that no processors have pursued managing CRT glass through hazardous waste treatment and disposal processes yet[64].

Under the emergency DTSC regulations, CRT glass sent for disposal is legally allowed, but is not eligible for reimbursement from the state's e-waste recycling fund. The state is currently engaging stakeholders in further discussion regarding CRT glass management, including assessing additional modifications to reimburse e-waste recyclers who manage CRT glass through any legal method of disposition (including disposal). In the view of California's e-waste program manager, this is consistent with the allowances made for other portions of the e-waste stream that are not readily recyclable and provides an immediate and environmentally sound solution for a short-term issue[65].

Comparison of Beneficial Use to Current CRT Management Methods

As previously demonstrated, there may be a need to develop additional CRT glass processing capacity to serve the U.S. over the next several years. Table 5 compares the beneficial use option developed by PDC to current CRT management conditions.

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60 Maine Revised Statutes, Title 38, Section 1310-N.5-A.B(2).

61 Massachusetts DEP, Final Permit Approval 12-061-002, May 31, 2012.

62 New Mexico Environment Department, Solid Waste Bureau Recycling Information, obtained from http://www.nmenv.state.nm.us/swb/recycling.htm, accessed July 10, 2013.

63 Association of State and Territorial Solid Waste Management Officials (ASTSWMO), "CRT Stockpile Issue - Background Paper", presented during Hazardous Waste and Materials Management Roundtable Sessions at the 2013 Mid-Year Meeting, April 25, 2013.

64 Jeff Hunts, Covered Electronic Wastes Program Manager, CalRecycle, personal communication, May 2013.

65 Jeff Hunts, Covered Electronic Wastes Program Manager, CalRecycle, personal communication, May 2013.

7. BENEFICIAL USE OF TREATED CRT GLASS

TABLE 5. COMPARISON OF BENEFICIAL USE TO CURRENT CRT MANAGEMENT OPTIONS

Current CRT Management Conditions	Impact of Beneficial Use Option
Four facilities are currently operating.	This option will provide an additional outlet for CRT glass.
Only one facility is operating in the U.S.	This option provides an additional domestic facility.
Proposed facilities are not yet operating, and most facilities have not received permits to develop.	This option is permitted and operating, requiring no lead time to implement.
Existing facilities have an estimated capacity of 128,000 tons of CRT glass per year. This is insufficient to meet current and projected demand.	This option will provide an additional 50,000 tons per year of capacity for CRT glass and a beneficial use of the processed glass.

The KleanKover CRT glass treatment technology provides an additional, immediately available, and environmentally sound option for CRT glass processing in the U.S., and will supplement the capacity provided by other existing and proposed facilities. It will also help to fulfill the immediate and near-term need for processing capacity as proposed facilities continue to develop and provide long-term convenient and reliable capacity to support the e-waste industry.

Environmental Aspects of CRT Management Options

The adoption of state electronic waste recycling programs and (in certain states) disposal bans have been driven by two primary policy goals: 1) reducing the amount of lead disposed in landfills; and, 2) recovering metals and other materials contained within electronic devices for recycling. As discussed in this section, there are potential environmental impacts associated with the recycling of CRTs and other electronic devices. Ultimately, the safe handling of CRTs requires proper management, whether by recycling or disposal.

Impacts of Existing CRT Processing Methods

Under federal regulations, two current methods of CRT glass processing (glass-to-glass recycling and secondary lead smelting) exempt CRT glass from classification as solid waste and from regulation as a hazardous waste. However, this does not mean that these processes operate without any impact on the environment, or result in 100 percent recovery and recycling of all CRT components:

> Existing, accepted CRT glass processing methods generate wastes for disposal and impact the environment.

- A U.S. EPA background report on processing of CRTs for glass-to-glass recycling identified public health and environmental impacts that may arise from a number of steps in the glass-to-glass process[66]. Specifically, glass-to-glass processing may generate airborne lead and particulate matter during the glass crushing process. Leaded glass fines are also generated and recovered from washwater and crushing operations and may be directed to smelters for use as flux, ultimately contributing to the production of slag. Transportation-related emissions are also generated by shipping CRT glass[67].

  Residues may also be generated during the recovery and processing of CRT glass, including glass for which the composition cannot be confirmed and therefore cannot be used to produce new CRTs, glass that does not meet optical quality standards, or glass that does not meet other performance standards[68]. Residual glass that is not usable by the processor or manufacturer will require management by another method.

  There have been reports of OSHA violations and environmental citations issued to processors related to worker exposure to lead and improper storage of CRT glass[69].

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66 ICF Incorporated for U.S. EPA Office of Solid Waste, *General Background Document on Cathode Ray Tube Glass-to-Glass Recycling*, May 1999 draft, pages 18-19.

67 As noted previously, large transportation distances are required to access existing end-use markets.

68 *Ibid.*, page 22.

69 OSHA Region 5 New Release (12-1859-CHI), September 24, 2012. Yuma Sun, Yuma Glass Recycler Cited for E-Waste Violations, August 16, 2009.

- Secondary lead smelters process lead-containing materials to recover the lead for reuse through an energy-intensive process. During the smelting process, materials are heated to a high temperature, resulting in air emissions that must be managed. Emission control systems within the smelting facility capture some, but not all, of the lead and some is therefore emitted into the air.

  Secondary smelters in the U.S. and Canada are permitted by state or provincial regulatory agencies pursuant to federal and state regulations and environmental standards. The permits identify conditions pertaining to facility operations, including allowable types and amounts of pollutant discharges from the facility. In 2010, permitted smelters in the U.S. and Canada emitted nearly 33,000 kg (72,500 pounds) of lead to the air[70]. These airborne lead emissions ultimately settle on the land and in surface water.

  Smelters also generate slag as a by-product of the lead recovery process. Slag is often characterized as a hazardous waste due to the presence of some remaining amounts of lead[71] and various other metals in concentrations above TCLP thresholds and disposed in on-site impoundments or in off-site hazardous waste landfills.

Impacts of CRT Glass Disposal in Municipal Waste Landfills

Like smelters, landfills are subject to federal and state regulation. When CRTs are placed in landfills, the primary environmental pathway for leachable metals is groundwater. Municipal waste landfills are engineered facilities which include a liner system and a leachate (liquid) collection system to contain and collect leachate for treatment, among other design, operational control and monitoring systems established by Subtitle D of the Resource Conservation and Recovery Act.

U.S. EPA has concluded that landfill disposal of e-wastes is safe and does not threaten human health and the environment, while noting that recycling of electronics can have other environmental benefits:

> *As for managing electronics disposed in the US in landfills, we believe that disposal of electronics in properly managed municipal solid waste landfills does not threaten human health and the environment. The results of landfill leachate studies, suggest that currently allowed disposal of electronics - including those containing heavy metals - in modern municipal solid waste landfills are protective of human health and the environment.*[72]

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70 Secretariat of the Commission for Environmental Cooperation, *Hazardous Trade? An Examination of US-Generated Spent Lead-Acid Battery Exports and Secondary Lead Recycling in Canada, Mexico, and the United States*, April 2013, Table 1-1, page 7. Note that, of the 16 secondary lead smelters operating in the U.S., only one facility (Doe Run) receives CRT glass.

71 CalRecycle CEW Recycling Program, "Residual CRT Glass Management and the CEW Recycling Payment System", Electronic Waste Recycling Stakeholder Workshop, March 13, 2013.

72 U.S. EPA, *eCycling Frequent Questions*, http://www.epa.gov/osw/conserve/materials/ecycling/faq.htm

> *While electronics can be safely disposed in properly managed landfills, there are significant environmental and economic benefits to recycling: preserving scarce materials, minimizing impacts of extractive industries, facilitating recovery of materials, and reducing the energy and resources used in manufacturing new electronic products.*[73]

The Solid Waste Association of North America (SWANA)[74] completed a research study in 2004 to evaluate the impact of the disposal of wastes containing heavy metals (including lead) on municipal waste landfills[75]. The research was spurred by increasing discussion at the time of banning certain products from disposal because of the concern that heavy metals in the products may be released to the environment.

SWANA's research specifically included a review of lead leachability from CRT glass. A previous study, performed by the University of Florida in 1999, measured the leachable lead content of mixed, broken CRT glass using the TCLP and found that the lead concentration of the glass averaged 18.5 mg/L, well above the federal regulatory lead threshold of 5 mg/L (above which material is designated a hazardous waste). However, SWANA went on to detail findings of other studies demonstrating that, under actual landfill conditions, the concentration of lead leached from CRT glass will be lower than indicated by laboratory TCLP results.

The SWANA study found that lead is present in much lower concentrations within landfill leachate. Using a U.S. EPA database of leachate data from more than 200 landfills across the U.S., with more than 2,500 samples tested for lead, SWANA calculated an average lead concentration in leachate of 0.133 mg/L, well below the regulatory lead limit.

Further, SWANA determined that landfill conditions provide an inherent ability to attenuate heavy metals such as lead through various processes including:

- Adsorption and absorption of heavy metals to soils and organic matter contained in the waste stream; and
- Precipitation of heavy metals to form insoluble compounds.

SWANA's research also included a review of prior groundwater modeling and landfill studies that indicated heavy metals are not likely to be remobilized within landfills for thousands of years. Further, the soil environments within and around landfills result in very low mobility of metals, enabling SWANA to conclude:

> *Thus, it is very likely that any releases of metals that may occur - due to changes in landfill conditions that occur over very long timeframes - will be contained either within the landfill itself or within the immediate vicinity of the landfill.*

The SWANA study concluded:

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73 U.S. EPA Office of Resource Conservation and Recovery, *Electronics Waste Management in the United States Through 2009*, May 2011, page 5.

74 SWANA is a professional association representing the public-sector and private-sector waste industry in the U.S. and Canada.

75 SWANA, *The Effectiveness of Municipal Solid Waste Landfills in Controlling Releases of Heavy Metals to the Environment*, March 2004.

MSW landfills can provide for the safe, efficient, and long-term management of disposed products containing RCRA heavy metals without exceeding limits that have been established to protect public health and the environment. MSW landfills should contain the releases of RCRA heavy metal pollutants at levels that protect public health and the environment for extremely long periods of time if not forever....Modern MSW landfills can provide an effective "safety net," as well as an environmentally sound means of disposal, for those products containing heavy metals that are not diverted through waste reduction and recycling programs.

All recycling processes generate residue that must be disposed. No program recycles 100 percent of the collected material.

Based on this information from U.S. EPA and SWANA, management of CRTs through beneficial use of treated CRT glass as ADC or disposal in municipal waste landfills is not expected to pose a threat to human health or the environment.

Residue in Recycling Processes

As noted previously, the intermediate processing of CRTs and subsequent recycling of the glass in glass-to-glass or secondary smelting processes generates residues. This is not unique to e-waste recycling; all recycling processes have some amount of residue that is generated during the various stages of processing and must be disposed of. It is unreasonable to expect that recycling of e-waste will result in no residue.

Significant amounts of residue, for instance, are generated even in recycling programs that have been established for more than two decades, such as residential curbside recycling. Residential curbside recyclables are typically taken to a Material Recovery Facility (MRF), where the material is separated and processed for shipment to end-user markets. Residue is generated through the processing of materials at the MRF, and is disposed in a landfill.

A second stage of processing often occurs at the end-use market to further remove contaminants to the re-manufacturing process. Again, this generates residue which must be disposed of.

The amount of residue generated through these stages of processing can be significant. Resource Recycling (an recycling industry trade magazine) and the Container Recycling Institute reported, based on a survey of single-stream MRFs and end markets, that only 73 to 78 percent of the material collected at the curb is recycled into new products; the remaining 22 to 27 percent of material is largely sent to landfills for disposal[76].

The report found that 8 to 10 percent of the incoming material received at the MRF is removed and handled as residue. This means that an additional 14 to 17 percent of the material, after initial processing at the MRF, is further removed as residue by the end-use market. Figure 14 shows the residue removed from processed recyclables delivered to a paper mill.

76 Susan Collins, "A Common Theme", *Resource Recycling*, pages 14-16, February 2012

Source: Peter Wang, CEO, America Chung Nam, "At the Mill", Presentation at the 2011 Residential Recycling Conference, March 2011.

FIGURE 14. RESIDUE REMOVED FROM SORTED PAPER SENT FOR RECYCLING

Lead and Glass Recovery Potential

Given the challenges facing the e-waste recycling industry with CRT glass, it is worth examining CRT glass recycling in the context of other programs that recover lead and glass.

In Section 2, it was noted that funnel glass contains approximately 22-25 percent lead by weight. Based on the analysis of demand presented in Section 4, it was estimated that 62,000 to 118,000 tons per year of funnel glass would be collected over the next 10 years, assuming overall CRT recovery rates of 50 percent and 100 percent, respectively. This corresponds to potential lead recovery from CRT glass of 15,500 to 29,500 tons per year.

By comparison, the secondary lead (metal scrap) market in 2012 recovered approximately 1.2 million tons of lead[77]. The principal source of recovered lead is lead-acid batteries, contributing nearly 95 percent of annual lead recovery[78]. Lead from CRTs would therefore represent only 1.3 percent of current annual lead recycling, or 2.5 percent if a 100 percent recovery rate for CRTs was achieved. All of this assumes that there is adequate capacity to process all the CRTs that are collected.

Similarly, average annual glass recovery from CRTs (including panel and funnel glass) is estimated to range from 190,000 to 362,500 tons per year, based on overall CRT recovery rates of 50 percent and 100 percent, respectively. Glass from CRTs would therefore represent about 6 percent of the annual recovery of container glass (food and

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77 U.S. Geological Survey, *2013 Mineral Commodity Summary: Lead*, January 2013.

78 U.S. Geological Survey, *2011 Minerals Yearbook: Lead*, January 2013, Table 3, page 42.9.

beverage bottles), which was reportedly 3.13 million tons in 2010[79], or 12 percent if a 100 percent recovery rate for CRTs was achieved. Container glass is recovered at a rate of approximately 33%. Other glass in the waste stream includes glass contained in durable goods, amounts to approximately 2.17 million tons, of which a negligible amount is recovered[80].

> The potential lead and glass recovery from CRTs is relatively small compared to the recycling of these materials from other sources.

Despite its frequent inclusion in recycling programs, glass recycling is challenging in some markets. Glass collected in commingled recycling loads can contaminate other material streams (such as paper and plastic) and increase the wear on recycling facility equipment, resulting in reduced market value of commodities and increased processing costs. Demand for recycled glass is not as great as other materials because virgin material used to produce glass (silica) is available in large supply at a reasonably low cost. Additionally, glass is manufactured specific to its proposed use, so manufacturers are able to use only a small fraction of recycled glass in the production of new products to meet quality and performance standards.

Glass is also a heavy material with high transportation costs. Glass processing facilities are typically local or regional facilities to reduce transportation distances and costs.

Recycling of CRT glass can pose additional challenges, due to the presence of lead. Some of these issues were identified by Regenesys at a recent scrap industry conference[81]:

> *Several companies are launching new ventures to make CRT glass more marketable through various processes of lead removal and sortation. ECS Refining (Santa Clara, Calif.) has launched a new company, Regenesys Glass Processing, to extract the metal oxides from CRT glass and chemically blend the glass for use by the automotive, fiber-glass, bead and lighting industries...One problem with CRT cullet is the wide range of lead it might contain, says Curt Spivey, ECS' vice president of corporate development. "The panel, unbeknownst to a large number of people, could have from 0.05 parts per million [of] lead" -- the amount you might typically find in a drinking glass or pickle jar, he says -- "up to 8 percent lead...If you can separate the panel from the funnel, and guaranteed that you have [no more lead than] 0.05 parts per million, there are consuming opportunities and repurposing uses in this country. But if these large consumers that make beads or fiberglass or auto [components] are not guaranteed that [the glass is] lead-free, they've got a problem because it will destroy their equipment."*

There could also be increased energy usage for recovering the funnel glass, since the material would be heated once to recover the lead, and then potentially heated a second

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79 U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2010*, December 2011, Table 5.

80 *Ibid.*

81 Institute of Scrap Recycling Industries, Scrap Magazine, November/December 2012, p. 57.

time by the glass manufacturer. This challenge was also noted by an MIT research scientist at the trade conference[82]:

> *A more promising approach is to extract enough lead from the CRT glass to make the glass suitable for other applications, though the challenge is to do it in an economically viable manner, Gregory says. "Glass is basically just sand, so it's pretty cheap to get virgin materials. … Trying to get the lead out of the glass is just another cost step." Any energy savings would depend on the energy needed to remove the lead from the glass, he points out. Recycling the glass itself "is not a huge energy savings because you have to heat up the cullet to get the glass molten—just like virgin glass—and remove the impurities."*

The transportation cost issues for container glass recycling are even more an issue for CRT glass, because there are only four current end-use markets, and four proposed facilities (including Regenesys). These transportation issues were also noted by an industry expert at the conference:

> *The main secondary lead smelters operating in North America—The Doe Run Co. (St. Louis), Teck Resources (Vancouver, British Columbia), and Xstrata (Zug, Switzerland)—can make use of both the lead and the glass in CRT cullet, with the latter serving as a flux agent, Powell explained at his conference session. Typically, CRT cullet is only a small portion of the infeed material, and some companies prefer cullet only from the CRT funnel and frit. Due to the weight of CRT glass, transportation costs tend to be high, Powell said, making these smelters a viable option only for nearby recyclers.*

In summary, although recovery and processing of CRT glass may result in increased quantities of glass and lead available for use in other products, the quantities recovered represent a relatively small fraction of the lead and glass recovered through other recycling processes. Additionally, there are capacity, transportation and other challenges associated with recovering these materials from CRTs.

82 *Ibid*, p. 56.

Conclusions

The e-waste recycling industry in the U.S. has developed rapidly over the last decade in response to the implementation of e-waste program laws in half the states in the nation and of e-waste disposal prohibitions in nearly as many states. Collection and processing infrastructure has developed to fulfill the requirements of various program laws, and markets for most recovered materials have been identified. However, CRTs, representing the largest component of recovered e-waste, have faced dwindling end-use markets and currently face a capacity shortage.

The electronics manufacturing industry is a dynamic industry, and products change rapidly. This is particularly evident in video display technologies, where old CRTs have been almost completely replaced by flat panel LCD and plasma screens. This change has impacted the landscape of CRT glass processing, because the primary end-use market for recovered CRT glass has historically been the production of new CRTs.

The research presented in this paper results in the following findings regarding the CRT glass processing market in the U.S.:

- Over 7.2 million tons of CRT devices remain to be recovered from homes and businesses in the U.S. and including CRTs reported as being currently stockpiled by recyclers and processors.
- The vast majority (85 percent) of these devices are projected to be collected and require management in the next 10 years, representing a large near-term demand for CRT processing capacity.
- On average, over the next 10 years, 206,000 to 392,000 tons of CRT glass may require processing annually.
- There are currently only four end-use markets processing CRT glass in North America. Of these, only one is located in the U.S.
- Existing processing facilities have an estimated 128,000 tons of capacity per year, which is insufficient to meet current and projected demand.
- Moreover, only one facility is centrally located in the U.S. The other facilities are located in Canada and Mexico, at the peripheries of the continental U.S., thereby necessitating long transport hauls to access.
- Four facilities have been proposed, but are not operating. Only one is under construction, and the other three have yet to secure necessary permits. It is unknown when they will be finally operational.
- Even including the four proposed facilities, total processing capacity would barely meet the projected demand of 206,000 tons per year and would be insufficient to meet the higher demand of 392,000 tons per year.
- The current and projected capacity constraints potentially act as a deterrent to more states adopting e-waste recycling legislation.
- An alternative treatment and beneficial use option has been permitted and is available immediately to provide an additional end-use market for recovered

CRT glass. This facility is located in the central U.S. and proposes to treat CRT glass and stabilize lead and other regulated metals to render them relatively non-leachable. The treated material would subsequently be beneficially used for alternate daily cover (ADC) at a municipal waste landfill.

- ADC is recognized in a number of states as a beneficial use that counts for recycling and/or diversion, and does not constitute disposal.

- CRT management options that provide a beneficial use of CRT glass may bridge the short-term demand for CRT glass processing, allowing the e-waste industry to turn its focus to developing necessary infrastructure to manage flat panel devices and other electronics that will require management for many more years in the future.