Review

E-waste Management in South Africa: Case Study: Cathode Ray Tubes Recycling Opportunities

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Abstract: Households and businesses are generating unprecedented levels of electrical and electronic wastes (e-waste), fueled by modernisation and rapid obsolescence. While the challenges imposed by e-waste are similar everywhere in the world, disparities in progress to deal with it exists; with developing nations such as South Africa lagging. The increase in e-waste generation increases the need to formulate strategies to manage it. This paper presents an overview of e-waste management on a global and South African scenarios with a specific case for Cathode Ray Tube (CRT) waste management practices in South Africa. CRTs present the biggest problem for recyclers and policy makers because they contain hazardous elements such as lead and antimony. Common disposal practices have been either landfilling or incineration. The research into the South African practices with regards to CRT waste management showed that there is still more to be done to effectively manage this waste stream. This is despite clear waste regulatory frameworks in the country. However, recent developments have placed e-waste as a priority waste stream, which should lead to intensified efforts in dealing with it. Overall, these efforts should aim to maximise diversion from landfilling and to create value-addition opportunities, leading to social and environmental benefits.

Keywords: electrical and electronic waste; recycling; legislative frameworks; environmental management; landfilling

PACS: J0101

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1. Introduction

The rapid global modernisation of the 21st century buoyed by rapid urbunisation, population growth and the once booming global economy, has led to unprecedented levels of end-of-life electronic waste (e-waste) [1-5]. Rapid obsolescence of consumer electronics and accessories such as cellular phone and computers is also adding disproportionately to the e-waste stream. The global production of e-waste is estimated between 20 and 50 million tons per annum, with current recycling rates ranging between 15 and 20 per cent worldwide [6-7]. In 2014, the combined total e-waste generated within the African continent was estimated to be 1.9 million tons, with Egypt (0.37 million tons), South Africa (0.35 million tons) and Nigeria (0.22 million tons) being the leading producers.6 There are, however, very few up to date reports available on e-waste in the African continent, which further blunts efforts in the management of this waste stream. In addition to the increase in locally-generated e-waste, a practice that was mainly rife in the 1990's was the shipping of e-waste from countries such as the USA to the developing nations, including those in Africa [8]. At the height of this practice, the developing nations were encouraging this practice as those sending the waste could manage to pay hefty sums to the receivers. In addition to the willingness of the receivers, the lack of government regulations against such practices further exacerbated the problem. Such diffusion of e-waste further diluted accurate tracking of growth of this waste especially in developing countries.

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Globally, volumes of e-waste are estimated to be increasing by approximately 3 to 5 per cent annually since the 1990s and it continues to grow three times faster than municipal solid waste [9].

The growth in e-waste generation equally presents a problem, because of the toxicity of some of its components materials, and an opportunity, as valuable minerals that are contained in the waste can be recovered [10]. Several studies have shown that the purity of metal components is e-waste can easily be superior to that of rich-content minerals [11-13]. Interest in electronic waste (e-waste) recovery and recycling has therefore been on the rise over the past two decades. This rise has been also been attributed to a number of other factors, including, inter alia, the depletion of mineral deposits, declining metal recoveries and grades, deepening mineral deposits, the concentration of strategic minerals in politically unstable regions and general risks associated with primary mining [14].

Ultimately, the increase in waste generated from electronic and electric equipment (EEE) has urgently increased the need to formulate strategies and interventions to manage this type of waste. The level of strategies and interventions differs from country to country, with some having progressed more than others. Like the majority of developing countries, South Africa's e-waste management industry is still at its infancy stages. Until recently, South Africa did not recognise e-waste as a threatening waste stream. According to the Department of Environmental Affairs (2015), e-waste currently makes up between 5 % and 8 % of the municipal solid waste in South Africa.15 This is expected to grow at an alarming rate over the coming years. According to the United Nations Environment Programme (UNEP), obsolete computers both in South Africa and China will increase by an alarming 500 % in 2020 compared to 2007 levels [15]. This has prompted government and other supporting institutions to develop e-waste management systems whose focus is not only on waste disposal but also waste reduction, waste reuse, recycling and recovery.

By definition, e-waste is a term used to define all EEE that have reached the end of their useful life. Table 1 shows that 10 different categories of e-waste according to the European waste electrical and electronics equipment (WEEE) Directives 2002/96/ European Commission (EC) and 2012/19/ European Union (EU). These include all products that are driven by electricity, including battery-operated products, and these include large household products, small household products, IT equipment, electric and electronic tools etc. [16].

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Table 1. Ten different categories of e-waste on the basis of European WEEE directives 2002/96/EC and 2012/19/EU.

Sr. no.	Waste category	Equipment	Label
1	Major household gadgets	Air conditioner, dish washer, refrigerator, washing machines, microwave oven etc.	Large HH
2	Minor household gadgets	CD and DVD players, video game consolers, alarm clock, television, grinder–juicer–mixer, electrical kettles and electric chimneys	Small HH
3	IT and telecommunication gadgets	LAN, modems, mobile phones, landline phones, printers and communication satellite	ICT
4	User gadgets	Radio receivers, television sets, MP3 players, video recorders, DVD players, digital cameras, camcorders, personal computers,	CE
5	Illumination gadgets	Ballast lamp, halogen, neon, LED and compact fluorescent lamps	Lighting
6	Electrical and electronics apparatus	Vacuum tubes, transistors, diodes, integrated circuits, wires, motors, generators, etc.	E and E tools
7	Toys, leisure and sports gadgets	Batteries in cars, trains, buses and aeroplanes etc.	Toys
8	Medical devices	Medical thermometers and biomedical engineering instruments	Medical equipment
9	Monitoring and control instruments	Relays, thermostat and microcontrollers	M and C
10	Automatic dispensers	Automatic soap dispenser , automatic water dispenser, automatic spray dispenser etc.	Dispensers

Electronic equipment are composed of three main components, namely, ferrous and non-ferrous metals, plastics and glass. For example, a typical computer is estimated to contain about 32 per cent ferrous metals, 23 per cent plastic and 15 per cent glass [17]. The recovery of metals from e-waste has been the primary focus for most recyclers, and extensive research is currently being done to develop environmentally sound recovery processes to salvage the economic potential from e-waste. Early efforts included crude methods such as acid-washing and open incineration, which lead to serious environmental problems [18-20].

The main challenge with e-waste is both the plastic and glass components. These two components have been very difficult to recycle because of the many hazardous substances that they are associated with. The Cathode Ray Tubes (CRT) glass constitutes the biggest problem because it contains hazardous elements such as lead, strontium, antimony and barium, amongst others. All these elements have the potential to harm the environment and human health if not handled properly. Currently, CRT glass is either incinerated or dumped in landfills resulting in soil and ground water pollution. With landfill capacities limited, there is an increasing need to investigate potential applications of waste CRT glass to minimise the volumes going to landfills, and to create viable business opportunities from the waste material.

It is through this background that the authors of this paper reviewed available options and the current scenario in South Africa with regards to e-waste and specifically the CRT glass. The objective

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of the study was to assess current research done on CRT recovery and recycling with the aim of providing a holistic understanding of the current gaps and opportunities that exist within the South African context.

2. CRT characteristics and composition

Cathode ray tubes have been extensively used for more than 70 years as critical components for televisions and personal computers (PCs). The first CRT was developed during the 1890s as an oscilloscope to view and measure electrical signals [21]. Since then, CRTs have been a popular medium used to send and receive images electronically in television systems. Although CRT technology has undergone many iteration, the core design and function has mainly remained the same over the last few decades [22-29].

CRTs are estimated to constitute between 60 and 70 per cent of the weight of a computer monitor or television [30]. The remaining material consists of plastic, printed circuit board (PCB), cabling and wires [31]. There are two types of CRTs, namely, monochrome (black and white) and colour. The structure of these two types is similar with only a few technical differences. The major difference between the two CRTs being the chemical composition of the glass contained in the CRT. Figure 1 shows the structure of a CRT.

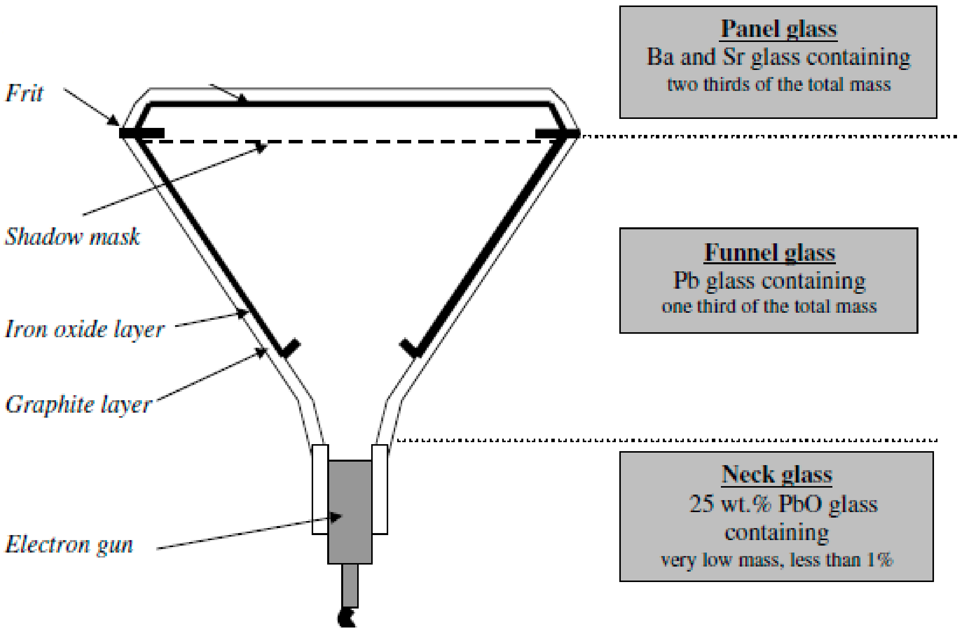

Figure 1. A schematic diagram showing CRT components, namely the panel glass, funnel glass and neck glass with a brief compositional information for each section.

CRTs are composed of three main components, namely, panel, funnel and the neck glass [32-34]. The panel glass constitutes approximately 65 per cent of the total weight. It is followed by the funnel glass which occupies approximately 30 per cent of the weight and lastly the funnel glass which occupies only 5 per cent [35].

The chemical composition of CRTs varies from manufacturer to manufacturer, version and time of production [36]. More so, the different types of glass components have different chemical compositions. Table 2 provides a typical chemical composition of both the monochrome and the colour CRTs [37].

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Table 2. Typical chemical composition of monochromatic and colour CRT [34].

Oxide	Monochrome CRT (wt%)			Colour CRT (wt%)		
	Panel	Funnel	Neck	Panel	Funnel	Neck
SiO_2	66.05	65.49	56.50	61.23	56.72	50.00
Al_2O_3	4.36	4.38	1.00	2.56	3.42	1.00
K_2O	6.65	5.72	9.00	5.56	5.73	10.00
Na_2O	7.63	7.05	4.00	8.27	6.99	2.00
CaO	0.00	0.00	0.00	1.13	3.12	2.00
MgO	0.01	0.00	0.00	0.76	2.02	0.00
BaO	11.38	11.92	0.00	10.03	4.03	0.00
SrO	0.99	0.94	0.00	8.84	1.99	0.00
PbO	0.03	0.00	29.00	0.02	15.58	34.00

Based on the chemical composition, there are no substantial differences between the monochromatic and the colour CRTs. The silica (SiO_2) constitutes the highest percentage in both CRTs. In both types, the panel glass contains very little lead (Pb). This is because the panel is manufactured from a barium-strontium glass which is free of lead. The lead in both CRTs is found in the funnel and the neck components – more so in the neck glass [38]. The addition of lead to this glass is to absorb UV and X-ray radiation produced during operation of the CRT [39]. Given the overall composition of the CRT, the main concern is the presence of lead. This is because lead is an extremely toxic element which could result in detrimental effects to human health and the environment if not handled properly [40-41].

3. CRT mass flow

As previously noted, advancements in e-waste recovery and recycling differ from country to country. Some countries such as the United States have progressed far more than others, particularly when compared with developing countries [10,20,41-44]. However, EEE production and the challenges it brings is a global phenomenon. Globally, the need to recover and recycle e-waste is increasing not only because of the dangerous substances contained in the waste, but also because landfilling is no longer a viable option as most of the landfills are closer to the brim. In addition, with environmental regulations and laws becoming more stringent, e-waste is regarded high risk [45].

In South Africa, the e-waste industry is still developing and hence there are still many barriers that exist. One of the main challenges delaying the development of e-waste management strategies is the lack of baseline data. This is in contrast to the other forms of waste, which has been studied well and an extensive body of knowledge exists, along with government and private initiatives to deal with these forms of waste [46-50]. With very few studies having been undertaken on e-waste (generally), there is currently very little quantitative and qualitative data for South Africa. However, things have begun moving in the right direction with South Africa having now recognised e-waste as one of the six priority waste streams. As a result, the magnitude of e-waste research is on the steady incline. One particular research which is specific to CRT recycling was conducted by Dominik Zumbuehl [51]. The research was a mass flow assessment of CRT in the Cape Metropolitan Municipality, South Africa. The primary objective of the research was to provide a foundation from

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which CRT management systems will be founded. As part of the assessment, Zumbuehl mapped out the CRT value chain indicating all key role players. Figure 2 shows a typical mass flow of CRT monitors and televisions.

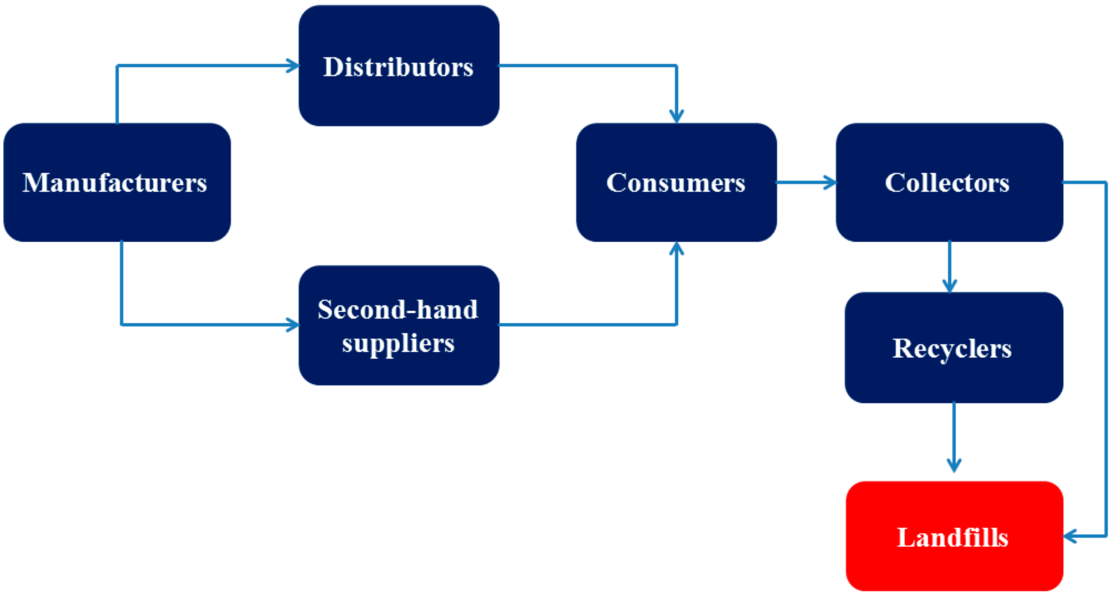

Figure 2. A typical mass flow of CRT monitors and televisions [51].

At present, there are no local manufacturers of CRT monitors or televisions and hence CRTs are imported into South Africa. The major brands manufacturing CRTs are Samsung, Proline, Sony, Mecer among others. Consumers usually purchase CRT products from distributors which are locally based. There is also an option to purchase from second-hand suppliers which import obsolete computers and refurbish them for the secondary market. Once the products or devices have reached their end-of-life (EOL), they are regarded as waste. This is the point where the recovery process begins. There are a number of companies that collect e-waste material to either sell the valuable material (i.e. PCBs) to recyclers or to dispose it in landfills. The collectors would dismantle the monitors or televisions to separate the different components such as plastics, PCBs, wires, metals, glass etc. Where there is a market, the components will be sold, otherwise they will be sent to the landfills.

As mentioned above, there is very little data on the amount of CRTs that enter the landfills. However, Zumbuehl estimated the number of CRTs disposed in the landfills in the Cape Metropolitan Municipality at 7950 CRT monitors per annum [51]. At present, there are no up-to-date national figures per each province, except for the annual estimate of 0.35 million tons quoted by Balde et al [6]. It is, however, known that a high percentage of CRTs end up in landfills with some incinerated. Currently, there are no CRT recycling facilities in South Africa.

3.1. CRT recycling technologies

Figure 3 provides a generic CRT processing flow sheet. Generally, the recycling of e-waste comprises of four main steps: collection, pre-processing, sorting and separation, and processing. The first stage of recycling is collection, where the e-waste material is collected from consumers once the EEE have reached their EOL.

Figure 3. A generic CRT processing flow-sheet.

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The next stage after collection is pre-processing stage. It is followed by sorting and separation. Once the different e-waste components are separated, they are sent to the different streams of production. The different sections of handling CRT (and generally e-waste) is briefly discussed in the following sub-sections.

3.1.1. Collection

As noted above, the main consumers are private, corporate and government institutions and so obsolete ICT equipment is collected from these three main sources. The collection process is not yet formalised in South Africa. However, the main collection method used today is the door-to-door approach. This is usually facilitated by collectors or recyclers. Most of the recyclers or collectors have now placed e-waste containers in public places such as shopping malls to try and attract consumers.

3.1.2. Pre-processing

The next stage on the value chain is pre-processing. This step essentially involves stripping and dismantling of CRT monitors and TVs. This process is done manually using hand tools such as screwdrivers, grippers and hammers. The process starts with the removal of the plastic casing, followed by the casings, cables and wires, and then circuit boards. The CRT glass is the last component to be removed. Figure 4 shows the CRT monitors once all the other components have been removed.

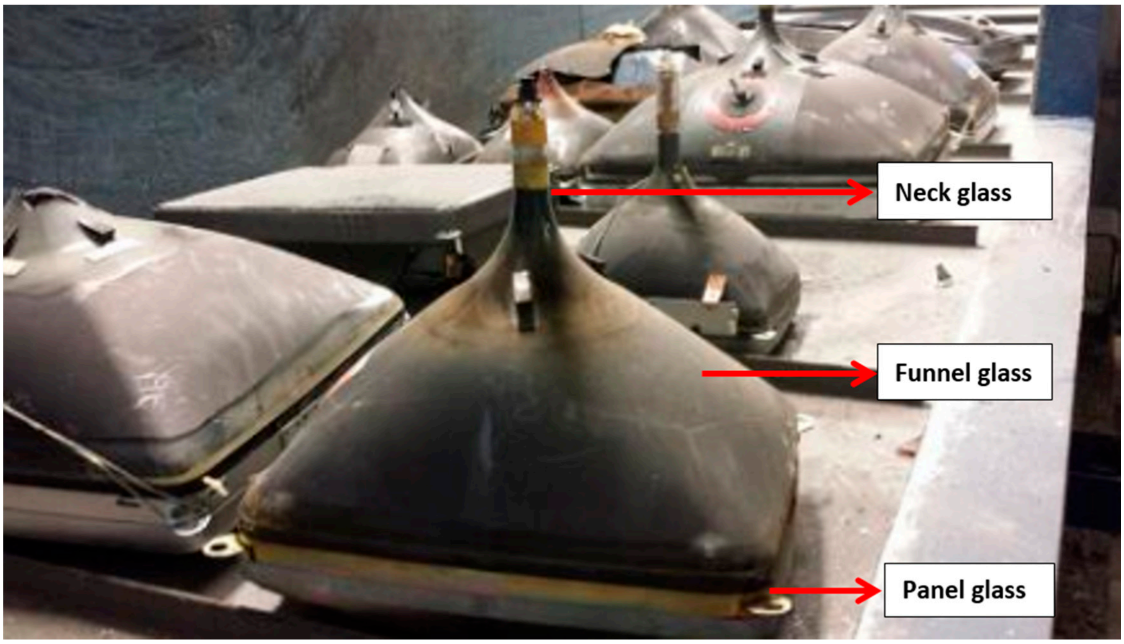

Figure 4. Stripped CRT monitors.

3.1.3. Sorting and separation

The sorting and/or separation stage and method depends on the final application and hence the requirements for the production process. For some applications, CRTs have to be crushed into different size fractions and be separated according to the different types of glass (i.e. leaded or non-leaded glass). As an example, this is currently being deployed at an industry-scale by SwissGlas in Switzerland processing approximately 5 tons of CRT cullets per hour.51 In some cases, the different types of glass have to be separated before they can be crushed or used for any application. There are several techniques that are currently being used to separate the panel glass from the funnel glass. These are discussed below.

- *Hotwire technique*: The hotwire technique involves the use of electric wire, wound at the panel-funnel glass interface, where the wire is heated by passing through an electrical current. The

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interface is heated for a certain time before cool air is blown on the surface leading to thermal shock. This method is widely used by processors because it is regarded as cheap, easy to use, and highly efficient. The hotwire technology is suitable for small to medium processing facilities – it can process up to 35 monitors per hour. The current market price of the technology is between R900, 000 and R2 million [36,52].

- *Laser cutting method*: This method was developed by a company called Proventia Automation in Finland. The technology uses a carbon dioxide laser beam which cuts the CRT below the frit and separates the CRT into the funnel and panel glass. This method has distinct advantages as it does not use any chemicals or water [36]. Much as it is highly efficient but also extremely expensive, costing approximately 500,000 Euros (R8.9million). This device can separate up to 75 CRTs per hour [53].
- *Diamond cutting method*: This technology uses a diamond wire to separate the two glasses. A continuous loop of wire cuts into the glass as the CRT is passed through the cutting plane. The main problem with this approach is that it is very slow and it also generates dust. This technology is capable of processing up to 70 CRTs per hour. It costs between R4 million and R5 million [52].
- *Acid melting*: Acid melting separates the funnel and the panel glass through the use of nitric acid. During this method, the interface is dissolved in a hot acid bath. This method is currently not efficient compared to the others – it generates large amounts of wastewater resulting in high disposal costs [36].
- *Water jet technique*: This technology uses a high-pressure spray of water containing abrasive, directed at the surface to be cut. The water is focused through a single or double nozzle-spraying configuration set at a specific distance. It is also highly efficient and hence only takes 30 seconds to separate a CRT monitor. This technology is currently being piloted in China [51].
- *Comparison of separation techniques*: Table 3 is a comparison of the different separation techniques. There are several technologies available on the market for CRT separation. However, the initial costs for most of these technologies are still very high.

Table 3. Comparison of separation techniques.

Indicators	Hot wire	Laser cutting	Diamond cutting	Water jet	Acid melting
Investment costs	Low	High	High	High	Low
Variable costs	Low	Low	High	High	Low
Quality of glass	High	High	High	High	High
Wet process	No	No	No	Yes	Yes

The laser and the hot wire technologies are currently the most attractive in the market because of the low variable costs. It is important to note that, despite difference in the costs, all available technologies can provide a separation that leads to high quality product. However, all factors, including health and safety, potential environmental issues should be taken into account when making the decision.

3.1.4. Processing

Traditional disposal strategies for CRTs have been landfilling and incineration because of their low recyclable value. Landfilling is no longer the cheapest option because not only do landfills occupy massive land, but there is a risk of soil contamination and groundwater pollution. Incineration was at a point a viable solution to reduce space required for disposal; however it now

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poses serious threats of air pollution. Thus there is a need for new and efficient methods for CRT waste management. The different recycling strategies are discussed in the subsequent section.

3.2. Overview of recycling strategies

Extensive research has been conducted at an international level on the different CRT recycling strategies [30-37,50-51]. Even though most of it is still at an exploratory level, a number of possible solutions have been proposed to deal with CRTs. These methods can be categorised into two, namely, closed-loop recycling (waste to new CRT) and open-loop recycling (waste CRT to new products) [16,36]. Figure 5 illustrates the two recycling routes with key potential end-products. The two methods are discussed in detail below.

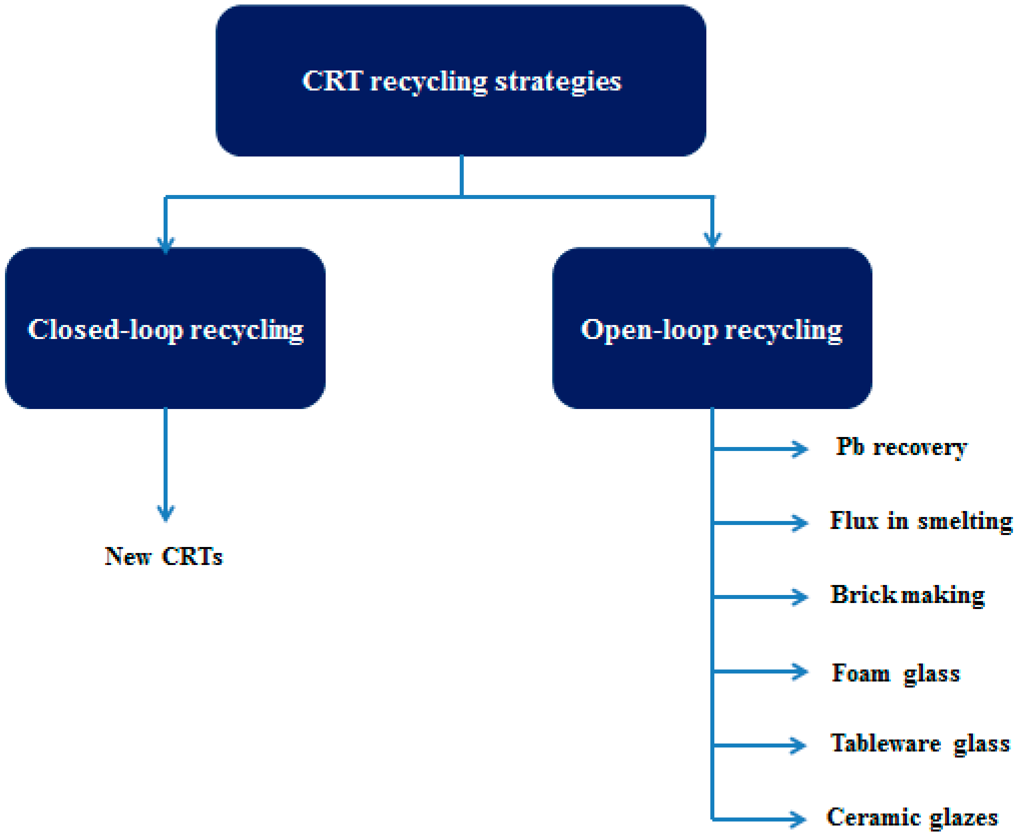

Figure 5. Potential recycling strategies for CRT glass.

3.2.1. Closed-loop recycling

Closed-loop recycling is an industrial-scale recycling of waste CRT to produce new CRTs [54]. During this process, the waste CRT glass is divided into the non-leaded panel glass and the lead-containing glass. Separation of the panel and the funnel glass is achieved using a variety of methods, as discussed above (i.e. electric-wire method, laser cutting methods or acid melting methods). According to Yu-Gong et al., this method has shown great progress in managing CRTs [36]. Compared to landfilling and incineration, this method is environmentally and economically sound. According to Zumbuehl, Samsung Corning in Germany and Thomson-Polcolor in Poland are manufacturing new CRT glass from waste material [51]. Additional benefits from the use of waste CRT are energy and raw material savings. Technological advancements such as the introduction of LCD technology in the market are threatening the sustainability of this business. With advances in ICT technologies, the decline in CRT demand for is expected to accelerate in the coming years.

3.2.2. Open-loop recycling

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The second proposed form of recycling is open-loop recycling. This option is currently being explored worldwide and it has become the attention for most studies. Open-loop recycling involves the use of waste CRTs to produce a wide variety of new products. Open-loop recycling is currently very attractive because it offers both environmental and economic benefits [36]. The various areas where waste CRT could be used are discussed below.

- *Smelting operation*: In smelting operations, CRT glass can replace sand as a flux. This only works if the metals contained in the glass (particularly lead) are compatible with the process and can be recovered. The recovery of metals is essential to ensure that the chemical composition of the slag is free of toxic elements so it could be utilised in other applications (i.e. aggregates for construction) [51].
- *Brick manufacturing*: Various studies have investigated the use of CRT glass in brick manufacturing. This application is only suitable for the panel glass since it contains no lead. Results have been promising so far. The first studies were conducted by Staffordshire University in the United Kingdom. Tests showed that the physical properties of the product made it suitable for a range of non-engineering applications, such as decorative bricks and cladding tiles [53].
- *Foam glass production*: Foam glass is an insulating material which can be made from post-consumer waste glass. Foam glass is already manufactured from waste glass on a commercial scale. The use of waste CRT therefore stands to be successful in this application as manufacturers have indicated no technical barriers [16,55-56].
- *Tableware glass*: The use of CRT glass in tableware production was conducted in Murano, Italy. The test-work for the project was conducted in full scale collaboration with a glass factory. The project yielded positive results with good quality glass products being produced. The leaching tests conducted on the products also come out positive [16].
- *Insulating glass*: Recytube, one of the popular CRT research projects investigated the use of CRT during the manufacture of fibre glass. The quality of the fibre glass from the addition of CRT glass was comparable to the commercial ones. Even though the laboratory test results proved positive, there is still some resistance from manufacturers [16].
- *Ceramic glazes*: Glaze suspensions are composed of different types of raw materials. Various studies have investigated the use of CRT glass as one of the raw materials. Because CRT glass contain barium, strontium, zirconium and lead oxides, it can be added to the glaze mixture to obtain specific properties such as brightness, chemical resistance and the matt effect [16].

There is a wide range of applications in which waste CRTs glass can be used. However, the concern is still the fact that CRTs contain hazardous elements and hence there is a risk of introducing these elements into the new production cycles. Currently, much of the work that is being carried out involves laboratory-work and testing. Most of these proposed solutions are yet to be adopted by manufacturers on an industry-scale.

4. Legislation affecting CRT recycling

As previously noted, the e-waste industry in South Africa is still at its infancy stages. It was only recently when e-waste was recognised as a priority waste stream in South Africa. At present, there is no specific legislation that regulates e-waste management in country. However, South Africa has in place progressive legislative frameworks that strongly recognise the principles of environmental protection and rehabilitation. At present, the industry is governed and guided, first and foremost by the Constitution of the Republic of South Africa, and the National Environmental Management Act under the Waste Act 59 of 2008. Other legislations that are applicable to e-waste are: Environment and Conservation Act (No. 73 of 1989), Occupational Health and Safety Act (No. 85 of 1993) and the Hazardous Substances Act (No. 15 of 1973). These are discussed in details below.2.

4.1. The Constitution of the Republic of South Africa

The Constitution of the Republic of South Africa is the main legislative framework in the country which safeguards and ensures that basic human rights are upheld. Environmental protection is of

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prime importance in South Africa, given the many environmental problems left behind by past apartheid policies and practices. Section 24 of the Constitution stipulates that: "*everyone has the right to an environment that is not harmful to their health or well-being; and the right to have the environment protected, for the benefit of the present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation; promote conservation and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development*".57 The Constitution gives all citizens the right to live in an environment that is not detrimental to their health. E-waste materials are known to contain hazardous substances – it is particularly important to ensure that the management of such waste does not harm the people or the environment.

4.2. The National Environmental Management Act: Waste Act

The National Environmental Management Act (Waste Act) is founded on the principles of the Constitution. The Waste Act provides a principal framework for sound environmental management practices for all development activities. The Act was enacted in 2008 to regulate and control the management of all waste including E-waste. Prior to the enactment of the Act, there was no specific legislation to manage waste in the country. Waste management is provided for in the Act, and refers to avoidance or minimisation and remediation of pollution, including waste reduction, re-use, recycling and proper waste disposal [58].

4.3. Environment Conservation Act (No. 73 of 1989)

The primary objective of The Environment Conservation Act (ECA) is to provide for the effective protection and controlled utilisation of the environment. Section 20 of the ECA makes specific reference to waste disposal and assigns the role of issuing permits for waste disposal to the Department of Water Affairs and Forestry (DWAF) [59].

4.4. Hazardous Substances Act (No. 15 of 1973)

Many of the substances contained in e-waste are considered hazardous. The Hazardous Substances Act provides regulations to control the management of hazardous substances and the disposal of hazardous waste. The Act classifies the different types of hazardous substances into four groups and imposes detailed requirements (through the use of Regulations and Notices) dealing with the handling, selling, using, operating, applying and installation thereof [60].

4.5. The Occupational Health and Safety Act (No. 85 of 1993)

The primary objective of the Occupational Health and Safety Act (OHSA) is to ensure that people work in an environment that is not harmful to their wellbeing. Some of the regulations that were enacted in terms of the Act offer provisions for dealing with the handling, use, exposure control, use of personal protective equipment, storage or disposal of hazardous substances/chemicals or waste in general. These include:

- Lead Regulations,
- Hazardous Chemical Substances Regulations,
- Environmental Regulations for Workplaces and
- General Safety Regulations [61].

4.6. Other applicable legislation

Other applicable legislations are:

- National Water Act (No. 36 of 1998)
- Atmospheric Pollution Prevention Act (No. 45 of 1965)
- Air Quality Act (No. 39 of 2004)
- National Health Act (No. 61 of 2003)

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- Precious Metal Regulation
- Second-Hand Goods Legislation
- Consumer Protection Act (No. 68 of 2008)

5. The path forward for South Africa: Waste RDI Roadmap (2015 – 2025)

The Waste Research Development and Innovation (RDI) roadmap is an initiative led by the Department of Science and Technology (DST) to stimulate waste research and development, waste innovation and human capital development in the waste sector. The waste sector has been recognised by government as an important vehicle to contribute to job creation and economic development in the country. The Waste RDI Programme is premised on: maximising diversion of waste from landfill, creating value-adding opportunities, optimisation of value-adds, leading to significant economic, social and environmental benefits, and creating a sustainable regional secondary economy. The Waste RDI roadmap aims to provide strategic direction, to coordinate and manage the country's waste investment:

- Strategic Planning
- Modelling and Analytics
- Technology Solutions
- Waste Logistics Performance
- Waste and Environment
- Waste and Society

E-waste is recognised as a priority waste stream in the roadmap. E-waste currently constitutes between 5 % and 8 % of the municipal solid waste in South Africa. The volumes of e-waste are expected to increase significantly in the near future. There is therefore an urgent need to development e-waste management systems which addresses challenges in consumer awareness, collection, recycling processes and waste disposal. The roadmap plans of divert 50 per cent of e-waste from the landfills by 2024 [62].

6. Research conclusions

There have been massive interests in e-waste globally. This has been fueled by the continuous increase in the production of EEE and subsequently the volumes of waste EEE generated each year across the world. The problems emanating from poor disposal and management of e-waste, and possible economic opportunities have pushed countries to reconsider old ways of managing e-waste. Equally so, the level of research on the subject has increased significantly on the global arena. High level and extensive research is currently being conducted at an international level to come up with efficient solutions to deal with e-waste.

With reference to the international studies, CRT related research is still at the developmental stages. This is because, for some time, landfilling and incineration were the best options for managing CRT waste. This has since changed largely because of the stringent environmental laws and policies. Globally, there is an urgent need to recover and recycle e-waste because it is regarded as a potential risk to the environment and the people. Governments are now forced to reconsider the old traditional methods of disposing waste.

CRTs have been extensively used for more than 70 years. According to the European Union (EU), the total Electrical and Electronic Equipment is estimated at 7.5 million tons per year with computer monitors and television containing CRT constituting about 80 per cent of that total. The disposal of CRTs is becoming a major concern because of their hazardous nature. Current research work is directed at finding new and efficient methods for CRT waste management.

In the case of South Africa, the e-waste industry is relatively young and hence very little information is available at a country-level. E-waste currently constitutes between 5 % and 8 % of the municipal solid waste in South Africa and these volumes are expected to increase significantly in the near future. South Africa is still faced with many challenges most of which are related to consumer

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awareness, collection, recycling processes and waste disposal, amongst others. However, the recognition of e-waste as a priority waste stream is a step in the right direction. Government with associated institutions are working towards establishing an e-waste management system. Government has vowed to divert as high as 50 per cent of e-waste from the landfills by 2024. By so doing, government hopes to create value-addition opportunities which ultimately lead to significant social, economic and environmental benefits for all citizens.

7. 7. Future opportunities: the South African perspective

Before a flourishing regional secondary economy can be created, there is a need to invest in research, development and innovation. South Africa currently does not have a sufficient research base on waste generated from EEE. Very few studies have been undertaken on e-waste and hence very little is understood about e-waste. There is therefore a need to invest in baseline studies to be able to comprehend fully the extent of the problem, and to build a case for South Africa. Statistical data is also required on the different components of e-waste – this will assist during policy formulation and implementation. Companies such as Mintek have been at the forefront in terms of researching the wide ranging potential applications of waste CRTs among other e-waste streams. These applications range from lead recovery, flux in smelting, brickmaking, jewellery, foam glass, tableware and ceramic glazes. These applications fit in perfectly with the need for a flourishing secondary economy and present South Africa with a perfect opportunity to stimulate the small, medium and micro enterprises (SMMEs) focusing mainly on recycling CRTs and other e-waste streams.

Acknowledgments: The authors thank Mintek (SA) for permission to publish the results and financial support.

Author Contributions: P.L. conceived the project; P.L. and N.S collected and analysed literature data. P.L. drafted the first manuscript; N.S. supervised and edited the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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