www.oeko.de

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

SPONSORED BY THE

Federal Ministry of Education and Research

Global Circular Economy of Strategic Metals – the Best-of-two-Worlds Approach (Bo2W)

Darmstadt,
April 2014

Recycling options for waste CRT glass

Authors:

Daniel Bleher (Oeko-Institut)

Geschäftsstelle Freiburg
Postfach 17 71
79017 Freiburg
Hausadresse
Merzhauser Straße 173
79100 Freiburg
Telefon +49 761 45295-0

Büro Berlin
Schicklerstraße 5-7
10179 Berlin
Telefon +49 30 405085-0

Büro Darmstadt
Rheinstraße 95
64295 Darmstadt
Telefon +49 6151 8191-0

info@oeko.de
http://www.resourcefever.org

Bo2W project consortium

Oeko-Institut e.V.

Germany

Umicore

Belgium

Vacuumschmelze GmbH & Co. KG

Germany

Johnson Controls Power Solutions

Germany, United States

Centre for Environment and Development (CEDARE)

Egypt

City Waste Management Co. Ltd.

Ghana

Content

List of Figures

List of Tables

List of abbreviations

g	gram
CRT	Cathode Ray Tube
EoL	End of life
PC	Personal Computer
WEEE	Waste electrical and electronic equipment
%	Per cent
EEE	Electrical and Electronic Equipment

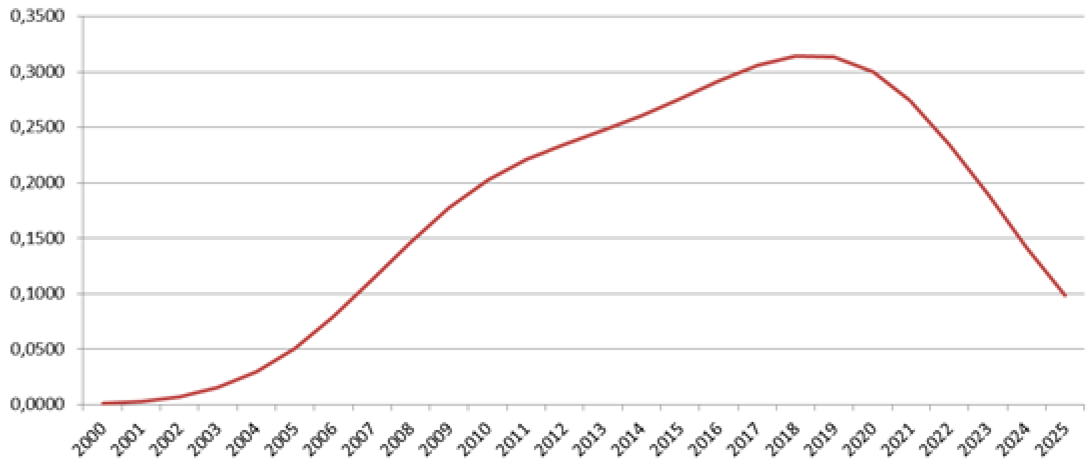
1. Introduction

The following document describes the findings regarding recycling possibilities for components with low or negative value within the project "Global circular economy of strategic metals - best-of-two-worlds approach (Bo2W)"[1].

In detail, the analysis focusses on cathode ray tubes (CRT) from e-waste as this fraction is considered as most relevant regarding mass flow and ecological damage potential.

The following Figure 1 shows the projected number of CRT TVs reaching each year the EoL (end of life) phase in Ghana. Currently, the number of EoL CRT TVs increases each year, reaching its maximum around 2018/2019 when annually more than 300 000 appliances reach the EoL. As LED and plasma TVs gain relevant market shares quickly, the CRT technology is phasing out and consequently less appliances reach EoL apart from the year 2020.

Figure 1 **Projection of number of EoL CRT- TVs per year in Ghana 2000-2025 [in million]**



Source: Manhart et al. 2014

Figure 1 also shows the importance of the problem how to handle the EoL stream of CRTs. Waste stock currently build up very fast. This report tackles the problem and shows possible solutions based on literature and desktop research as well as numerous talks with company representatives from the related recycling sector.

[1] See: http://www.resourcefever.org/project/items/global_circular_economy_of_strategic_metals.html)

2. Cathode ray tubes

Over many decades, televisions and later computer monitores used cathode ray tubes to create the visible image on the screen. The cathode ray tube is a vacuum tube containing an electro gun at the rear side of the unit. The electron beam produced by the electro gun is accelerated and deflected inside the CRT unit. By striking the fluorescent layer at the inner side of the screen glas, the visible image is produced.

With the appearance of LCD and plasma televisions and monitors, CRT based appliances faced a heavy selling cut back. Today, CRT is nearly phased out on the global market and the production of new appliances is only found in some asian markets. In combination with the production phase out, CRT based appliances dominate the end of life stream of monitors and televisions.

As from an environmental point of view, the recycling of CRT units is problematic, different aspects have to be considered and discussed in the following chapters.

Figure 2 Dismantling of a CRT monitor

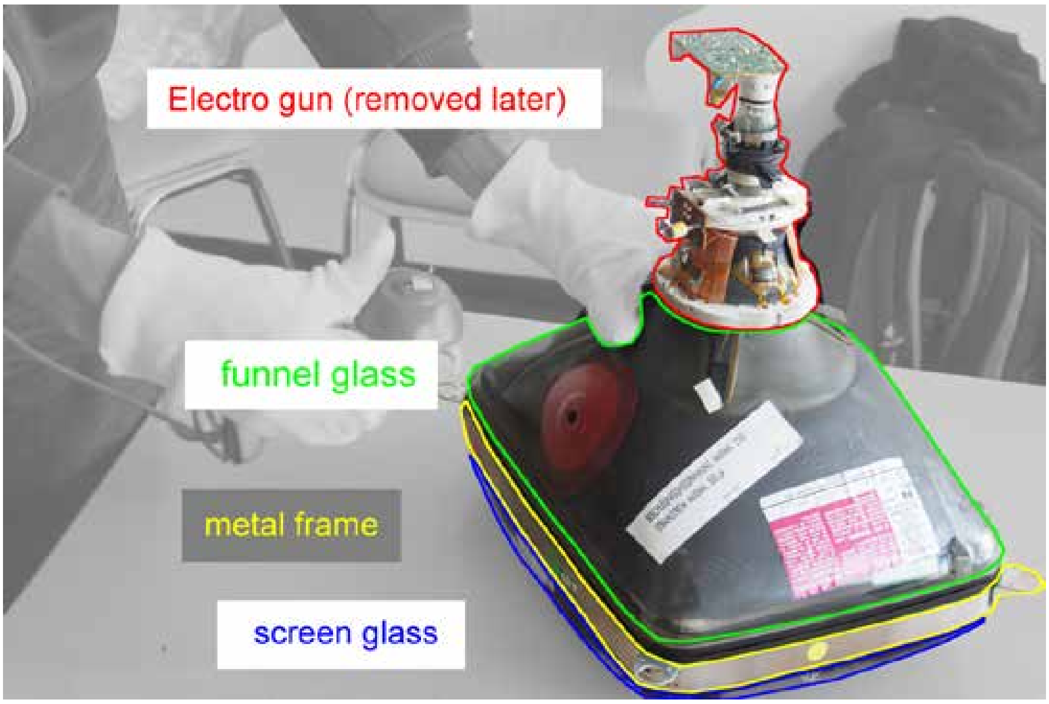
Source: Andreas Manhart, Öko-Institut

2.1. Construction details and recycling aspects

A best practice dismantling process of CRT monitor or television as it is done for example in the recycling facility of the project partner CityWaste in Ghana can be described as follow: All thermoplastics forming the housing of the unit are removed, valuable fractions are dismantled. Namely, cables, printed circuit boards and the copper wire at the neck of the funnel glass are of economic interest. Finally, the stripped CRT unit is vented by removing the vaccum in order to prevent the risk of implosion (see Figure 2). Dismantling done by the informal sector is different, mainly regarding health and safety issues (missing safety equipment like protective goggles and breathing masks).

What remains is the so called stripped CRT unit (see Figure 3). The unit mainly consists of a funnel glass and screen glass. Both parts are compounded with a frit joint. An additional metal frame protects the sealing frit and prevents the unit from implosion risks. Inside the CRT unit, a metallic shadow mask remains (steel panel). The shadow mask has the function to regulate the electron beam and control the point where the electron beam hits the inner side of the screen glass. Several coating layers are applied to the inner side of especially screen but also funnel glass. The coating layers are used to either prevent the surface from reflection or to enhance brightness and color of the incoming electron beam (in case of the screen glass). The coatings consist of different substances like carbon slurry, graphite and fluorescent colors (green, blue, and red)[2] (Lee 2002). The coatings at the inner side have to be considererd when discussing the different recycling paths.

Figure 3 Nearly full-stripped CRT unit



Source: Andreas Mannhart, Öko-Institut, own image edited

[2] The fluorescent layer also contains hazardous substances. In old color TVs, cadmium substance were used.

The recycling of CRT glass becomes problematic as especially the funnel glass contains significant lead concentration in form of lead oxide (see Table 1). Lead is needed to prevent an uncontrolled diffusion from the electron beam out of the tube. The funnel section contains up to 25% lead (ICER 2003), this the same lead concentration as used for e.g. lead crystal glass. The lead is bound in the glass matrix and therefore persistant and difficult to recover. The main risks for the workers carring out the CRT tube dismantling are: implosion of the tube and emissions of dust from the flourescent layer. Therefore, careful dismantling procedure (appropriate tube venting) and protective equipment is necessary.

Even the lead in the funnel glass is supposed to be bound, studies from (Yang & Gordon 1993) and (Townsend et. al 1999) examined the lead leachability of cathode ray tubes. The latter study used the U.S. EPA Toxicity Characteristic Leaching Procedure (TCLP) and showed that the average lead eluate-concentration exceeds the US-regulatory limits significantly. The different fractions of CRT glass show different leaching results. The funnel glass produces higher lead concentrations than screen glass. By far, the major source for lead leaching comes from the frit. Beside the differing concentrations from the distinctive CRT glass fractions, the leaching variety is also significant within each fraction. Even the same TV model from the same producer and year of production show large varieties of lead leachate. Obviously, it is not possible to predict ex-ante the leachability from CRT glass. Yang & Gordon 1993 pointed out, that crushing (increase of surface) and weathering of CRT class leads to high long-term lead emissions. Consequently to the results of the investigations, landfilling of waste CRT was re-evaluated in order to protect soil and groundwater from lead contamination. Meanwhile, the waste management laws in several countries do not allow to landfill waste CRT glass (see chap. 2.2.2). Beside lead, barium oxide and strontium oxide are further incorporated substances and of additional concern but investigations are less existent (ICER 2003).

As CRT appliances vary greatly in size and dimension, an average CRT TV and CRT monitor had to defined for all calculations within the Bo2W project. The definition is based on (Wecycle 2009), a research that measured the weight of nerly 1.900 CRT appliances. Table 1 shows the mass balance of CRT appliances as used for the entire Bo2W project. For an average CRT monitor a total lead content is calculated. The total amount of 0.9 kg lead content results for an average CRT TV. Studies like (Parsons 2008) demonstrate that very large CRT appliances contain up to 4 kg of lead.

Table 1 Mass balance of average CRT appliances

Weight of different fractions	Total appliance (kg)	CRT unit (kg)	Sum glass components (kg)	Lead in glass components (kg)
CRT Monitor	14,2	7,0	5,8	0,5
CRT TV	24,1	11,9	9,8	0,9

Source: Lee 2002; Parsons 2008; Wecycle 2009; baseline calculation for the Bo2W project

2.2. Currently available recycling paths (rp)

The following chapter presents the currently available recycling paths for waste CRT glass. For a better understanding, recycling paths are clustered into four categories.

Recycling solution	Identifier
Glass-to-glass	rp 1
Glass-to-landfill	rp 2
Glass-to-lead	rp 3.1
special features glass-to-lead	rp 3.2 / rp 3.3
Glass-to-further application	rp 4

While in this chapter recycling possibilites are introduced, corresponding recycling costs are subject of the following chapter.

2.2.1. Glass-to-glass

Glass-to-glass means that post-consumer CRT is used in the production of new CRT appliances. When glass fractions are separated and cleaned, glass-to-glass recycling is from a technical point of view favourable. Studies, conducted in the mid 2000's, highlighted this recycling option as most advising (Lee 2002); (IZT 2004).

Meanwhile, CRT appliances have virtually disappeared from the market. Indications suggest that actually two producers of new CRT glass remain in Malaysia and India. These manufactures accept only cleaned funnel glass cullets with a certain lead content. German CRT dismantler refuse from sending wasted CRT to these destinations as prices are low and companies do not intend long-term supply contracts (Schulte 2013). While in the mid 2000's, prices for waste funnel glass reached around 120-150 €/ton, today prices decreased to actually 20-30 €/ton. Recent literature sources indicate, that production facilities now charge suppliers for accepting processed CRT glass for around 100 €/ton (WMW 2013).

2.2.2. Glass-to-landfill

Landfilling of wasted CRT glass can not be regarded as recycling in the proper meaning but describes a disposal solution. In order to keep the classification sheme simple, glass-to-landfill is presented as recycling solution.

Landfilling of wasted CRT glass seems an simple solution but is prohibited in countries like e.g. USA and UK due to leach ability of lead containing funnel glass. In contrast, German Landfill Regulation allows to use waste CRT glass under the precondition that is used as construction material to cover closed landfill sites. Therefore, CRT glass has to be crushed and glass cullets are incorporated in concrete to form covering layer. Alternatively, CRT cullets can be used as additive for the construction of supply roads on the site. Backfilling

CRT glass in closed underground salt rock mines is from an regulatoraty point of view also feasible (Laga 2009). Personal communication withs representatives form the recycling sector show that backfilling is not common practice. In contrast, German recycling companies benefit from the possibility to landfill waste CRT glass and import large amounts CRT glass from the rest of the world. In the beginning of the research for this topic, it seemed that the “German way” of landfilling CRT glass is quite unique. Recent news now indicate that in the USA companies develop new techniques to incorporate CRT glass in landfill cover material or directly dispose CRT glass in landfills by stabilizing the lead content in the funnel glass to prevent it from leaching into the environment [see: (1800recycling 2014) and (Recycling Today 2014).

Discussions with company representatives indicate, that in principle funnel glass as well as screen glass may be used as construction material. Thus, most recycling companies only send funnel glass to landfill facilities as recycling options for the lead free screen glass exist (see below). In any case, the fluorescent layer at the inner side of the CRT unit has to be removed. As the fluorescent layer contains hazardous substances like cadmium, the removed layer substance has to be send to an landfill which is designated for hazardous waste. Nevertheless, the amount of hazardous waste per CRT unit is very low (0.04% per CRT unit, see (Laga 2004).

2.2.3. Glass-to-lead

Several studies recommend to use waste CRT glass as flux agent in the technical process of lead smelting. This is feasible as lead smelter use silicate sand as flux agent to produce slag. During the lead smelting process, a certain amount of the total lead input is lost as it moves to the slag (Jehle 2013). By adding lead-containing CRT glass, the process loses less lead compared to the usage of silicate sand. This aspect makes the usage of CRT glass in the process economically attractive. Nevertheless, the claim that lead from the CRT glass is recovered or recycled from such a process is misleading.

The glass-to-lead option possesses the advantage that the fluorescent layer has not to be cleaned/removed in advance. The fluorescent material goes into the slag and is afterwards land- or backfilled.

Most of the European lead smelting facilities have been contacted to assess their acceptance of CRT glass in their process. The results are diverse. Some lead smelters do accept CRT glass. But even in thesethese cases, the price structure for CRT glass differs significantly. Most CRT glass accepting facilities do charge the supplier for receiving material. For price details see chapter 2.3. Only one facility was identified that accepts CRT glass free of charge. Probably as a result, CRT capacities are booked out for the next years.

The following reasons have been cited from facility representatives that don’t accept CRT glasses:

- The diameter of CRT cullets causes problems in the transport and conveying system of the facility
- The usage of CRT glass leads to significantly higher emissions of the facility

Special feature Glass-to-lead

Beside the option to use CRT glass as flux agent, some new development pursue the intention to completely remelt the glass and hereby regain lead and glass separatly. The most prominent company is Nulife Glass, operating a commercial plant in Kent, UK and recently opened a new plant near Buffalo, New York State. By chemical treatment and remelting in an own developed furnance, Nulife Glass is able to recover lead and glass from the funnel glass. Despite the process is probably very energy intensive, the company aims to open six or seven new sites within the next years (WMW 2013).

Other companies like SIMS (NL) and Greene Lyon Group (CAN) work on comparable processes to recovery lead by chemical solving of CRT glas. All these processess seem to be in trial-phase (see also (Rosato 2013).

2.2.4. Glass-to-further applications

Under Glass-to-further applications, we subsume CRT glass recycling processes which are mostly relevant for lead-free screen glass. Precondition is a separation of funnel and screen glass. This can be achieved by either removing the screen glass with laser or diamond saw techniques. It is also feasible to break the frit between screen and funnel glass with target heating. The punctual heating produces tensions in the glass that finaly lead to breaks in the glass structure (Laga 2009). In case that CRT unit are already broken and only mixed cullets remain, the crushed CRT glass can also be sorted by x-ray detection methods (Beck 2011). Alternatively, crushed CRT cullets can also be sorted using the different thickness of glass fractions. Screen glass is much thicker than funnel glass and consequently breaks into larger pieces than funnel glass cullets (Schulte 2013).

Once the screen glass is separated, it can be further processed by removing the fluorescent coating. This can be achieved either with ultra sonic, mechanical abrasion (dry or wet) or by brushing and vacuuming (Laga 2009).

Due to the low lead concentration, screen glass can be incorporated in container glass industry. This seems the most common recycling option for screen glass. Furthermore, screen glass may also be incorporated in the glass wool industry. Statements indicate, that this recycling option becomes more and more unattractive as quality standards increase (Schulte 2013).

Research has been conducted to examine the possibilities to incorporate crushed screen glass particles into cement bricks. Results show, that up to 30 % of screen glass can be added to cement bricks without lowering the product quality. Beside the application in cement bricks, the study also found out, that up to 10 % of funnel glass can be added to clay bricks. Thus, there is actually no(?) commercial usage of this approach (Lee et al 2012). Reports on this recycling option indicate, that processes are in pilot stage or do not have sufficient manufacturing capacities. Also technical feasible but less common is the production of housing-tiles or industrial abrasives. Recycling companies that practice screen glass recycling send the funnel glass into the above described recycling paths, mainly landfilling or lead smelter.

Lead containing funnel glass can be used to produce x-ray protection glass, radiation protected rooms or, if funnel glass is incorporated to a small percentage to produce tiles.

2.3. Costs for recycling or disposal

The aim of this report is to give an actual overview about the cost structure of CRT glass recycling. Therefore, all contacted company representatives were asked to give cost estimations for their specific recycling process. The received information are displayed in the following table.

Asprecise recycling costs depend on the amount and quality of the provided CRT glass, we obtained only rough cost estimations. We therefore refrain from presenting detailed costs per company but give a range of expected costs per recycling option.

Table 2 Recycling paths and costs of CRT glass recycling

Recycling path	Description	CPT* Cost (EURO/ton)
rp 2	funnel and screen glass to landfill	~ 26
rp 2 & rp 4	funnel glass to landfill & screen glass for other applications	~ 42-70
rp 3.1	funnel glass to lead smelter	~ 50
rp 3.1 & rp 4	funnel glass to lead smelter & screen glass for other applications	~ 50-75
rp 3.2	recovery of lead and glass	~ 150

CPT = Carriage Paid To. The seller pays for notification and transportation to destination facility

Interpretating the table, it is very clear that the recycling of CRT glass costs money. Days are gone when suppliers of CRT glass achieved a positive revenue for the delivered material.

For the supplier of CRT glass, the most economic recycling solution is landfill the entire material (cost of around 26 Euro/ ton, excluding shipment and notification costs). As indicated above, this is currently outlawed in several countries but legal in countries like for example Germany. Recycling options that separate funnel and screen glass are more costly than landfilling the entire glass (approx. 42-70 €/t). This finding is surprising, as it has to be assumed that the recycling company is able to generate a certain profit from reselling processed screen glass to e.g. the container glass industry. Apparently, the process costs for separating and removing of the fluorescent layer augment the achievable benefit from this material.

With cost from approx. 50 to 75 €/t, the recycling option funnel glass to lead smelter and screen glass to further applications is slightly more expensive than landfilling/further applications. The option to send the funnel glass to a lead smelter facility is at around 50 €/t but requisitions first an separation of both glass fractions and second an separate solution for the remaining screen glass.

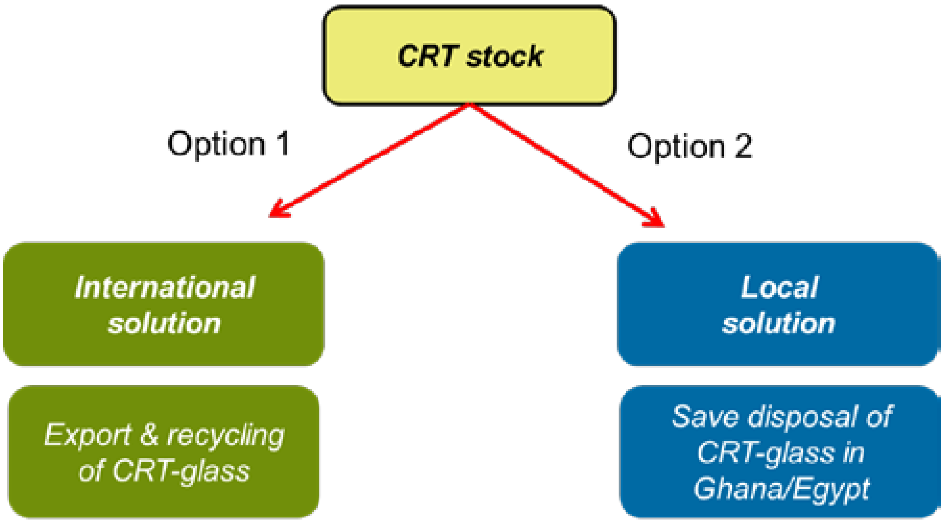
Special processes like the remelting and regaining of lead and glass is the most costly recycling option.

2.4. Proposed recycling solution for waste CRT glass

Based on the presented findings, the Bo2W team proposes two options for an appropriate recycling of CRT glass in the partner countries Ghana and Egypt.

Option 1 implies an international approach by exporting and recycling of the entire CRT stock from the partner countries to appropriate facilities overseas. Option 2 implies a local solution through a safe disposal of CRT glass in Ghana or Egypt.

Figure 4 Proposed recycling solutions for waste CRT glass



Source: own illustration

International solution

The international solution by exporting and recycling of CRT-glass means that the Bo2W partners cooperate with recycling companies that separate the CRT glass and send the funnel glass to lead smelting facilites and screen glass to the container glass industry or alternative applications. The advantage would be a best combination of environmental aspects and cost efficiency. The disadvantage of this approach would result in the creation of an uneven playing field compared to informal recycling sector. By not dealing with the recycling costs and dumping the CRT glass uncontrolled in the landside (as it is the status quo), the informal recycling sector would have comperative economic advantages compared to the proposed solution.

In order to display the cost structure for this solution, recylcing costs for an average CRT television were calculated. Based on the assumption for the average unit weight and information on notification, shipment and treatment cost, recycling costs of approx. 2,1 Euro per CRT TV result. These costs compose of 1,4 Euro per stripped unit notification and transportation cost plus 0,7 Euro/unit treatment costs. Although the net material value of other fractions such as copper can compensate these costs, the structural economic disadvantage in relation to the informal sector prevails. Thus, such management option would require well structured policy intervention in order to outweight these disadvantages.

By adopting this recycling option, the challenge of training for notification process according to the procedures of the Basel Convention has to be ensured.

The Bo2W-team calculated the (theoretical) total recycling cost for all CRT units (TV & Monitor) that enter the end-of-life (EoL) phase in Ghana in the year 2014 for approx. 583.000 Euro. This calculation assumes, that all CRT appliances which enter the EoL-phase are being collected and brought to a recycling solution in the presented manner. Due to decreasing volumes of CRT's in EoL, the annual recycling cost for Ghana in the year 2020 will drop to approx. 210.000 Euro.

Finally, an answer for the question has to be found which incentives are needed to bring already dumped CRT glass into recycling?

Local solution

The local solution means a safe disposal of CRT-glass within the Bo2W partner countries Ghana and Egypt. This can only be achieved by building a state-of-the-art landfill, capable solitarily or additionally for hazardous substances. Precondition for this option is a pretreatment of the designated waste CRT glass by removing the flourescent layer. This can be achieved by either dry or wet washing technologies. The small amount of hazardous waste (flourescent layer) separated from CRT glass has to be disposed in a special landfill. Furthermore, two different landfill construction options are thinkable. Either the possible landfill is constructed in a very safe way with an sophisticated collection and treatment of drainage/infiltration water. This would allow to dispose all fractions (funnel and screen) of the CRT units. If a less secure landfill is in favour, a more profound pretreatment of the CRT units is needed. The intention is that all lead leaching parts are removed before discharging. Especially the heavy lead containing frit seal needs to be removed and alternative recycling options therefore need to be identified.

The intention is to realise such an approach with the countries own capacities or in form of an international cooperation. The advantage of this approach is that with the provision of a suitable disposal solution, it becomes possible to prevent illegal dumping by law. Without such a landfilling alternative, it will be challenging to enforce a possible prohibition of illegal dumping. The precondition for such an approach is that low or free disposal fees for suppliers are realised. This will reduce unit costs and efforts for an environmentally sound management.

Challenging is the fact that a long duration of cooperation is needed. Additionally, it has to be considered that with the provision of landfilling capacities, the additional illegal e-waste import needs to be cut.

Same as with the proposed international solution, it is obvious that sound local disposal is associated with costs. It is therefore important to work on policy approaches and finance mechanisms to insure that such sound disposal options are installed and tied to a system that offsets the structural economic disadvantages for environmentally sound recyclers. This might – amongst others – be achieved by proper utilisation of funds raised through an extended producer responsibility (EPR) scheme.

3. Conclusion

This report demonstrated that waste CRT glass is a crucial issue which has to be adressed when discussing sustainable recycling options in emerging countries like Ghana or Egypt. CRT technology is currently about to be displaced by LCD and plasma appliances. Consequently, the amount of CRT appliances that annually reach the EoL phase is still increasing year by year. Together with the already discharged waste CRT units, a considerable waste stream is actually piling up. It is not only the amount of waste CRT units entering the waste stream but the combination with the problem of lead leachability from CRT glass when dumped in the natural environment that shows the need for action.

Different recycling options exist to manage waste CRT glass. Especially the lead free screen glass can be used as substitute for primary glass in different applications. Things get tricky when looking at the lead containing funnel glass. A true recycling with the recovery of the individual components glass and lead is less abundand. The most relevant recycling solutions either use funnel glass as slag additive in lead smelters or treat the material in a way to minimise negative environmental impacts (secure landfilling). Altogether is becomes obvious that waste CRT glass is a component with a negative value. Considering an entire CRT appliances, there are benefits from printed circuit boards and copper wire. But if recyclers use these benefits to pay the recycling of the negative value fractions, disadvantages arise compared to other actors that do not care for environmentally sound disposal of CRT glass (and just dump the the glass uncontrolled). As a result, all proposed options for a sound and sustainable management of waste CRT glass (local or international) need additional fundings!

In order to internalise the costs of proper disposal to prevent negative environmental impacts, recyclers from the formal sector need additional legislative and financial support. Otherwise, no incentives will result for a sustainable management of CRT glass. The financial support can be organised either through private or political actors. This means for example the establishment of a fund to pay treatment cost of waste CRT glass. The fund can be financed through the extended producer responsibility from actors that put EE-devices on the market or through national political actors. Ideally from our point of view, is a customized national solution, founded and controlled from national actors but technically and financially supported in the build up phase from a consortium of an international donor group.

4. Literature

1800recycling 2014	1800 recycling.com: Alternate Daily Cover Could be CRT Glass Landfilling Solution http://1800recycling.com/2014/02/alternate-daily-cover-crt-glass-landfilling-solution (retrieved on 12th, March 2014)
Beck 2011	Beck, M.: Griag Glass Recycling. Transparently successful in recycling glass. April 2011
ICER 2003	Industry Council for Electronic Equipment Recycling (ICER): New approaches to cathode ray tube (CRT) recycling. London 2003.
IZT 2004	Institut für Zukunftsstudien und Technologiebewertung (IZT): Display-Märkte im Umbruch. Neuorientierungen für Umweltschutzstrategien. WerkstattBericht Nr. 63
Laga 2009	Bund/Länder-Arbeitsgemeinschaft Abfall (LAGA): Anforderungen zur Entsorgung von Elektro- und Elektronik-Altgeräten. 2009
Lee 2002	Lee, C.-H.; His, C.-S.: Recycling of scrap cathode ray tubes. In: Environmental Science Technology. 2002, 36, 69-75
Lee et al. 2012	Lee, J.-S.; Cho, S.-J.; Han, B.-H.; Seo, Y.-C.; Kim, B.-S.; Heo, S. P.: Recycling of TV CRT Funnel Glass by Incorporating to Cement and Clay Bricks as Aggregates. 2012 International Conference on Ecology, Waste Recycling, and Environment Advances in Biomedical Engineering, Vol.7
Manhart et al. 2014	Manhart, A.; Schleicher, T.; Degreif S.; Global circular economy of strategic metals - best-of-two-worlds approach (Bo2W) Work package 2.3: Generation WEEE and ELV in Ghana; (funded by The German Ministry for Education and Research), 2014
Parsons 2008	Parsons, D.: End-of-Life Cathode Ray Tubes: A Life Cycle Assessment for Australia. Faculty of Engineering & Surveying, University of Southern Queensland, Australia. 2008
Recycling Today 2014	Kuusakoski processes CRT glass in Illinois. Published March 18, 2014 https://www.recyclingtoday.com/kuusakoski-crt-glass-recycling-illinois.aspx (retrieved on 30th, April 2014)
Rosato 2013	Rosato, M. Sustainable Technologies SL: PbO recovery from CRT Glass http://www.resource-recycling.com/ESC2013/Rosato.pdf (retrieved on 30th, April 2014)
Schulte 2013	Mr. Schulte, company AgroDrisa, personal communication 06.08.2013
Townsend et. al 1999	Townsend, T.; Musson, S.; Jang, Y.C.; Chung, I.-H.: Characterization of Lead Leachability from Cathode Ray Tubes using the Toxicity Characteristic Leaching Procedure. State University System of Florida 1999
Wecycle 2009	Bepaling van gewichten van huishoudelijke elektrische apparaten in de afvalfase. Witteveen+Bos 2009Jehle 2013 Jehle, B.; ZME Elektronik Recycling GmbH. Personal communication 21.08.2013
WMW 2013	Waste Management World (WMW): Leading the way to clean CRT recycling. Nov.-Dec. Issue 2013

Yang & Gordon 1993 Yang, Gordon C. C., 1993: Environmental threats of discarded picture tubes and printed circuit boards. Journal of Hazardous Materials. 34(2): 235-243

5. Appendix

Table 3 List of contacted companies working in the field of CRT glass recycling

Company
AGRO DRISA GmbH Dresden
Boliden Bergsö
BSB Recycling GmbH
C.C. Umwelt AG Krefeld
EGR GmbH
Elmet S.L.U
GRIAG Glasrecycling AG
H.J.Enthoven & Sons
Muldenhütten Recycling und Umwelttechnik GmbH
Nulife Glass Ltd
SIMS Recycling Solutions
Weser-Metall GmbH
WKR Altkunststoffproduktions- und –vertriebsgesellschaft mbH
ZME Elektronik Recycling GmbH