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# Global circular economy of strategic metals - best-of-two-worlds approach (Bo2W)

Recycling options for gas discharge lamps in Ghana and Egypt

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Johnson Controls Power Solutions

Germany, United States

Centre for Environment and Development (CEDARE)

Egypt

City Waste Management Co. Ltd.

Ghana

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# List of Abbreviations

| | |
|---|---|
| % | Per cent |
| B2B | Business-to-business (transactions to another business) |
| B2C | Business-to-consumer (transactions to end-consumer) |
| CFL | Compact fluorescent lamps |
| EEE | Electrical and Electronic Equipment |
| EoL | End of life |
| g | gram |
| GLS | General lighting system (i.e. incandescent lighting, “Edison’s electric bulb”) |
| HID | High intensity discharge lamps |
| LFL | Linear fluorescent lamp |
| lm | lumin |
| PC | Personal computer |
| POM | Put / placed on market |
| USD | Currency, United States Dollars ($, US$) |
| WEEE | Waste electrical and electronic equipment |

# 1. Introduction

As part of the project "Global circular economy of strategic metals – best-of-two-worlds approach (Bo2W)", this document presents research into methods and recycling options for collection, transport and disposal of all varieties of end-of-life (EoL) gas discharge lamps. The aim is to analyse current processes surrounding safe disposal of the lamps to offer ideas for safe disposal in the Bo2W pilot countries Egypt and Ghana.

The risks associated with mercury and other toxic substances used in gas discharge lamps demand that EoL lamps be handled with care and disposed of in designated areas separate from general municipal waste. Because the cost of dumping lamps in specially lined waste locations is, in the long term, more expensive than recycling, which can be partially funded through the sale of recycled materials, this study proposes two lamp recycling options: recycling in the home country or exporting the waste for recycling elsewhere. The social and economic benefits of setting up recycling systems close to waste sources promote this study's conclusion to support the first option, to **recycle EoL gas discharge lamps in their country of final use**. For recycling to be successful, awareness campaigns are critical. The general public needs to understand the harmful consequences that improper lamp disposal can cause. Collection sites need to be set up to safely collect lamps and allow for their easy transport to the recycling centre.

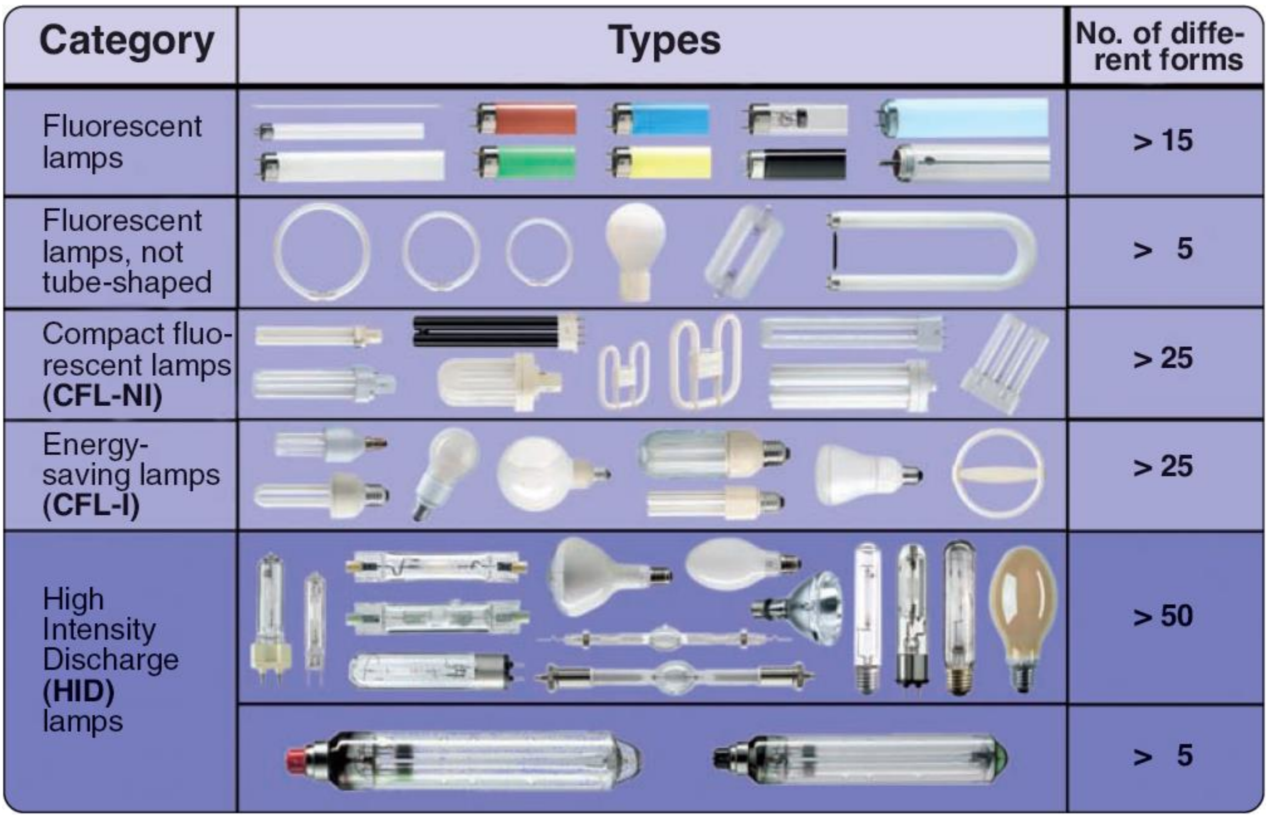
The next section defines gas discharge lamps and describes their standard specifications. Section 3 reviews health and environmental concerns, especially surrounding mercury. This is followed by a summary in Section 4 of the state of gas discharge lamp disposal in Europe as a sample of a functioning lamp recycling scheme. Section 5 then presents the European gas discharge lamp market and figures. Two case studies are described in Section 6, presenting gas discharge lamp recycling centres in different regions of the African continent. This study's two proposed options for proper and viable lamp disposal are presented in Section 7 before the last Section 8 summarizes the suggested way forward.

# 2. Gas discharge lamp specifications

This study discusses **gas discharge lamps**, here often simply **referred to as "lamps"**, which contain an ionized gas lit with an electrical charge. The many gas discharge lamp varieties mostly contain a noble gas that may be mixed with other substances like metal halides, mercury and sodium. Gas discharge lamps also contain materials such as glass and aluminium that can be reused. In step with governmental initiatives to transform perceptions of waste to view it as a valuable resource for a circular economy, many countries have mandated gas discharge lamp recycling. Health and environmental concerns, surrounding mercury and any other hazardous materials that gas discharge lamps may contain, particularly drive schemes to separately collect and dispose of these lamps.

Gas discharge lamps, designed for both commercial and household use, come in myriad sizes, shapes, colours and connectors. These include straight and circular fluorescent lamps, compact fluorescent lamps (CFLs) with different connectors as well as high intensity discharge (HID) lamps, among them high- and low-pressure sodium lamps, metal halide lamps and mercury lamps – all of which are considered hazardous waste because of the varying levels of mercury, lead and/or phosphors they contain. Most gas discharge lamps in use are compact fluorescent lamps (CFLs) or tube-shaped fluorescent lamps with end types T5, T8 or T12. Light emitting diodes (LEDs) and halogen and incandescent lighting (general lighting systems, GLS) are not categorised as gas discharge lamp types. Although certain inefficient mercury and fluorescent lamps have been banned from sale in the European Union, including halo phosphate linear fluorescent (a type of fluorescent lamp, not tube-shaped) and high pressure mercury lamps (a type of HID lamp) [Lighting Europe 2015: 1], these lamps are included in this study since they are still in use and require proper disposal. The chart in Figure 1 shows the variety of gas discharge lamps available today for EoL disposal.

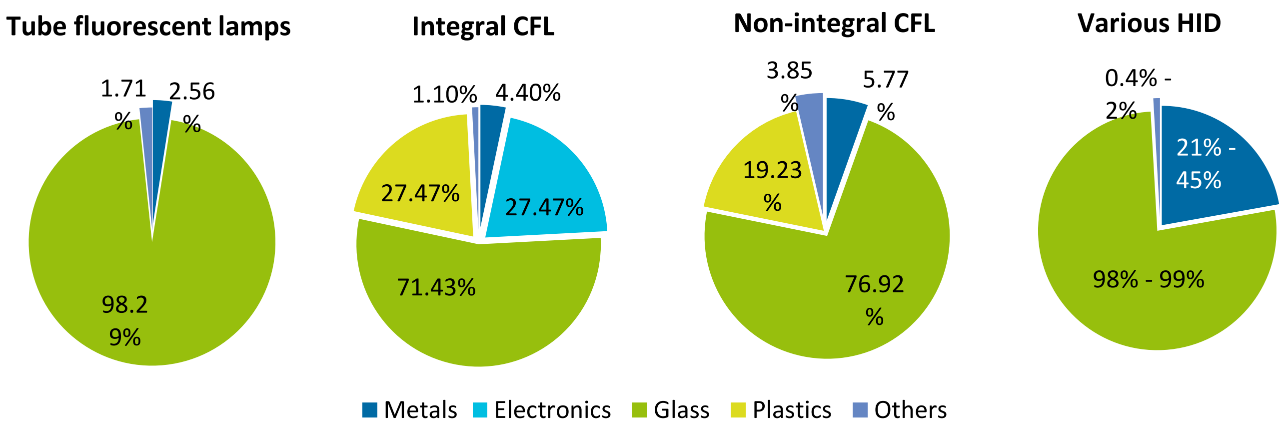
**Figure 1: Most relevant gas discharge lamp types included in this study**




Source: [AGVL/ZVEI 2008:4]

Exact lamp composition varies depending on the lamp type, which is often selected based on the desired lighting intensity and lamp size. Figure 2 shows the general material composition of three common gas discharge lamp types.

**Figure 2: Material composition of three typical fluorescent lamp types**




Source: Oeko compilation from [ELCFED 2016] and [Guarde 2010]

Many companies around the world recycle gas discharge lamps using several methods to recover the **recyclable materials** – metals, glass and plastics – in the lamps. Among the various recyclable metals in discharge lamps, such as aluminium and rare earths, the hazardous materials mercury and various phosphors containing rare earths require special care and separation systems so that they can be recycled into new lamps. Recycling turns waste into a resource, thereby also reducing the amount of primary mining needed to recover materials for new lamps and other metals applications. Less metals mining logically results in less instances of the associated mining risks for humans and the environment.

The amount of **mercury** in a gas discharge lamp depends on its type and intended application (see Table 1), ranging from around 2mg to over 50mg of mercury per lamp. [Philips 2014] Lighting power generally increases with more mercury content. Among the various high-intensity discharge lamps (HID) available, which generally contain more than 30mg of mercury per lamp, high-pressure mercury lamps, with 40 to 60 lm/W, are the least efficient. [EU Tech 2015: 137]

**Table 1: Mercury content per lamp type**

| Lamp type | Mercury (mg/ lamp) |
|---|---|
| CFL | 3.871 |
| T5 fluorescent | 2.479 |
| T8 fluorescent | 4.526 |
| T12 fluorescent | 9.979 |
| HID[1] | 38.462 |
| Miscellaneous lamp types | 13.714 |

Source: Oeko compilation from data in [Wilburn 2013:19]

In addition to extracting mercury, recycling processes can clean the approximately 10% **metal** content in lamps to be used for other applications, including extracting lead. [Lightcycle Recycling 2015] Likewise, **sodium-lime glass**, the majority of recyclable material in lamps, can also be reused for making new lamps. Plastics are often thermally recovered. These EoL lamp materials can be reused for making new lamps or can enter other markets, as listed for fluorescent lamps in Table 2.

**Table 2: Market alternatives for EoL fluorescent lamp materials**

| Material | Market for fluorescent lamp waste |
|---|---|
| Distilled mercury | Various mercury applications or transformation to mercury sulphide for safe disposal |
| Brass, aluminium, steel, and other metals | Recycling into new lamps and other products |

[1] For these figures, [Wilburn 2013] defines HID (high-intensity discharge lamps) as including high-pressure sodium, low-pressure sodium, metal halide, and mercury vapour lamps.

| Material | Market for fluorescent lamp waste |
| --- | --- |
| Glass (and glass powders) | Glass applications or<br>Construction sector |
| Plastics | Energy recovery |
| Fluorescent powders | Disposal or<br>Construction sector |

Source: [Guarde 2010:3]

## 3. Health and environmental concerns and regulations for gas discharge lamps

Gas discharge lamps use certain metals for their fluorescent properties. Among these, mercury (Hg) poses the most concerns and is listed as a hazardous material. Mercury, found in most gas discharge lamps, especially offers high energy-saving potentials for lighting compared to incandescent lighting technologies. However, mercury’s reduced energy demand entails certain health and environmental risks that require secure measures to correctly process end-of-life lamps.

Most waste-disposal problems for gas discharge lamps are associated with elemental mercury, mercury vapour and other trace metal content that can leak from the lightbulbs to harm humans and pollute the environment. Though gas discharge lamps may contain only small amounts of mercury, often as vapour (<0.01% of the lamp’s material, [HazSafe 2016]), this heavy metal presents environmental problems that can severely affect humans. For example, the mercury in one fluorescent tube is reportedly enough to pollute approximately 30 000 litres of water. [eWaste Africa 2016] Mercury impairs human sensory abilities, including vision, speech and hearing, and may damage the lungs, liver, kidneys and brain. Mercury vapour, the element’s most toxic form, can enter the lungs and pass into the circulatory system for distribution within the body. In the environment, the metal can poison flora and fauna and collect within the food chain. Consequently, proper handling and disposal of gas discharge lamps is critical to preventing release.

However, mercury hazards associated with electricity production and use pose an odd paradox for mercury-containing lamps. At the source of energy production, burning coal releases mercury, in Germany approximately 0.0147mg per kilowatt-hour. [Lightcycle Returns 2015] Because coal-burning power plants still produce a significant portion of electricity worldwide, mercury emissions are typically far higher for traditional incandescent lamps than for the more energy-efficient gas discharge lamps. Mercury-containing lamps demand approximately a quarter of the electricity needed with incandescent lighting for equal light generation. Although gas discharge lamps today may contain only 2 mg or more of mercury, provided that the lamps are correctly processed in energy-efficient systems, these energy-saving lamps significantly reduce overall mercury emissions.

### 3.1. Mercury separation from municipal waste

Separating gas discharge lamps from other waste ensures that mercury, the primary toxic element in these lamps, is handled with the proper precautions to prevent health damage and environmental pollution. Separation and recycling schemes also allow mercury to be recovered from the waste lamps for reuse. The mercury vapours may be gleaned directly from the waste lamps, or they may be first dusted with sulphur to create the stable and water-insoluble compound mercury sulphide before recovery. More detailed information about recycling can be found in

Section 4. LED lighting has entered the market as a viable and popular non-hazardous, energy-saving lighting alternative. However, figures indicate a significant number of gas discharge lamps still produced, sold and widely in use (see Section 2). These lamps will eventually need proper disposal to separate mercury from general waste, for which producers and societies must prepare.

### 3.2. Transport conditions according to the Basel Convention

The *Technical guidelines for the environmentally sound management of wastes consisting of elemental mercury and wastes containing or contaminated with mercury*, as adopted in the 10$^{th}$ Basel Convention in October 2011, regulates how to handle mercury-containing gas discharge lamps, including collection, packaging and labelling, transportation, and disposal. Mercury-containing gas discharge lamps are designated as "hazardous waste" and should be handled and transported following the appropriate international and local laws and regulations. [Basel 2012]

As stipulated by section F-5(133) of these *Technical guidelines*, lamps and other waste containing mercury

> *should be transported*
>
> - *in an environmentally sound manner … in accordance with the 'United Nations Recommendations on the Transport of Dangerous Goods: Model Regulations (Orange Book)'*
> - [by] *qualified and certified carriers of hazardous materials and wastes.*

[Basel 2012]

The *Technical guidelines* further detail in Section F-5(134) that, even within one country, carriers "should be certified [for] hazardous materials and wastes, and their personnel should be qualified." In particular, these lamps should be handled and transported "in a way that prevents breakage, release of their components into the environment and exposure to moisture." [Basel 2012] In general, lamps must be transported and handled with care to prevent their hazardous contents from leaking.

## 4. Gas discharge lamp recycling systems

Gas discharge lamp disposal can take two forms: waste disposal or recycling. Because the lamps contain mercury vapour, disposal of lamps strictly as waste is rather challenging to ensure that the mercury vapours do not escape into the atmosphere. Waste lamps in general waste streams need to be properly packaged to ensure that they can never be broken and sealed packaging is necessary to prevent escape of any gases from broken lamps. Consequently, the lamp industry and governments have determined that recycling is the only sensible and viable option to dispose of lamps.

Many **lamp producers and recycling companies** around the globe offer services to properly dispose of EoL gas discharge lamps. The National Register for Waste Electric Equipment (Stiftung ear) in Germany serves as the clearing house for electronics producers, including lamps, to legally register their electrical and electronic equipment before they may place their products on the German market. [Stiftung 2014] All producers, whether B2B or B2C, are then tracked within Germany to ensure that they responsibly offer proper recycling and disposal options. This association collects data on how many tonnes of EoL gas discharge lamps are collected annually. Other organisations in different regions, such as the Association of Lighting and Mercury Recyclers

(ALMR) based in the United States or the European Lamp Companies Federation (ELCFed) in Europe, also provide forums for networking among member companies – collectors, transporters, recycling machinery manufacturers and recyclers. [LampRecycle 2016; ELCFED 2016]

**Recycling** EoL gas discharge lamps entails several steps: collection and public awareness, transport, and recycling/ disposal. Each of these phases requires special consideration, as different risks and associated costs apply. Overall **recycling costs** can vary depending on the selected recycling system, available transport infrastructure and administrative burden. The Environmental Protection Agency in the United States offers price ranges, reported in Table 3 below, which businesses should set aside per lamp type to properly dispose of their lamps on the US lamp recycling market. These prices often exclude handling and transport costs.

**Table 3: Expected prices (USD) for disposal of common lamp types**

| Lamp type | Price range for disposal |
|---|---|
| Fluorescent tubes | 0.04-0.12 US$ per linear foot |
| HID | 1.50-2.00 US$ per lamp |
| CFL | 0.50-1.00 US$ per lamp |

Source: Oeko compilation using [EPA 2016]

Once a lamp reaches EoL, it must be **collected** in proper receptacles. In Europe, this generally occurs at designated collection sites, which for private consumers are often located at the points of sale or directly at businesses. Some jurisdictions and countries, such as the United States with its Universal Waste Rule, regulate how long lamps may be stored before they are transported to disposal locations. Collection points may store lamps in any of various containers available on the market, as regulated by local or national laws (see Section 3.2 for information about international regulations).

For private households, customers are themselves encouraged and expected to bring the old lamps to public lamp collection receptacles. These bags or special cartons are typically designed to collect all types of used lamps, which are then sent to the recycling centres. Collection point costs for Europe's household consumers are absorbed by the lamp producers (through higher lamp prices), who are required to set up collection sites and manage transport and recycling. Other countries with larger rural populations, such as in the United States, have tried mailback schemes that require the user to return the EoL lamps in their original packaging to the producer by post. (NEWMOA 2009)

European businesses, governments and other large consumers are instructed to themselves collect their facilities' EoL lamps into special bags or containers at their own facilities. They must coordinate with producers directly to arrange proper transport to recycling centres, often through mailback schemes. Since organizations frequently have many lamps of the same type, these EoL lamps are pre-sorted and can be easily recycled in product-specific processes described below.

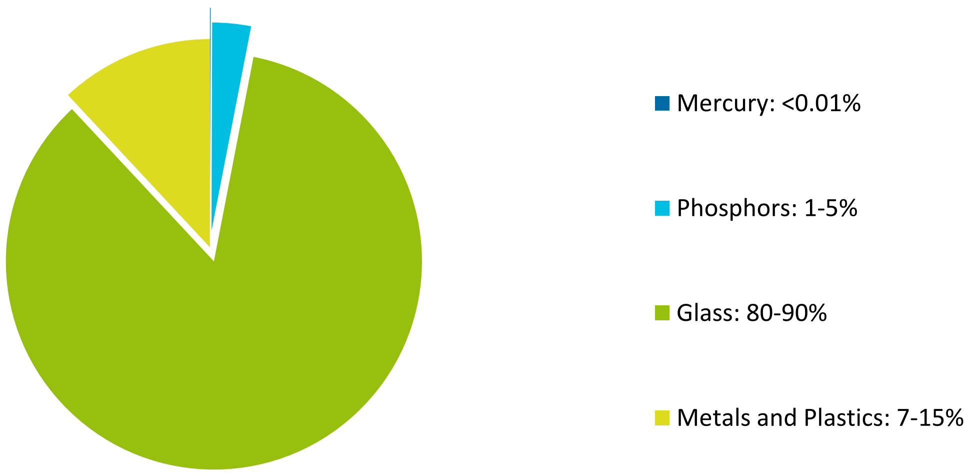
For collection to be successful, individuals and businesses need to be made aware of the dangers associated with gas discharge lamps. Information about lamp dangers is provided on packaging, and laws require that lamp producers organize collection and recycling efforts.

**Handling and transport** of EoL gas discharge lamps also account for a significant portion of overall lamp recycling costs. After lamps are collected, either at collection points or in receptacles at businesses and other organizations, they must be carefully transported to recycling plants, all the while ensuring that toxic gases and metal vapours do not escape. Transport volumes can be reduced by crushing and compressing EoL lamps in specially sealed containers directly at the collection point. eWaste Africa, from Case study 1 below (see Section 6.1), reports that pre-crushing lamps can reduce transport volumes by up to 80%. [eWaste Africa 2016] This compression reduces transport costs by decreasing the number of vehicles and trips needed to move the same weight of lamps to the processing centres. However, pre-crushed lamps can only be recycled using the shredding method or the broken-glass washing method described below in Section 3.2. The distance that the recycled materials must be transported and market prices of recycled materials consequently impact the calculations to determine which transport method is most cost-effective.

As Section 3.2 presents in detail, the Basel Convention regulates transport and handling of products containing hazardous materials, such as gas discharge lamps. In general, it states that lamps should be handled and transported in an “environmentally sound manner” and transported by carriers who are trained and certified for handling hazardous waste. [Basel 2012]

Several **recycling methods** have been developed to safely dispose of gas discharge lamps. The shredding method securely processes all types of discharge lamps and separates the material components for further recycling. This method does not require precise separation at collection, which reduces its costs; however, it cannot consequently recover as much recyclable material. Several other product-specific methods seek to maximize recycling possibilities. Of these, four methods are commonly used: end-cut, broken-glass washing, product-specific stripping and centrifugal separation. [AGVL/ZVEI 2008; ERP 2015; Lightcycle 2015] These methods strip lamps of their reusable components, which are detailed in Figure 3.

**Figure 3: Proportions of reusable materials in gas discharge lamps**



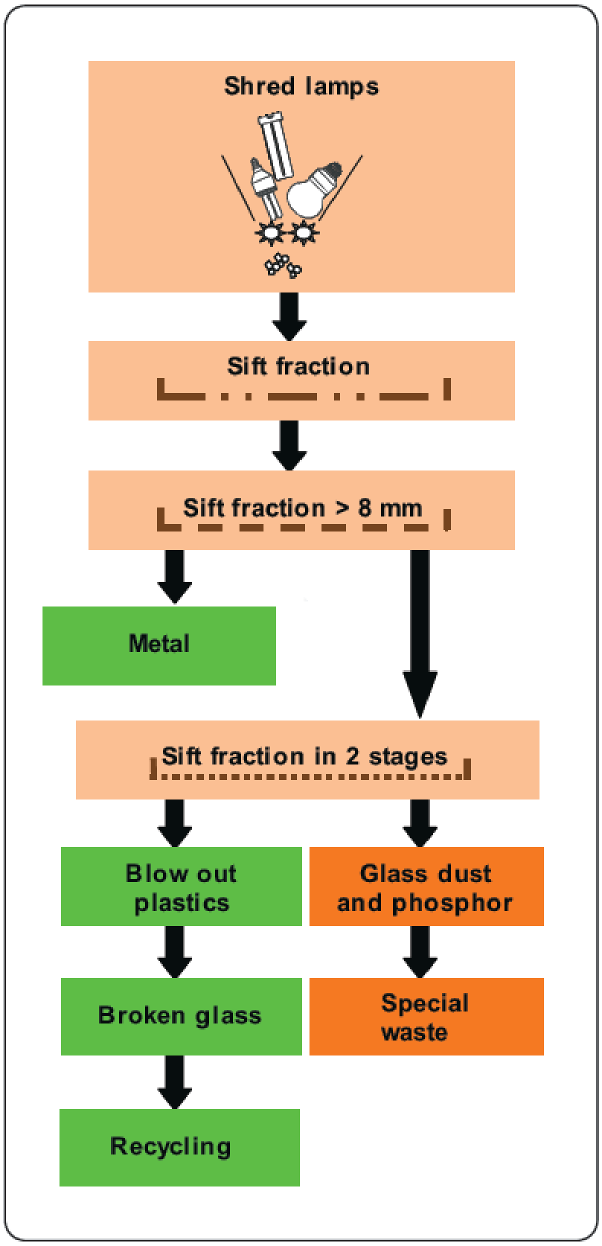

Source: Oeko-Institut compilation from [Lightcycle Recycling 2015]

### Shredding method

All variety of gas discharge lamp types can be collected together for recycling with the shredding method. Gas discharge lamps are smashed and treated in specialized containers. Within two sifting phases, metals from the end caps and other components are removed. Hazardous metals, including mercury and phosphors, are sifted out in several stages. All remaining parts are separated into metals, glass and plastics for further treatment and reuse or disposal. [AGLV/ZVEI 2008; Lightcycle 2015]

Many recyclers report that the recovered phosphors and mercury can be used for new lamps along with the cleaned soda-lime glass. The mixed glass can be recycled into applications with low glass quality standards such as insulation glazing. Remaining metals, including aluminium, also re-enter the market in new lamps and other products.

**Figure 4: Shredding method**



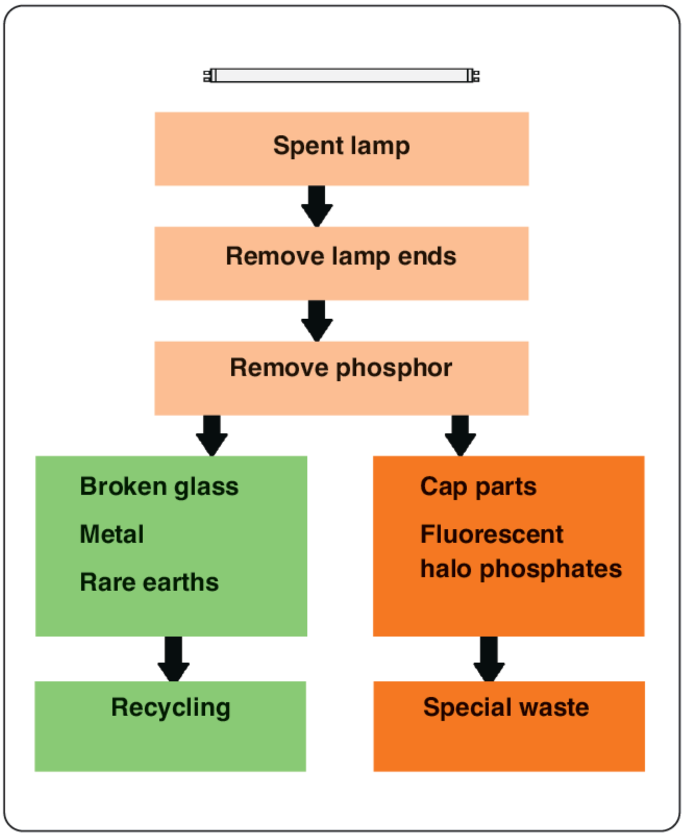

Source: [AGLV/ZVEI 2008]

### End-cut method

The end-cut method is more product-specific than the shredding method and can be employed strictly for straight fluorescent lamps. The lamp's metal ends are removed from the lamp tube to securely capture and process the mercury vapors, gasses and metals within. [AGLV/ZVEI 2008]

Lead, mercury, phosphors, rare earths and other metals are separated from the glass for use in other applications, while the cleaned glass can be reused in making new lamps. Unlike the shredding method, the end-cut method can recover and recycle more of the lamps' components and materials; less material becomes waste.

**Figure 5: End-cut method**



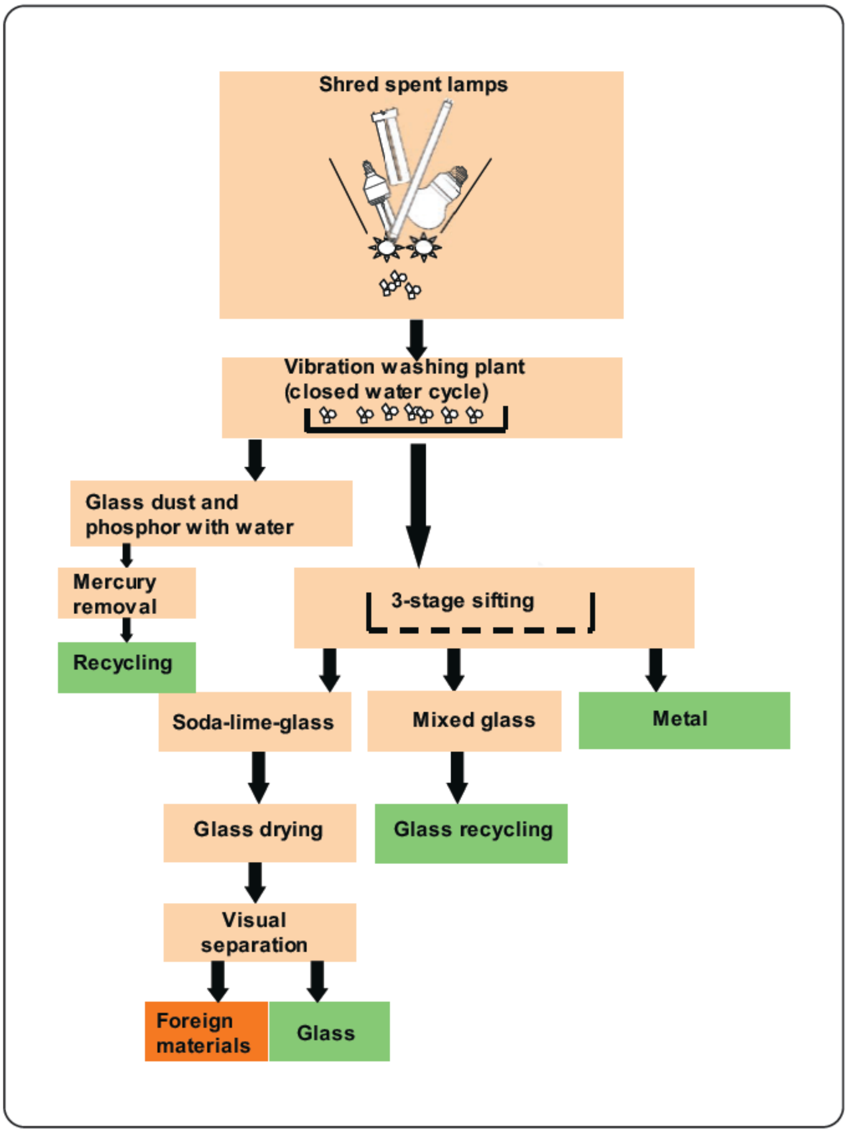

Source: [AGLV/ZVEI 2008]

### Broken-glass washing method

Similar to the shredding method, the broken glass method does not require lamp sorting by size or specific type and can still recycle large amounts of lamps into different glass and metal categories. However, the broken glass method can only be used for fluorescent lamps. Bags of lamps are crushed and the material washed in a closed water cycle. Through rotary distillation, mercury is separated from the phosphor power. The remaining materials are then sifted into soda-lime glass, other mixed glass types and metals. A metal separation unit uses automated detection to sort aluminium and other metals for reuse, including lead glass. Soda-lime glass is cleaned and dried for reuse in new lamps The remaining glass and materials are sorted for further processing and disposal or reuse. [AGLV/ZVEI 2008]

As Figure 6 shows, many materials can be separated out and recycled with the broken-glass washing method. Soda-lime glass is sorted and cleaned for reuse in new lamps, while the materials, mostly phosphors, washed from it may be further recycled or disposed of. Other glass is also recycled for general glass applications. Metals, such as aluminium, can be separated and recycled. Mercury is filtered from the wash water to be reused in new lamps or other applications.

**Figure 6: Broken-glass washing method**




Source: [AGLV/ZVEI 2008]

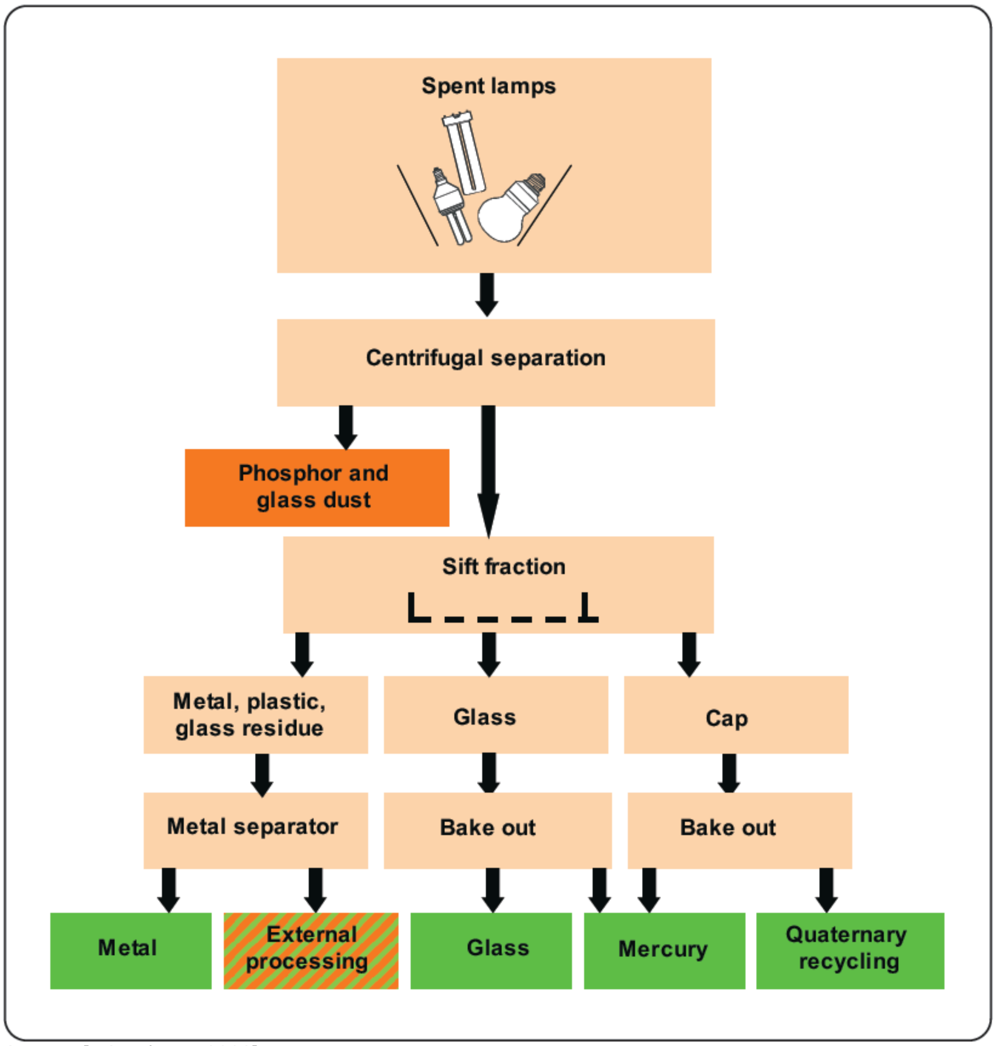
### Centrifugal separation method

Non-tubular gas discharge lamps, including compact fluorescent lamps and energy-saving lightbulbs, can be effectively processed with the centrifugal separation method. Using this recycling method, phosphor and glass dust is filtered out for landfill, while intact lamp caps and electronic components are separated from glass, metal and plastic components for further recycling. The lamp caps and electronics are shredded and passed under a separator magnet to remove any metal parts for further metal recycling. The lamp's glass components are thermally treated in heating chambers and processed for reuse.

A large portion of lamp materials can be recycled with this method. Mercury vapours are sucked from the system as the lamps are broken and remaining mercury is recovered when the glass, lamp ends and sockets are heated. [Lightcycle Recycling 2015] Remaining plastics are frequently used to feed energy recovery systems. [AGLV/ZVEI 2008] Mixed glass is separated from soda-lime glass for reuse, while aluminium and other metals are sorted for further processing and recycling.

Like for other product-specific methods, centrifugal separation requires manual sorting to collect the correct non-tubular fluorescent and energy-saving lamps.

**Figure 7: Centrifugal separation method**




Source: [AGLV/ZVEI 2008]

### Product-specific stripping

For product-specific stripping, which Germany most commonly uses, lightbulbs are manually sorted into groups of similar lamp types, sizes and shapes. This allows more of the lamps' materials to be recycled, although more manual labour must be invested to correctly sort the lamps. [AGLV/ZVEI 2008] Using techniques from the end-cut and shredding methods, the mercury is first extracted before stripping the remaining metals, phosphors and glass for reuse.

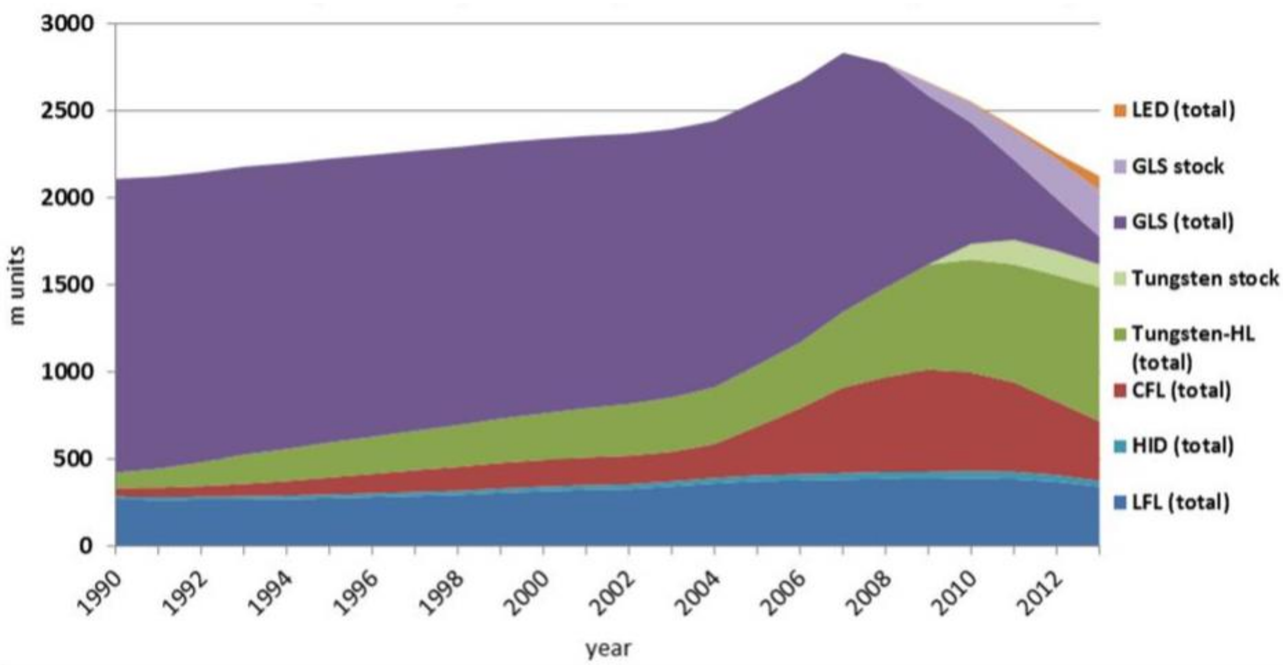
## 5. EU and German gas discharge lamp market figures

Gas discharge lamps sales have predictably lost **market share** in Europe and globally over the years as light emitting diode (LED) technologies have penetrated the lighting market. In 2009, gas discharge lamps represented approximately 55% of the worldwide lighting in use (approximately 30% CFLs, 23% fluorescent lamps and 2% HID). [Statista Globally 2015] In Germany alone in

2009, 10% of new lightbulb purchases were for CFLs at a time when approximately 64% of lighting was with gas discharge lamps. [Statista DE 2015] By 2012, [Statista DE 2015] data indicates that the market share of gas discharge lamp lighting had sunk to under 50% of German lighting used. As LEDs continue to gain market share worldwide, gas discharge lamp use globally is expected to decrease to under 50% of the global market by 2016 and drop to about 30% worldwide market share by the year 2020. [Statista Globally 2015]

For Europe, Eurostat [2016] figures indicate a decrease in numbers, tonnes and per capita amounts of gas discharge lamps put on the market (POM) since the peak in 2010. By 2013, POM lamps for the EU-28 (excluding Italy, for which data was missing) totalled **75,362 tonnes, or approximately 169g per person**. Germany alone had 16,219t of POM lamps in 2013, or 199g per capita. [Eurostat 2016] Taken from the [EU Markets 2015] report presenting the MELISA “Model for European Light Sources Analysis”, which uses LightingEurope data, the following Figure 8 summarises this decreasing trend by showing EU-28 cumulative sales in millions of units for certain gas discharge lamps (specifically CFL, HID and LFL) as compared to other lighting types, including incandescent lighting (GLS, tungsten and tungsten-HL) and LEDs.

**Figure 8: EU28 cumulative total of light source sales for all sectors (unit sales 1990-2012; in million units)**

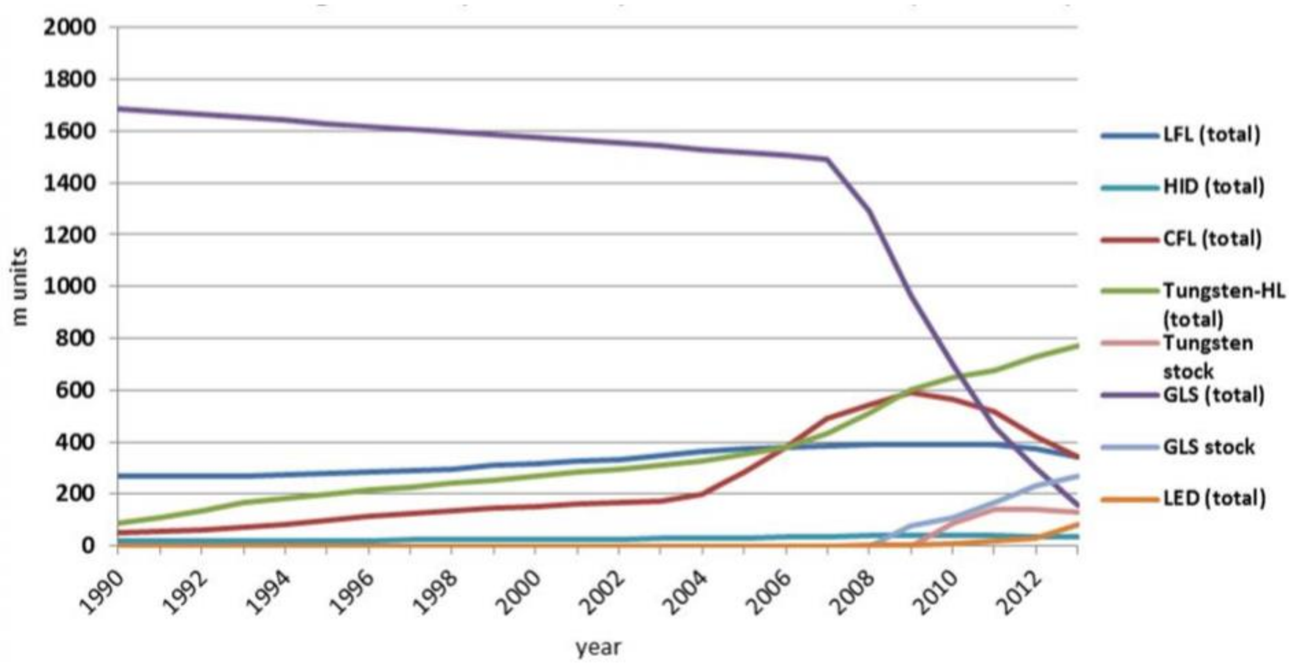



LED: light-emitting diode; GLS: general lighting system (incandescent lighting);
CFL: compact fluorescent lamp; HID: high intensity discharge lamp; LFL linear fluorescent lamp

Source: [EU Markets 2015:15]

Figure 8 shows that EU-28 cumulative unit sales for lighting have generally decreased since 2007. Even more clearly detailed in Figure 9, individual gas discharge lamp sales in million units (LFL, HID and CFL) have particularly dropped since 2009, presumably as lamp lifetimes lengthen. [EU Markets 2015]

**Figure 9: EU-28 sales per lighting-source type for all sectors (unit sales 1990-2012; in million units)**




Source: [EU Markets 2015:15]

From this data, lamp EoL **recycling rates** are rather challenging to assess because of the decrease in POM volumes starting in 2007 and the tendency to horde EoL lamps for some while before disposal. Some reports indicate a recycling rate increase, for example in the UK from 23.2% of new lamp sales in 2008 to an estimated 39.5% of 2012 sales. [WMW 2013] However, the reliability of such figures is difficult to determine, considering that recycling rates varied significantly between EU member states. Eurostat data shows a gas discharge lamp recycling average for EU-28 (excluding Italy and Ireland) of approximately 44% of POM lamps in 2013.

## 6. Gas discharge lamp disposal in Egypt and Ghana

Over the past several decades, gas discharge lamps have overtaken incandescent lighting technologies worldwide. This increased market share of gas discharge lamps, which are generally less energy-consuming that traditional incandescent lighting, means an expected increase in gas discharge lamps needing proper disposal. While currently in Europe the gas-discharge lamp market share is steadily decreasing as LED technologies gain popularity, Oeko-Institut believes this declining trend to be more relaxed in Ghana and Egypt. Table 4 shows the lamp amounts expected to be currently produced in Ghana and Egypt, assuming POM lamp volumes mirror the EU's average per-capita POM lamp volumes annually.

**Table 4: Current Egyptian and Ghanaian lamp market figures (based on EU-28, 2013)**

| | Egypt | Ghana |
|---|---|---|
| **Population** | 88 487 396 | 26 327 649 |
| **Estimated POM lamps per person (g)** | 170 | 170 |
| **Estimated total POM lamps (t)** | 14 970 | 4 450 |
| **Estimated total POM lamps (units)**[2] | 89 824 000 | 26 725 000 |

Source: Oeko-Institut compilation from [Eurostat 2016] and [CIA 2016]

These predicted POM lamp amounts for Egypt and Ghana are expected by Oeko-Institut to remain relatively stable for the next years until LEDs have fully penetrated the markets in Ghana and Egypt and gas discharge lamps have been phased out.

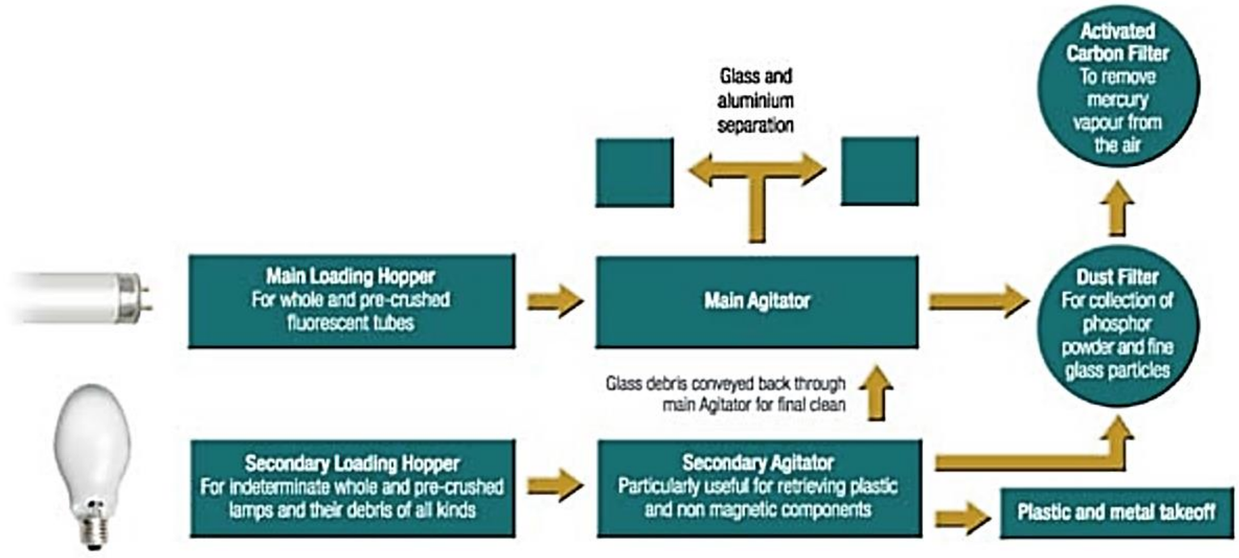
To calculate the overall **cost to dispose** of gas discharge lamps in Egypt and Ghana, all steps in the disposal process should be considered, including promoting awareness of disposal and recycling systems, collection, transport and final disposal. It should be noted that social and environmental awareness campaigns often take many years to have an impact. One method to estimate recycling campaign costs is proposed in Section 7. Two case studies have been found to exemplify options for lamp disposal in Africa. The first, in South Africa, is still in operation; the second option, in Egypt, has been closed.

## 6.1. Case study 1: South African lamp recycling plant

In 2014, the recycler eWaste Africa reported setting up the first fluorescent lamp recycling plant in South Africa. The plant processes many types of gas discharge lamps, including straight fluorescent, u-tube, HID, sodium, and compact fluorescent (CFL) lamps. In their “one lamp recycling system”, which uses a variant of the shredder recycling method (see the end of Section 3.2 above), whole and pre-crushed gas discharge lamps can be processed. (eWaste Africa 2016: ‘Technology: One lamp recycling system’) According to the corporate website, all varieties of mercury-containing lamps can be handled without needing to separate lamps by type and with relatively little energy expended (15kW to run the entire plant). The plant’s lamp processing machine – the Balcan lamp recycling system – is used in many developing countries, since it can process a variety of materials together. Figure 10 shows the recycling process that eWaste Africa systems follow.

[2] Sweep Net, the “regional solid waste exchange of information and expertise network in Mashreq and Maghreb countries”, calculates that 1 tonne equals approximately 6000 lamps. [Sweep Net 2011]

**Figure 10: eWaste Africa recycling process for mercury-containing lamps**




Source: [eWaste Africa 2016], "Technology, One Lamp Recycling System – All Lamps"

As part of its business plan, eWaste Africa offers its business customers services leading up to final EoL lamp processing, such as onsite storage systems, EoL lamp collection, pre-transport crushing and lamp transport to the recycling facility. For onsite storage, the company can provide sealed containers or drums that are specially designed to seal in broken lamps. Integral to their collection service, lamps are compressed before transport. The resulting reduced volume, reports eWaste Africa, should allow collection vehicles to carry up to five times more lamps, significantly reducing transportation costs for the same weight of lamps. To safely crush lamps before transport, eWaste Africa offers Balcan Lamp & Bulb Crushers, which can handle drumsful or simply handsful of EoL lamps. Still in its first critical years, the company deals primarily with businesses.

## 6.2. Case study 2: Egyptian lamp recycling plant

At the Nasreya Hazardous Waste Treatment Centre near Alexandria, Egypt, the Korean International Cooperation Agency (KOICA) agreed to finance a project to set up a fluorescent lamp waste treatment unit, in connection with the Hazardous Waste Management Project between Finland and Egypt. [Sweep Net 2011; MFAF 2010] In September 2011, the project to properly dispose of mercury-containing waste in fluorescent lamps was inaugurated with the Alexandria Governorate and the Korean government. Even upon opening, CEDARE [2011] predicted challenges for the plant's successful operation, since no incentive scheme had yet been devised to encourage public and private sector businesses and private households to collect their fluorescent lamps. According to El-Nasria interviews, private businesses were not willing to offer their waste lamps without payment. [CEDARE 2011:14]

According to interviews with CEDARE[3], the recycling facilities at Nasreya included a hazardous waste landfill, laboratory, weighing bridge, electric generator, storage facility and other administrative buildings to guide the process for separating, collecting and treating mercury from gas discharge lamps. Companies bringing their unbroken EoL lamps to the facility could receive a certificate of safe disposal. Before processing the lamps in the recycling systems, lamps may be

[3] January 2016 interviews with a CEDARE-KOICA Officer and with a chemical engineer in the Hazardous Waste Treatment and Management Project.

temporarily stored at the facility. The lamp recycling systems had horizontal and vertical conveyors, grinding and milling units, electric heating units, magnetic separation units, filters and fans to crush various lengths of tube fluorescent lamps up to 120cm and safely extract the mercury.

Recent interviews[4] with CEDARE have confirmed that the Nasreya fluorescent-lamp recycling plant is currently closed, with no known plans for reopening. As a consequence, no public facility is now available in Egypt for processing EoL gas discharge lamps.

CEDARE [2011] further reported that at the time of the report, Toshiba El-Araby's Mubarak Industrial City facility was maintaining an option to process mercury-containing lamps. Toshiba was running an underwater lamp crusher capable of recovering approximately half of its yearly mercury demands. Though no recent information about this machinery has been collected, in 2011 CEDARE also noted that the most viable lamp recycling option might be a take-back scheme already under discussion between lamp retailers and Toshiba's distributors. [CEDARE 2011:20]

## 7. Proposed gas discharge lamp collection and disposal for the Bo2W project

The costs offset by preventing environmental contamination and health problems when mercury is released through improper lamp disposal clearly argue in favour of governmental planning and regulations to encourage lamp producers and distributors to organize collection and recycling initiatives. This means that, no matter what lamp disposal option is chosen, governments will need to encourage recycling awareness and ensure than collection points are readily available. The following paragraphs describe schemes essential to any lamp disposal options and present two recycling options of particular interest for the Bo2W pilot countries Ghana and Egypt.

**Awareness** of the need for proper lamp disposal is critical for the success of any disposal scheme. Effective programmes include regulator support. For example, lamp recycling can be required to be mentioned in lamp ads. As well, the price for both imported and locally-produced lamps can be required to include a tax to fund recycling. Linking awareness campaigns to lamp marketing and sharing the responsibility for proper lamp disposal with lamp producers can help mitigate the costs and increase awareness campaign success.

Parallel with informing the public and industry of their duties to properly dispose of EoL lamps, **accessible collection points** need to be organised. Costs for collection can be embedded in the initial lamp price.

In parallel with local initiatives to set up gas discharge lamp recycling facilities, governments can continue to promote the **removal of mercury-containing devices** from general use. For lighting technology, this means promoting LED technology over gas discharge lamps and passing regulations requiring producers of mercury-containing devices to register their products. These initiatives would still support lamp recycling facilities, which can be equipped to also recycle LED lamps and other WEEE.

Since the mercury content in lamps eliminates the option of municipal waste disposal, this study offers **two recycling options** for how Egypt and Ghana might approach gas discharge lamp disposal. Both schemes are based on implementing secure gas discharge lamp collection processes.

[4] January 2016 interviews with a CEDARE-KOICA Officer and with a chemical engineer in the Hazardous Waste Treatment and Management Project.

**Option 1**: Set up disposal centres within the country of final use, or

**Option 2**: Arrange for transport of collected lamps to international disposal facilities.

**Cost estimations** should consider costs for awareness, collection, recycling centre inauguration and waste transport, while acknowledging the benefits from avoided mercury pollution and job creation. To estimate costs, this report suggests releasing competitive calls for:

- Materials (i.e. EoL lamps), inquiring about the price at which businesses would give up their waste;
- Transport, to learn how much transporters would charge to transfer EoL lamps to the recycler.

The Environmental Protection Agency in the United States outlines steps on its website, "How to establish a recycling program for mercury-containing light bulbs", that guide businesses in setting up in-house recycling schemes to manage their gas discharge lamps. While these recommendations presuppose a local recycling industry, many of the suggested measures are universally applicable for any country, organisation or business seeking to develop a recycling programme. Listed here is a summarised version of the most relevant implementation steps for countries like Ghana and Egypt: [EPA 2016]

a. **Assess the business's or regions' facilities** to understand where and how many lamps exist and at what rate they reach EoL.

b. **Select a recycler** who is willing to team with local business to develop recycling know-how. They can provide information about pricing, services and risk management.

c. **Establish a process for managing used fluorescent lamps** within each business facility that is appropriate for storing lamps.

d. **Safely handle and store used fluorescent lamps** at each business in specialised containers to avoid breakage and reduce risks if lamps are accidentally broken, as recommended in the Basel Convention.

e. **Properly manage broken lamps** following predetermined procedures.

f. **Identify and follow EoL lamp transport procedures**, which are generally through a pick-up service programme, such as dedicated pick-up, regularly scheduled pick-up ('milk-run') or mailback services. Self-transport may also be an option.

g. **Educate employees** and/or the general population about the hazards from improperly handled lamps to promote awareness and compliance.

h. **Include recycling costs in annual budgets** to allot resources to safe and environmentally sound business practices.

**Funding** is a necessary prerequisite for successfully recycling gas discharge lamps. Various financing sources could offer options, including governmental programmes, producer responsibility funds or international development aid funds. Donations and lamp import fees could also help cover initial costs to set up recycling programmes.

In Egypt and Ghana, a **hybridised recycling programme could be initially implemented**, wherein EoL lamps are exported to international facilities (Option 2) while local recycling facilities are being developed (Option 1). In the meantime, awareness programmes can inform businesses and communities of the need to properly dispose of lamps, supported by collection schemes in businesses and communities.

## 7.1. Option 1: Recycling in the country of final use

Local investment would be needed to develop know-how and the appropriate technologies would need to be procured through cooperation with recycling companies in other countries with developed recycling systems. As new business is developed, jobs would be created for various skill levels, including for unskilled workers, lorry drivers, marketers, managers and engineers.

In Ghana, research has not found any significant attempts to set up gas discharge lamp recycling centres. For recycling options to be successfully inaugurated, obstacles must be identified and overcome, such as how to raise recycling awareness, where a recycling centre would be best located, who should regulate the programme, what investors would be interested in participating, which recycling systems would be most cost-effective and safe, etc.

Recycling centres would be best located not far from urban areas, where a higher density of gas discharge lamps are used and reach EoL. This proximity would reduce the waste lamps' transportation costs. The experience described in Case study 2: Egyptian lamp recycling plant showed how the recycler benefitted from the close vicinity to large industry and EoL lamp producers.

One lesson learned from the Nesreya facility is that waste stream sources must also be granted incentives in order for the recycler to collect enough EoL lamps to stay in business. **Recycling awareness** and businesses' commitment to resource efficiency programmes are essential to successful recycling programme implementation. One major disadvantage, as a result, is that recycling programmes will take time, several years at least, to initiate.

Despite the large undertaking to develop new business and encourage different waste-disposal behaviour, local lamp recycling initiatives entail lower transport costs between collection sites and disposal centres than would be found for exporting lamps.

Certain recycling methods are simpler and generally more cost-effective than others. The **shredding** method, though not the most resource efficient technique of currently available recycling options, processes the largest variety of gas discharge lamps. As the Case study 1 in South Africa has found, setting up systems that can process a variety of lamps and other mercury-containing waste diversifies the materials that feed into the recycling process. This gives recyclers a larger pool of processible materials to make it easier to cover basic costs.

## 7.2. Option 2: Exported recycling

The second option, for Egyptian and Ghanaian authorities to export the collected EoL gas discharge lamps to international lamp disposal facilities, alleviates the need to accrue recycling know-how locally and set up recycling facilities. Recycling facilities closest to North African cities are located in Europe, for example in the Belgium, Germany, Netherlands and Switzerland. [ELCFED 2016] To precisely estimate the cost of exporting EoL lamp waste, transport costs and import fees for different recyclers would need to be compared.

A primary advantage to exporting EoL gas discharge lamps is the immediacy of implementing a recycling programme. Certified international transporters already exist who could bring waste lamps to recyclers. Many recyclers are located in various regions, such as Europe and the

Americas. South Africa also has one recycling plant on the west coast. However, international regulations on transporting hazardous waste must be investigated and followed.

One significant drawback to exporting waste lamps is the loss of cost control. External recyclers and transporters can set prices according to worldwide markets, which might not remain parallel to local market trends. By exporting waste, countries become dependent on the external markets.

A long-term economic loss is another prominent disadvantage to exporting recyclable materials. Work is exported and business opportunities foregone. Countries exporting their waste thereby transfer resources out of the country, paying external groups to perform work that may also be done locally. Resources move out-of-country to fund jobs in external markets, which might be kept local if the appropriate schemes were implemented.

## 8. Conclusion

Gas discharge lamps – common lighting sources that use significantly less energy and therefore release less mercury into the environment from coal-burning power plants – nonetheless contain mercury and other materials that are hazardous to human health and the environment. This mercury content means that waste lamps must be properly handled and disposed of to prevent releasing their toxic chemicals into environments and causing harm. Because disposal in municipal waste is not environmentally safe and, even in specially designated hazardous waste sites, it is not economically viable, this study proposes two **recycling options** for the Bo2W pilot countries Ghana and Egypt.

As figures in this document indicate, many gas discharge lamps are estimated to be on Egyptian and Ghanaian markets. While substitution of gas discharge lamps with LEDs is a rather certain market change, this is not expected for some time still in Egypt and Ghana. And regardless, the existing discharge lamps will need proper disposal options for at least a decade. Though some case studies have found that recycling schemes for lamps cannot generate a net profit to economically encourage the lamp recycling business, at least one group in South Africa demonstrates how effective recycling initiatives can operate.

For any lamp recycling option to successfully remove lamps from general waste, **funding** and a financial plan must be secured as a precondition. In Europe, lamp recycling schemes are regulated by law; no recycling schemes function entirely independently. Likewise, this report recommends investigating similar financing sources, such as through producer responsibility funds, government coffers or international development aid funds. However, operational efficiency has not yet been piloted and thus no secure predictions can be made about business opportunities. This study has not focussed on developing funding schemes.

This study proposes two options, both for recycling gas discharge lamps. For either of the options, programmes must be implemented to guide **recycling awareness campaigns and collection initiatives** in the most economically efficient way. This report recommends surveying the waste collection and transport markets to understand regional costs before issuing formal calls for materials and tenders. Governments can then proceed in pursuing the recycling option of their choice.

The first recycling option, to invest in setting up **local recycling centres**, brings communities the best results, especially for the long-term. Recyclers would shred waste lamps to safely extract the hazardous metals and other recyclable materials using the shredding method, a recycling technique also used to recycle other hazardous waste. The sales of materials recycled from lamp waste could then partially fund the recycling effort, which would reduce the cost of such programmes for local governments. In the long-term, governments would need to invest less resources and effort for managing environmental clean-up and caring for individuals who could become ill from improperly handled lamps. At the same time, jobs would be created locally, allowing communities to help themselves improve and care for their surroundings. Once recycling systems become stable, recycling processes could be optimized to extract purer materials from the lamp waste streams. Retaining and properly managing waste locally keeps the revenues and opportunities in the community.

While the second option, which proposes exporting EoL lamps, also protects communities and the environment from the hazards of waste lamps, costs for recycling programmes would be higher in the long-term. Instead of returning recycling revenues to the community to fund the recycling initiatives, it is expected that revenues would remain abroad and out of the control of local investors and governments. Exporting waste would mean exporting opportunity.

To begin the process it might be a reasonable first step to set up awareness and collection schemes as waste is exported for processing (Option 2). This would protect populations and the environment from the dangers of not properly managing gas discharge lamp disposal until local recycling centres can be inaugurated (Option 1).

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