WHITEPAPER

ReSoCart-ED

Recycling Solutions for Non-Reusable Toner Cartridges in Emerging and Developing Countries

UmweltCluster Bayern

ECOLOGICON
circular economy & consulting

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Preamble ReSoCart-ED Whitepaper

"Is it possible to establish an economically feasible recycling of waste toner cartridges of printers in emerging and developing countries? – The Environmental-Technology-Cluster Bavaria together with our partner and member-company ECOLOGICON think: Yes, it should be possible if the right surrounding conditions are present and financial conditions are prepared.

This is the idea of the EXI project funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) to explore the possibilities and obstacles in the selected target country Ghana, which is a typical representative for the West-African region. We need to bring together all necessary stakeholders and establish a value chain fitting to the country's specific framework conditions. For this it was necessary to evaluate the market of printing cartridges, the waste sector (especially the e-waste sector), the legal aspects, and the informal sector activities. We also experienced that the awareness of citizens needs specific training to soundly dispose of toxic waste materials.

We are happy to share this whitepaper about the relevant project outcomes and conclusions made by the project partners from Germany and the supporting partners in Ghana to hopefully give a start to a business model that can prosper well for the people in emerging and development countries."

Alfred Mayr, Dipl. Kfm. (Univ.) | Managing Director, Environmental-Technology-Cluster Bavaria

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Executive Summary

The ReSoCart-ED (Recycling Solutions for non-reusable printer Cartridges in Emerging and Development countries) project aims at evaluating recycling potentials for specific countries as examples for greater regions of countries with similar conditions. Therefore, Ghana was selected as example for the West-African region and until a first negative evaluation Malaysia was selected for South-East-Asia. For these regions waste management is known to be very limited, and disposal of landfills is a regular way for e-waste treatment. In addition, the toner dust is harmful to the health of people that handle the cartridges. There are no producers nor a formal collection infrastructure for toner cartridges in Ghana. The goal was therefore to evaluate the feasibility of economic recycling of toner cartridges to protect health and the environment.

Within roughly two and a half years, local networks were established, and local experts were commissioned in the field of waste management to get an insight in the market of toner cartridges in Ghana. In addition, a six-month trial collection of waste cartridges was established with a permission by EPA Ghana to get detailed insight in the marketing of such a collection and the resulting cartridge numbers, their types and states. This collection was performed in Accra, Kumasi and Tamale to cover almost the whole country or at least significant economic centers in their regions. An advertisement of the local contacts in the network of waste collection as well as of EPA Ghana was used to raise awareness in the public and commercial sectors. The informal sector was also informed via their networks to participate, and an incentive was paid for each waste cartridge collected.

In the end it was obvious that the clear size of the cartridge market is unclear due to not available numbers in cartridge sales or waste collections. Cartridges are refilled by mainly informally organized refiller entities and therefore not in a direct end of life waste stream that could be tracked. Therefore, we had to use two estimations: From bottom up we received data from the state department responsible for import data and the experts interviewed a sufficiently large number of larger users. From top down we estimated the number corresponding to the GDP. The finding is that roughly 300,000 to 500,000 cartridges are bought per year, which would result in a sufficient market for the systematic recycling.

However, the trial collection revealed valuable outcomes concerning the legal and informal market aspects, that need to be solved before economic recycling could be installed. People are in general open to support waste collection systems as far as they profit from the collection with new jobs and income. Nevertheless, the value of the cartridges is much lower than the material cost of their parts, which cannot result in an

economic recycling selling the materials on the international scrap market. Therefore, an eco-levy is required, which is not available for cartridges with the legal situation given at the moment. Cartridges are not (yet) part of the e-waste fund but count as hazardous waste. This again results in a different required treatment of this waste and increased responsibility to reduce harm to people and environment.

The project offered only limited time to evaluate deeply the market details of toner cartridges in Ghana but due to the established network offered many valuable insights. Additionally, the limit of budget to be present in Ghana for the project negatively influenced the result. As we clearly experienced, there is huge necessity of awareness rising and introduction of the ideas to the local (informal) structures to avoid competitional issues, that are probably not reasonable.

In general, recycling could be economically feasible if regulations to fund by the e-waste fund are changed and when the collection system can be integrated to already built-up structures for e-waste collection. The ecological necessity is present, and people, entities and state institutions are in general willing to support this recycling. Nevertheless, the question of the proper treatment of waste needs to be solved in general as a long term solution in which our project could give insights and ideas for further steps.

Figures and Tables

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Table of Abbreviations

AAS	**Atomic Absorption Spectroscopy**
ABS	**Acrylnitril Butadien Styrene**
BMUV	**Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection**
CD	**Compact Disc**
decaBDE	**Decabromodiphenyl Ether**
DGIC	**Delegation of German Industry and Commerce**
DIN	**German Industry Norm**
DVD	**Digital Versatile Disc**
EC	**European Comission**
EN	**European Norm**
EPA	**Environmental Protection Agency Ghana**
EPR	**Extended Producer Responsibility**
ETIRA	**European Toner & Inkjet Remanufacturers Association**
EU	**European Union**
FSP	**Formal Service Providers**
GASDA	**Ghana Scrap Dealers Association**
GDP	**Gross Domestic Product**
GIZ	**German Agency for International Cooperation**
HDPE	**High Density Polyethylene**

HP	Hewlett Packard Inc.
IARC	Interntional Agency for Research on Cancer
ICP OES	Inductively Coupled Plasma Optical Emission Spectroscopy
IRC	Informal Recyclables Collector
ISO	International Organisation for Standards
ISP	Informal Service Provider
IWS	Informal Waste Sector
KCARP	Kumasi Compost And Recycling Plant Limited
LCA	Life Cycle Assessment
LED	Light-Emitting Diode
LI	Lawful Interception
LMIC	Low- and Medium-Income Countries
MESTI	Ministry of Environment, Science, Technology, and Innovation
MRI	Mountain Research Institute
MSW	Municipal Solid Waste
NGO	Non-Governmental Organisation
OEM	Original Equipment Manufacturer
PBDE	Polybrominated Diphenyl Ether (Poly Brominated Flame Retardants)
PET	Polyethylenterephtalat
PS	Polystyrene
PSt	Product Stewardship
QR	Quick Response
TRGS	Technical Rule for Hazardous Substances
UCC	University of Cape Coast
USD	US Dollar
UV	Ultraviolet
WEEE	Waste Electrical and Electronical Equipment
°C	Degrees Centigrade

1 Introduction

1.1 Background

Ghana is grappling with a mounting waste management crisis, fuelled by rapid urbanization and increasing consumption of electrical and electronic equipment. Among the overlooked contributors to this issue are toner cartridges from printers and copiers, which are frequently discarded improperly. These cartridges are composed of durable, non-biodegradable plastics and often contain residual toner particles that can release harmful chemicals and microplastic particles into the environment. With limited recycling infrastructure and awareness, Ghana faces significant challenges in preventing these materials from accumulating in landfills or ending up in informal recycling systems, posing risks to ecosystems and public health.

Figure 1: Waste copiers on an informal scrapyard (left) and printers in a formal recycling facility (right). (Dr. Viktor Klein|UCB 2022)

The ReSoCart-ED Project "Recycling solutions for non-reusable toner cartridges in emerging and developing countries" took it on itself to explore possible economical and environmentally friendly recycling solutions for waste cartridges in Ghana and showcase the most suitable solutions for low- and middle-income countries based on business case calculations and modelling. As ECOLOGICON GmbH has many years of expertise in the field of toner and ink cartridge collection and preparation for reuse, the project was focussed on this waste stream. The results of the project related to the collection process are also directly transferable to a collection system for ink cartridges, as well as to collection or delivery systems for other small fractions of waste electrical and electronic equipment (WEEE) such as fluorescent tubes and smartphones.

The project has been carried out from 2022-2024 by Umweltcluster Bayern e. V. and ECOLOGICON GmbH and is funded by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) as part of the "Export Initiative for Environmental Protection" funding programme. As part of its activities, ReSoCart-ED worked closely with the local authorities in Ghana and the Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in Ghana. GIZ has been implementing the comprehensive project "Environmentally and socially responsible handling of e-waste" in Ghana since 2016. The ReSoCart-ED project aligns well with the objectives of GIZ in Ghana.

The ReSoCart-ED project built a detailed stakeholder network and explored - with the support from local experts- the current market situation and the legal status of toner cartridges, as well as the involvement of the informal sector in the activities of collection, treatment and disposal of electronic waste, especially toner cartridges. The results of the project are presented in this whitepaper.

E-waste management in Ghana

E-waste management in Ghana is characterized by significant challenges intertwined with opportunities for improvement. At the forefront of this issue was Agbogbloshie, a large e-waste site in Accra that has gained global notoriety from 2011 (e.g. by a German tv documentation "Toxic City" and a movie from 2018 "Welcome to Sodom"). This site epitomized the informal nature of WEEE recycling in Ghana, where hazardous methods such as open-air burning are used to extract metals, releasing toxic substances and posing severe health and environmental risks.

Ghana imports a substantial volume of used electronics, some of it non-functional and labelled as "second-hand goods" to bypass strict import regulations. The handling of this waste falls largely to the informal sector, where unsafe techniques are prevalent. Workers, including children, face daily exposure to harmful chemicals like lead and mercury, resulting in chronic health issues such as respiratory problems and organ damage. Environmental contamination is another major consequence of informal WEEE processing. Pollutants released into the air, soil, and water impact not just the immediate surroundings but extend to nearby communities, disrupting agriculture and water safety.

Although Ghana has legislation like the "Hazardous and Electronic Waste Control and Management Act", enforcement remains weak. Regulatory bodies lack the necessary funding and resources to effectively monitor and control illegal imports or ensure safe processing practices. While some progress has been made with the development of formal recycling facilities, these efforts are limited to manage the increasing volume of WEEE.

The international community, including NGOs and global organizations, has recognized the urgency of Ghana's WEEE crisis. Various projects have been initiated to improve recycling practices and promote worker safety. However, reliance on informal recycling for income remains a barrier to change, as it is a vital source of livelihood for many. Transitioning to safer, formal recycling practices requires economic alternatives and support for those dependent on the informal sector. Public awareness of the dangers associated with WEEE handling is gradually increasing, but more extensive educational campaigns are necessary. Proper

disposal and recycling practices must be promoted nationwide. The potential economic benefits of WEEE management are substantial; WEEE contains valuable metals like copper and gold, which could be harnessed through formal recycling to boost the economy and create jobs.

To achieve efficient WEEE management, Ghana needs to develop a modern recycling infrastructure. Formal recycling could drive economic growth by creating jobs and attracting foreign investment in the green sector. Worker training programs that teach safer recycling methods are crucial for reducing health risks and transitioning workers from informal to formal settings. Effective collection systems are also essential. Implementing take-back schemes and incentive programs could encourage consumers to return old electronics for proper disposal. While policies exist, loopholes allow many non-functional electronic devices to enter the country under the guise of donations or reusable items. These policy gaps need to be addressed to ensure sustainable solutions.

Regulatory agencies face funding constraints, hampering their ability to enforce WEEE laws and support new initiatives. Collaborating with international partners and private companies can help introduce best practices and advanced technologies, modernizing Ghana's approach to WEEE management. Comprehensive solutions that address policy enforcement, education, economic incentives, and infrastructure are essential for transforming the status quo. By tackling these interconnected factors, Ghana can mitigate the health and environmental risks associated with WEEE and build a sustainable economic future.

1. 2 Scope and Purpose

This whitepaper aims to highlight the current state of toner cartridge waste in Ghana, exploring the environmental and economic impacts associated with inadequate recycling practices. It will provide an analysis of existing challenges, examine potential solutions, and propose strategic approaches for implementing effective recycling programs. By focusing on the toner cartridge segment of e-waste, this document will offer targeted recommendations to enhance waste management practices and promote sustainability.

1.3 Objectives

The primary objectives of this whitepaper are:

- To raise awareness of the environmental hazards posed by improper disposal of toner cartridges.
- To identify the key challenges hindering effective recycling efforts in Ghana.
- To outline practical, scalable solutions that involve policymakers, businesses, and communities.
- To encourage the adoption of sustainable waste management practices that could foster economic growth and job creation through recycling initiatives.

2 Characteristics of toner cartridges

2.1 Toner cartridge usage worldwide

Toner cartridges and ink cartridges are part of the WEEE fraction, but some of them also contain valuable components. A toner cartridge (contains toner) or ink cartridge (contains ink) is an essential component of a printer, which is responsible for transferring the image or text to the print medium. There are various types and models of toner cartridges and ink cartridges on the market worldwide. According to our own web research, there are currently around 80 well-known printer manufacturers worldwide, including manufacturers of 3D printing as well as thermal and UV printing devices. Apart from the specialised printing devices that are designed for 3D printing, thermal and UV printing, users can choose between printers with toner cartridges or ink cartridges for printing on paper and cardboard. The difference between the two systems is that a toner cartridge uses fine toner powder instead of liquid ink to produce a printed product. In the toner and inkjet printer sector, the following companies are among the largest original equipment manufacturers (OEMs) according to products put on the market: Brother, Canon, Dell, Epson, Hewlett Packard, Kyocera, Lexmark, Minolta, Oki, Olivetti, Ricoh, Toshiba and Xerox.

In Europe, around 135 million toner cartridges and 370 million ink cartridges are sold every year (2024), which corresponds to a market volume of EUR 10.2 billion for toner cartridges and EUR 9.4 billion for ink cartridges. Around 20-25 % of toner cartridges do not come from original equipment manufacturers (OEM) but are compatible or remanufactured. It is estimated that there are currently 200 different types of toner cartridges and between 400-600 different types of ink cartridges on the market (Waugh et al., 2018). Using the 2019 European Gross Domestic Product (GDP) as a reference and extrapolating the volume of cartridges to the global GDP (2019), the volume of toner cartridges sold worldwide per year could be around 734 million units with a market value of up to EUR 56.1 billion (or 2 billion ink cartridges with a market value of EUR 51.7 billion) (own research). With an average weight of approx. 0.7 kg per toner cartridge (own research), this means that approx. 513,800 Mg (1 Megagramm = 1,000 kg = 1 metric ton) of toner cartridges would be put into circulation every year. In relation to Ghana, which had a GDP of around USD 68 billion in 2019, this results in an estimated annual market volume of 587,896 units or 412 Mg. Since 2008/2009, the market share of remanufactured cartridges from Asia, especially China, has been increasing. These cartridges are often of lower quality, violate current patent law and can contain hazardous chemicals in the plastics (European Toner & Inkjet Remanufacturers Association, 2023).

Toner cartridges can be differentiated according to laser printer technology and cartridge types. On the technology side, there are the standardized toner cartridges. These contain, (a) among other things, the print head, the photoconductor drum and the toner reservoir and

can consist of up to 100 moving parts. For private households and smaller office units, this results in simplified operation. Another variant (b) is the toner cartridge with a separate print head. In this case, the print head is permanently installed and must be serviced at regular intervals. The cartridge only contains the toner, which leads to a simplified construction and lower material costs. The print head is more robust and more expensive than standardized toner cartridges and is therefore mostly used in large offices (European Commission, 2018, p. 27). For example, Kyocera uses ceramic material for the durable print head (European Commission, 2018, p. 23). Since no electronic components are built into this type of cartridge, the WEEE directive does not apply here. Another technology variant is (c), the cartridge-less systems. Here, as in the household cartridges the print head is permanently installed. The toner is not supplied in cartridges but in refillable toner containers, for example from Xerox. Xerox also offers products with fixed toner (European Commission, 2018, p. 27).

Table 1: Types of toner cartridges according to DIN 33867.

Type of toner cartridge	Definition
Original manufactured	Manufactured by the printer manufacturer
Compatible NON-OEM	Alternative cartridge to the original that can be used in the same way
Remanufactured/Rebuilt	Made from new parts (from OEM or third-party suppliers) and refilled with new toner
Refilled	Used cartridge refilled with new toner without remanufacturing
Newbuilt	Do not originate from the brand owner, but are sold under this brand name
Clone	New produced cartridge, copied from an existing cartridge by an alternative manufacturer without respecting intellectual property rights

Apart from their technological differences, cartridge types can be categorised by their production route before sold on the market. An overview of these different cartridge types is shown in table 1.

OEM cartridges, which are manufactured by the same company that produces the printer, offer guaranteed compatibility, optimum performance and high print quality. Due to their superior quality, OEM cartridges are usually the most expensive option but offer the advantage of being covered by part of the printer manufacturer's overall warranty.

In contrast, compatible cartridges produced by third-party manufacturers offer a cost-effective alternative to OEM cartridges. They are generally cheaper, and their quality and compatibility vary depending on the manufacturer. Although the compatible cartridges aim

to reproduce the performance of the original cartridges, there may be differences in print quality and consistency.

Remanufactured cartridges are another option that involves the recycling of OEM cartridges. In a remanufacturing process, these cartridges are collected, cleaned and refilled for reuse. This environmentally friendly approach offers a cost-effective alternative to original and compatible cartridges. However, the quality and performance of remanufactured cartridges varies depending on the remanufacturing process and company.

To summarise, the choice between OEM, non-OEM, compatible and remanufactured cartridges depend on various factors, including user budget constraints, print quality requirements and environmental considerations. While OEM cartridges guarantee optimum performance and compatibility, compatible and remanufactured cartridges offer cost-effective alternatives, but are inferior to OEM cartridges in terms of quality and consistency.

2.2 Construction and function of a toner cartridge

The functional principle of a cartridge is based on an electrophotographic process. The toner, a powder with a grain size in the micrometre range, is in the toner tank. For monochrome laser printing, one cartridge with the toner colour black is required, for colour printing four cartridges with the colours cyan, magenta, yellow and black respectively. The toner is mixed with a carrier material that consists of magnetic material such as steel. Mixing by means of the toner mixing shaft causes a triboelectric charge to build up due to the friction between the toner and the carrier (Goldmann, 2001, as cited in Hoffmann, 2004, p. 16). The photoconductor is evenly electrically charged by the loading drum. The light sources (laser or LED) are each aligned to a print point, whereby the distances between these determine the corresponding resolution of the print image. The bundled light discharges predefined printing points (Abiko, 1986, as cited in Hoffmann, 2004, p. 16).

Electrostatic forces separate toner and carrier on the magnetic drum, using the magnetic properties of the carrier to build up a brush between the magnetic roller and the photoconductor so that the toner particles can adhere to the uncharged areas of the photoconductor (Hoffmann, 2004, p. 17). Underneath the inserted paper is the oppositely charged transfer roller.

Electrostatic processes pull the toner particles from the photoconductor onto the paper surface. During the process, a residual amount of toner remains on the photoconductor. This is electrostatically neutralized and fed to the waste toner tank by means of a drum wiper. The steps described take place during one rotation of the photoconductor. The heating rollers fix the toner on the paper at around 120 °C to 140 °C (Böhringer et al., 2014, p. 316). In total, a toner cartridge can consist of more than 100 moving parts (European Commission, 2018, p. 23). Figure 1 shows a cross-section of a toner cartridge. Further schematics of toner cartridges and component groups are attached in the annex of this report.

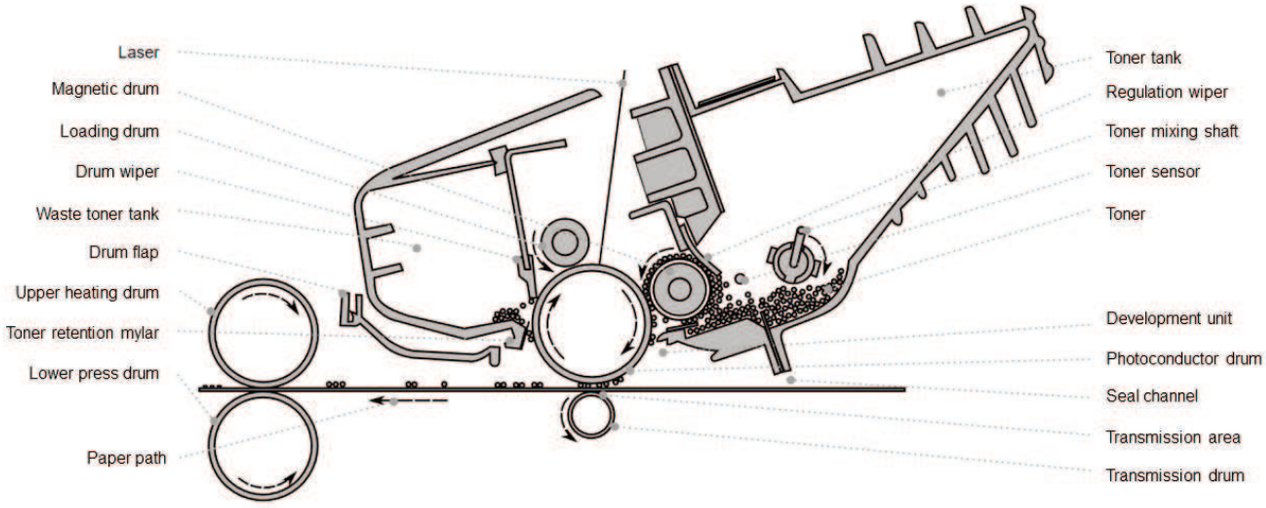

Figure 2: Schematic cross-section of a toner cartridge. (CC BY-SA 3.0)

2.3 Toner cartridge composition

Cartridges consist of approximately half non-ferrous and ferrous metal and half plastic. In addition to polystyrene (PS), other plastics used in cartridge production are acrylonitrile butadiene styrene (ABS), high-density polyethylene (HDPE) and polyethylene terephthalate (PET). The results of a study by Ruan, Li & Xu (2011), who shredded 590 kg of toner cartridges at the end of their life and then sorted them, largely confirm the results shown in Figure 2, but also found that approx. 8 % of the shredded mass was toner dust.

Berglind and Eriksson (2022, p. 9) have examined the exact material structure of an original HP C4127X toner cartridge. The following data shown in Figure 2 excludes the packaging and the toner. The total weight of this specific empty cartridge is 971.6 g.

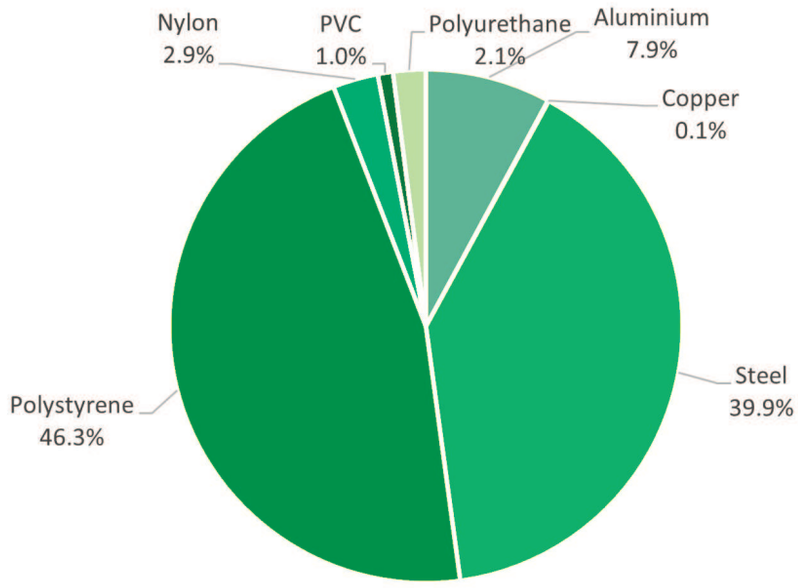

Figure 3: Composition of HP C4127X toner cartridge. (Berglind and Eriksson, 2022, p. 9)

Due to the different manufacturers and product requirements, there is a wide range of toners with different compositions. Generally, a toner consists of 90 % resins. Predominantly, this is styrene acrylate copolymer. Polyester and epoxy resins are used in smaller quantities. Furthermore, a toner consists of 5 % colouring pigments, which are usually made from the basic materials triphenylmethane pigments, perylenes or azo pigments if it is a colour toner. The remaining 5 % consists of waxes, iron oxide and charge control agents (Brüning, 2006, p. 12). Yordanova et al. calcined four toner samples and determined the inorganic components by absorption spectroscopy (AAS) and inductively coupled plasma-optical emission spectrometry (ICP-OES) (Table 2). This showed that yellow and magenta toners have the highest silicon content and cyan toners have the highest copper content, whereas black toner has the highest iron content. In addition, the presence of carbon black was detected (Yordanova et al., 2014).

Kwan and Kan (2022) reviewed 1,473 material safety data sheets from a total of four manufacturers. It was found that the ingredients are similar, but not the same. Between four and 42 different chemicals were found in toner powders, with toners of different colours also being included here. In addition, the recommended precautions of the manufacturers were summarized. These include avoiding contact with skin, eyes and clothing, keeping toner away from water, cleaning contaminated surfaces thoroughly, storing toner in a dry, cool place and providing adequate ventilation, avoiding direct sunlight, heat and sources of ignition and storing out of reach of children (Kwan & Kan, 2022).

Table 2: Inorganic components in waste toner powder. (Modified after Yordanova et al., 2014)

Element	Black [%]	Cyan [%]	Magenta [%]	Yellow [%]
Silicon	7.05	32.20	40.83	41.05
Aluminium	0.12	0.73	1.52	0.75
Titanium	0.80	0.95	5.39	1.45
Barium	0.03	1.64	0.001	0.04
Calcium	0.47	0.33	0.42	0.82
Magnesium	0.04	0.31	0.23	0.18
Sodium	0.20	0.50	0.10	0.60
Potassium	0.10	0.55	0.30	1.65
Iron	57.86	0.35	1.10	0.35
Copper	0.22	12.66	0.10	0.62
Zinc	0.68	2.65	0.20	0.95
Cromium	0.04	< 0.001	< 0.001	< 0.001
Nickel	< 0.001	< 0.001	0.19	0.11
Manganese	0.03	< 0.001	< 0.001	< 0.001
Cobalt	< 0.001	< 0.001	0.02	0.01
Lead	< 0.001	0.03	< 0.001	< 0.001

The high content of chemicals is probably also why people who are sensitive to certain substances could experience allergic reactions to the skin and the respiratory tract because of contact with toner powder (Gebel, 2015).

According to Ahmadi et al., the efficiency of transferring the toner onto paper in the cartridge is 90 %. The remaining 10 % ends up in the waste toner tank. However, the toner waste cannot be reused because it contains 34 % foreign matter such as paper fibers and staples. The reprocessing can be implemented using a screening process. This allows the toner particles to be separated from the foreign matter. That is 66 % of the waste toner that ends up in the waste tank (Ahmadi, Williamson, Theis, & Powers, 2003).

2.4 The toner cartridge lifecycle

The following Error! Reference source not found. shows the typical life cycle of a toner cartridge. After the raw materials have been extracted, the toner cartridge is manufactured by an OEM or a NON-OEM that specialises in the production of compatible or cloned cartridges. The cartridge then enters the consumer use phase. If the cartridge is damaged or emptied during the use phase, the consumer can have the cartridge repaired or refilled at specialised refill centres. Most cartridges can be refilled between 5 and 7 times or some even more. Tracking how many times a cartridge has been refilled is not done automatically and digitally. Instead, cartridges that reach the end of their life are marked manually so that a trained eye can recognise how often a cartridge has already been refilled (own research).

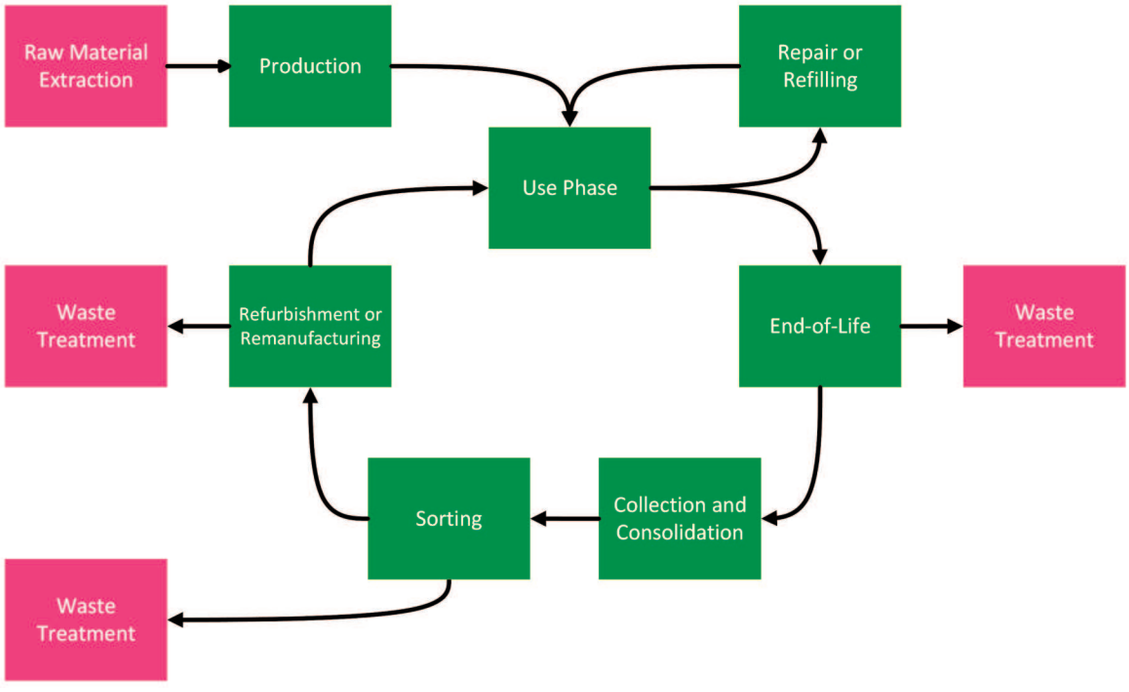

Figure 4: The toner cartridge life cycle worldwide. (green boxes: life cycle steps; black arrows: transfer and transport steps; red boxes: cradle and grave - (own research)

If a cartridge can no longer be repaired or refilled by the consumer, it has reached the end of its life. In this case, it is possible that the consumer does not use a collection system intended for the cartridge, so it may end up in the residual waste treatment stream. This results in the cartridge and the raw materials it contains being lost in thermal waste treatment or landfill. An alternative is for the consumer to use a take-back system specialising in the collection of cartridges, provided by the local authority, the manufacturer or third-party companies. After the cartridges have been collected from many different locations, they are usually consolidated and sorted by a company that's specialised in this.

The toner cartridge lifecycle is also an international life cycle as sorting and refurbishing of cartridges is usually done in other countries where they are collected and consolidated.

Figure 5 shows two pictures of sorted cartridges. They are not yet sorted for refurbishment only by cartridge type.

This sorting process is not explicitly shown in the diagram, but it determines whether the cartridges are sent to a refurbishment and remanufacturing process or to waste for disposal. The three most important aspects that determine which category a cartridge falls into are the current market value for a refurbished cartridge, the market demand and the current quality condition of the cartridge. In the remanufacturing and recycling process, there is a further decision step after which a cartridge can end up as waste, namely if it turns out that it is not suitable for remanufacturing or recycling due to its quality aspects. Recycling toner cartridges requires a large mass flow of recyclable toner cartridges that have been manufactured without plastics that contains flame retardants. As the system in Germany has so far tended to focus on preparing cartridges for reuse, it is not shown in Error! Reference source not found. explicitly.

2.4.1 Toner cartridge manufacturers and distributors

Toner cartridges are a necessary component to print with a laser printer, so a common practice of OEMs in the residential and small office unit sector is to sell the printers at a significant discount and make high profits on the sale of the cartridges. As usage increases, the initial loss is recovered. The assumption here is that private users and smaller offices, which do not use the devices as intensively as, for example, in larger office buildings, are more likely to base their purchase on the initial cost. In larger office buildings, institutions or professional users, the higher costs are in the printing devices themselves. These have more advanced features, faster printing speeds and higher printing volumes. In addition, the devices are less susceptible to damage. The print heads are usually fixed, and the cartridges are simple toner containers. The toner refills have higher capacities compared to those of home users, which reduces the cost per printed sheet (European Commission, 2018, pp. 23–24).

According to Art. 2 No. 4 2009/125/EC, "placing on the market" means making a product available on the community market for the first time, whether in return for payment or free of charge, for distribution or use within the community, irrespective of the distribution method." This means that ultimately every online shop selling cartridges is considered a distributor.

Figure 5: Example images of waste toner cartridges (left: all-in-one cartridges; right: copier toner bottles with and without printhead). - (Rückert, 2023).

2.4.2 Cartridge collection in Germany and Ghana

In Germany, most toner and ink cartridges are considered waste from electrical and electronic equipment when they have reached the end of their life, as they contain microchips or electrical components. End users should then use one of the four options listed here to dispose of their empty cartridges properly:

- Return in the shop using the 0:1 or 1:1 method: As cartridges and cartridges count as electrical appliances, consumers can take advantage of the free return in the shop based on the German Electrical and Electronic Equipment Act. You can either return a cartridge without buying a new one (0:1) or return the cartridge after buying a new one (1:1).

- Participation in an OEM's take-back system: Many OEMs offer their own take-back systems for their empty products. Private customers can often take part in the take-back system on the OEM's website and are provided with a dispatch bag with which they can send the cartridge back to the OEM. Commercial customers, who often have more than one cartridge to dispose of, can also order shipping boxes from the OEMs for collection and transport.

- Participation in a third-party take-back system: In addition to the OEM take-back systems, there are also third-party providers who take back cartridges as part of a privately organised collection. This is particularly profitable for the collecting companies because the cartridges have a market value ranging from a few cents to several euros - even when they are empty.

- Disposal at recycling centres: In addition to the disposal options mentioned above, private consumers and commercial customers can also use the municipal collection points. Many recycling centres already have "red bins" (Die Rote Tonne: The collection system for printer cartridges), which are operated by the private collection company CR-Solutions GmbH. In addition to toner and ink cartridges, CDs, DVDs and BluRay discs can also be disposed of here.

Even if the disposal solutions described above are available to consumers, a large proportion of used products often end up in the wrong waste stream. It can be assumed that a lack of knowledge regarding the status of cartridges as waste electrical and electronic equipment is one of the main reasons why only a fraction of the cartridges to be disposed of end up in the designated collection structures.

As already mentioned, there is a law in Ghana that is intended to regulate the assumption of producer responsibility for importers of waste electrical and electronic equipment, but there is a lack of enforcement and implementation of such a system in the country. None of the four above mentioned systems are yet available to consumers of cartridges in Ghana. Consumers in Ghana therefore have the following options for disposing of their old products:

- Disposal of used products to the formal sector: In Ghana, several companies are formally authorised to collect hazardous waste such as toner cartridges. Consumers therefore have the choice to hand in their empty products at formal collection points free of charge. However, the formal collectors are mainly active in high- and middle-income neighbourhoods with a collection system. In low-income neighbourhoods, drop-off systems are more common (Oduro-Appiah et al., 2017).

- Transfer of end-of-life products to the informal sector: In addition to the formal collection companies, there are a large number of informal collectors who make a living from waste management activities. In addition to the collection and transport of waste, this also includes the dismantling and recycling of waste. This is often associated with practices that are hazardous to health and the environment, such as the burning of plastic sheathing off copper cables, which is often due to insufficient awareness and ignorance of the risks involved. It is not uncommon for WEEE to be purchased by the informal sector due to its market value. If the informal actor does not recycle the cartridge themselves, valuable cartridges are sometimes also purchased by refillers and thus given a second life cycle (own research; (Kwarteng & Cudjoe, 2023)).

- Disposal of used products in household waste: Due to consumers' ignorance of the status of the cartridge at the end of its life or due to a lack of a separate collection system, many used products are disposed of in regular household waste, which ends up in the local household landfill after collection by the informal or formal sector (Kwarteng & Cudjoe, 2023).

A commissioned survey by Kwarteng & Cudjoe (2023), which aimed to clarify the disposal routes of toner cartridges in Ghana, found that one third of respondents (N=229) even burn the cartridges. An overview of the percentage distribution of other responses is shown below

in Figure 6. It is easy to see that the majority of toner cartridges end up in household waste collections.

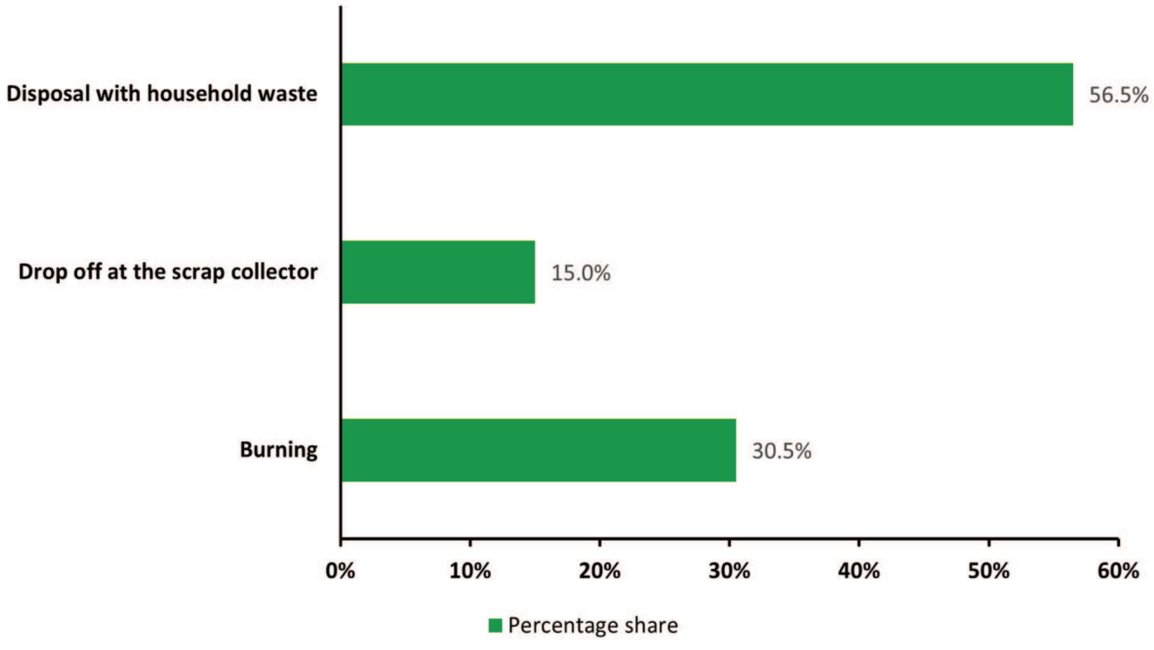

Figure 6 : Disposal options of toner cartridges among 229 respondents in Ghana (Kwarteng & Cudjoe, 2023).

The project team planned a collection system for used toner cartridges in Ghana (Figure 7). The idea is to provide the relevant stakeholders from the public and commercial sectors with a separate collection box that can be used to collect the cartridges separately. Users would fill this box with their empty toner cartridges and seal it to prevent toner dust from escaping during transport. A printed QR code can then be used to visit a website where the user can indicate that the collection box is full and where it should be collected. The collection company promptly exchanges the full collection box for an empty one and transports the full collection box to the planned recycling facility. The following figure shows a concept for such a collection scenario.

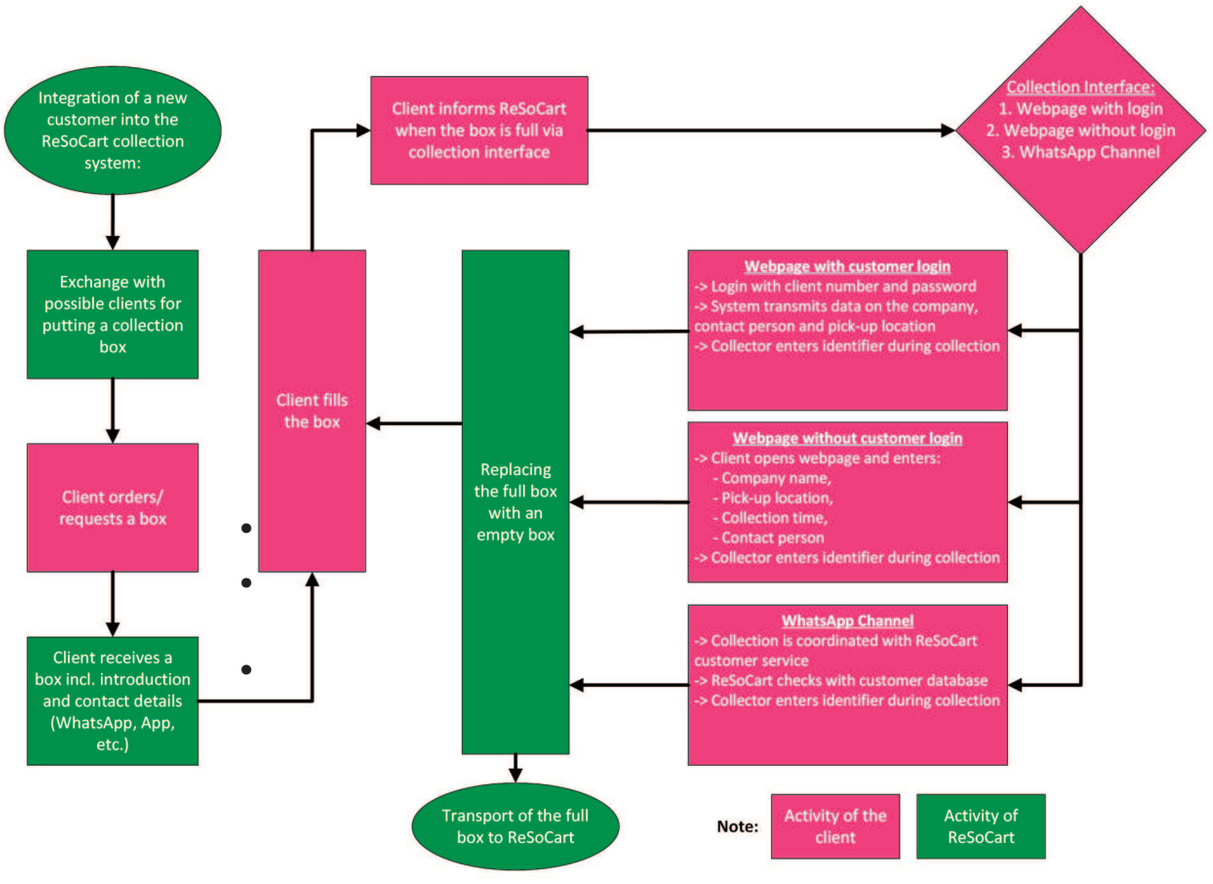

Figure 7: Collection scenario for end-of-life printer cartridges. (own research)

2.4.3 Remanufacturing and Refurbishing

There are different strategies for collecting empty toner cartridges for recycling or remanufacturing and refurbishing. The company can rely on the voluntary return by the customer or buy back the empty cartridges. A third option is to purchase the cartridges from a cartridge dealer (E. Sundin & Ostlin, 2005). The remanufacturing or refurbishing process itself is divided into the steps of collection, consolidation, control, sorting, cleaning, dismantling, refilling, reassembly and testing, as shown in Figure 8. Remanufacturing describes the preparation for reuse by OEMs while refurbishing describes the preparation for reuse by third party operators.

In many cases, refurbishers must cut open the cartridge to refill it, as the OEMs have designed the cartridges to make such a process difficult. Special tools may also be needed for disassembly, as special screws may be installed. Another obstacle for refurbishing are computer chips for function control. These must be reprogrammed so that the cartridge functions after the refilling process are fully available (E. Sundin & Ostlin, 2005).

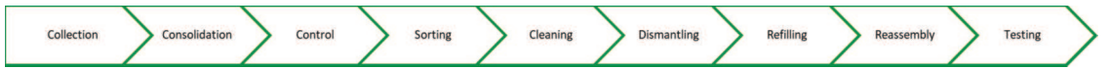

Figure 8: Steps in the remanufacturing and refurbishing process of toner cartridges. (after Erik Sundin et al., 2012)

2.4.4 Recycling

Besides remanufacturing and refurbishing cartridges, it is possible to recycle waste toner cartridges in different processes that can be distinguished in a manual process, semi automatic process and fully automatic process depending on the level of mechanisation. All three recycling options entail different investment costs, running costs and fixed costs. Special safety precautions must be taken when recycling toner cartridges due to their nature and the associated risks to people and the environment. This includes adequate personal safety equipment for employees, technical training in the handling of hazardous waste and technical equipment and installations for the safe handling of toner dust.

After a shredding and cleaning process, the components listed in Table 3 would leave the process.

Table 3: Comparison of the valuable and cost-causing fractions of the process.

Valuable	Cost-causing
Plastic recyclate	Packaging material
Ferrous metal	Misses
Non-ferrous metal	Toner dust
Reusable ink cartridges	Contaminated plastic recyclate
Reusable toner cartridges	

2.5 Challenges specific to toner cartridges

2.5.1 Contaminated plastics

The European Toner & Inkjet Remanufacturers Association (ETIRA) had Newbuilt cartridges tested for hazardous substances in 2019. As a result, four of the cartridges showed highly elevated flame retardant (decaBDE = decabromodiphenyl ether) levels ranging from 2,000 mg/kg to 17,000 mg/kg (European Toner & Inkjet Remanufacturers Association & Remanufacturers Association, 2021). DecaBDE is a polybrominated flame retardant. It was included by ECHA in 2012 as a candidate substance in the list of substances of very high concern due to its persistent, bioaccumulative and toxic properties. The sum of polybrominated flame retardants (PBDEs) is permitted in homogeneous materials up to 1,000 mg/kg according to the RoHS Directive Annex II (up to 17 times the allowed concentration

limits have been found). According to EU Regulation 2019/1021 Art. 7 para. 2 and 3, waste with a PBDE concentration above 1,000 mg/kg must be recovered or disposed of in such a way that the persistent organic pollutants (POPs) it contains are irreversibly transformed or destroyed. According to Annex IV of this Ordinance, the limit values are to be successively reduced to 200 mg/kg by 2028.

During disposal, it should be noted that uncontrolled incineration can lead to the formation of dioxins and furans, which is promoted by the presence of bromine. Furthermore, PBDEs can debrominate by substituting a hydrogen atom for a bromine atom. This can convert the substances into lower congener groups, which may be even more toxic (Umweltbundesamt, 2021).

The plastic material itself consists mainly of hard plastics (e. g. PS, ABS, HDPE, PET), which are rather harmless materials.

2.5.2 Hazardous toner powder

When printing with a laser printer, dust emissions occur. These are complex mixtures of volatile compounds, liquid aerosols and solid dusts, of which toner dust makes up a small part (Gebel, 2015, p. 39). On average, around 8–10 % of toner powder remains in the waste toner tank at the end of a toner cartridge's life cycle, or in the toner tank if it is not completely emptied. This means that a toner cartridge contains a certain amount of dust at the end of its life, which poses a risk to human health and the environment if it escapes from the housing due to improper handling of the cartridge. The greatest potential danger of toner dust lies in the small size of the toner particles.

According to DIN EN 481, dust particles up to a size of 15 µm are considered alveolar (enter the alveoli) and up to 40 µm are considered thoracic (enter the lungs) (German Institute for Standardization, 1993). The average diameter of toner particles is about 10 µm (Koseki, 2014), therefore fall into the alveolar fraction. According to the Technical Rules for Hazardous Substances (TRGS 900) Chapter 2.4. No. 7, an occupational exposure limit of 1.23 mg/m^3 applies to this fraction at an average density of 2.5 g/cm^3 (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2008). Since pure toner dust has a density of approx. 1 g/cm^3, this results in an occupational exposure limit of 0.5 mg/m^3. This means that when recycling toner cartridges, great importance must be attached to occupational safety measures to protect employees from dust emissions.

Other components, some of which are hazardous and depend on the manufacturer's toner formulation, are emitted in very small quantities. Overall, exposure at office workplaces to alveolar dust is estimated at 7 µg/m^3, which is below the limit value. So far, no substance-related illnesses caused by the discharge of laser printers have been proven. People who are sensitive to certain substances could develop allergic reactions in the skin and respiratory tract due to the emissions (Gebel, 2015). The BMUV also confirms the non-hazardousness at the workplace, citing further sources such as the University Clinic Munich (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, 2023). In the case of toner cartridge recycling, the emissions are largely toner dust. By evaluating measurement data and considering the protective measures applied, a concentration of 60 µg/m^3 of alveolar

dust is estimated, which is below the limit value. Thus, no additional measures are required (Gebel, 2015, p. 40). According to Sundin et al., staff complain of irritated eyes and throat when reprocessing cartridges. In addition, the use of compressed air for cleaning the cartridges results in increased noise levels (Sundin et al., 2012).

Due to its small particle size, there is a risk of dust explosion during the recycling process in addition to the health hazard of respirable dust. This risk must be minimised early in the recycling process by installing suitable extraction equipment or by installing a laminar air flow in the process. Furthermore, the risk of a dust explosion also requires special care when unpacking the cartridges after delivery to the recycling process. Large dumping heights during emptying should therefore be avoided.

Even though individual research approaches to the material recycling of toner dust from used cartridges can be found in the scientific literature, toner dust is currently not recycled worldwide. In Germany, it is thermally disposed of in hazardous waste incineration plants due to its harmful nature. In Ghana, there is only one plant for the thermal disposal of hazardous waste, which already accepts toner cartridges from its customers for disposal. However, most toner cartridges that accumulate as waste end up in the country's municipal waste landfills either directly or after collection and improper treatment by the informal sector.

According to experts, market prices for empty toner cartridges and finished products are falling, with logistics costs rising. It is estimated that these will remain permanently elevated, even now after the Corona pandemic. The cheap cartridges from Asia are pulling down the price benchmark. In addition, many consumers look at the price rather than sustainability aspects and thus also accept a loss of quality in the product.

3 Status quo of toner cartridges in Ghana

The following section on the market situation for toner cartridges in Ghana is based on information from a study commissioned by ReSoCart-ED to analyze the market situation for printer cartridges (toner) in Ghana, carried out by Kwarteng & Cudjoe, (2023) from the Mountain Research Institute.

3.1.1 Market analysis of toner cartridges in Ghana

In Ghana, toner cartridges are more common than ink cartridges, especially for commercial printing. According to a Ghanaian government report, about 70 % of businesses in Ghana use laser printers, which require toner cartridges. Inkjet printers, on the other hand, are more common in homes and small businesses. The printer cartridge market in Ghana is highly competitive with several international brands. HP, Canon, Brother, Kyocera, Dell and Samsung are some of the popular brands in the Ghanaian market. These brands compete on price, quality, and features such as cartridge yield. The findings and observations from the field research indicate that in the Ghanaian market, price is the primary consideration when customers make purchasing decisions, often leading them to choose cheaper alternatives instead of the original cartridges.

Research commissioned by Oduro-Appiah & Abankwa-Duodu (2023) lead to the extrapolation that around 355,000 toner cartridges are used annually by universities, government ministries and banks alone.

3.1.2 Import data of toner cartridges

The importation of printer cartridges in Ghana is primarily organised by individual entrepreneurs, both within formal businesses and in the informal sector. The Informal Waste Sector (IWS) isn't directly involved in the import or export of toner cartridges; instead, this task is undertaken by entities such as the Adabraka Toner Dealers Association, whose members have their core business in Adabraka (Accra) and outlets in other regions such as Kumasi, Takoradi and Tamale. These dealers import toner cartridges and sell them to printer users. Defective cartridges are occasionally sent to printer repair shops for refurbishment, including replacement of components such as the recovery blade, drum charger and magnetic roller (Oduro-Appiah & Abankwa-Duodu, 2023).

Ghana's toner and ink cartridge imports for 2020, 2021 and 2022 show some fluctuations for toner cartridges. While the volume of ink imports remains relatively stable. The quantity of ink cartridges imported remains at around 5.000 units. While the quantity of toner cartridges imported increases from 77924 in 2020 to 164049 in 2022. This fluctuation can be attributed to various factors, including shifts in market demand, changes in pricing and advances in

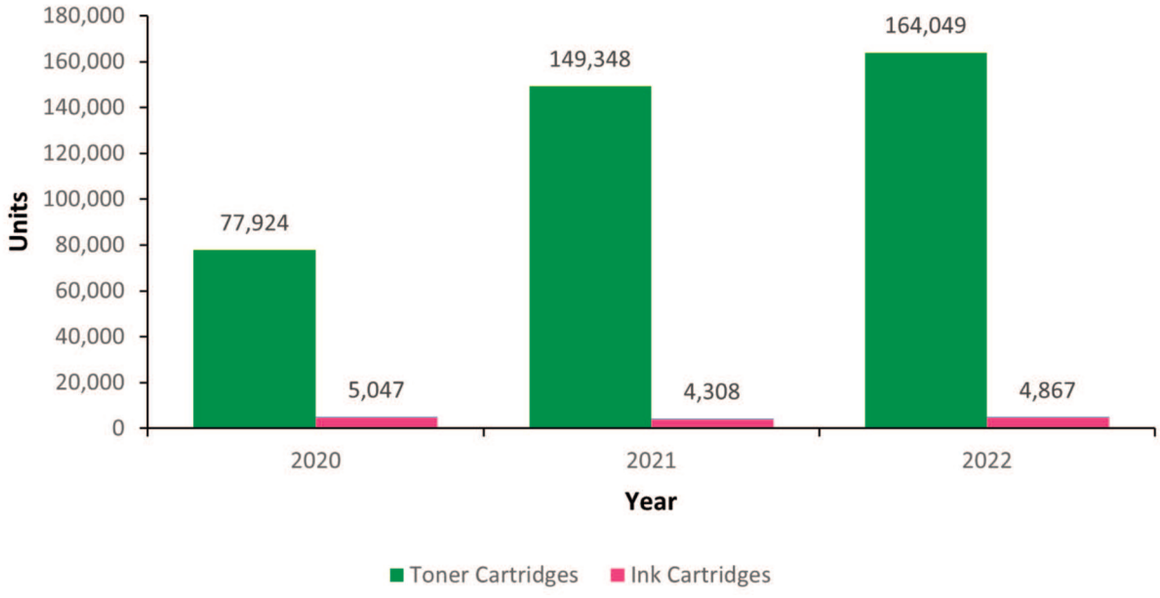

Figure 9: Numbers of cartridges imported to Ghana, Ghana Revenue Authority (Customs Division)

printing technology. The ink-to-toner analysis shows an ink-to-toner ratio of about 1:15 in 2020 and 1:35 in 2022 (Figure 9).

The toner cartridge market is strongly dominated by HP, with Canon a close second. In 2020, a total of 17,100 HP cartridges were imported, while 154 Canon and 95 Xerox cartridges were also imported. These import figures change to 28,176 for HP in 2021 and fall again to 17,476 in 2022. These figures do not represent the total number of HP cartridges placed on the market. They only capture the formal import process, but they give an indication of the increased demand for HP products. In addition, a correct declaration of the imported goods as cartridges cannot be guaranteed, which further increases the actual number of imported units. If the cartridges are wrongly declared as electronic good or spare part, they were not listed in the requested import data. Therefore, the assumption of at least 355,000 units per year is expected to be more realistic than the numbers purely derived from the import data.

3.1.3. Bulk users of toner cartridges

The main users of toner cartridges are universities and printing centres. This is mainly due to their high volume of printing. This means that cartridges need to be replaced more frequently. Print centres can purchase toner powder and refill the cartridges themselves. According to the market survey, the presence of these refill cartridges is quite significant with 39.13% of toner cartridges from bulk users (mainly printing centres). This indicates that a significant portion of the market prefers refill cartridges over other options. Refill cartridges are also sold by the majority of retailers. This confirms that there is a demand for these products and that retailers recognise the need to cater for customers who prefer them.

3.1.4 Remanufactured cartridges

Remanufactured cartridges are used by approximately 17.39% of bulk users. The main reason given by those who choose compatible toner cartridges is their affordability. These cartridges are generally less expensive than original cartridges. The study, which used importers, the Toner Distributors Association, retailers and customs data, found that the majority of these compatible toner cartridges are imported from China, Dubai, the USA and Nigeria.

3.1.5. OEM companies present in Ghana

According to a study conducted by Mountain Research Institute in Accra and Kumasi (Cudjoe & Kwarteng 2023), there are no Original Equipment Manufacturers (OEMs) of printer cartridges in Ghana. This means that local companies in Ghana do not produce printer cartridges to the exact specifications and branding of major printer manufacturers. As a result, the printer cartridge market in Ghana is largely dominated by imported products from international OEMs or third-party suppliers. The availability of take-back schemes for printer cartridges in Ghana is non-existent due to the lack of local OEMs.

Take-back programs are typically set up by OEMs to collect used cartridges for recycling or proper disposal. Without local OEMs, the implementation of such programmes becomes a challenge. The lack of local OEMs for toner cartridges in Ghana can be attributed to several factors, including limited demand for OEM products, difficulties in establishing local manufacturing facilities, or a preference for more affordable third-party alternatives. In addition, the absence of local OEMs could be influenced by market dynamics, such as the dominance of imported printer brands and their associated consumables.

3.1.6 Collection, treatment, and recycling of cartridges in Ghana

Refilling Manufacturers

The presence of refill manufacturers and operators is significant in Ghana. They are responsible for collecting, refilling and refurbishing used printer cartridges. Several key players have emerged in Ghana (especially in the bigger cities). Notable refillers and operators include Dr Ink, Donbills Enterprise, Great Things Ventures, Rchive Solutions and Tonnerfills. (Cudjoe & Kwarteng, 2023)

The refill manufacturers are experts in the field of refilling and refurbishing various types of printer cartridges as well as recovering materials from them. They provide their services to both individuals and corporate organisations. They also actively collect used and damaged cartridges from private and government institutions, including the Universities and other organisations, although this collection is non-official. Typically, the refill manufacturers cooperate with the local printing hubs, where an informal market is established for used and refilled cartridges.

Since these are typically small enterprises in small shops, the limited space available for their activities poses a significant risk to their health. Specific protection equipment for the workers or sealed boxes for the storage of defect cartridges are not available. The disposal of broken cartridges and parts is not recorded, and we must assume they are burnt or end up in landfill.

Collection, treatment and recycling

Consumers, including high-volume users, typically dispose of used printer cartridges by placing them in household or office waste bins. This eventually leads to the municipal solid waste system. These toner cartridges are mixed with other solid waste and are typically not sorted or separated for recovery processes. If the toner cartridges are sent to a recycling facility. Plastic and metal components are usually separated for recovery. Other parts, such as the toner or its residues, are usually landfilled or incinerated.

Prior to treatment methods such as refilling, respondents indicated that a common action is to clean the cartridge internals. This involves removing any residual ink or toner from the cartridge and cleaning the internal components. Others also stated that they inspect the cartridges for damage or defects. This includes checking for physical damage such as cracks or leaks and assessing the condition of critical components such as the print head. Damaged cartridges may need to be repaired or deemed unsuitable for reuse. In addition, operators ensure compatibility between the cartridge and the ink or toner to be refilled. This involves selecting the appropriate ink or toner formulation to match the cartridge specifications. Compatibility tests can be performed to ensure that the refilled cartridge will provide satisfactory print quality and performance. It is important to note that these actions are not standardised across all operators and may vary depending on their specific processes and quality control measures. Each operator may have their own set of procedures and criteria for determining the suitability of cartridges for reuse and material recovery.

In Ghana, the main actors involved in the collection of used and waste toner cartridges are mainly waste management and recycling companies. While there are no specific companies dedicated to the collection of printer cartridges, some major players in the waste management and recycling sector in Ghana are known to collect printer cartridges along with other solid waste like City Waste, Electro Recycling Ghana, Zoomlion Ghana Limited, Jekora Ventures, Coliba Ghana and KCARP. (Cudjoe & Kwarteng 2023)

3.1.7 Waste disposal options for toner cartridges

The discarded cartridges are collected by bulk users, retailers and individuals/shop owners who store them in boxes on their premises. Common disposal practices identified in the research include open burning or placing them in rubbish bins for collection. Some institutions retain cartridges for audit purposes before burning them in the open or placing them in waste bins. Refillers and recyclers dispose of their waste cartridges (plastic) in bins or by open burning after recovering the materials. There is no evidence that waste toner cartridges are exported from Ghana for special treatment.

Exact data on the generation of waste from toner cartridges is not available. However, the Ghana Environmental Protection Agency (EPA) estimates that 170,000 Mg of electronic waste (E-waste) is generated in Ghana each year, with printer cartridges making up a significant proportion of this waste
(Source: https://wedocs.unep.org/bitstream/handle/20.500.11822/33010/Ghana_%20E-MAGIN.pdf?sequence=1&isAllowed=y)

3.2 Legal requirements for waste toner cartridges in Ghana

The following section on the legal situation for toner cartridges in Ghana is based on information from a study commissioned by ReSoCart-ED to analyze the legal situation for printer cartridges (toner) in Ghana, carried out by Karikari & Graf (2023) from the Delegation of German Industry and Commerce (DGIC) in Accra, Ghana.

3.2.1 Waste classification

Ghana is a signatory of the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal (Basel Convention). This convention, commonly referred to as the International Waste Classification System, is a global agreement that aims to control the transfer of hazardous waste between nations. Under this Basel Convention, used printer toner cartridges can be expansively categorized as hazardous waste (although sub-categorized as electronic waste as it forms part of the printer) based on the chemical make-up of the toner according to Environmental Protection Agency. However, under the Hazardous, Electronic and Other Wastes (Classification, Control and Management) Regulations, 2016 LI 2250 used printer toner cartridges are specifically categorized under the codes "08 03 17" and "08 03 18".

- "08 03 17" describes waste printing toner containing dangerous substances. All waste printing toners (full, empty, damaged, destroyed) in this category are considered hazardous waste by the regulation.

- "08 03 18" describes waste printing toner other than those mentioned in 08 03 17, therefore waste printing toner not containing dangerous substances. All waste printing toners (full, empty, damaged, destroyed) in this category are considered non-hazardous waste by the regulation.

- There are no specifications in the act regarding printer toner cartridges intended for refilling. A printer toner cartridge is considered waste as soon as it is disposed or discarded, even if it is disposed or discarded at a collection centre for refilling. There is no category such as "preparation for reuse" as known in other countries and the current regulation does not allow for such a category.

However, the Environmental Protection Agency (EPA) confirmed that currently all waste printer toner cartridges fall under the first category and are all considered hazardous waste, mainly because of the toner residue but also because of issues with harmful microplastic.

Hazardous waste can generally be defined as waste with properties that make it potentially dangerous or harmful to human health and the environment. Carbon black, one of the ingredients in toner, has been categorized as "possibly carcinogenic" (Group 2B) by the International Agency for Research on Cancer (IARC). Toner, as a fine powder, can remain suspended in the air for a while and is considered to have comparable effects to that of dust upon inhalation.

Additionally, printer toner cartridges are not listed as electrical or electronic waste in the 8th schedule of LI 2250, however, the Environmental Protection Agency confirmed that currently printer toner cartridges are treated as electronic and electrical waste and laws are applicable accordingly.

3.2.2 Collection

For the purpose of the ReSoCart-ED project, and on the assumption that a follow-up project will be operating a collection centre for collecting printer toner cartridges, LI 2250 Hazardous, Electronic and Other Wastes (Classification) Control and Management Regulations, 2016, Section 47 applies, and the responsibilities of the collectors are states as follows:

A person who operates a collection centre shall

(a) obtain an Environmental Permit from the Agency in accordance with the Environmental Assessment Regulations, 1999 (LI 1652);

(b) provide to the public through print and electronic media the following information:

(i) physical address of the collection centre.
(ii) telephone number.
(iii) helpline number and
(iv) electronic mail address.

(c) ensure that the electrical and electronic waste that the collection centre collects is stored in a secured manner until the electrical and electronic waste is sent to the registered dismantler or recycler.

(d) ensure that damage is not caused to the environment during the storage and transportation of the electrical and electronic waste;

(e) maintain records of the electrical and electronic waste that the operator handles and make the records available to the agency upon request; and

(f) file annual returns as set out in Form F of the Seventh Schedule with the Agency on or before the 15th of March of the ensuing year.

3.2.3 Transportation

The following rules apply to the transport of electrical and electronic waste and therefore also for waste toner cartridges:

- A transporter of electrical and electronic waste shall transport the waste in an environmentally sound manner.
- A transporter of electrical and electronic waste shall register and obtain a permit from the Environmental Protection Agency in accordance with the Environmental Assessment Regulations, 1999 (LI 1652) before the waste is transported.
- Where an accident occurs at a facility where electrical and electronic waste is processed or during the transportation of electrical and electronic waste, the transporter or recycler shall report the incident to the Environmental Protection Agency in the form set out in Form of the Seventh Schedule.

3.2.4 Storage

In accordance with LI2250 Section 53, the Environmental Protection Agency ensures that a person who stores hazardous wastes

- takes measures to prevent any risk of pollution or damage to humans or animals;
- does not mix hazardous waste with other wastes;
- does not mix different types of hazardous wastes together may cause a risk of pollution or create a problem in the further management of the waste.

As stated in LI 2250 Hazardous, Electronic and Other Wastes (Classification) Control and Management Regulations, 2016 Section 53, a waste manager shall not store waste for more than eighteen months from the date of the generation of the waste or receipt of the waste from the person who generates the waste. However, the re-use, recycling and treatment of waste stored in a facility shall commence within two years from the date of the coming into force.

LI 2250 Section 53

(1) A producer, dismantler, recycler or a person who operates a collection centre:

(a) may store electrical and electronic waste for a period of not more than one hundred and eighty days,

(b) shall maintain a record of the following in respect of the waste:

(i) collection,
(ii) sale,
(iii) transfer,
(iv) storage, and
(v) segregation; and

(c) shall make the records available for inspection upon request by an authorised officer of the Agency

(2) The Agency may extend the period referred to in paragraph (a) of sub regulation (I) up to two years in the following instances

(a) where

(i) a collection centre in a region or district does not have a dismantling or recycling facility which has been registered; or
(ii) a dismantler in a region or district does not have a recycling facility which has been registered; and

(b) where the electrical and electronic waste is required to be specifically stored for the purpose of development of a process for the recycling or re-use of the electrical and electronic waste.

(3) A person who contravenes paragraph (b) or (c) of sub regulation (I) is liable to pay to the Agency an administrative penalty of one thousand penalty units.

3.2.5 Reuse and recycling

Refilling printer toner cartridges is the practice of replacing the toner powder in a cartridge after it has been exhausted. This procedure is primarily performed by specialized service providers or by individuals using refill kits. Cartridge re-filling can significantly reduce printing costs. Compared to purchasing brand-new cartridges, refilling is relatively cheaper, making it an attractive alternative for people and businesses hoping to cut down on printing expenses. The practice of refilling also enhances environmental sustainability by reducing the amount of waste generated. Rather than discarding empty cartridges, replacing them increases their lifespan and reduces the number of cartridges that wind up in landfills. This helps conserve resources, reduce energy consumption, and minimize the environmental impact associated with the disposal of printer cartridges.

There are currently no regulations regarding the refilling of used printer cartridges.
A person who installs and operates a recycling plant shall as per LI 2250 Section 7 shall abide by the following:

- Apply for and obtain a permit in accordance with the Environmental Assessment Regulations, 1999 (L. I. 1652) as stated above.
- The Environmental Protection Agency may impose additional requirements or requirements which are stricter than those set out in the Fourth Schedule depending on the local conditions and characteristics.
- The Environmental Protection Agency may direct otherwise in an emergency to protect human health, property, or the environment, the foreclosure of the facility.

As stated in LI 2250 Section 57, a person in charge of a treatment facility of electrical and electronic waste shall ensure that

- A system has been put in place to provide for the treatment of electrical and electronic waste using the best available technology and the best available practice.
- The electrical and electronic waste is treated at a treatment facility or exported by an approved exporter for treatment outside the country.
- A person who contravenes the provision of this regulation is liable to pay the Environmental Protection Agency an administrative penalty of two thousand penalty units.

3.2.6 Disposal

LI 2250 Section 55 provides the following regulations regarding the disposal of electrical and electronic waste:

- A District Assembly shall not permit the disposal of electrical and electronic waste and other waste in a waste facility of that District Assembly unless the disposal is done in accordance with standards determined by the Environmental Protection Agency.

- A District Assembly which contravenes this law and permits the disposal of electrical and electronic waste in the waste facility of that District Assembly commits an offence and is liable on summary conviction to a fine of not less than two thousand five hundred penalty units and not more than sixty thousand penalty units.

3.2.7 Hazardous waste in Ghana

As stated in the Ghanaian law (Hazardous, Electronic and Other Wastes (Classification, Control and Management) Regulations, 2016 LI 2250), the following conditions must be met before hazardous waste can be purchased, stored, transported, disposed of, or dealt with

- Be registered with the Environmental Protection Agency and issued an environmental permit in accordance with the Environmental Assessment Regulations, 1999
- Application for registration with the Environmental Protection Agency requires the following documentation:
- A copy of the certificate of incorporation in the case of a body corporate
- A copy of a national identification card for individual applicants
- A statutory declaration of the partnership agreement in the case of a partnership
- A copy of proof of proprietorship for an unlimited company
- The required fee determined in accordance with the Fees and Charges Act, 2009

  Any other information the Environmental Protection Agency may request including an environmental impact statement in accordance with the Environmental Assessment Regulations, 1999
- Upon submission and acknowledgement of the application, the Environmental Protection Agency shall validate the information received and either grant or refuse to grant an environmental permit to the individual or organisation.

3.3 Impact of a collection and recycling system on the informal sector in Ghana

The following section on the impact of a collection and recycling system on the informal sector In Ghana is based on information from a study commissioned by ReSoCart-ED to analyze the market situation of printer cartridges (toner cartridges) to identify current informal activities of dealers, collectors and disposers of printer cartridges concerning the return, refilling, reuse or disposal of printer cartridges in Ghana, carried out by Oduro-Appiah & Abankwa-Duodu (2023) from the University of Cape Coast Ghana.

3.3.1 Definition of the Informal Waste Sector

The Informal Waste Sector (IWS) refers to individuals, groups and micro-enterprises that are involved in the purchase, collection, repair, dismantling, recovery and recycling of solid waste, but are not necessarily recognised or supported by the formal authorities, putting them at risk of being considered in breach of legal contracting procedures.

In Ghana, IWS can be identified separately as dealing with municipal solid waste (MSW) on the one hand, and ferrous metals and waste electrical and electronic equipment (WEEE) on the other. In general, however, IWS can be divided into two groups:

1. Informal service providers (ISPs) operating within the service chain, and
2. Informal recyclables collectors (IRCs) operating within the value chains.

3.3.2 Categorization of the Informal Waste Sector

In the MSW sector, informal service providers (ISPs), mainly MSW collectors, use various means such as tricycles and wheelbarrows to collect MSW from households, markets and institutions. The collected waste is then disposed of at designated transfer stations and landfills. Informal recyclables collectors (IRCs) in this sector play a variety of roles.

- Waste pickers collect recyclables such as plastics, non-ferrous metals and glass from landfills,
- while itinerant buyers purchase non-ferrous metals and plastics from households and resell them to actors in the higher value chain.
- Recyclers and processors, known as junk dealers, buy recyclables from waste pickers and itinerant buyers and sell them to formal end-user recyclers.
  Informal innovators transform processed recyclables into marketable goods. The difference between innovators and end-user recyclers lies in the degree of formality in their processes, with innovators being informal actors who produce new products from processed recyclables.

In the WEEE sector, the focus is on recovering valuable materials from discarded electronic equipment. This involves a chain of recycling actors, including

- Itinerant buyers and scrap metal collectors (also referred to as "scrap boys") who buy used/broken or obsolete WEEE (printers, photocopiers, etc.), automotive ferrous scrap, non-ferrous metals and plastics from households, institutions and WEEE repair shops, and send/sell them to their superiors in the scrap yards
- Shed-holders (higher value chain actors), mainly within the scrap yards, repair, dismantle and reassemble broken, obsolete and non-functioning WEEE for sale to consumers and global markets.
- Tech-sector repair and retail shops that repair for a fee damaged but functional WEEE, including laptops, desktops, microwaves, etc., received from households and/or institutions and return them after repair.
- Tech sector repair and retail shops that purchase and repair damaged but functional WEEE, including laptops, desktops, microwaves, etc., received from households and/or institutions and sell them back to willing customers.
- Repairers and retailers in the technology sector who receive (for free or for a fee) and repair (without knowing the condition, i.e. whether it is working or not) WEEE, including flat-screen TVs, laptops, desktops, etc., received from households and/or institutions and sell them back to willing customers.

3.3.3 Organisation and Structure of the Informal Sector

In Ghana, the informal waste sector, particularly E-waste, faces a lack of public sector oversight and institutional recognition. There are no official records of the Informal Waste Sector (IWS), but it is estimated that by 2020 there were 16,000 informal waste actors in the e-waste sector alone, affecting the livelihoods of around 200,000 people and contributing significantly to the country's economy. 52,000 tons of e-waste were produced in Ghana in 2019, of which almost everything was collected and recycled by the informal sector. The wastes were collected in the “well-established door-to-door" procedure due to the lack of public collection systems in wide parts. (K. Owusu-Sekyere et al., Waste Management 139 (2022) 158–167)

Despite their significant contributions, these informal waste actors have not been integrated into the formal waste management system, nor have they received adequate support. There is no single national association for informal waste actors. However, the Ghana Scrap Dealers Association (GASDA) was formed in 1979 and operates mainly in Accra, with other local associations in Kumasi. These associations have leadership structures and hold regular meetings but lack formal governing constitutions.

In Accra, GASDA members, both within and outside the association, are scattered across several areas, including Cable and Wireless (within Bubuashie), Galloway (the 'old Agbogbloshie'), Mortuary Road (the 'little Agbogbloshie') and the main Agbogbloshie, which has recently been evicted by the city authorities. GASDA-related activities were concentrated in "Agbogbloshie", a major hub for scrap metal, especially ferrous scrap from cars and non-ferrous scrap from WEEE.

In Kumasi, the IWS operates in locations such as Dagombaline, Akwatialine and parts of Swame Magazine, known for car repair, refurbishment and parts sales. Despite their scattered presence, these informal waste actors remain essential players in waste management, highlighting the need for formal recognition, support and integration into the overall waste management framework to harness their contribution more effectively.

3.3.4 WEEE material flow

While developed countries typically have formal waste management systems supported by Extended Producer Responsibility (EPR) and Product Stewardship (PSt) regulations, Ghana faces a different scenario due to lax enforcement of environmental laws and the absence of EPR systems. As a result, the collection of e-waste and recyclables has become an entrepreneurial venture for marginalised informal groups, driven by profit and basic livelihoods. Unlike formal systems in developed countries, there is no structured mechanism in Ghana for the direct collection of WEEE or used printer cartridges from households, agencies, or institutions. These items often end up as part of the Municipal Solid Waste (MSW) system, with only a few environmentally conscious individuals or organisations retaining them for future recycling efforts.

The IWS operates through negotiated purchases, acquiring WEEE and valuable materials from a variety of sources, including households, institutions, technology sector repairers and government agencies. Depending on their condition, the collected items are either sent to technology sector repairers or to scrap yards. At the junkyards, individuals known as "scrap boys" work primarily under the guidance of their leaders, the Recyclers. Some use crude methods, such as burning, to extract valuable metals from items such as electrical waste insulators and circuit boards. This practice, which is particularly prevalent at the Agbogbloshie scrap yard, has been criticised for its environmental impact. Leaders (recyclers) within the scrap yards have extensive industry knowledge that enables them to identify valuable and profitable materials. Items deemed to be of little or no value are often not brought to the scrap yards and when they do arrive, in an 'all or nothing' scenario, they are usually dumped in open dumps or incinerated. This is because the main drivers of the IWS are value, profitability, and the market. Currently, printer cartridges (toners) do not fall under these three drivers and are therefore not covered by the IWS.

3.3.5 Projects and collaborations with the Informal Waste Sector

Three organisations were identified as working with the IWS in the E-Waste Sector in Ghana. They are the German Agency for International Cooperation (GIZ), the Environmental Protection Agency of the Ministry of Environment, Science, Technology, and Innovation (MESTI) and the Non-Governmental Organisation (NGO), Caritas Ghana. The GIZ Environmentally Sound Disposal and Recycling of E-Waste in Ghana (referred to as the E-Waste Programme) has three fields, one of which engages directly with GASDA to initiate the transition of the Scrapyard in Old Fadama to a sustainable recycling industrial park in a conflict-sensitive manner.

The other fields consist of the capacity improvement of state actors for managing WEEE and strengthening private sector actors in the recovery of WEEE along the value chain. The EPA under MESTI has an ongoing 5 Year (2020-2025) World Bank Project in which they are establishing five (5) E-Waste Collection and Holding Centres across five regions (Tamale, Sunyani, Kumasi, Accra, and Koforidua) of Ghana to which they have included the IWS as part of their strategy for the collection of E-Waste to the centres. Caritas Ghana engages the IWS in collecting E-Waste for storage as part of their Livelihood Promotion Activity for the marginalised and poor in Society. It is also worth noting that SNEW Ghana (a Netherlands-based Tech Company) engages actors in the E-Waste Sector to collect used mobile phones and laptops to refurbish them for sale to residents and schools in Ghana (and other developing countries) at relatively lower prices.

3.3.6 Toner cartridges and the informal waste sector

There is no recognised company in Ghana that specialises in the treatment or recycling of printer cartridges. The collection process is a combination of efforts by Formal Service Providers (FSPs) and Informal Service Providers (ISPs) dealing with Municipal Solid Waste (MSW), with some going to MSW landfills. A small number of cartridges find their way to scrap yards where they are dismantled for metal recovery, thanks to the "all or nothing" purchasing conditions in the e-waste sector.

However, this activity is not as prominent as for other valuable materials, as the metal components of printer cartridges are of limited importance to scrap dealers and recyclers. Some minor refilling of toner cartridges takes place, mainly by private photocopiers in tertiary institutions, but it's not widespread in households or public institutions.

Although used printer cartridges are classified by the Ghana EPA as hazardous waste with separate treatment requirements, current practice is to include them in the MSW management system. As a result, both MSW and some used cartridges end up in municipal landfills and dumpsites, as observed at sites such as Adepa and Nsumia landfills, which receive MSW from the Greater Accra Region.

3.3.7 Possibility of cooperation with the informal waste sector

Once used in Ghana, cartridges go through no special process to treat and recycle them. It is discarded for collection by waste collection companies and informal waste collection service providers and sent to landfills for disposal. The informal waste sector actors in the e-waste and ferrous metal collection value chain also do not pay much attention to the collection of waste printers and toner cartridges, partly because of its low value, low profitability and lack of readily available market. As already introduced in Section 3.1.6, the refilling of waste toner cartridges occurs more regularly with printing shops and less with public/private institutions and individuals. The IWS in the e-waste sector has shown willingness to act as an agent in collecting toner cartridges from banks, government offices and within residential areas for interested companies, based on the agreement that they will be paid an amount equivalent to the value of the metals in a cartridge. This was used to estimate the incentive value for the trial collection of waste cartridges in the ReSoCart-ED project.

4 Challenges in toner cartridge recycling

4.1 Technical challenges

Waste toner cartridges are complex products that always contain a residual amount of toner dust at the end of their life. This causes problems during collection, transport and subsequent treatment. During collection and transport, the potential contamination of environmental media and human health by toner dust is an issue that needs to be addressed. That's why collection boxes for toner cartridges need to be dustproof so that no dust is released. Also, workers who handle waste toner cartridges must wear personal protective equipment against dust to protect their health from possible hazards. Especially in closed spaces in which toner cartridges are stored or handled, air suction with an air filter system needs to be installed. This is necessary due to the high risk of dust explosion that is connected to airborne toner dust. For the workers personal protection equipment must be provided to protect hands (gloves) and lungs (facemasks) from the toner dust.

In order to obtain a high-quality recycled product from the plastic housings, the plastic types must be identified and sorted after the dust and metal parts have been removed. This requires a testing or identification system or process that allows toner cartridge recyclers to identify the different types of plastic. Especially when clone cartridges are collected, these typically do not have the same plastic quality as the branded ones. Additionally, it needs to be ensured that no flame retardants are contaminating the recycled plastics. Issues with the collection, transportation, and processing of cartridges.

During collection, it is possible that some cartridges are discarded in their original packaging, which increases the effort required by cartridge processors to unpack the cartridge, sort the different wastes, and begin the recycling process.

4.2 Economic barriers

The financial implications of toner cartridge recycling vary significantly based on the chosen recycling process and the prevailing economic context. Investments can range from approximately €50,000 to nearly €1 million, depending on the selected method (refer to the detailed Business Case Document). To establish a viable recycling process, a consistent supply of materials is indispensable. This necessitates the implementation of an effective collection and transportation system prior to commencing recycling activities. Alternatively, partnerships with external collectors or suppliers should be formalized to ensure a steady material supply.

Collection and transportation costs often constitute the largest expense in waste management. Therefore, securing financing for these activities through an extended producer responsibility (EPR) scheme is critical. Ghana's existing eco-levy on imported electronic and electrical equipment, which funds an e-waste management program, presents a potential financing avenue for collection, transportation, and recycling efforts. However, a significant challenge arises from the classification of imported toner cartridges. As these are categorized as printing accessories rather than electronic or electrical equipment, they are exempt from the eco-levy.

To address this, it is recommended that Ghana's regulatory body amend the law to include toner cartridges under the scope of the eco-levy. This amendment would enable the allocation of funds to cover the costs associated with the collection, transportation, and recycling of cartridges.

Recycling toner cartridges, particularly with low annual volumes, is not a viable business model under current conditions. The revenue generated from secondary raw materials is insufficient to offset the operational costs of recycling, particularly the environmentally sound disposal of toner dust through incineration. As a result, exporting collected cartridges should be considered as a temporary measure until adequate material volumes and financing are secured to support local recycling operations.

4.3 Regulatory hurdles

As previously outlined, the classification of toner cartridges as printing accessories creates a financing gap that cannot be covered by the secondary raw material revenue stream. It is imperative that legislative amendments are introduced to guarantee the availability of financial resources for this vital process and the formation of producer responsibility organisations. Additionally, without producer responsibility organisations no activities towards public awareness and research can be launched and financed.

Due to the absence of a widespread collection system, its development must be supported by regulatory measures. Without a working collection system supported by the state (and maybe an incentive system) and consequent penalties for violation of the regulations, a broad awareness for environmentally sound waste treatment will not be reached.

To follow the regulations of an environmentally sound collection and treatment of waste cartridges, a licensing procedure with the EPA Ghana is recommended and mandatory. Within this procedure the different methods of collection, expected amounts, and disposal of must be clarified and approved. The EPA supports in procedure clarification and sharing information about the outlined collection program with stakeholders in the vicinity of the identified value stream.

4.4 Public awareness

In general, the life cycle of toner cartridges is a topic that is often overlooked, even by those who are environmentally conscious and committed to sustainable practices. So public awareness campaigns by producer responsibility organisations or OEMs are essential to educate consumers of toner cartridges about correct disposal, the environmental dangers associated with toner dust and possible return schemes for end-of-life cartridges. These campaigns can be spread by regular (Radio, TV, newspapers) or digital and social media, however, in the latter two, the reachability for people of different ages needs to be considered. It will be part of a successful recycling campaign to raise public awareness, not only with the people that use or work with cartridges. Especially the low-income citizens that work for the informal sector for example in scrap collection or scrap dealing must be informed about the possible hazards affecting their health. Secondary, the protection need for the environment is obvious, but not as present as hunger and costs for a living are. Therefore, people must be trained with specific training program on the scrapyards for their work safety and own health.

5 Opportunities for improvement

5.1 Environmental benefits

Although ISO 14040 outlines minimum requirements under sections 5.2 and 5.3 (German Institute for Standardization, 2009), a standardized and transparent methodology for achieving better comparability between life cycle assessments (LCAs) is still lacking (Institut für Energie- und Umweltforschung Heidelberg GmbH, 2016). As a result, varying assumptions, objectives, framework conditions, and specific scenarios can lead to limited or no comparability between LCAs. This issue is exemplified in a study comparing different brewery packaging materials (Institut für Energie- und Umweltforschung Heidelberg GmbH, 2016, p. 28).

A similar challenge arises in LCAs for toner cartridges. Even a comparison of geographical boundary assumptions reveals substantial differences. For instance, the work of Xanfeon assumes that components are manufactured in various East Asian cities and Australia, with assembly taking place in Hong Kong. The use and remanufacturing occur domestically in the UK, while recycling of OEM cartridges is conducted in Nantes (France) and Genk (Belgium) (Xanfeon, 2008).

In contrast, a second research work identifies Japan as the location for manufacturing and assembly. Usage and repair are conducted in Sweden, with recycling performed by the OEM in France (Berglind & Eriksson, 2002). Both studies concluded that refilling and remanufacturing toner cartridges could result in significant CO2 savings compared to purchasing new cartridges.

However, a study commissioned by HP presented contradictory findings. This research assumes that HP cartridges are manufactured in Japan and Virginia, USA, used across various European countries, and recycled in Britanny, France. For newbuilt cartridges, manufacturing is assumed to take place in China, followed by usage in different European countries and disposal by users. Assembly locations were not specified for either cartridge type. The study concluded that using original toner cartridges results in lower CO2 emissions than using newbuilt cartridges. This finding was attributed to the lower quality of newbuilt cartridges, which leads to increased paper consumption due to misprints (Four Elements Consulting, LLC, 2018). A position paper by EuroVAprint supports this conclusion (EuroVAprint, 2017).

A recycling process for printer cartridges can increase secondary raw material supply and support a transition to a circular economy along the WEEE-valuechain. Investigating this process further shows how recycling can reduce landfill waste, lower the carbon emissions, and prevent harmful chemical pollution.

5.2 Economic incentives

Recycling toner cartridges in low- and middle-income countries (LMIC) like Ghana, offers significant opportunities beyond environmental benefits, including job creation, income generation, and economic empowerment. These initiatives engage various sectors and skill levels, fostering inclusive economic development, particularly within informal and small-scale enterprises.

The potential for job creation is substantial, as recycling activities span multiple stages of the value chain. Collection and transportation efforts can involve informal waste pickers and small enterprises, creating employment opportunities for low-skilled workers, including marginalized groups. Skilled work is required for tasks such as inspecting, sorting, and refurbishing cartridges, with training programs helping to develop a semi-skilled and skilled workforce. Additionally, workers are needed for processing and recycling activities, such as dismantling, cleaning, and recovering materials, particularly in settings where manual or basic equipment is utilized.

Recycling initiatives also open avenues for income generation by capitalizing on market demand for remanufactured cartridges and recovered materials. Remanufactured cartridges, often sold at a lower price than original products, appeal to cost-conscious consumers, supporting micro and small enterprises while retaining profits within the community. Furthermore, recovered materials like plastics and metals can be sold to local industries, creating an additional revenue stream. These initiatives also foster entrepreneurial ventures in areas such as collection, repair, and resale, with potential collaborations with local businesses, including print shops, to expand opportunities.

In terms of economic empowerment, recycling initiatives can drive local industrial growth and sustainable development. Recycling centers or cooperatives can act as hubs for community-based economic activities, promoting self-reliance. Skill development programs that train workers in repair, remanufacturing, and recycling not only enhance employability, but also build a skilled workforce that can transition to other industries. By producing remanufactured cartridges domestically, LMICs can reduce reliance on imports, improving trade balances and strengthening local economies.

In summary, toner cartridge recycling offers a multi-faceted approach to addressing environmental challenges while simultaneously supporting economic growth and social development in low- and middle-income countries.

6 Case study: Trial collection for printer cartridges

6.1 Reasoning for a trial collection

As there is no local production of toner and ink cartridges in Ghana, all printing accessories are imported. However, no precise statistics are kept on which types of cartridges are imported. In addition, the number of imported cartridges is uncertain due to assumed errors in the declaration. The lack of an obligation to pay an eco-tax on the products could be seen as one reason for this datagap. Additionally, since land borders shared with neighbouring countries may be used to informally transfer electronics and other goods, import statistics become less traceable. In conclusion, this makes it very difficult to measure the real market volume and its composition from the official statistics. The ReSoCart-ED team has therefore commissioned a sample collection (License by the EPA: HA 611/618/01) with a network of Ghanaian organisations who have the required licences to collect the cartridges (E-waste collection licenses). The results should provide information on the composition and volume of the market to assess whether the feedstock for a recycling process is large enough to justify the implementation of such a process.

6.2 Trial collection setup

The local partners Caritas Ghana and MAREDES as coworking institutions were contracted to collect toner cartridges in Accra, while their extended collection network collected cartridges in Kumasi and Tamale. The collection was supported by cold acquisition through telephone and e-mail as well as mouth to mouth propaganda and a social media campaign to raise awareness. The social media campaign included informative pictures and texts as well as an informative video. Launched by the EPA several information activities for private companies and public entities were carried out and two newspaper advertisements were released in the Daily Graphic, which is the newspaper with highest print run in Ghana. The collection areas were differentiated into three sectors:

- ***Public sector:*** *The public sector includes organizations and activities owned, controlled, and operated by the government at various levels (local, regional, national). These entities are funded by taxes and serve to provide public goods and services*
- ***Private sector:*** *The private sector consists of businesses and organizations owned by individuals, groups, or corporations. Its primary goal is to generate profit through goods and services for consumers*
- ***Informal sector:*** *The informal sector includes unregistered, unregulated, and often small-scale economic activities. These operate outside formal governmental oversight, which means participants are not taxed, licensed, or protected by formal labor laws*

During collecting the cartridges in the three areas and sectors they were sorted according to four categories. In addition, we expected few cartridges in original packaging probably disposed of due to not any longer working printers they fit in. The four categories were chosen

to evaluate the potential for reusability in the market – thus, they would achieve different values for the recycling company. They were as follows:

- *OEM-undamaged: These are toner cartridges that are manufactured by the Original Equipment Manufacturer (OEM) (e.g., HP, Canon, Brother) and are in perfect, undamaged condition*
- *OEM-damaged: These cartridges are manufactured by the Original Equipment Manufacturer (OEM) but have incurred some form of damage (physical or functional)*
- *Non-OEM-undamaged: These are toner cartridges produced by third-party manufacturers (not the OEM) that are in undamaged condition*
- *Non-OEM-damaged: These are toner cartridges produced by third-party manufacturers that have incurred damage (physical or functional)*

There are a lot of other categories, but we chose to use these, since it would be possible to separate in these categories even for unexperienced personnel after a short introduction to the specifications to be found on a cartridge. Out of the same reason, we chose that further categories such as "Printer Cartridge" or "Copier Cartridge" were omitted as well as the sorting or specific cartridge types for specific printers or production years.

6.3 Trial collection results

The initial goal of the trail collection was to collect as many cartridges as possible with a maximum amount of 40.000 cartridges. This limit was set due to the available funding amount in the project which can be used for an incentive-based collection system and environmentally sound disposal of the collected cartridges. The trial began in April 2024 and lasted six months until end of October 2024.

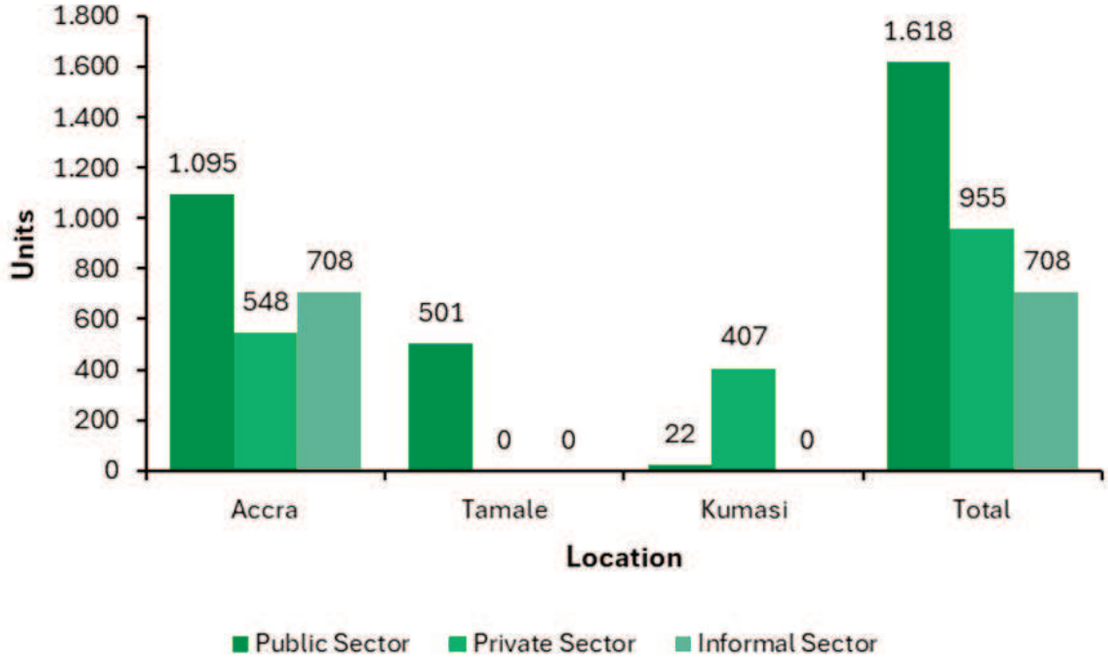

Figure 10: Cartridges collected during the trial, broken down according to location of collection.

As mentioned only for this trial collection each collected cartridge was incentivised by 0,20 € for the contracted collector. This price is higher than the material value of the waste cartridge, but it was intended to allow the contracted partners to pay a reasonable incentive and cover additional costs such as storage and transport. It has to be mentioned that this high incentive could never be achieved in a free market scenario as most toner cartridges have even a negative monetary value when they reach the end of their life, since their disposal/recycling cost should be expected higher than the material value.

The primary objective was to collect between 30,000 and 40,000 cartridges. However, the initiative yielded only counted in 3,281 cartridges, representing less than 10 % of the anticipated target. This significant shortfall underscores the need to reassess and optimize collection strategies for used cartridges.

The collection in Ghana's capital Accra showed the highest results with 2.351 (see Figure 10) cartridges collected, ranging before Tamale with 501 pieces and Kumasi with 429. About half of the total cartridges (49,3 %) were sourced within the public sector of the country including universities, hospitals and development organisations. One third (29.1 %) was sourced in the private sector, while the remaining 21.6 % were sourced from informal sector participants. The initial source of the informal sector participants could not be retrieved. Although the numbers lack behind the expected goal of the trial collection, they show the potential of an organised collection system as the collection only lasted six months and only a handful of organisations were actively participating. A more professional collection system could probably achieve a much higher yield than the obtained results.

Figure 11 depicts the fractions of the OEM vs. Non-OEM (top left) and potentially re-usable or non-re-usable (top right) cartridges in the collection. Only approximately 67% of the collected items were OEM cartridges (almost only HP), which shows that there is a significant fraction of non-original cartridges on the market, which potentially cannot be refilled or refurbished. In addition, roughly 35% of the collected cartridges were damaged and by this not reusable. The conclusion of these data shows that there is a huge fraction of cartridges at end of life, that require an environmentally sound recycling and disposal of treatment.

The total fractions of the cartridges collected in the three targeted cities, as depicted in Figure 11 in the third graph, reflects, that the collectible number of cartridges follows the economic productivity. It can easily be expected, that in the larger cities with the highest population and economic productivity in Ghana the most cartridges will be available. This is because the head offices of companies and public infrastructure is located there. Once again this shows the potential of a collection system set up specifically for formal public and private entities.
Although the total numbers were much lower than expected in the first place, we could identify from these indicators that a recycling at larger scale could be successful and positive for the people, environment and economy under further explained circumstances in the following sections.

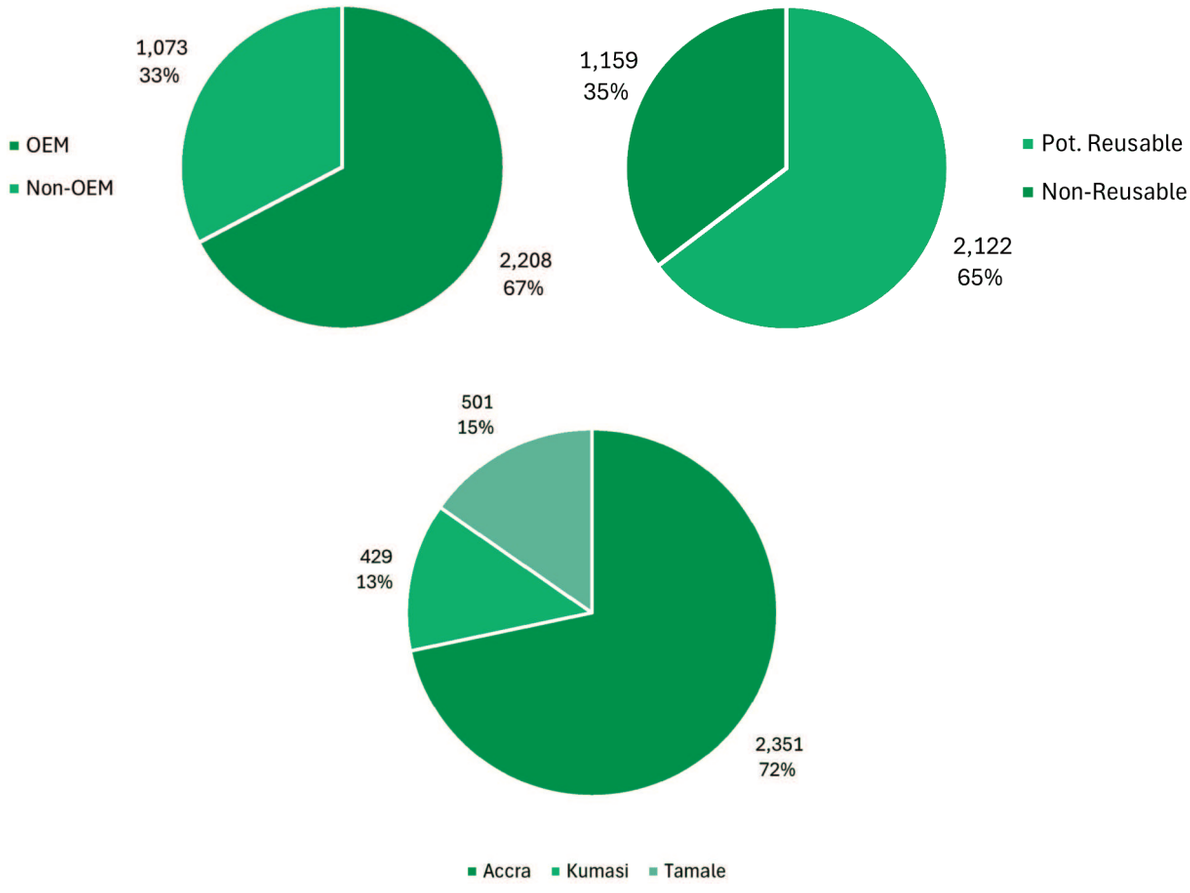

Figure 11: Cartridges collected during the trial. Left: broken down according to OEM/Non-OEM category; Right: broken down according to Pot. Reusable/Non-Reusable category. Bottom: broken down according to collection place.

6.4 Trial collection lessons learned

What Worked Well

The project demonstrated strong teamwork and effective communication among the participants, which were significant factors in achieving the progress made. The organisational framework and the support provided to Ghanaian partners were also well-executed. One of the standout successes was the collaboration with Ghana's EPA, which granted approval to collect hazardous waste, making the project one of the first to achieve such a milestone in the region.

Challenges and Areas for Improvement

The project fell short of its collection targets, underscoring the need for improved strategies. There was a clear disconnect between the enthusiasm shown by stakeholders during initial discussions and their actual participation. For example, the public sector contributed minimally, and the lack of proper engagement with refillers and repair businesses created resistance and misunderstanding about the project's intentions. Data collection was another issue, with inconsistencies and incomplete reports, particularly from Tamale and Kumasi, and errors such as misclassification of non-OEM cartridges as OEM. Communication challenges

also emerged, including rather late deployment of social media campaigns and a heavy reliance on time-consuming manual follow-ups like phone calls, which limited efficiency.

Proposed Improvements

The team identified the importance of engaging key stakeholders, such as refillers and repair businesses, early in the project to align goals and strategies effectively. Conducting workshops and campaigns ahead of the trial would have built trust and clarified objectives. A bottom-up approach, involving these stakeholders from the outset, was suggested as a better strategy compared to the top-down method used. The German team also recognized the need for more on-site support, proposing that they spend extended periods in Ghana to offer hands-on assistance. Simplifying the collection system to minimize the effort required from participants was highlighted, along with adjusting incentives to better match local realities. The absence of full-time project staff was also a limitation, leading to a recommendation for future projects to budget for dedicated personnel. Lastly, the team emphasized the need for better education campaigns about environmental risks and the economic benefits of proper cartridge disposal to motivate participation.

Financial and Operational Considerations

The financial incentives offered during the project were inadequate to drive significant participation. The team noted that two Ghanaian Cedis per cartridge was not sufficient motivation. There was also a debate about the effectiveness of performance-based payment versus upfront payment. Some felt that performance-based incentives might encourage greater effort, while others observed that upfront payments did not always guarantee better results. A mixed payment model, combining a base salary with bonuses for performance, was proposed as a potential solution for future projects. The team also emphasized the need for better resource allocation, particularly for sustained communication and follow-up efforts.

Final Steps and Deliverables

To conclude the project, the team planned to finalize audits in Kumasi, Tamale, and Accra, with accurate numbers expected by mid-month. These figures would be used to produce a comprehensive final report and a white paper on cartridge recycling in Ghana. There was also interest in expanding collection-centres and refining systems for improved operations in future initiatives.

Broader Reflections

The team reflected on cultural and systemic barriers, such as resistance to environmental practices and weak enforcement of waste disposal laws, which posed significant challenges. Stakeholders often prioritized monetary incentives over environmental concerns, underscoring the need for practical adjustments to the project's design. Ultimately, the team expressed optimism about applying these lessons to future initiatives and highlighted the potential for expanding collection efforts with better planning and engagement.

The technological approaches of toner cartridge recycling can be differentiated in three process types:

- Manual dismantling
- Semiautomatic dismantling
- Fully automatic processing

7 Technological approaches and recycling options for toner cartridges

The different process types differ concerning the key aspects of process management: process flexibility, investment cost, error susceptibility, throughput rate, manual labour intensity, dangers to human health, availability, scalability, maintenance complexity and energy consumption. The following table 4 shows the process types and the different process related aspects.
The table 4 shows that the semiautomatic process poses a middle way between the manual process and the automatic process concerning all process criteria. An exception being the danger of explosion that is high in all three process types.

In a manual or semimanual process, the cartridges are cracked with handheld tools or semiautomatic machines like drill press, bandsaw or alligator shear. The dust is removed using

Table 4: Comparison of different process criteria and the process types. (Own research)

Process Criteria	Automatic Process	Semi-Automatic Process	Manual Process
Process Flexibility	Low	Middle	High
Investment Cost	High	Middle	Low
Error Susceptibility	Low	Middle	High
Throughput Rate	High	Middle	Low
Manual Labour Intensity	Low	Middle	High
Dangers to Human Health	Low	Middle	High
Danger of Explosion	High	High	High
Availability	High	Middle	Low
Scalability	Low	Middle	High
Maintenance Complexity	High	Middle	Low
Energy Consumption	High	Middle	Low

compressed air lances on converted welding tables with dust extraction. After the dust is removed from the waste cartridges, the metal parts are separated, the cartridge can be sorted according to its plastic type and colour and shredded to small flakes. The flakes can be remarketed as secondary raw material on the market.

In a fully automatic setup, the cartridges can be shredded for recycling by using a four-shaft shredder, for example. The resulting toner dusts can either be extracted or inertized with nitrogen or with the addition of calcite. This is important because deflagration or explosions can occur. A vibrating screen technique can then be used to remove residual toner adhesions. Ferrous and non-ferrous components are then separated, for example with the help of an overbelt magnet. The remaining plastic fraction is then sorted according to plastic type. Adhesions of labels on the cartridges are problematic because they consist of different types of plastic. The experts see the different plastic qualities of the cartridges as a further challenge. While the quality of the OEMs' cartridges is mostly good, there are also inferior qualities, for example, in counterfeit products from third party manufacturers (i. e. from China). The quality of remanufactured cartridges varies widely. The shredded material from these can get into the recyclates and thus hinder clean and compliant recycling.

Chapter **11.3** in the annex gives an overview about different process scenarios, that were developed during the project. The manual **(Figure 12)** and semiautomatic process **(Figure 13)** were developed from the flowchart that was produced based on the process executed by WBM Ltd. in Manchester - semiautomatic recycling of toner cartridges. The process flowcharts for the automatic processes are based on the process provided by Doppstadt **(Figure 14,** thermal pretreatment) and US Automation Systems (**Figure 15,** mechanical treatment).

8 Implementation Roadmap

8.1 Short-Term Goals

At the current state, the short-term goal in Ghana can be set to one major goal: Raise awareness. How a higher awareness for the hazardousness of end-of-life toner cartridges can be raised, is described in the following.

Increasing awareness of hazardousness of toner cartridges for the environment and humans Through the following strategies, you can inspire positive action and contribute to a more sustainable future. To effectively spread awareness about the hazardousness of toner cartridges, the following methods can be considered:

- Educational Initiatives: Host engaging workshops or webinars to educate people on the environmental and health impacts of toner cartridges. Share visually appealing infographics and videos that explain the risks and highlight eco-friendly solutions.
- Collaboration with Schools and Offices: Partner with schools, offices, and organizations to implement policies promoting eco-friendly cartridge usage and recycling. Organize cartridge collection drives to ensure proper disposal and recycling.
- Social Media Campaigns: Leverage social media platforms like Instagram and Twitter to share quick facts, challenges, and practical tips for reducing toner waste. Use attention-grabbing statistics, such as the millions of cartridges discarded annually, to emphasize the environmental toll.
- Corporate Responsibility: Encourage businesses to adopt green printing practices and prioritize partnering with manufacturers who offer refillable or recyclable cartridges. Showcase these efforts as part of their corporate social responsibility initiatives.

8.2 Medium-Term Goals

The medium-term objectives are to change the legal status of toner cartridges from office equipment to electronic and electrical equipment and to make this product category eligible for the eco-levy. The eco-levy claim will enable the implementation of an EPR scheme that will fund collection activities in Ghana to implement a free collection system for used toner cartridges from the public and private sectors. The changes should also affect the ink cartridge fraction.

Change legal status and claim eco-levy for printer cartridges

To implement and enforce an eco-levy on printer cartridges, it is crucial to establish appropriate legal and regulatory frameworks. The levy should apply to all new printer cartridges, whether imported or locally manufactured, with exemptions or reduced rates for

eco-friendly options such as remanufactured cartridges. A flat fee or percentage-based levy structure can be adopted, with higher rates imposed on single-use or non-recyclable cartridges. The collected revenue must be allocated to targeted environmental programs, including collection systems, recycling systems, public awareness campaigns, and initiatives fostering green innovation.

Implement an EPR-scheme

An Extended Producer Responsibility (EPR) scheme is a policy approach that holds manufacturers accountable for the entire lifecycle of their products, including end-of-life management. To implement an EPR scheme for printer cartridges, the first step is to enact laws that mandate EPR, defining specific obligations for producers, importers, and distributors. Manufacturers would be required to register with a national EPR authority and set annual collection and recycling targets to ensure their compliance. To track adherence to these targets, a monitoring system should be established, which includes regular reporting and audits. Penalties would be imposed on those who fail to meet the requirements. Additionally, public awareness campaigns must be launched to educate consumers on the importance of recycling printer cartridges and provide clear instructions on how to return them, fostering active participation in the recycling program.

Implement free of charge collection system

To facilitate the recycling of printer cartridges, accessible drop-off points should be established in convenient locations such as offices, schools, public libraries, and retail stores. For larger contributors, partnering with logistics companies to offer on-site pickup services will ensure hassle-free participation. It is also essential to collaborate with certified recycling firms to handle the collected cartridges responsibly, ensuring they are processed in an environmentally sustainable manner. To track the program's effectiveness, the number of cartridges collected should be monitored, and detailed reports on the program's impact should be shared. These success stories will help motivate ongoing involvement and foster accountability among participants.

Reuse locally or export for refill

To promote sustainability and reduce waste, collected cartridges can be either refilled and reused locally or exported for refilling to trusted partners abroad. By refilling cartridges locally, we can create a circular economy, reducing the demand for new cartridges and minimizing environmental impact. This also supports local businesses and creates jobs in the recycling and remanufacturing sectors. Alternatively, cartridges can be exported to international partners specializing in refilling and remanufacturing, leveraging established infrastructure and expertise. Either approach ensures that cartridges are reused, reducing the need for new resources and contributing to a more sustainable and eco-friendlier lifecycle for printer cartridges.

8.3 Long-Term Goals

The long-term goals for sustainable cartridge management include the establishment of a full-scale collection infrastructure, a comprehensive refill system for reusable printer cartridges, and an efficient recycling system for non-reusable printer cartridges.

The full-scale collection infrastructure aims to create a widespread network of accessible drop-off points and collection services, ensuring that both consumers and businesses can easily return used cartridges for recycling or refilling. This infrastructure would be designed to handle large volumes of cartridges, creating a seamless process for participation.

In parallel, the full-scale refill system for reusable cartridges focuses on developing local refill facilities or collaborating with global partners to refill and remanufacture cartridges. This system would reduce the need for new cartridges, supporting a circular economy and promoting resource efficiency.

For non-reusable printer cartridges, the goal is to implement a robust recycling system that responsibly processes cartridges that can't be refilled. This would involve partnering with certified recycling companies to ensure these cartridges are broken down and the materials are properly recycled, minimizing waste and environmental harm.

Together, these initiatives will contribute to a more sustainable printing industry by reducing e-waste, conserving resources, and fostering eco-friendly business practices.

9 Conclusion

The waste-management of toner cartridges in Ghana faces significant challenges, stemming from a lack of a structured national collection systems, inadequate funding mechanisms, and reliance on informal practices such as refilling and landfilling. While as assumed large quantities of toner cartridges are used in the country, the absence of reliable market data hampers planning for a sustainable recycling process. Additionally, the high cost of entering the waste management market and the absence of regulated disposal structures prolong project initiation times and limit the development of a formalized system.

Currently, there is no recycling of toner cartridges in Ghana; informal sector activities dominate, with no contributions from an ECO-Levy or distributions through the e-waste fund to support proper recycling efforts. Economic viability is further constrained by the low material value of used cartridges, which cannot offset process costs without substantial throughput. Compounding these challenges are occupational and process safety risks, including microplastic contamination and explosion hazards, which demand stringent safety measures.

To address these issues, a phased and strategic approach is essential. Initial efforts should focus on setting up manual recycling processes, which can be expanded into semi-automated systems as collection networks and throughput increase. Concurrently, building a robust collection infrastructure and fostering stakeholder networks, including partnerships with the informal sector, will be critical. Advocacy for policy reforms - such as levying an ECO-fee and ensuring the allocation of funds for structured recycling - will be pivotal in creating a sustainable system.

Raising awareness among consumers and policymakers about the environmental and health impacts of improper disposal is equally crucial, alongside efforts to gather reliable market data to guide future initiatives. While the current economic and regulatory landscape poses barriers, these recommendations provide a pathway toward an environmentally sound, economically viable toner cartridge recycling system in Ghana.

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11 Annex

11.1 Technology providers for recycling processes

TECHNOLOGY	NAME AND ADDRESS	CONTACT DETAILS
Complete toner cartridge recycling system	URT Umwelt- und Recyclingtechnik GmbH Am Hammersteig 5a 97753 Karlstadt Germany	Phone: +49 9353 9068-0 Fax: +49 9353 9068-68 info@urt-recycling.de https://www.urt-recycling.de Phone: +49 421 63 96 96 40
Technology	**Name and Address**	**Contact Details**
Big Bags fulfil the safety factor 5:1, TRGS 519 or TRGS 521	Bindemann Verpackung Treuburger Platz 2 D-28779 Bremen Germany	Fax: +49 421 83 54 69 10 info@bindemann-verpackung.de https://www.bindemann-verpackung.de/
Big Bags fulfil the safety factor 5:1, TRGS 519 or TRGS 521	Storopack Deutschland GmbH + Co. KG Untere Rietstraße 30 D-72555 Metzingen Germany	Phone: +49 800 1874 001 direct-online@storopack.com http://www.storopack.de
THE ALL-ROUNDER - APRON + BASE CLOSED - 1,000 LITRES - UNCOATED/COATED	AVS Ahlheim Verpackung und Service AG Olbrichtstr. 8 69469 Weinheim	Phone: +49 (0) 6201- 48827 10 Fax: +49 (0) 6201 – 488 27 27 info@big-bag.com https://big-bag.com
Identification and weighing of big bags (scales) Hanging, crane, and platform scales		
Hanging, crane, and platform scales	Steinberg Systems / expondo GmbH Dessauer Str. 28-29 10963 Berlin Germany	Contact via website https://www.steinbergsystems.de

TECHNOLOGY	NAME AND ADDRESS	CONTACT DETAILS
Hanging, crane, and platform scales	Kern / Ascuro Service GmbH Eggenweg 24a 79540 Lörrach Germany	Phone: +49 7621 510 96 63 info@kern-waagen.shop https://www.kern-waagen.shop/
Hanging, crane, and platform scales	Waagenet AF GmbH Christburger Str. 12 10405 Berlin Germany	Phone: 030 255 59824 E-mail: info@waagenet.de https://eu.waagenet.de
Sorting by type of plastic and application Near infrared (NIR) spectral analysis systems		
Near infrared (NIR) spectral analysis systems	trinamiX GmbH Industriestraße 35 67063 Ludwigshafen Germany	Phone: +49 621 60-77750 info@trinamix.de https://trinamixsensing.com/plasticsorting
Near infrared (NIR) spectral analysis systems	Fraunhofer-Institut für Photonische Mikrosysteme IPMS Maria-Reiche-Straße 2 01109 Dresden Germany	Phone: +49 351 8823-0 info@ipms.fraunhofer.de https://www.ipms.fraunhofer.de/
Crushing and breaking up Hand and band saw		
Puksaw 150mm	Presch Tools GmbH Bülterei 9 27777 Ganderkesee Germany	Phone: +49 4223 9699 490 info@presch-tools.com https://www.presch-tools.de/
Mini metal saw (3 in 1: hacksaw, flexi saw, or angle saw) 300mm	Presch Tools GmbH Bülterei 9 27777 Ganderkesee Germany	Phone: +49 4223 9699 490 info@presch-tools.com https://www.presch-tools.de/
Portable metal band saw BS-125V	Georg Noll Werkzeugmaschinen GmbH Im Taubental 4 41468 Neuss Germany	Phone: +49 2131 / 38 06 – 0 Fax: +49 2131 / 38 06 – 59 team@noll.de https://www.noll-maschinen.de
Horizontal bandsaw HB 150	KNUTH Werkzeugmaschinen GmbH Schmalenbrook 14 24647 Wasbek Germany	Phone: +49 4321 – 609 0 Fax: +49 4321 – 689 00 info@knuth.de https://www.knuth.com

TECHNOLOGY	NAME AND ADDRESS	CONTACT DETAILS
Wood bandsaw MJ9	Paulitschek Maschinen- und Warenvertriebsgesellschaft mbH Zeppelinstraße 3 89231 Neu-Ulm Germany	Phone: +49 731 23232 support@paulimot.de https://www.paulimot.de
Bandsaws	Graf-Stauffenberg-Kaserne Binger Straße 28 | Hall 120 DE - 72488 Sigmaringen Germany	Phone: +49 7571 755-0 info@hokubema-panhans.de www.panhans.de
	Alligator shears	
Hydraulic alligator shears: GRS-AS/60	GRS Feinwerkmechanik Unterfeldstr. 4 86554 Pöttmes Germany	Phone: +49 176 2747 2441 info@grs-feinwerkmechanik.de http://www.grs-feinwerkmechanik.de/de.html
Hydraulic alligator shears: DTX 200	Proroh Günther Fromm Ostlandstr. 7 59387 Ascheberg Germany	Phone: +49 2599 740168 Signal: +49 163 1695355 info@proroh.de http://www.proroh.de
	Drill press station	
Bench drilling machine ALZ-STAR 18-T/S	ALZMETALL GmbH & Co. KG Harald- Friedrich- Straße 2-8 83352 Altenmarkt Germany	Phone: +49 8621 88 0 Fax: +49 8621 88 213 info@alzmetall.com https://alzmetall.de/
Bench drilling machine DP16VLS	Scheppach GmbH Günzburger Str. 69 D-89335 Ichenhausen Germany	Phone: +49 8223 4002 0 Fax: +49 8223 4002 20 info@scheppach.com https://www.scheppach.com/de
Bench drilling machine	Theodor Eberlei GmbH & Co. KG Stahlstraße 37 26215 Wiefelstede Germany	Phone: +49 (0)44 028 63 66-0 Fax: +49 (0)44 028 63 66-49 info@eberlei-maschinen.de
	Shredding of cartridge casings	
Recycling machine type DS4 for shredding toner cartridges Separation of toner dust and separation of metal parts	Verfahrenstechnik GmbH Germakehre 7 D-25479 Ellerau Germany	Fax: +49 4106 7672-50 info@bomatic.de https://bomatic.de/de/startseite/

TECHNOLOGY	NAME AND ADDRESS	CONTACT DETAILS
Primary crusher A PC 200 with counter-rotating crushing rollers or cutting granulator ROTOPLEX RO 28/40 for electronic scrap	HOSOKAWA ALPINE Aktiengesellschaft Peter-Dörfler-Str. 13-25 86199 Augsburg oder Postfach 10 11 51 86001 Augsburg Germany	Phone: + 49 821 5906 – 0 Fax: + 49 821 5906 – 101 marketing@alpine.hosokawa.com https://www.hosokawa-alpine.de/
Data disc shredder type VDS	Vecoplan AG Vor der Bitz 10 56470 Bad Marienberg Germany	Phone: +49 2661 62670 Fax: +49 2661 626770 welcome@vecoplan.com https://vecoplan.com/de
Cleaning of casings on welding table		
TableBox Air (with lighting and silencer on request)	ESTA Apparatebau GmbH & Co. KG Gotenstraße 2-6 89250 Senden Germany	Phone: +49 7307 804-0 Fax: +49 7307 804-500 info@esta.com https://www.esta.com/
DraftMax Eco (without filter) or DraftMax with HEPA filter	Plymovent GmbH Rolandsecker Weg 30 53619 Rheinbreitbach Germany	Phone: +49 22 24-91 99 30 Fax: +49 22 24-91 99 3-30 info@plymovent.de https://www.plymovent.de
Air purifiers, extraction systems and compressed air systems		
Air purifier AIC 1000 220-240V	Hilti Deutschland AG Hiltistraße 2 86916 Kaufering Germany	Phone: +49 800 - 888 55 22 Fax: +49 800 - 888 55 23 de.kundenservice@hilti.com https://www.hilti.de
SmartMaster or ProfiMaster extraction unit with filter class E12	KEMPER GmbH Von-Siemens-Str. 20 D-48691 Vreden Germany	Phone: + 49 25 64 68 – 0 Fax: + 49 25 64 68 -120 mail@kemper.eu https://www.kemper.eu/de
FK 120 compact + 6-piece compressed air set	HuW24 e.K. Germendorfer Dorfstr.37 16515 Oranienburg OT Germendorf Germany	Phone: + 49 3301 689756-0 Fax: + 49 3301 689756-99 info@huw24.de https://weldinger.de/

TECHNOLOGY	NAME AND ADDRESS	CONTACT DETAILS
Small dust extractor of the TK series	ESTA Apparatebau GmbH & Co. KG Gotenstraße 2-6 89250 Senden Germany	Phone: +49 7307 804-0 Fax: +49 7307 804-500 info@esta.com https://www.esta.com/
Dust consolidation in barrels		
Lidded containers/drums made of PE and steel (12 l - 213 l)	Siepe GmbH Hüttenstraße 185 50170 Kerpen Germany	Phone: +49 2273 569-0 Fax: +49 2273 569-29 info@siepe.net https://www.siepe.net
Lidded drum 120 litres made of HD-PE with lid and UN approval	H. H. Rotert GmbH & Co. KG Niedersachsenstr. 5 49186 Bad Iburg Germany	Phone: +49 5403-79690-0 Fax: +49 5403-79690-19 info@rotert.com https://www.rotert.com/

11.2 Expert interview results on the global toner cartridge market

Agreements Among Experts

The interviewed experts unanimously highlight the significant environmental issues posed by toner cartridges, focusing particularly on the challenges in recycling and the environmental costs of disposal methods like incineration. They emphasize the high carbon footprint associated with cartridge production, transportation, and recycling, calling for local solutions to mitigate environmental impacts. Recycling toner cartridges effectively is a common challenge, with all experts pointing to issues like material complexity, contamination by toner powder, and a lack of standardisation in design. These issues lead to high costs and logistical challenges in collecting, sorting, and processing used cartridges. Specific barriers include the high dust content in shredded cartridges and the presence of brominated flame retardants in some plastics.

A shared concern is the role of Original Equipment Manufacturers (OEMs), whose strategies—such as incorporating proprietary chips and firmware updates—make it increasingly difficult to reuse and remanufacture cartridges. Additionally, OEMs fail to provide spare parts or support remanufacturing processes, further complicating efforts to extend cartridge lifecycles. Another consensus point is the dominance of low-cost new-build cartridges from Asian markets. While these cartridges make printing more affordable, they are often of lower quality, harder to recycle, and contribute significantly to environmental problems. Finally, the experts agree that material quality varies widely across cartridge types. OEM cartridges are consistently high-quality, whereas remanufactured and new-build cartridges exhibit significant inconsistency, making quality control and recycling more difficult.

Points of Disagreement

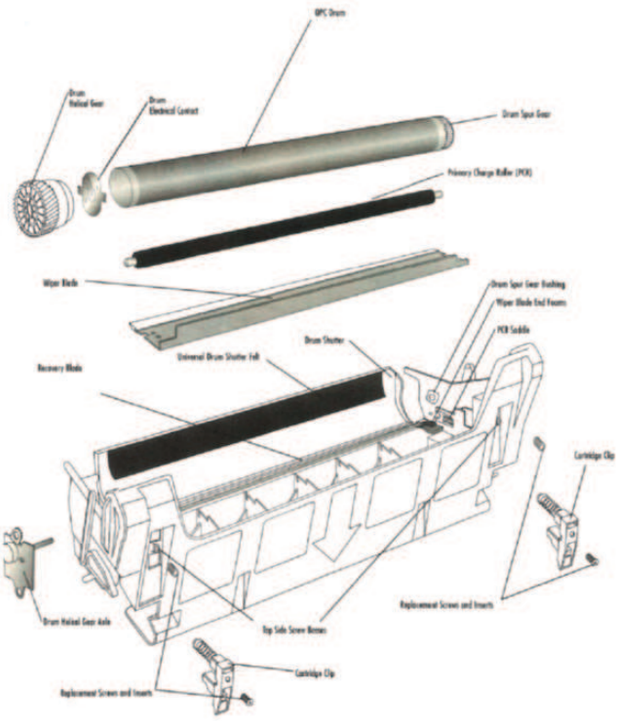
There is notable divergence in the experts' views on the economic viability of recycling toner cartridges. Some believe that large-scale recycling, especially of residual toner powder, is economically impractical due to high costs and insufficient market demand. Others argue that niche applications and emerging technologies may eventually make recycling and reuse more viable, though not yet on a global scale. Similarly, while all experts acknowledge the challenges of handling toner powder, they differ on the best solutions. Some advocate for incineration or its use in the cement industry, while others explore the potential for small-scale reuse or innovative recycling technologies.

Opinions also vary regarding the adequacy of current recycling technology. Some experts argue that existing machinery, with modifications, can address the challenges, while others assert that entirely new equipment tailored to toner cartridge recycling is needed. The role of non-OEM cartridges (new builds and compatibles) also sparks debate. Some see these as a major environmental concern due to their poor recyclability, while others emphasize their economic importance in emerging markets and their role in providing affordable printing solutions.

Finally, the experts are divided on future market trends. Some predict a decline in printing volumes due to increasing digitization and the transition toward paperless environments. Others argue that new applications and markets will sustain demand for toner cartridges, despite changes in traditional printing practices.

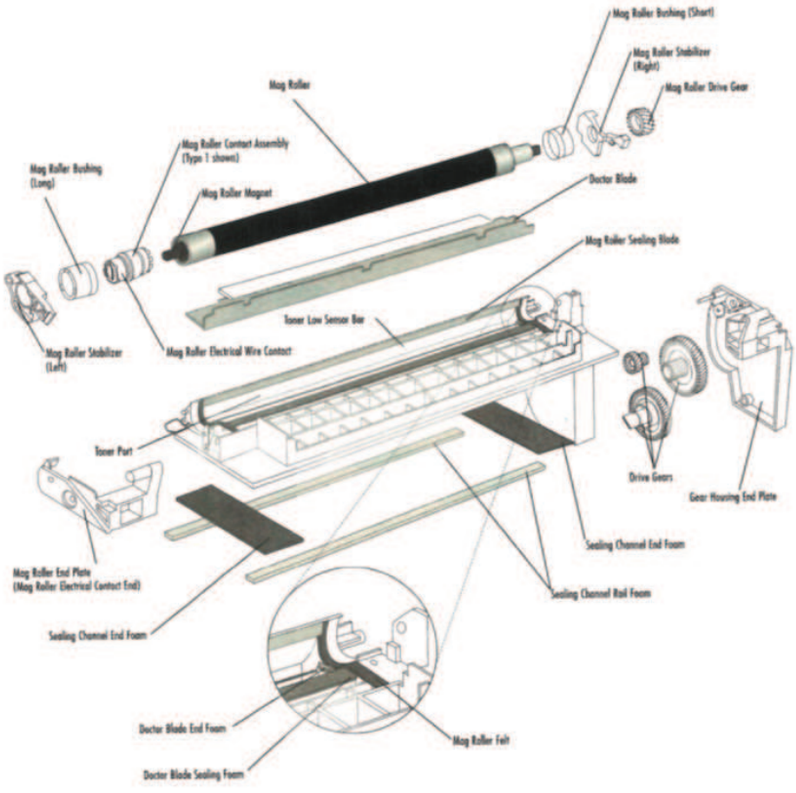
11.3 Supporting Data and Charts

All pictures taken from a Journal provided by SCC-INK.com (year unknown).



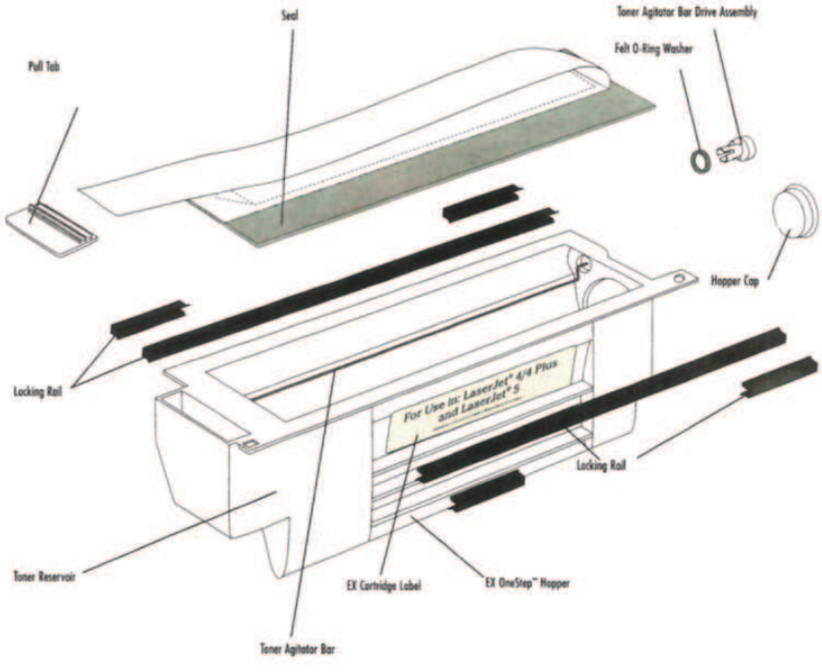
Canon EX

Waste Bin Assembly



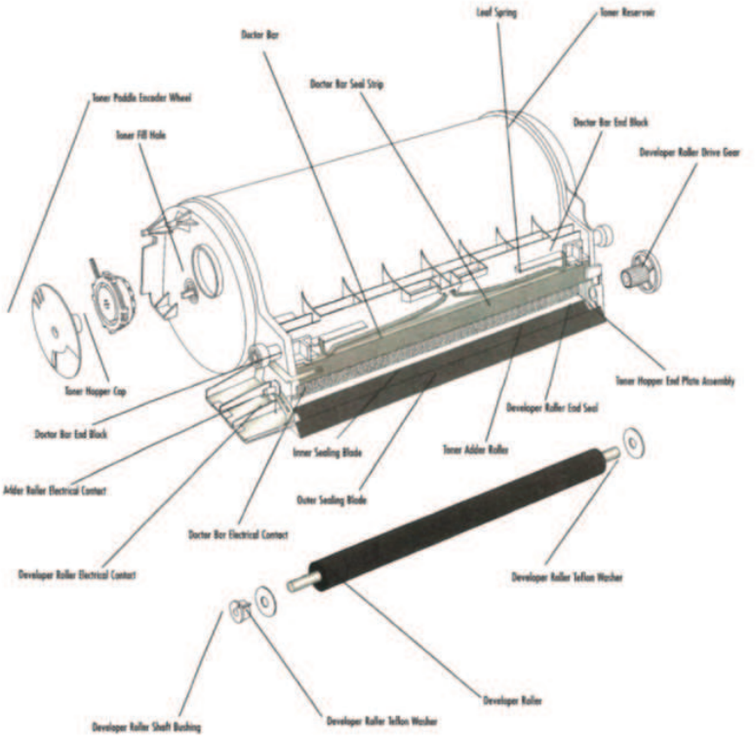
Canon EX

Mag Roller Assembly



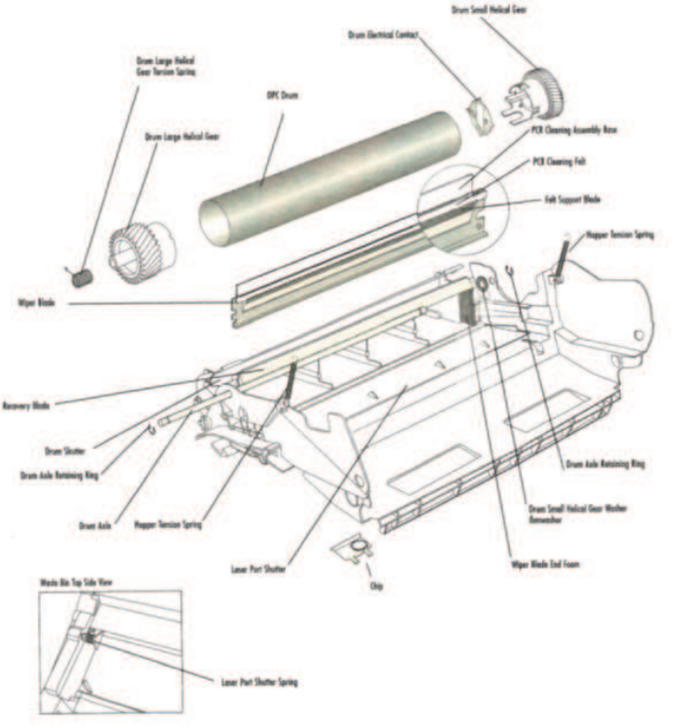
Canon EX

Toner Hopper Assembly



Lexmark Optra Se 3455

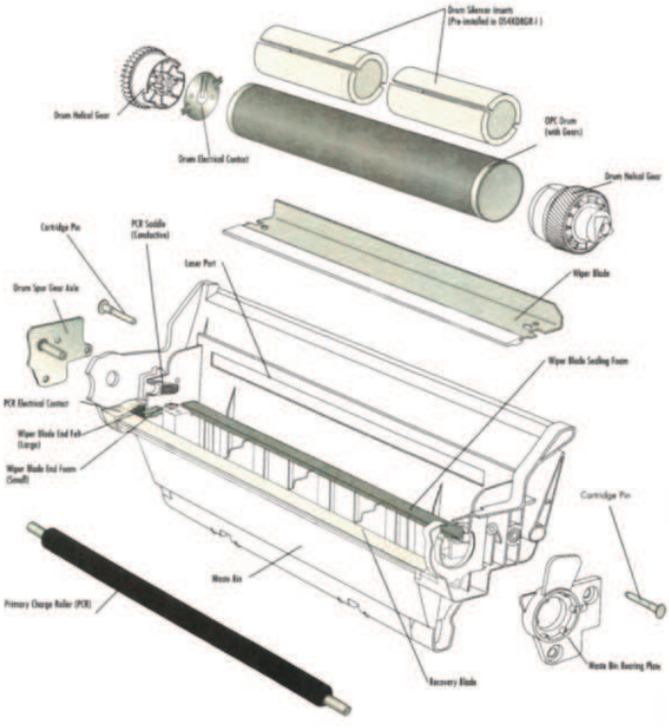
Toner Hopper Assembly



Lexmark Optra Se 3455

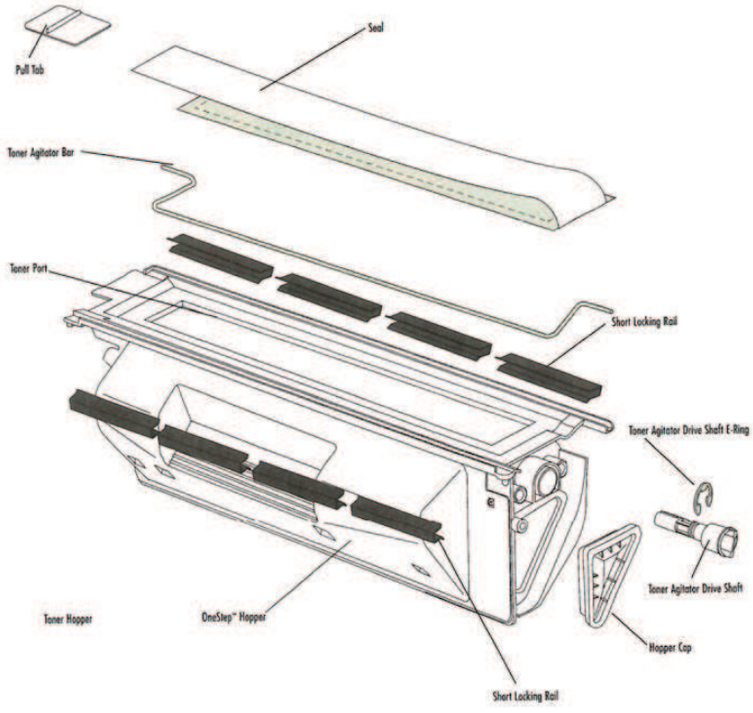
Waste Bin Assembly

HP 4000/4005 (LBP-52X)



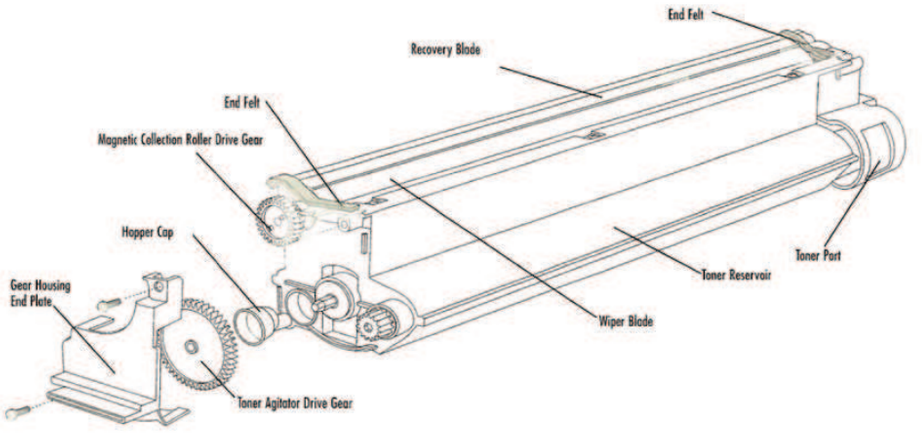
Waste Bin Assembly

HP 4000/4005 (LBP-52X)



Toner Hopper Assembly

Ricoh 3000L/3200L



Waste Bin Assembly

11.4 Technical recycling approaches

11.4.1 Manual Process

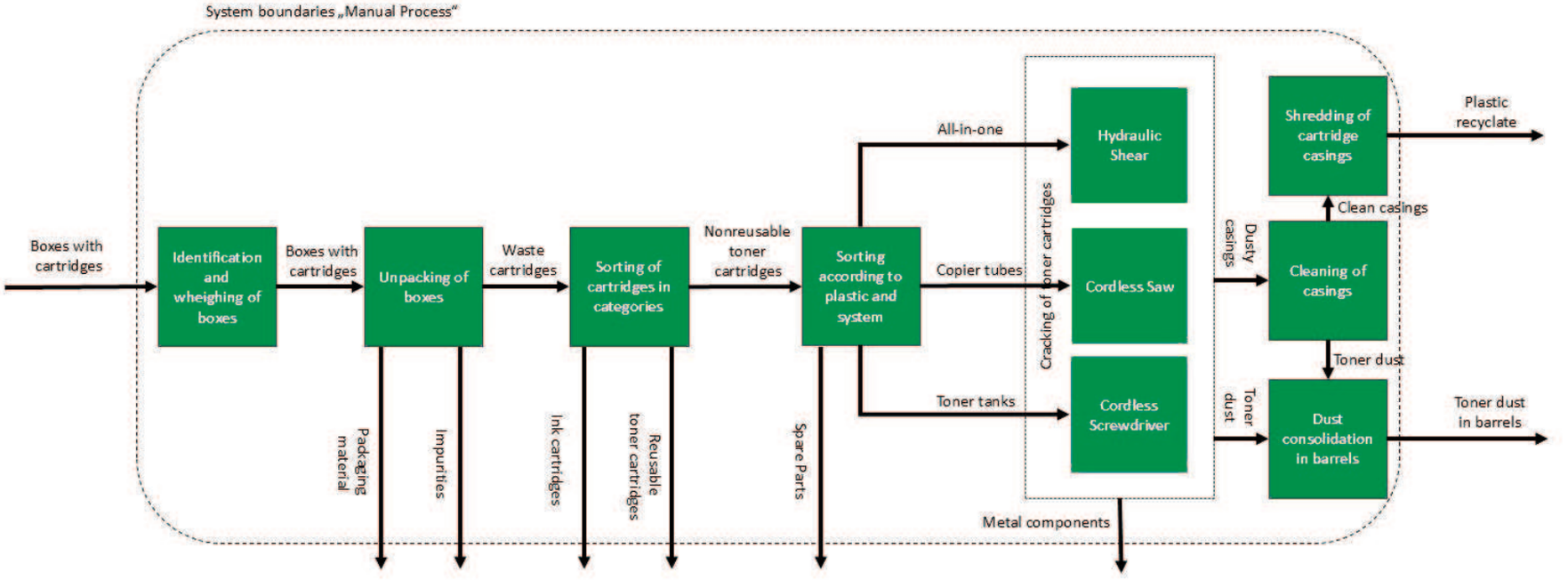


Figure 12: Flow chart of a manual process with hand tool cracking processes (adapted from WBM Ltd workflow).

11. 4.2 Semi-Automatic Process

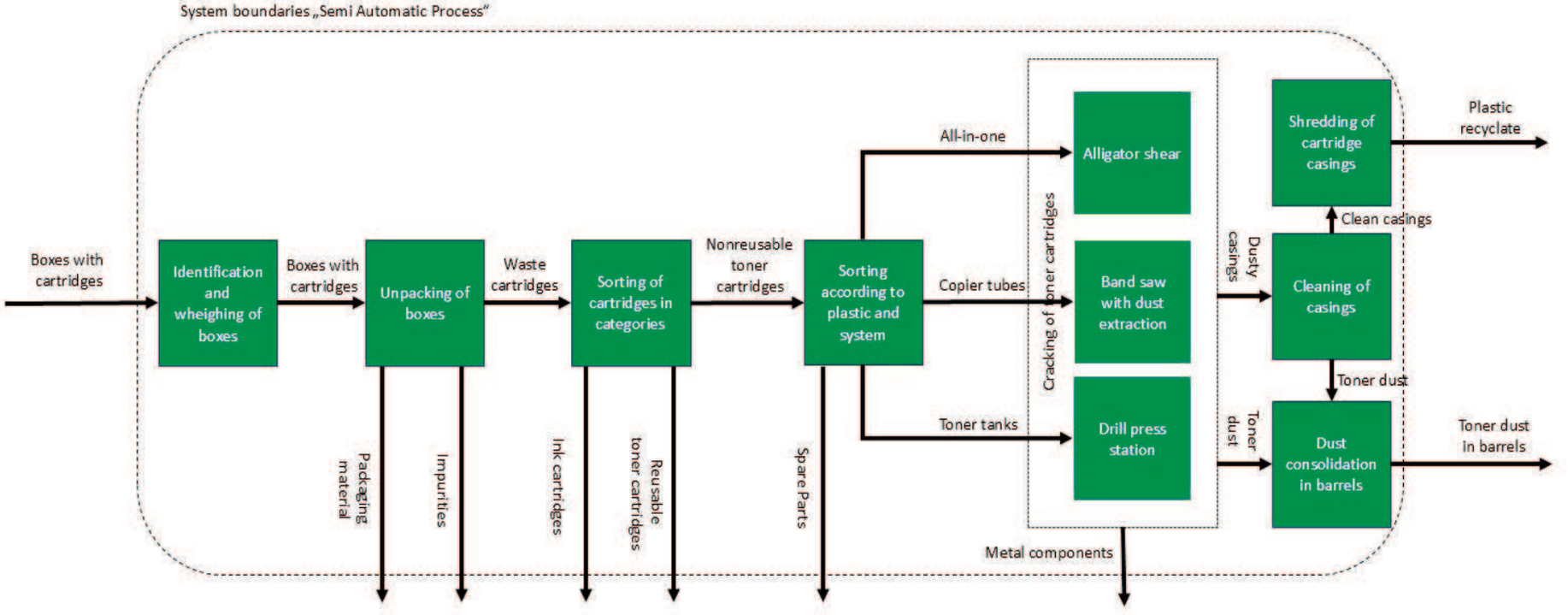


Figure 13: Flow chart of a Semi-Automatic Process with machine supported cracking process (based on WBM Ltd work flow)..

11.4.3 Automatic Process

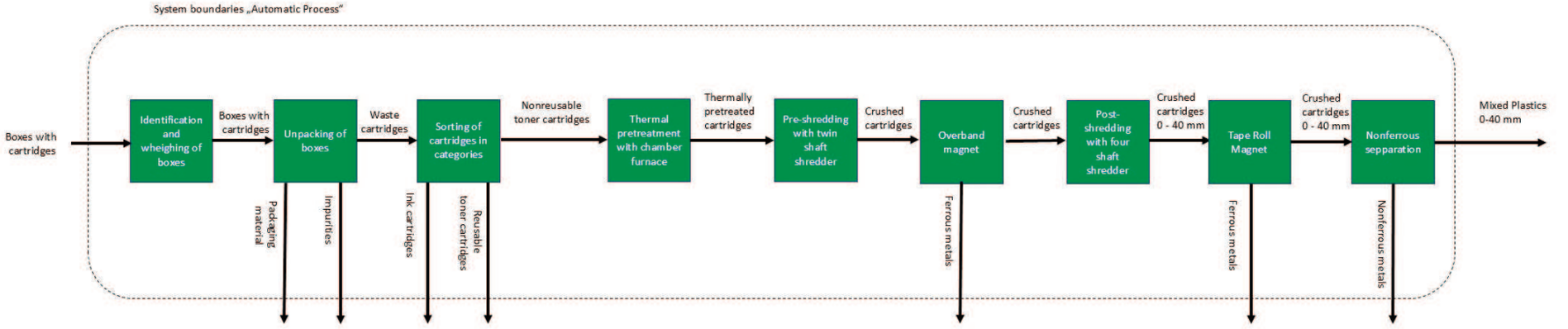
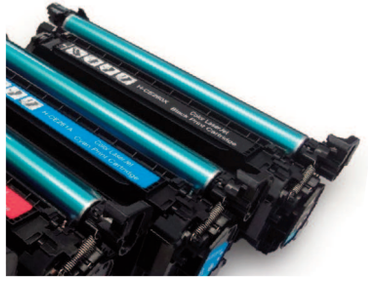


Figure 14: Flow chart of automatic process with thermal pretreatment (based on Doppstadt Systemtechnik GmbH workflow).



11.4.3 Automatic Process

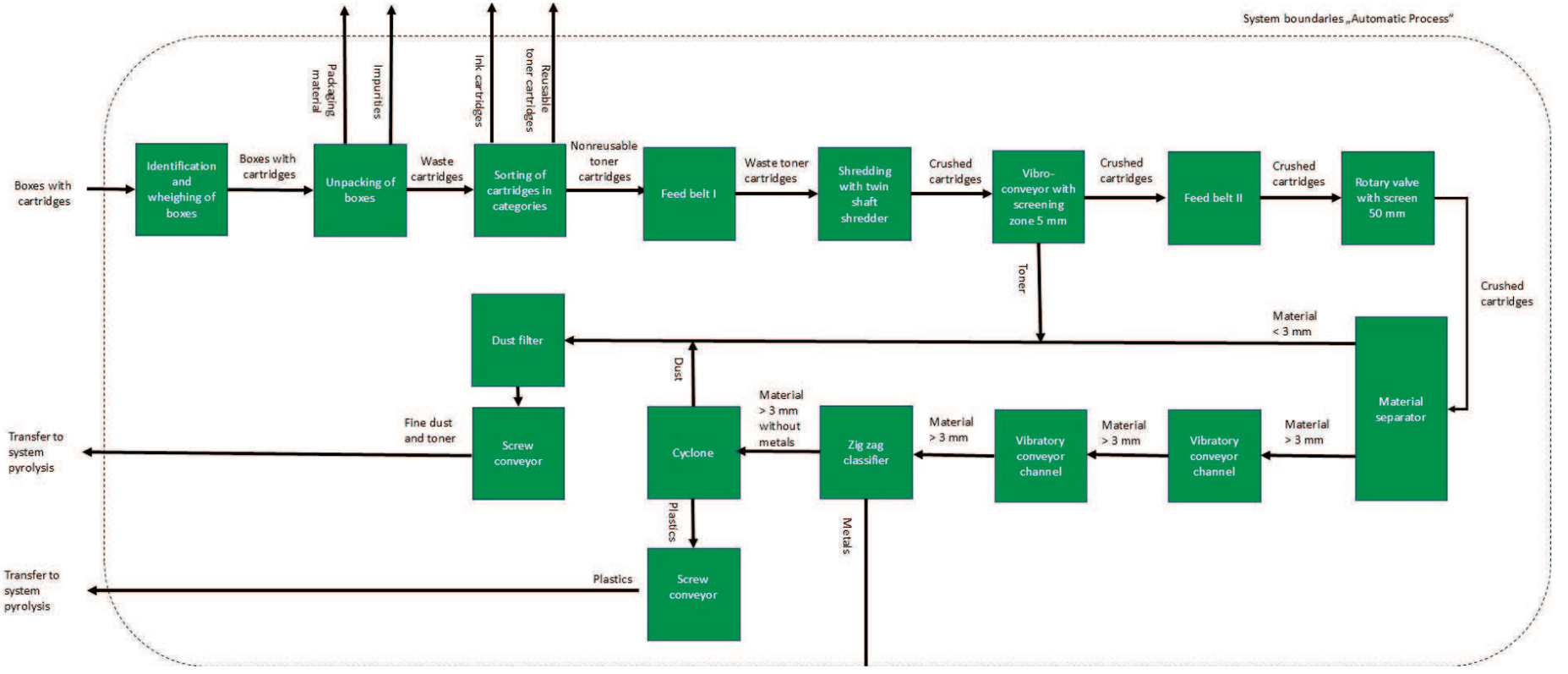


Figure 15: Flow chart of automatic process with solely mechanical treatment (based on US Recycling Automation Systems workflow).

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