THE LIFE CYCLE ASSESSMENT OF CYANIDE CONTAINERS IN GHANA

by

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DECLARATION

I, Deborah Engelbrecht hereby declare that ñThe Life Cycle Assessment of Cyanide Containers in Ghanaò is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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ABSTRACT

Ghana, a West Africa country, is deeply burdened by poverty, and relies on the production of gold for economic sustainability. The gold mining companies in the country have international origins and receive most of their requirements from international sources. The extraction of gold from the crushed ore requires sodium cyanide as a lixiviant, which is imported into Ghana from other countries in wooden intermediate bulk containers (IBC) for further distribution to the mines. A life cycle assessment was completed to determine the burden that this packaging, which includes the wooden container and polyethylene and polypropylene liners, places on the environment in Ghana when disposed of. It was found that the life cycle of the incinerated IBC impacted on the Ghanaian environment the most, due to the incineration and the transportation of the IBC. The International Organization for Standardization 14040 management standard was used as a methodological framework for the assessment.

Key terms: Ghana, gold, sodium cyanide, life cycle assessment, intermediate bulk container, polyethylene liner, polypropylene liner, ócradle to graveô

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Then finally to my Father in Heaven: Thank you.

ACRONYMS

AGA	AngloGold Ashanti
AGR	Australian Gold Reagents Pty Ltd
Chirano	Chirano Gold Mines Limited
CIL	Carbon in Leach
CIP	Carbon in Pulp
DALY	Disability Adjusted Life Years
DEAT	Department of Environmental Affairs and Tourism
EIA	Environmental Impact Assessment
EI99	Eco-Indicator 99
EMS	Environmental Management Systems
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
GGL	Goldfields Ghana Limited
GGL Tarkwa	Goldfields Ghana Limited Tarkwa
GPS	Global Positioning Systems
GSR	Golden Star Resources
IBC	Intermediate Bulk Container
ICMC	International Cyanide Management Code
ICMI	International Cyanide Management Institute
ISO	International Organisation of Standardisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LSI	Lemms Services Inc.
NMVOC	Non-Methane Volatile Organic Compounds
NOEC	No Observed Effect Concentration
NO_x	Nitrogen Oxides
PAF	Potentially Affected Fraction
PDF	Potentially Disappeared Fraction
PM_{10}	Particulate Matter that is smaller than 10 micron
PPE	Personal Protective Equipment
RA	Risk Assessment
SETAC	Society for Environmental Toxicology
SO_x	Sulphur Oxides
UN	United Nations
UNEP	United Nations Environment Programme
USA	United States of America
WHO	World Health Organisation

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CHAPTER 1

INTRODUCTION

This chapter is an introduction to the research conducted on the life cycle assessment of containers used for the transportation of sodium cyanide which is imported into Ghana. This section presents the research problem and rationale, broadly describes the research design and methodology, provides the aim and objectives, and concludes with a chapter outline of the complete study.

1.1. LIFE CYCLE ASSESSMENTS

1.1.1 Definition

Life cycle assessment (LCA) is defined as an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying energy and materials used and waste released to the environment, and it is used to evaluate and implement opportunities to effect environmental improvements (UNEP, 2009).

1.1.2 Background

As industries grow at a tremendous rate throughout the world, so the environmental loadings associated with the industries increase. These loadings generally have a negative influence on the air, water and land, causing widespread degradation. It is with the idea of combating this degradation that LCA was born.

All products have an 'origin' (cradle) and eventually an 'end' (grave). During this cycle of life each product affects the environment in some way, whether by atmospheric emissions, use of energy or liquid and solid waste that is discharged to the water or soil in some manner. Life Cycle Assessment is used as a tool to draw up an inventory and assess each of the effects and to ascertain the overall effect that the product has on the environment (Clements, 1996; Puri, 1996). The environment includes the surroundings in which people, animals or plants live, and which affect their lives (Oxford Dictionary, 2006).

Puri (1996) states that publications such as the "*Limits to Growth*" written by Meadows *et al* (1972) as cited in Puri (1996), focus attention on resource depletion in a period (1970s) when the world was experiencing an energy crisis (Puri, 1996). During this time, the idea of developing a system that could analyse the use of resources was born. This was the first rudimentary form of an LCA. The LCA as it is known today was developed for analysing raw material use and energy demands associated with production systems in the late 1990s. These first LCAs only considered the energy consumption over the life cycle of the product. However, LCA has now evolved to include every aspect of the life cycle of the product (Puri, 1996; DEAT, 2004).

The Society for Environmental Toxicology (SETAC) was instrumental in defining and documenting the LCA. This gave rise to the conceptual and methodological structure of the LCA, which consists of several distinct, but mutually dependent, phases described in the following sections (Taylor, Hutchinson, Pollack, & Tapper, 1994). The International Organisation of Standardisation (ISO) has since been entrusted with developing an accepted standard methodology for conducting an LCA. The methodology has not yet been completed and thus the ISO structure only serves as a guideline (Clements, 1996; DEAT, 2004; Uihlein, Ehrenberger & Schebek, 2008).

According to the South African Department of Environmental Affairs and Tourism (DEAT) (2004), LCAs can be considered as one of three different types applicable to different scenarios:

- Conceptual: generally qualitative
- Simplified: integrate both quantitative and qualitative data
- Detailed assessments: quantitative

When a qualitative assessment is required a conceptual LCA is used as it is the simplest. The impacts that have the greatest effect are presented by using graphics, simple scoring systems, qualitative statements and flow diagrams (DEAT, 2004).

Simplified assessments focus on the most important environmental aspects and/or stages of the life cycle. They make use of generic data and standard modules for energy production. Data are thoroughly assessed for reliability (DEAT, 2004).

A detailed LCA uses extensive and in-depth data which specifically focus on the target in question. It quantifies all relevant impacts that the product may have on the environment (DEAT, 2004).

This dissertation commences with a conceptual assessment that will develop into a simplified assessment. This will be discussed later in this chapter.

Life cycle assessments are known to be comparative, with the function of products often being compared (Hochschorner & Finnveden; 2003). The methodology can furthermore incorporate a prospective or retrospective outlook. Prospective LCAs provide information on the environmental consequences of individual actions, and retrospective LCAs provide information about the environmental properties of the life cycle investigated and of its subsystems (Ekvall, Tillman, & Sverker, 2005). Ekvall *et al*. (2005) further advise that a retrospective LCA should be used for learning purposes and possibly marketing, whereas a prospective LCA should be used for actual decision-making.

This study made use of a retrospective outlook as the research was directed at obtaining information on cyanide containers in Ghana, thus for learning purposes. The impact of the containers was investigated for each subsystem in the life cycle. The life cycle is known as a ‘gate’ to ‘grave’ assessment as it commenced as the containers entered Ghana towards the point of disposal.

1.1.3 Goal and objectives of life cycle assessment

Life cycle assessments enable a manufacturer to quantify the following:

1. How much energy and raw materials are used
2. How much solid, liquid and gaseous waste is generated and the effect that the waste may have on the environment, at each stage of the product's life

LCAs are used to control these processes more effectively and to understand the effect that the product may have on the environment. Ultimately, the results of an LCA may be incorporated into the environmental management systems (EMS) of a company. The EMS strives to manage the adverse environmental impacts that the company may have on its environment before, during and after operation (Puri, 1996; Lee & George, 2004; GDRC, 2009). Life cycle assessments are data-intensive and generally have four interrelated components, which are summarised below and represented schematically in Figure 1.1 (DEAT, 2004):

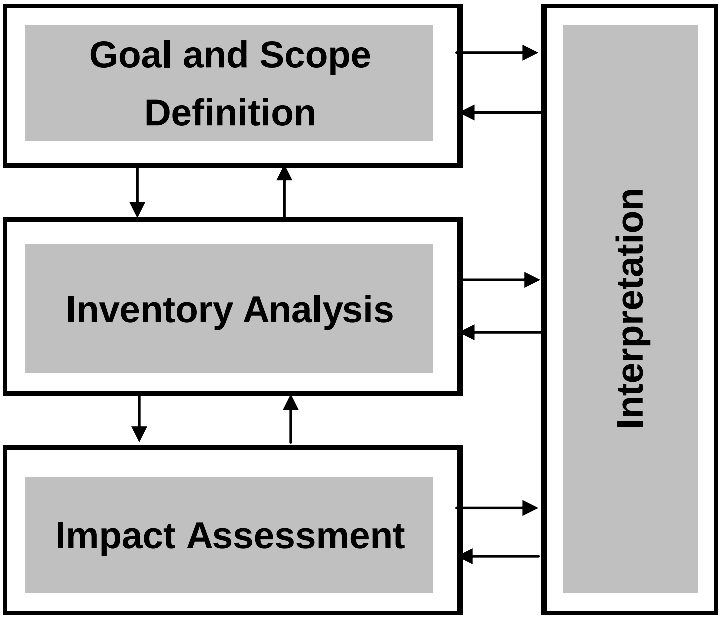

Figure 1.1: The phases of LCA according to ISO 14040 (Adapted from DEAT, 2004)

- Definition of goal and scope: During this stage, the goal of the study is explained and the intended use of the results is specified. The scope establishes the main characteristics of the LCA study and the alternatives are defined.
- Inventory analysis: The product system is defined during this phase. System boundaries are determined and set and the flow diagrams are designed to indicate the unit processes. Data are collected for each process/site and final calculations are made. An inventory table is drawn up listing the quantified inputs and outputs to the environment, for each functional unit.
- Impact assessment: The effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories that may then be weighted for importance.
- Interpretation: The results are reported in the most informative way possible and the need and opportunities to reduce the effect of the product or service on the environment are systematically evaluated (DEAT, 2004; UNEP, 2009).

This study made use of the phases as presented in Figure 1.1 to discuss the life cycle of the cyanide containers in Ghana.

1.2. CYANIDE

The noun 'cyanide' refers to a chemical compound that contains one atom of carbon and one atom of nitrogen. It is commonly written as CN^- and it combines with other elements to form different compounds and complexes. Cyanide, which is used in a variety of processes, is found in small quantities in many daily household goods such as table salt, coffee, cigarette smoke, and almonds (Lorösch, 2001; OTM n.d.). One of its most useful properties is that it can be used in the gold mining industry for the extraction of gold. The most common method of extracting gold, present in ore, is as water-soluble complexes in an aqueous solution of sodium cyanide (NaCN). It is then extracted from the solutions (Gurbuz, Ciftci, & Akcil, 2009). Cyanide was used in the extraction process of 90 per cent of the 2 444 metric tons of gold produced worldwide in 2007 (Larson, Trapp, & Pirandello, 2004, Gold News, 2009). Sodium cyanide is used in Ghana for the extraction of gold and will be referred to as cyanide in this dissertation.

Sodium cyanide is manufactured by the Andrussow process using ammonia, air, methane and caustic soda. Figure 1.2 provides a simplified representation of this process.

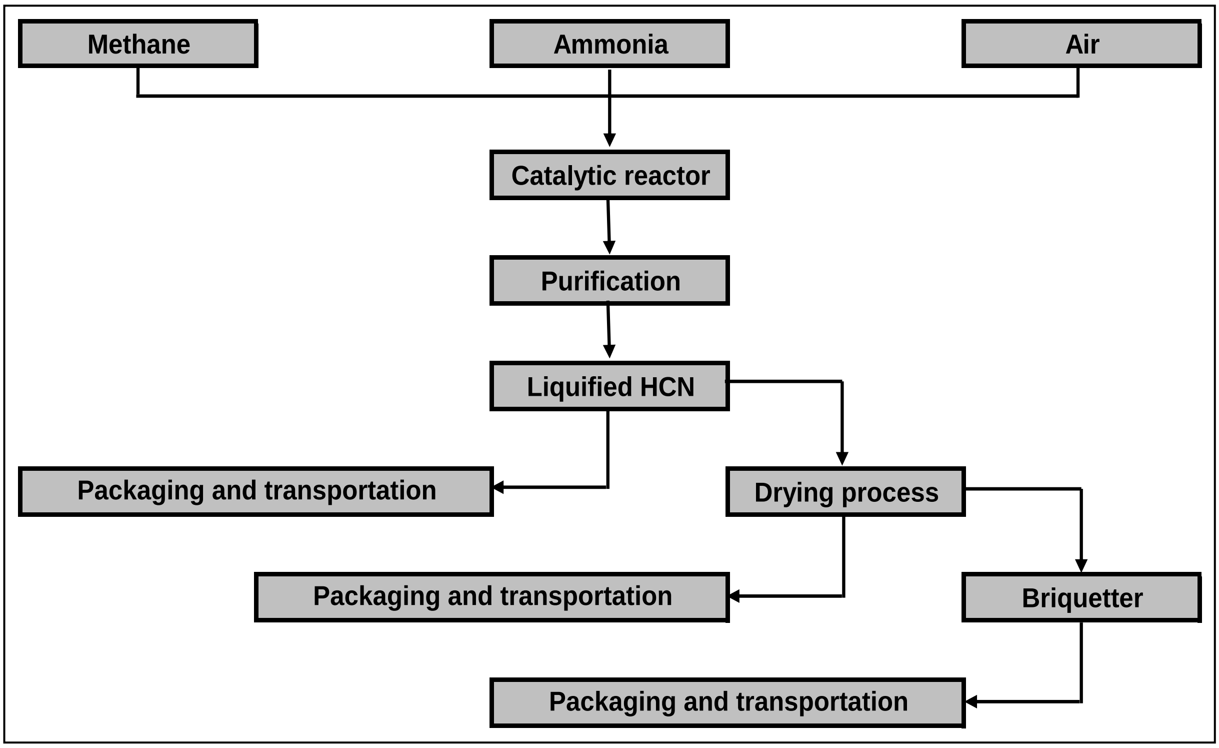

Figure 1.2: Simplified representation of the Andrussow process (adapted from OTM, n.d.)

During the manufacturing process ammonia is reacted with methane and air over a platinum/rhodium catalyst to produce hydrogen cyanide gas. The hydrogen cyanide gas is then reacted with sodium hydroxide to form liquid sodium cyanide with a solution strength of approximately 30 per cent w/w. Sodium cyanide can be transported as a liquid, or dehydrated to form crystals. After dehydration these crystals are compacted into one of three solid forms; powder, granules or briquettes and is then packaged before transportation (Chemlink, 2009; Pacia, 2009).

The principal producers of cyanide include Orica (Australia), DuPont (United States), Sasol Polymers (South Africa), Australian Gold Reagents (Australia), Cyplus (Germany) and Teakwang (South Korea) (Cyanide Code, 2009). The manufactured cyanide is freighted by sea, in bulk containers, to the non-producing countries such as Ghana.

Cyanide is highly soluble in water and reacts with acids to produce hydrocyanic gas (HCN), which is toxic to humans, animals and plants. Care needs to be taken when packaging cyanide to ensure that the cyanide is not exposed to sun and water. Cyanide is able to decompose when exposed to sunlight. In a liquid form, cyanide tends to disintegrate if not treated with an oxidizing agent such as sodium hydroxide (OTM, n.d.; Lorösch, 2001).

1.3. CYANIDE PACKAGING

Following the production of cyanide at the plant, it needs to be packaged for transportation to the respective user sites. The United Nations have specifications for each of the types of cyanide packaging used, one of them stating that dangerous goods that are transported must be waterproofed (UN Guidelines, Alphabetical Index, n.d.). The different types of cyanide packaging used for liquid and solid sodium cyanide are introduced in the paragraphs following.

1.3.1 Liquid sodium cyanide

When the Andrussow process has been completed the manufactured cyanide is in a liquid form with a concentration of about 30 per cent NaCN (sodium cyanide). Given that the bulk of this solution is water, it is normally only transported in liquid form to clients that are close to the manufacturing plant.

The preferred method for transporting liquid sodium cyanide is by using an iso-tanker (International Standards Organisation – ISO). The solution is pumped into the iso-tanker directly from the storage facility at the plant, and then transported via road to the client. The tanker can hold up to 18 000 litres of liquid cyanide. Out of country end-users, or end-users that are situated far from the supplier, do not receive any cyanide in this form (Cyanide Handbook, 2009).

1.3.2 Solid sodium cyanide

After the liquid sodium cyanide has been treated and the resulting powder, crystals or granules formed, the product is packaged. The packaging for the solid sodium includes drums, tuff-paks, wooden intermediate bulk containers (IBC) or bulk sparge iso-tankers (each of these are discussed below). The clients are provided with sodium cyanide in the packaging of choice, although the volumes required also dictate the packaging used (DuPont(a), n.d.; Cyanide Handbook, 2009).

1.3.2.1 Steel drums

Before packaging in either 50 kilogram or 100 kilogram drums, the solid sodium cyanide is hermetically sealed in a polypropylene liner. In general, the drums are non-returnable (DuPont(a), n.d) and must not be re-used at the site as residual cyanide may be present.

1.3.2.2 Tuff-Paks

A tuff-pak is a 20 kilogram pinch-bottom, multiwall composite bag. When loaded with cyanide, the bag is hermetically sealed and is water resistant. The bags are packaged in a wooden box and the net weight of the box is nominally 960 kilograms, which equates to 48 tuff-paks. The bags are not sold separately and are non-returnable (DuPont(a), n.d.; Cyanide Handbook, 2009).

1.3.2.3 Wooden intermediate bulk containers

The wooden intermediate bulk container (IBC) has a capacity to hold approximately 1000 kilograms (1 ton) of sodium cyanide. The solid product is first placed inside a polyethylene bag and then hermetically sealed inside a polypropylene liner before being sealed inside the wooden IBC (DuPont(a), n.d.; Cyanide Handbook, 2009).

1.3.2.4 Bulk sparge iso-tankers

The sparge iso-tanker can be used as an alternative to packaging, or as an intermediary between the supplier and the end-user. The solid product is placed inside the enclosed system and transported to the end-user in its dry form. On arrival at the site, the tanker is coupled to the cyanide mixing system and high pH water (pH>10) is added. The whole mixing process takes place in an enclosed circuit. Typically, a sparge tanker will contain 20 tons of solid sodium cyanide. The volumetric capacity of the steel iso-tanker is 28 cubic metres (OTM, n.d.; Cyanide Handbook, 2009).

1.3.3 Cyanide packaging in Ghana

Cyanide is received in Ghana in metal sea-containers. These sea-containers typically hold 20 IBCs with a weight of one ton each. The cyanide is generally transported to the mine sites by truck, inside the sea-containers. Here the IBCs are unloaded from the metal sea-container for mixing with water. In two situations in Ghana the cyanide is emptied into an iso-tanker at the warehousing premises of the in-country agent. The cyanide is then transported to the mine site in these tankers where it is mixed and discharged.

1.4. GHANA

Ghana, a country situated in West Africa, is bordered by the Gulf of Guinea to the south, the Ivory Coast to the west, Togo to the east and Burkina Faso to the north (Figure 1.3). The country comprises a total area of 239 460 squared kilometers and is divided into 10 administrative divisions, namely Ashanti, Brong-Ahafo, Central Region, Eastern Region, Greater Accra, Northern Region, Upper East, Upper West, Volta Region, and Western Region. The total population is estimated at 23 832 495 (CIA, 2009) using population growth figures based on the 2000 census.

Lying just north of the equator, Ghana has a tropical climate, warm and comparatively dry along the southeast coast, hot and humid in the southwest and hot and dry in the north. The terrain is made up mostly of low plains with dissected plateaus in the south-central area. The capital of Ghana is Accra, and is found on the coordinates 5º33’N and 0 º13’W (CIA, 2009). The country has two dry seasons and two wet seasons. In the wet seasons (April to July and

October to November) the annual rainfall ranges from about 1 100 millimetres in the north to about 2 100 millimetres in the southwest (Briggs 1998; CIA, 2009; Ghanaweb, 2009).

Figure 1.3: Administrative regions in Ghana (Regions, 2009)

The trade in gold is an essential part of the history of Ghana and can be dated back to 1471, when Ghana supplied 10 per cent of the world's gold. Following its colonisation, Ghana was known as the Gold Coast (Briggs, 1998). Today, Ghana still boasts of a wealth of natural and mineral resources, the most notable of which are cocoa and gold. Other resources that are traded include timber, tuna, bauxite, aluminium, manganese ore, and diamonds (World Atlas, 2009).

Figure 1.4 indicates the contribution of different economic sectors to the gross domestic product (GDP) of Ghana, as recorded in 2006. Industry contributes to 25 per cent of the GDP, of which the export of gold totals 5.7 per cent (World Atlas, 2009; Intute, 2009).

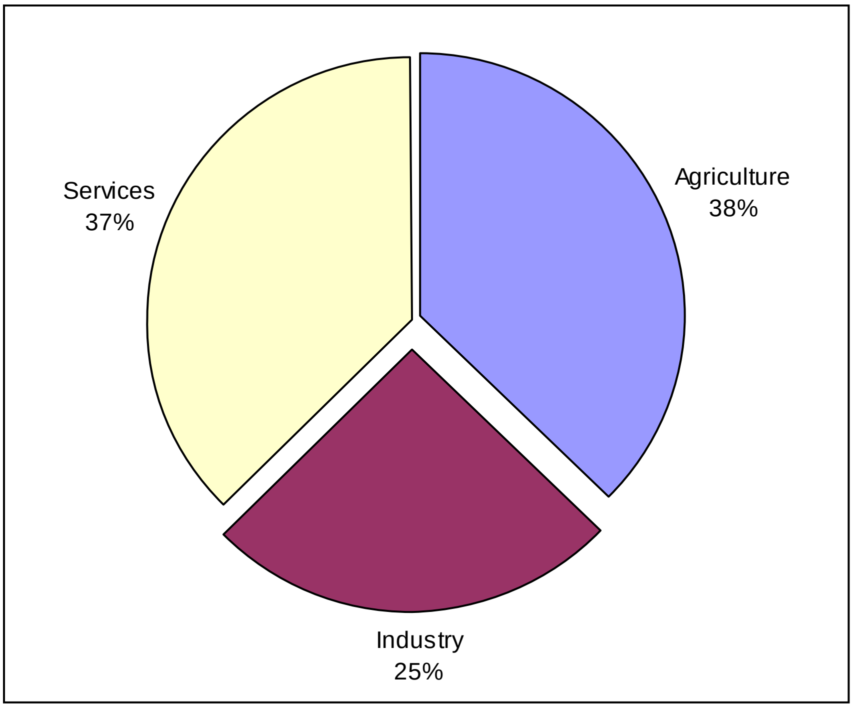

Figure 1.4: Sector contributions to GDP of Ghana in 2006 (GDP, 2009)

Ghana is an impoverished country and its economy relies heavily on the production of gold (United Nations, 2009; State, 2009; Information, 2009). After South Africa, Ghana is the second largest producer of gold in Africa (Briggs, 1998). Most of the gold in Ghana is produced by using cyanide in the gold recovery process.

The gold production in Ghana can be directly linked to the amount of cyanide imported into the country for use in the extraction process.

1.5. RESEARCH PROBLEM AND RATIONALE

Sodium cyanide is a toxic chemical that is classified as a dangerous chemical and all entities that use this chemical must comply with the relevant United Nations legislation pertaining to storage, transportation and disposal thereof. In developed countries, all cyanide containers are required to comply with stringent regulations during manufacture as well as in disposal.

Currently there is no Ghanaian legislation controlling the import, transport, storage or any other aspects that relate to cyanide use in the country. The manufacturers and users follow guidelines that originate from legislature from Australia and the United States of America (USA) (Quagliata, 2007; Tabi, 2007; Webster, 2007).

Most of the major mining companies in Ghana are in the process of obtaining accreditation from the International Cyanide Management Institute (ICMI). The ICMI has produced a set of standards and practices defined in the International Cyanide Management Code (ICMC). The ICMC allows for a more holistic approach to cyanide in the gold mining industry and provides guidelines for the whole life cycle management of cyanide, which covers the manufacture and disposal of cyanide packaging, as well as the transportation of the chemical (ICMI, 2005). Participation in the ICMC is voluntary but is encouraged by the government of Ghana.

Sodium cyanide is imported to Ghana in wooden IBCs, inside a 20 foot cubed (ft^3) shipping container. The containers are unpacked, the IBCs removed, and the cyanide emptied from the liners according to procedures documented by the mine site. The IBC and the liners are then generally disposed of by incineration. If the wood is reusable, the container can be dismantled and returned to country of origin. In some cases open air burning is the disposal method of choice, and it is purported that some containers are sold to the communities as building material.

A case study approach was used to identify the different methods and procedures used by the agents, end-users, and suppliers of cyanide with regard to the life-cycle of the IBC and its liners within the confines of the supply of cyanide to mining operations in Ghana. A LCA will be used as a tool to identify the likely problems and impacts on the environment. Problems associated with IBC use in Ghana will be identified and alternatives provided where possible.

1.6. METHODOLOGY AND RESEARCH DESIGN

The research was largely experiential and involved participatory research on each mine site identified. Each of these sites constituted a case in its own right and was included in comparative studies, to reach a conclusion.

Initially all data collected were of a qualitative nature as no known research of this kind has been conducted in Ghana (Hoogervorst, 2007). Qualitative research is often used to gain a general sense of phenomena and to form theories that can be tested using further quantitative research (Leedy & Ormrod, 2005). On the basis of these facts the data that were collected were evaluated qualitatively to enable the compilation of flow sheets, and from there a quantitative approach was adopted.

Quantitative research explores the relationship between variables and uses this information to explain, predict and control (Leedy & Ormrod, 2005). The results are usually tabulated, presented in the form of graphs or statistically calculated. Quantitative research is generally approached using scientific methods which include the following:

- the generation of models, theories and hypotheses
- the development of instruments and methods for measurement
- experimental control and manipulation of variables
- collection of empirical data
- modeling and analysis of data
- evaluation of results

The qualitative process essentially involved the conceptual LCA. On completion of the conceptual LCA, data of a quantitative nature were collected to be able to complete a simplified LCA. The simplified LCA uses both quantitative and qualitative data.

To summarise: the methodology that was used was that of Life Cycle Assessment. It commenced with a qualitative study (conceptual LCA) and proceeded to be completed quantitatively (simplified LCA). Each site was conducted in a case study format using participatory research. This culminated in the integration of data to enable a comparison of the sites in Ghana with each other. Boundaries were set, but the LCA structure in Figure 1.1 was followed as closely as possible.

1.7. STUDY AREA AND UNITS

The research conducted with regard to IBCs was limited to Ghana, although operations and manufacturers outside the area are referred to where applicable. The research conducted is presented in a case study format in this dissertation. A total of 13 cases were identified for the study, which were subdivided into three divisions:

- Cyanide suppliers (manufacturer) (3)
- Agents (2)
- Cyanide end-users (mine sites) (8)

Following is a brief introduction to each of these units. A more complete discussion will follow in Chapter 4.

1.7.1 Suppliers

The main producers of cyanide for the Ghanaian mining sector are as follows:

- Orica is an Australian company, with the manufacturing plant located in Yarwun, Queensland (Cyanide Code, 2009). A representative for the company resides in Accra (Ghana).
- DuPont, a North American company, has offices in Centurion, South Africa. The manufacturing and packaging plant is located in Memphis in North America (Cyanide Code, 2009).
- Australian Gold Reagents (AGR) is a joint venture between Wesfarmers, holding 75 per cent of the shares (CSBP Pty Ltd), and Coogee Chemicals with 25 per cent of the shares. The manufacturing plant for this company is in Kwinana, Western Australia (Chemlink, 2009).

1.7.2 Agents

The agents responsible for the clearance and transportation of the cyanide in Ghana are discussed below.

- Barbex Technical Services Limited (Barbex), an agent, imports the cyanide through the port of Takoradi in the Central Region for DuPont and Orica. From here, it is transported in the shipping containers with flatbed trailers to the warehouse close to Tarkwa, which is adjacent to Goldfields Ghana Limited Tarkwa (GGL Tarkwa) and

Iduapriem Gold Mines. The Head Office of Barbex is located in Accra, in the Greater Accra Region.

- AngloGold-Ashanti has contracted Vehrad Transport and Haulage Limited (Vehrad) to attend to clearance formalities at either Takoradi Port in the Central region or Tema port in the Greater Accra region. Tema is a suburb of Accra, the capital of Ghana. After clearance formalities Vehrad then transports the IBC to the relevant sites.

Figure 1.5 (page 15) is a representation of all the units included in the study in Ghana. The end-users are represented in red, the agents in yellow and the ports are in green.

1.7.3 End-users

The end-users are situated in the administrative regions as follows (Figure 1.3):

- Western Region: GGL Tarkwa and Damang (Goldfields Ghana Limited), Wassa and Bogoso / Prestea (Golden Star Resources Limited), Iduapriem (AngloGold-Ashanti)
- Brong Ahafo region: Chirano (Redback Mining Incorporated) and Ahafo (Newmont Ghana Gold Limited)
- Ashanti region: Obuasi (AngloGold-Ashanti).

1.8. AIM

The aim of this study was to assess the life cycle ('cradle to grave') of Intermediate Bulk Containers (IBCs) of Sodium Cyanide, as used by the Gold Mining Sector in Ghana.

1.9. OBJECTIVES

The primary objectives of this study were to:

- determine the origin of the IBC;
- quantify the number of IBCs imported to Ghana annually;
- evaluate methods of disposal of the IBC and its liners and the effect thereof on the environment;
- identify which category in terms of human health, ecosystem quality and resources is impacted on the most by the different life cycles;
- ascertain whether transportation within Ghana has a noteworthy effect on the environment.

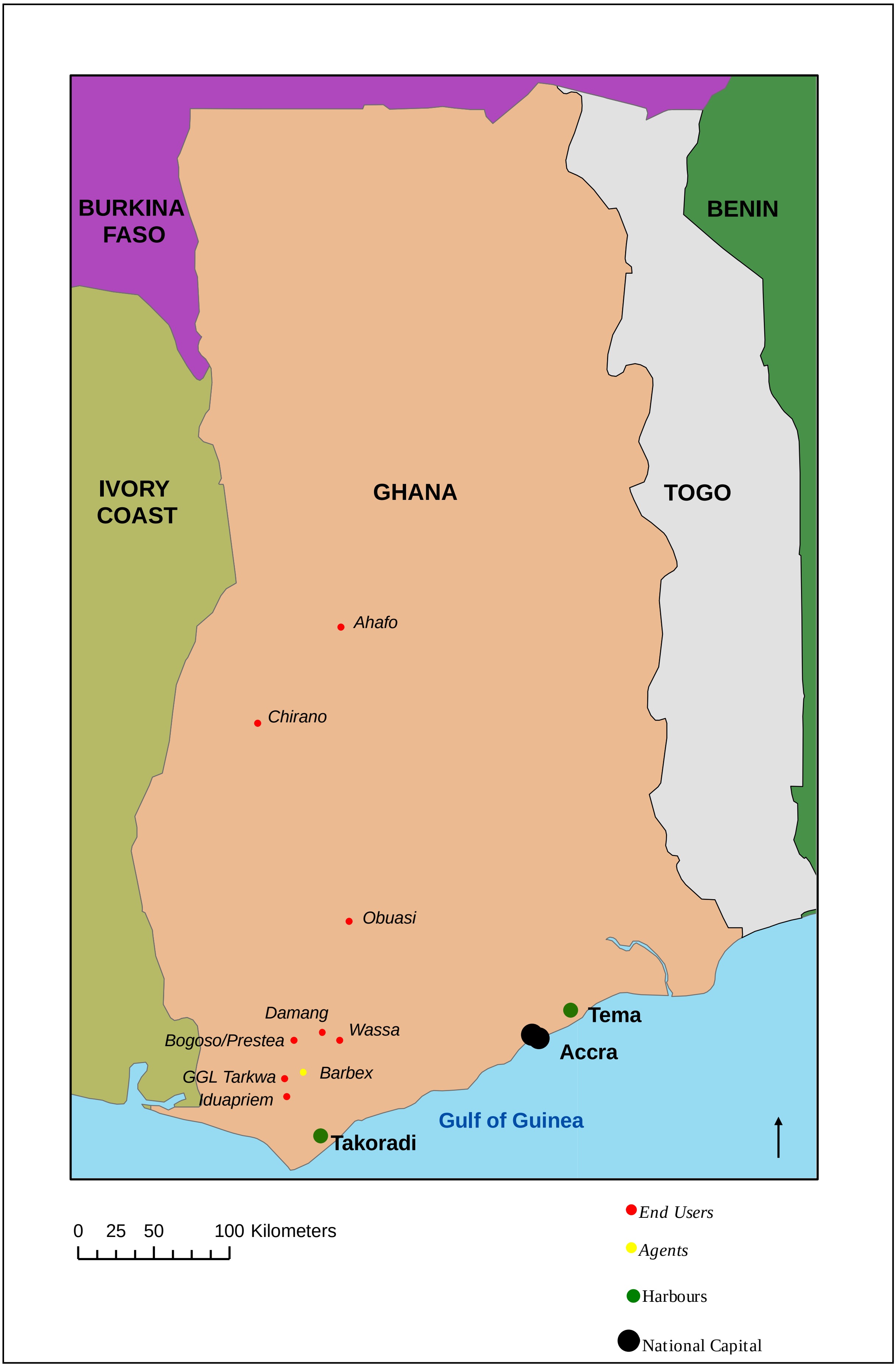

Figure 1.5: Map of Ghana showing main study areas

1.10. CHAPTER OUTLINE

This section provides the layout of the dissertation.

Chapter 1: Introduction

In this chapter the use of cyanide in the gold industry in Ghana as well as the packaging and transportation thereof was briefly reviewed. The concept of life cycle assessments was introduced and the purpose of the study stated. The aims, objectives, and study areas were also discussed in this chapter.

Chapter 2: Literature review

In this chapter literature pertaining to life cycle assessments, the use of sodium cyanide in gold mining operations and the packaging and transportation methods of cyanide are investigated. Various waste disposal methods are also investigated.

Chapter 3: Research design and methodology

The principal sampling and data collection methods are described. The key concepts and variables used in the study are defined and the research design and methodology used is presented. This includes a presentation of the methodology used according to the ISO standards.

Chapter 4: Case studies

This chapter serves to demarcate the overall study area. Each of the different case studies is outlined giving a general background and the manner in which business is conducted.

Chapter 5: Results, presentations and discussions

The results from the life cycle inventory (LCI) and life cycle impact assessment phases of the LCA are presented in a logical manner using tables and graphs. Main trends are identified and discussed.

Chapter 6: Interpretation

In this chapter the results are interpreted and the completeness, sensitivity and consistency checks are conducted according to the ISO standards.

Chapter 7: Synthesis, recommendations and conclusions

Each objective is presented and discussed separately to determine whether it was achieved or not. Recommendations are made and finally conclusion are drawn by integrating all information obtained throughout the study.

1.11. CHAPTER SUMMARY

This chapter has given a basic background to the study by introducing the life cycle assessment framework that will be used to complete the study. It has provided some information on sodium cyanide and its packaging, and highlighted the study area (Ghana). The research problem, rationale, methodology, research design, aim and objectives have also been defined.

Chapter 2 will expand on these concepts in a literature review to provide a theoretical background the LCA and the use of cyanide in the gold mining industry in Ghana.

CHAPTER 2

LITERATURE REVIEW

The first chapter provided a brief introduction to the concept of life cycle assessment (LCA) and the use of sodium cyanide in the gold mining industry, with special attention given to Ghana as the study area. This chapter will expand on these areas to provide a more comprehensive background to the study.

2.1. LIFE CYCLE ASSESSMENT

Environmental management systems (EMS) have been devised to provide a systematic, comprehensive and flexible framework by which companies can develop measurable action programmes to minimise or remove threats to the environment (Taylor *et al*., 1994). Various tools, such as environmental impact assessments (EIAs) and risk assessments (RAs), are already used in the EMS. Life cycle assessment is an emerging tool that is being developed to supplement the EMS.

At each stage of the manufacture of a product, and in the activities and services associated with it, there are effects on the environment. Life cycle assessments enable the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, and often include impacts that, in more traditional analyses, are generally not considered (Curran, 2006). Life cycle assessment has been designed to investigate the magnitude of these impacts on the environment at each different stage over the entire life span of the product, as all the stages are interdependent. It has also been named a ócradle-to-graveô assessment, as it spans the life of the product from inception to destruction (Curran, 2006).

Life cycle assessments are used to gain a better understanding of all the systems involved in the life of a product that contribute to environmental degradation. When these systems have been identified, assessed and are understood, new systems can be devised that will have less of a degrading impact on the environment. Although the LCA is still a developing technique it can be of immense benefit to companies that want to identify the impact of their product on the environment (Clements, 1996; DEAT, 2004).

The section that follows investigates the methods used to conduct an LCA.

2.1.1 Methodology for life cycle assessments

As stated in Chapter 1, the general structure used for LCAs is the one proposed by the Society for Environmental Toxicology (SETAC). The internationally accepted standard that has been developed, which defines how the assessment should be conducted, is called ISO14040. When using this standard all the stages of the productôs life cycle need to be examined so that all the inputs can be better understood and controlled, and in so doing, the impacts that the product may have on the environment may be reduced (Clements, 1996).

Each of the stages in the LCA is distinct, yet they are mutually dependent on each other. It can be said that a LCA comprises a set of different methods all enclosed in a common framework. These stages (methods) represented in Figure 1.1 include goal and scope definition, life cycle inventory (LIC), life cycle impact assessment (LCIA) and interpretation. Each of these stages is discussed below (Taylor *et al.*, 1994; Clements, 1996; Burgess & Brennan, 2001).

2.1.1.1 Goal definition and scope for life cycle assessments

The key aspect of an LCA is the modeling of a system in such a way that the inputs and outputs to the system are followed from the ócradleô to the ógraveö. An LCA is a complex process that is data- and time-intensive and thus the goal and the scope of the study need to be defined from the start. This initial phase defines the study purpose and method of including life cycle environmental impacts in the decision-making process (Finnveden, 1999). Clements (1996, 83) summarises the goal definition and scope in the following way:

> In this stage of the process, you begin the life cycle assessment by defining the overall goals of the study, the product involved, the intended audience, the scope of the study, data requirement, and the type of critical review to be conducted.

The essence of the goals analysis is to develop appropriate goals for the study and match the study scope and assumptions to its appropriate end use (Taylor *et al.*, 1994). The initial step is the identification of the product that will be assessed during the LCA. Thereafter, the intended audience needs to be identified by the assessor (*e.g.* end-users, manufacturers, recyclers or researchers). A statement of the goals of the study allows the categorisation of the aspects to be addressed and defines the data needs. Finally, the reviewer that is named should be able to evaluate the product of the LCA critically to ensure that the data are acceptable and the assumptions clear and accurate.

After defining the goal of the study, the assessor is ready to determine the scope of the assessment. The scope of the LCA:

- lays out the functions of the systems being studied;
- defines functional units;
- determines the boundaries of the systems;
- states how the environmental impacts will be evaluated;
- indicates how the data requirements will be determined;
- states the basic assumptions being made;
- establishes the limitations that will be involved.

These are all the parameters that are required for doing an LCA (Clements, 1996). For clarification purposes, functional unit and system boundaries will be explained below.

During scoping, a functional unit that appropriately describes the function of the product or process being studied requires identification so that there is a common unit for comparison between all the alternatives (Curran, 2006). All resource inputs and outputs can then be considered and the environmental impact of each functional unit can be assessed. All other operating parameters that are kept constant throughout the study should also be defined (Burgess & Brennan, 2001). To illustrate this point, the functional units that were used in this study are the intermediate bulk container (incinerated and reused), the polyethylene liner and the polypropylene liner. These functional units are designed to hold approximately one ton of cyanide for transportation.

The system boundary (Ghana) defines the breadth of the study and is the interface between the product and service and the environmental impacts. The ultimate system boundary is between the technological system and the receiving environment. All upstream and downstream inputs and outputs of the systems should ideally be followed; this will include the flows between the environment and the technological system (Tillman, Ekvall, Baumann, & Rydbergl, 1994). If these flows are studied and documented, the assessment will become very large, thus it is important to identify the areas of importance. Examples of system boundaries that can be delimited include boundaries between the technological system and nature: the geographical area, a time horizon, production of capital goods, and the boundaries between the life cycle of the studied product and the related life cycles of other products. It is important to endeavour to restrict the LCA geographically (Tillman *et al.*, 1994). The following figure (Figure 2.1) illustrates the system boundary and how it can be related to the surrounding environment.

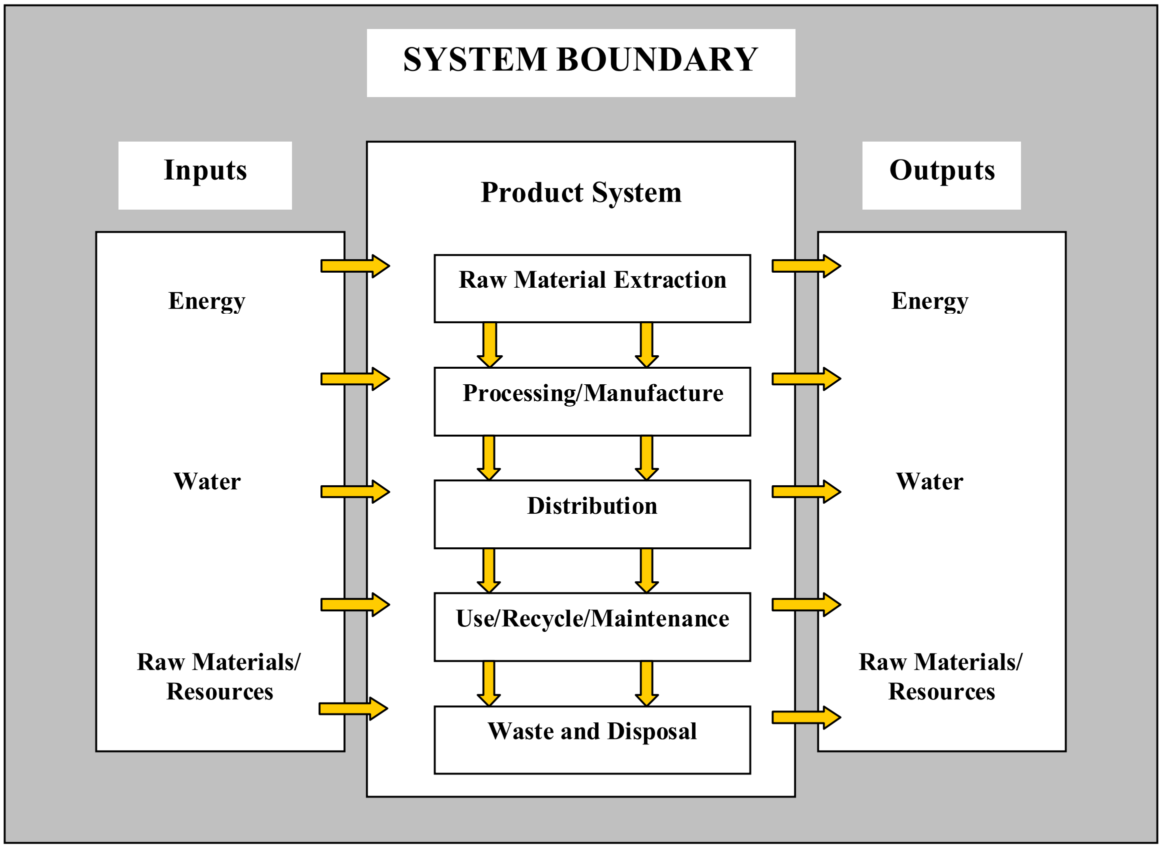

Figure 2.1: System boundaries and how they relate to the environment (DEAT, 2004)

2.1.1.2 Inventory analysis

Clements (1996, 83) defines the inventory analysis of the LCA in the following manner:

> The life cycle of a product is a series of processes and systems tied together in their common purpose of creating the product. Inventory analysis is a listing of these processes and systems, their boundaries, and the potential impact of each process and system.

Curran (2006) states that the LCI is a process of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, process, or activity. Curran (2006) explains that, without an inventory phase, there is no basis to evaluate comparative environmental impacts or potential improvements.

After the system boundaries have been defined the inventory analysis commences. According to Taylor *et al*. (1994), Clements (1996), and Curran (2006), the inventory phase can be broken into four steps:

1. **A flow diagram of the processes that are to be evaluated**: This diagram models all the alternatives that are being considered. All the inputs and outputs for each stage of the life cycle are identified when the flowchart is drawn up. All the inputs and outputs to water, air and land need to be categorised separately for each stage in the life cycle (Taylor *et al*., 1994).
2. **A data collection plan**: The sources of data required to complete this step should be evaluated for quality and accuracy in the goal definition and scoping phase. It is important to define the data quality goals, determine the sources and types of data, identify data quality indicators, and then finally develop a data collection worksheet and checklist (Curran, 2006).
3. **Collecting the data**: Various methods exist for data collection, e.g. research, site visits, and personal communication with professionals. The flow diagram that was drawn up at the outset provides a map that guides the assessor to obtain the relevant data. The data are then converted into information by drawing graphs and producing tables, amongst other interpretative methods. All data collected should be relevant and of good quality (Curran, 2006).
4. **Evaluation and reporting**: As part of this step, the system boundaries need to be described and the methodology employed, stated. If any assumptions were made, they should be clarified and the basis for comparison amongst systems should be given. The results need to be presented in the clearest form possible (graphs or tables work the best) and finally a list should be compiled containing the quantities of pollutants released into the environment and the amount of energy and materials consumed (Curran, 2006).

The inventory analyses for this LCA were determined for the IBC and the two associated liners. All data collected in Ghana (system boundary) were related to the inputs and outputs of these items.

2.1.1.3 Impact assessment

According to Curran (2006), during the life cycle impact assessment (LCIA) phase the potential human health and environmental impacts and releases identified during the LCI are evaluated. An attempt is made to quantify the impacts on the environment that are associated with the resource consumption and pollution that was identified during the LCI.

The seven steps documented below are the steps defined by the ISO for carrying out an LCIA (Steps 1, 2, 3, and 7 are mandatory):

1. **Categorisation of impacts:** The data collected in the LCI are placed in a damage category according to its effect on the environment (e.g. resources, human health and ecosystem quality). The categories selected will depend on the goal of the study.

2. **Classification:** The LCI results are assigned to the impact categories (e.g. classifying carbon dioxide emissions to potential climate change which then form part of ecosystem quality damage category).

3. **Characterisation:** The extent and effect of each of the impacts are characterised. The LCI impacts are modelled within impact categories using science-based conversion factors (e.g. modelling the potential impact of carbon dioxide and methane on climate change).

4. **Normalisation:** This step expresses the potential impacts in ways that can be compared (e.g. comparing the climate change effects of carbon dioxide and methane for the two options).

5. **Grouping:** This includes the sorting or ranking of the indicators (e.g. location, into the following: local, regional, and global).

6. **Weighting:** During weighting the indicator results are converted and aggregated across the impact categories. This results in a single data point that emphasises the most important potential impacts.

7. **Evaluating and reporting LCIA results:** During valuation the assessor is able to make a subjective analysis of the various impact categories that are evaluated. It provides a way to distinguish between the various impact categories analysed in an impact assessment (Taylor *et al*., 1994; Clements, 1996; Clift, Doig & Finnveden, 2000; Curran, 2006).

The LCI of the IBC and the two liners will form the basis on which the LCIA of the study will be conducted. The identified impacts on the air, water and soil will be categorised, classified and characterised. Thereafter normalisation will take place, followed by a grouping procedure and weighting. The final stage of the LCIA, namely evaluating and reporting, will then take place.

2.1.1.4 Interpretation

Curran (2006) states that the interpretation phase is the last stage in the LCA. It is a systematic technique that is used to identify, quantify, check, and evaluate information from the results of the LCI and LCIA, and to communicate them effectively. The information that has been collected in both the LCI and the LCIA is combined and analysed by integrating the information acquired with the goal and scope identified at the outset. The analysis is done by considering those issues addressed and aligning them with the objectives of the study. Finally, recommendations are made that are relevant to the study and that the target audience can apply. It is in this step that improvements are communicated (Clift *et al*., 2000).

ISO (1998) as cited by Curran (2006) summarises this last phase in three steps:

1. Identification of the significant issues based on the LCI and LCIA
2. Evaluation which considers completeness, sensitivity, and consistency checks
3. Conclusions, recommendations, and reporting

Figure 2.2 illustrates the steps of the life cycle interpretation process in relation to the other phases of the LCA process.

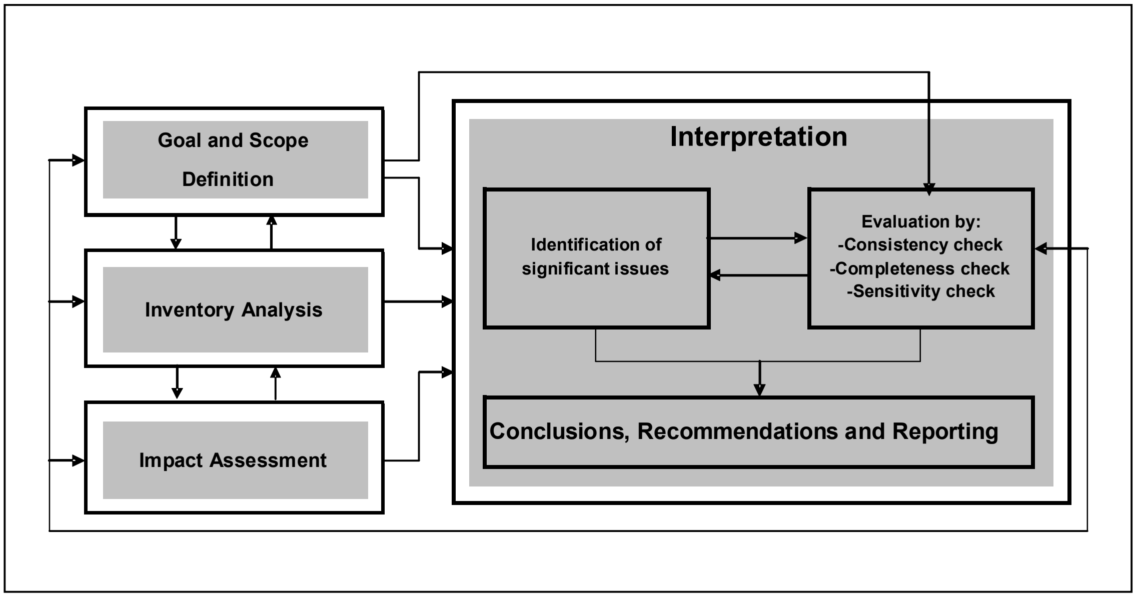

Figure 2.2: The steps of the life cycle interpretation process in relation to the other phases of the LCA process (Curran, 2006)

In this final stage the impact that the packaging of the cyanide has on the environment will be evaluated. This will enable conclusions to be drawn from which recommendations can be made.

2.1.2 Strengths and limitations associated with life cycle assessments

All studies have associated strengths and limitations, and it is important to identify them to enable the reader to recognise, in the case of limitations, specific issues that need addressing and improving on. Limitations can provide guidelines for future research. The strengths of a study provide insight into matters that have been addressed satisfactorily and are repeatable in future scenarios.

As with any other environmental tool, the LCA also has specific strengths and limitations. Some of these strengths and limitations are stated below.

2.1.2.1 Strengths

The following are the strengths of LCA:

- It informs of the direct impacts a product may have on the environment. The decision makers can then select the product with the least impact on the environment.
- It quantifies the information obtained during an LCA to facilitate with comparisons and analyses.
- It extends beyond an environmental impact assessment by involving all the stages of the life of the product.
- It allows for tracking of environmental pollution between the air, water and soil.
- It identifies the transfer of environmental impacts from one medium to another and/or from one life cycle stage to another.
- It provides a tool for decision makers and managers to characterise the environmental trade-offs associated with product or process alternatives.
- It assesses the human and ecological effects of material consumption and environmental releases to the local community, the region, and the world.
- It enables the analyst to compare the health and ecological impacts of two or more rival products/processes or to identify the impacts of a specific product or process.
- It promotes the identification of impacts on one or more specific environmental areas of concern (DEAT, 2004; Curran, 2006).

2.1.2.2 Limitations

The following are the LCA limitations:

- An LCA is resource- and time-intensive.
- Availability of data can be problematic and can impact on the accuracy of the final results.
- Results from the LCA must be used as a component of a more comprehensive decision process, such as assessing the trade-offs with cost and performance e.g. life cycle management.
- The study is usually conducted under normal operating conditions and does not take abnormal conditions into account.
- Data shortages and restrictions could occur.

- The expertise of the LCA assessor determines the reliability of the data, which can be improved with training.
- It assumes linearity of impact, i.e. the greater the pollutant, the greater the impact, which does not allow for variability in local conditions or critical loads.
- Project and investment actions can be delayed because it takes long to conduct a detailed LCA (DEAT, 2004; Curran, 2006).

In this section the methodology used to conduct LCAs was discussed by dividing the LCA into the relevant phases. In the next section gold will be discussed briefly.

2.2. GOLD

Gold, a precious metal, has been valued by humanity from time immemorial. It has been used, for example, as an adornment in the form of jewellery, been considered an external indication of wealth and been buried with Egyptian mummies for use in the afterworld. The economy of countries such as South Africa boomed after the discovery of gold. In Ghana (then the Gold Coast) the mining of gold started playing a role in the twentieth century. Today gold bars are traded internationally. These gold bars form the basis of the Worldôs monetary system (Habashi, n.d.).

Gold, which is an unstable metal due to its incomplete outer electron shells, is found complexed in gold-bearing ores in one of two oxidation states, aurous (Au^{+1}) or auric (Au^{+3}), or as the more stable native metal (nuggets). As a nugget it can be panned out and then smelted for purification, but when complexed needs to undergo metallurgical extraction processes to eliminate unwanted complexed ions (Habashi, n.d.; Lorösch, 2001).

As technology and machinery developed so did the methods of extracting gold from low-grade ore. The most common methods include amalgamation, chlorination and cyanidation.

- **Amalgamation**: During amalgamation gold-bearing slurry is passed over copper diodes. The gold then adheres to the diodes and later it is recovered when the charged diodes are melted with fluxes at high temperature. The use of mercury is now considered illegal as it is a major environmental pollutant. This is a physical extraction process (Habashi, n.d; Engelbrecht, 2009). In areas of Ghana illegal miners make use of amalgamation to extract gold.

- **Chlorination**: Aqua Regia, a mixture of hydrochloric acid and nitric acid, is able to dissolve gold; alternatively an aqueous solution of chlorine gas can be used. Although chlorination was the first chemical extraction method to be developed it had limited success rates (Habashi, n.d.; Lorösch, 2001).
- **Cyanidation**: This electro-chemical method is the method of choice today for the extraction of gold. It was discovered in 1884 and was a major breakthrough for gold mining. It is especially popular with low-grade extractions, it is cost effective, is biodegradable and does not bio-accumulate in the environment. Cyanide in its different forms is considered an environmental hazard due to its toxicity (Habashi, n.d.; Lorösch, 2001).

The use of sodium cyanide in the cyanidation process is discussed below in more detail.

2.3. SODIUM CYANIDE

Sodium cyanide consists of a positively charged sodium cation (Na^+) and a negatively charged cyanide anion (CN^-). The cyanide ion contains a carbon atom that is triply bound to a nitrogen atom.

2.3.1 Chemical properties for gold recovery

Cyanide is of interest to the gold mining industry as it has a property that allows it to dissolve gold when in an aqueous solution. This occurs by complexation according to the reaction below (Hilson & Monhemius, 2006; Cyanide Code, 2009):

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN)^{2-} + 4OH^-$$

The carbon atom of the cyanide group binds directly with the gold atom in the complex to aid with the extraction process. During the extraction of gold the cyanide ion (CN^-) is generally used as a lixiviant and has thus featured prominently as a leach reagent due to its high efficiency and low cost (Hilson & Monhemius, 2006).

The most common form of cyanide used during the cyanidation process is sodium cyanide (NaCN), although calcium cyanide ($Ca(CN)_2$) and potassium cyanide (KCN) are also effective in the extraction process (Lorösch, 2001).

2.3.2 Toxicity

Cyanide is not regarded as a persistent toxin but it is a deadly poison in high concentrations. Short-term exposure to high-levels of cyanide can harm the nervous, respiratory, and cardiovascular systems of humans and animals. Human and animal systems are able to detoxify cyanide at lower concentrations. The toxicity of cyanide is related to the complex in which it occurs. Depending on changes in environmental conditions, cyanide may degrade from one complex to another complex, so affecting other compartments (air, water, soil) of the environment. Natural, physical, chemical, and biological processes are able to transform cyanide into less toxic or non-toxic forms (Hilson & Monhemius, 2006; Gurbuz *et al.*, 2009). Plants and a number of soil microorganisms are able to use the cyanide as a carbon and nitrogen source (Lorösch, 2001).

In gold recovery, cyanide is found in various forms in the cyanidation process as a result of the cyanide ion that reacts with numerous chemical agents and molecules, thus forming a variety of different compounds. Each form is toxic to different degrees and many of these compounds are lethal to organisms (Hilson & Monhemius, 2006). Some of the compounds are described below:

- **Hydrogen cyanide (HCN)**: This is the most toxic form of cyanide due to its high metabolic inhibition potential. It binds to the iron-carrying enzymes required for cells to use oxygen. It is taken up by inhalation, ingestion or dermal contact. The formation of HCN can be inhibited by working in a pH-controlled environment ($pH > 10$) (Hilson & Monhemius, 2006).
- **Free cyanide (CN_{Free})**: Cyanide in its free form is the only form effective for the dissolution of gold. A sufficient amount is required during the leaching process to ensure the optimum functioning of the leaching process (Lorösch, 2001).
- **Weak acid dissociable cyanide (CN_{WAD})**: ï This includes molecular hydrogen cyanide, the cyanide ion, and the weakly complexed cyanide. It can be detoxified directly with chemicals to form the cyanate ion (Lorösch, 2001).
- **Total cyanide (CN_{Total})**: This is defined as the sum of the cyanide ions, which includes molecular hydrogen cyanide, free cyanide and weak acid dissociable cyanide ($CN_{Total} = HCN + CN_{Free} + CN_{WAD}$) (Lorösch, 2001).

Incidents involving cyanide poisoning of humans, plants and animals have raised awareness of the toxicity of cyanide. Consequently, alternative methods of extracting gold have been investigated and developed, with varying degrees of success (Lorösch, 2001; Gurbuz *et al.*, 2009). However, cyanide has still been shown to be the most efficient and cost-effective of the methods tried.

2.3.3 Sodium cyanide manufacturing process

The sodium cyanide suppliers included in this research use the Andrussow process (Figure 1.2) for cyanide manufacturing. In this process ammonia, methane (natural gas), air (oxygen) and sodium hydroxide are used as the raw materials. The liquid ammonia is first converted into a gas by passing the ammonia over steam tubes. The ammonia gas (NH_3) is then reacted with the oxygen (O_2) and methane (CH_4) in a gas phase converter to produce hydrogen cyanide gas (HCN), water and other combustion products according to the following stoichiometric reaction (OTM, n.d.; Maxwell, Edwards, Robertson, & Shah, 2007):

$$NH_3 + CH_4 + \tfrac{1}{2}O_2 \text{ Ÿ } HCN + 3H_2O$$

The products are cooled and a 50 per cent sodium hydroxide (NaOH) solution is added to produce sodium cyanide (NaCN) of approximated strength 30 per cent w/w. This reaction is represented below (OTM, n.d; Maxwell *et al.,* 2007):

$$HCN + NaOH \text{ Ÿ } NaCN + H_2O$$

The product is liquid sodium cyanide. If required as a solid, the solution is pumped into an evaporator to remove the water where the cyanide crystals grow rapidly. These crystals and the liquid are separated in a centrifuge; the crystals are then dried in a gas-fired drier and are compacted into ovoid shaped (pillow-shaped) briquettes (Figure 2.3).

Each briquette weighs approximately 18 grams and each has an approximate density of 1.6 ï 1.62 grams per centimetre cubed. The dimensions of each briquette are approximately 3.5 x 2.8 x 1.8 centimetres. The briquettes are then packaged and transported to the end-user. Cyanide can also be produced as granules or flakes (DuPont(a), n.d.).

Figure 2.3: Sodium cyanide briquettes inside opened liners (OTM, n.d.)

2.4. CYANIDE PACKAGING AND TRANSPORTATION

After the first manufacturing stage, when the cyanide is in a liquid form it may be pumped into an iso-tanker in which it is transported to the end-users (Section 1.3.1). Alternatively, as stated in Section 1.3.2, the solid form (granule, flake or briquette) of cyanide can be packaged in steel drums (50 or 100 kilograms), tuff-paks (20 kilograms), wooden intermediate bulk containers (±1 000 kilograms) or bulk sparge iso-tankers (20 tons).

All cyanide imported into Ghana is in IBCs within a sea container. The solid cyanide is then transported to the end-user in IBCs or the briquettes are emptied from the IBC into a sparge iso-tanker at an intermediate shipping and transfer facility for delivery to the end-user (Quagliata 2007; Webster, 2007). The following sections provide more detail on these two types of packaging.

2.4.1 Wooden intermediate bulk container

The most common IBC is manufactured from plywood reinforced with steel straps, and has a capacity to hold between 1 000 kilograms and 1 100 kilograms of cyanide briquettes. Each IBC is fitted with an integrated pallet base (Figure 2.4, photo 1), which enables a conventional forklift truck to move it. The IBC is either returnable or non-returnable. Each IBC is marked with a unique number for identification purposes and a hazardous materials label. The dimensions and engineering design allow the safe stacking of up to three boxes (Figure 2.4, photo 2) (DuPont (b), n.d.; OTM, n.d.; Personal observation, 2008).


Photo 1


Photo 2

Figure 2.4: Wooden IBCs (Personal Collection; 2008)

As stated in Chapter 1, the cyanide is sealed in two liners (polyethylene and polypropylene) to ensure that exposure to the elements is limited (Figure 2.5, photo 1). The sealed liners containing the cyanide are then placed inside the IBC and the wooden container is sealed with either screws or nails. After the IBC has been closed, it is placed inside a 20-foot cubed sea-container, which is sealed for transportation (Figure 2.5, photo 2) (DuPont(c), n.d.; OTM, n.d.; AGR, 2002; Personal observation, 2008).


Photo 1


Photo 2

Figure 2.5: Open IBC (wooden box), showing polypropylene (white), and polyethylene (translucent) liners in photo 1, and locked sea container in photo 2 (OTM, n.d.; Personal collection, 2008)

The hazardous nature of sodium cyanide dictates that the manufacture of the wooden IBCs should be in accordance with United Nations (UN) standards. All IBCs are subjected to stringent tests to ensure that these specifications are met. Testing includes vibration and lifting tests for leakage and rupture, and stacking and drop tests for deformation. The liners are tested for leakage, waterproofing and deformations (DuPont(b), n.d).

2.4.2 Sparge iso-tanker

The sparge iso-tanker [1] is specially designed to transport solid cyanide briquettes in an enclosed system to the end-user. The iso-tanker is constructed of steel and has a volumetric capacity of 28 cubic metres. Typically, 20 tons of solid cyanide are emptied into the iso-tanker but it can hold up to 24 tons. The unique design of the iso-tanker has two end frames welded into each end of the tank. The end frames contain the conventional iso-corner locking connections for handling and transport of equipment (Figure 2.6) (OTM, n.d.).

Figure 2.6: Sparge iso-tanker offloading at a site (OTM, n.d.)

In Ghana, the cyanide briquettes are transferred from the IBCs into these tankers and then transported to the end-user. This results in no reduction in the packaging but manual handling and mixing of cyanide by the end-user is minimised (Personal observation, 2008). When the cyanide is used in the country of manufacture, liquid cyanide can be transferred directly into the iso-tanker without being dried or packaged first, thus reducing processing costs and packaging requirements. This is not possible in Ghana as all the cyanide used in Ghana is imported.

[1] International Standards Organisation Tanker ï Iso-tanker

2.4.3 Storage and transportation

Sodium cyanide is manufactured and packaged at a manufacturing plant. The chemical is then transported to the end-user via road, rail and sea. Due to its toxic nature, the UN has developed guidelines and recommendations, based on a toxicity classification, to which the transportation and storage of cyanide must adhere. The UN Transportation hazard classification for sodium cyanide is 6.1 (a poison), and it has an identification number of 1689 (DuPont (a), n.d.; UN Guidelines Alphabetical Index, (n.d.); AGR, 2002).

The UN guidelines Part 7, (n.d., 617) state:

> Dangerous goods shall not be accepted for transport, or transported, unless those goods have been properly classified, packaged, marked, labelled, placarded, described, and certified on a transport document, and are otherwise in a condition for transport as required by these Regulations.

Furthermore, dangerous goods are to be secured during transportation so that the orientation of the packages cannot be altered or damaged, and IBCs must be contained in an alternate packaging (i.e. sea-container) (UN guidelines Part 7, n.d.).

The guidelines also state that cyanide may not be transported or stored with dry or liquid acids, human or animal food, and products intended for consumption (human or animal) (*e.g.* food, pharmaceuticals, and food supplements). Flammable substances and strong oxidising reagents should not be stored or transported in the same vessel or area as cyanide, as complications with fire fighting and cyanide contaminated runoff could occur. IBCs that are used for powdery or granular substances need to be sift-proof or be lined (UN guidelines Part 4, n.d.; UN guidelines Part 7, n.d.).

Depending on company policy, the sealed shipping containers are loaded onto flatbed trailers at either the port or the agent, for the final section of the journey to the end-user. If the mine is International Cyanide Management Code (ICMC) compliant, the transportation routes are pre-approved, and the vehicles are required to travel in a convoy with security personnel acting as an escort. A method for tracking the vehicles (e.g. a global positioning system (GPS)) should be installed and the vehicle may not be left unattended at any stage of the transportation (ICMI, 2005).

The transportation of cyanide using an iso-tanker is required to comply with all the regulations as stated above.

2.4.4 Offloading

On arrival at the end-user the sea-containers which are still sealed are off-loaded from the trailer using a hoist. The waybills are checked by a mine employee to make sure that the correct consignment has been received and if compliant they are signed. The agent then leaves and the container containing the cyanide is the property of the end-user. Alternatively, the sea-container may be immediately opened and the IBCs removed and placed in their secured storage area until cyanide is required for mixing (Personal observations, 2008).

The method of unloading, which depends on the manner that the cyanide was transported, is outlined in the following sections.

2.4.5 Intermediate bulk container unloading

To remove the cyanide from the packaging the IBC requires unloading (destuffing). The process used is the same irrespective of whether it takes place at the agent or at the end-user. Intermediate bulk containers are unloaded at Barbex when sparging is used.

The IBC is placed on the ground in front of the mixing tank and the lid is removed by mechanical means using pincers or crowbars, amongst other things. The polyethylene liner is then slit to expose the polypropylene liner containing the cyanide, and a hoist is attached to this liner. This hoist elevates the full polypropylene liner and moves it up into the housing containing the conical cutter. The cutter is enclosed to prevent cyanide from being exposed to the atmosphere when the cyanide is emptied from the liner. The full polypropylene liner is lowered onto the cutter which then slits the bag and the cyanide is emptied into the mixing tank. The mixing tank contains pH adjusted water ($pH>10$) to prevent the formation of hydrocyanic gas (HCN). Often a pH sensitive dye is added to the water to indicate the correct pH (Amoah, 2008; Personal observation, 2008). After the solution has been mixed thoroughly the cyanide is either used by the end-user in the plant or transferred into the iso-tanker for transportation to the end-user.

In Figure 2.7, the discharge sequence, as described above, of the opened IBC is demonstrated:

- Photo 1: The opened IBC with liners intact.
- Photos 2, 3 and 4: The cutting open of the external liner (polyethylene) to expose the polypropylene liner with the cyanide inside.
- Photo 5: The hooks are slipped onto an overhead crane.
- Photos 6 and 7: The liner is lifted into the discharge unit.
- Photo 8: The bag is lowered onto the discharging spike, which cuts the polypropylene liner and allows the cyanide to fall into the cyanide mixing tank.
- Photo 9: The empty bag is lowered and replaced in the IBC containing the polyethylene liner.
- Photo 10: The lid is replaced on the IBC and the wooden box is placed inside the sea-container and returned to the supplier (OTM, n.d.).


Photo 1


Photo 2


Photo 3


Photo 4


Photo 5


Photo 6


Photo 7


Photo 8


Photo 9


Photo 10

Figure 2.7: Sequence showing the discharging of the cyanide from the IBC, to the reloading of the sea-container (OTM, n.d.; Personal collection, 2008)

2.4.6 Iso-tanker discharging

At the destination, the tanker containing the solid cyanide briquettes is coupled to a cyanide mixing tank and high pH water (pH>10) is circulated through the iso-tanker. The solid cyanide is dissolved and the solution (± 33% concentration) is transferred to the cyanide mixing tank. The dissolution process is carried out in a closed circuit (OTM, n.d.; Environment Australia, 1998).

Sparging is an effective way of reducing the handling and mixing of cyanide as the closed circuit ensures that employees do not have direct contact with the cyanide during the offloading procedure. It also eliminates the need for employees to handle the cyanide during the mixing process and removes the necessity of returning the IBCs and internal packaging to the agent for disposal.

If iso-tankers are used in the country of origin, a considerable reduction in packaging also results as the briquettes are transferred directly into the tanker and are not packaged in IBCs, drums, or tuff-paks. This, in turn, reduces the amount of material that requires recycling, incineration, or reuse (OTM, n.d.; Environment Australia, 1998; Golder Associates, 2008). Alternatively, in the country of origin, the end-user may receive cyanide in liquid form, which also amounts to a reduction in packaging.

2.4.7 Disposal/reuse/recycling of the intermediate bulk container

The ICMC stipulates that no empty containers should be reused on or off the mine site for any purposes other than holding cyanide and that all liners are to be triple-rinsed before disposal (ICMI, 2005; ICMI, 2009).

The disposal of the IBC depends on the condition of the box as well as on supplier specifications. Some suppliers require the incineration of all IBCs, whereas others recycle boxes that are in a reusable condition. If the IBC is to be recycled, it is dismantled and returned to the supplier in a sealed sea-container. No decontamination is necessary as it is assumed that the wood was not exposed to cyanide because of the use of double lining. Any boxes that are not returned to the supplier should be burned in an incinerator. All liners are replaced in the IBC at the end-user, but removed from the IBC at the agent. All the liners are incinerated separately (DuPont (a), n.d.; OTM, n.d.; ICMI, 2005; ICMI, 2009).

2.5. WASTE DISPOSAL METHODS

In Ghana most waste was historically disposed of in landfill sites without being separated into different categories. More recently, however, communities have become more aware of the dangers associated with waste, as well as of the space requirements of land-filling. This has resulted in waste being analysed and classified. Different methods of disposal have been devised to dispose of waste in manners appropriate to their classification. Waste can be broadly classified as hazardous or non-toxic:

- Non-toxic waste: Waste that has no toxic effect on humans and includes garden waste and general domestic waste. It takes up space in landfill sites, and could cause harm to the groundwater systems due to leachates that are generated during decomposition of the organic waste (Boadi & Kuitunen, 2003; Vasanthi, Kaliappan, & Srinivasaraghavan, 2008).
- Hazardous waste: Waste that poses a substantial present or potential hazard to human health or to the environment when improperly treated, stored, transported, or disposed of (Buchholz, 1998).

Due to the increase in population and development, waste is increasing worldwide and the public is becoming more aware of the possible dangers of untreated waste. Landfill sites have become overburdened and thus alternative disposal methods have been designed which include incineration, recycling, storage and reuse (Tchobanoglous, Theisen, & Vigil, 1993; Adeyemi, Olorunfemi, & Adewoye, 2001).

2.5.1 Landfills

The traditional method of disposing of hazardous and non-hazardous solid wastes is by making use of landfills (Orloff & Falk, 2003). In essence landfills are burial sites that may be lined with impermeable materials and they require constant monitoring. Noxious fluids are collected in trenches found in the base of the landfills and pumped to the surface where they are treated until inert. Landfill sites can be hazardous to human health (Tchobanoglous *et al.*, 1993; Hecht & Werbeck, 1998). Methane, a greenhouse gas responsible for climate change, is generated by the waste in landfill sites (FOE, 2008).

- In general, waste requires stabilisation and pre-treatment prior to disposal in a landfill site. Pre-treatment is required as not all waste decomposes quickly, if at all, in these sites (Visvanathan, 1996). Methods of pre-treatment include bulk reduction (dewatering of sludge, incineration, compaction) and reduction of hazardous potential when handling and/or transporting.

Landfilling requires a lot of space and runs a high risk of leakages to air, water and soil. It also makes little use of the energy content of waste. Therefore, it is often considered as the worst option for disposal (Dijkgraaf & Vollebergh, 2004).

In Ghana, the waste disposal sites are generally inadequately managed and in many cases management is non-existent. Residents may collect solid waste in open containers made available for public use. These containers are often not removed timeously and waste spills from them into the surrounding environment. When removed, the waste is dumped into poorly designed landfill and waste dump sites (Boadi & Kuitunen, 2003; Barton, Issaias & Stentiford, 2008).

Mine sites in Ghana generally have specific areas demarcated for the disposal of solid waste and these are managed by mine employees according to stricter guidelines. If any residual cyanide is present it could pose a threat to the receiving environment (ICMI, 2005). The size of these IBCs poses a further problem in that they would fill disposal sites too quickly.

2.5.2 Incineration

Incineration is an alternative method of disposal and is often the method of choice for hazardous waste that cannot be recycled, or safely deposited in secured landfill sites. In developed countries the energy generated from the incineration of waste is often used to generate electricity or heat (Warhurst & Watson, 2006).

When waste is incinerated, it is burned in an enclosed vessel at very high temperatures. Incineration is a thermal oxidation process in which the hazardous waste reacts with oxygen from the atmosphere and is converted to gases and incombustible solid residue (Tchobanoglous *et al*., 1993; Visvanathan, 1996). These emissions consist mainly of carbon dioxide, nitrous oxides, oxides of nitrogen, ammonia and organic carbon, amongst others, of which carbon dioxide is generally the highest. As these emissions are able to alter climatic conditions they are known as climate relevant emissions (Johnke, n.d.).

The advantage of using this method is that it reduces the weight of the waste with as much as 90 per cent and the volume can be reduced by as much as 75 per cent. The incinerators do not pollute groundwater and, if equipped with emission control devices, the emissions have little effect on the atmosphere. On the negative side, incinerators are expensive to acquire and the residual waste (25%) is still disposed of in landfill sites. This residual waste may contain hazardous substances such as lead, cadmium, mercury and dioxins (Tchobanoglous *et al*., 1993; Orloff & Falk, 2003; Dijkgraaf & Vollebergh, 2004).

Waste that is disposed of in incinerators consists of biogenic waste and non-biogenic waste. Biogenic waste is waste resulting from products that were manufactured from biodegradable, biologically derived or renewable sources such as paper or wood. The carbon dioxide generated from burning biogenic waste is treated as having no impact on climate change, as it is considered part of the natural carbon cycle. To simplify, it is understood that the amount of carbon dioxide used by, for example, a tree during growth negates or reduces the amount of carbon dioxide emitted during burning (Johnke, n.d.; Hogg, 2006; Warhurst & Watson, 2006). Non-biogenic waste, on the other hand, is waste that generates fossil fuel carbon dioxide on incineration. This waste originates from products that have fossil fuels such as oil, gas or coal as constituents and includes plastics such as polyethylene and polypropylene. Fossil fuel carbon dioxide has been shown to be the main cause of climate change (Johnke, n.d.; Hogg, 2006; Warhurst & Watson, 2006).

It is accepted practice in many rural communities in Ghana to fill a pit with solid waste and then burn the waste to reduce the volume of the waste, and subsequently prevent digging of additional pits. In rare cases where incinerators are in use they are used solely to reduce the waste and are not used for heat or energy generation. Uncontrolled burning of waste contributes to air pollution, and burning of hazardous waste could result in the leaching of the chemicals into the soil (Boadi & Kuitunen, 2003).

2.5.3 Recycling

Recycling is an option that is being pursued more and more. It is the process in which waste is converted into a new product. Hazardous waste can only be recycled if the hazard is managed, whereas it is easier to recycle non-toxic waste. Both low-technology and high-technology processes exist for recycling (Tchobanoglous *et al*., 1993; Buchholz, 1998).

During recycling, waste is separated to recover glass, iron, aluminium and other useful materials. These resources are then used as raw materials for the production of other items. Recycling is advantageous because, compared to producing new materials, air or water pollution is reduced, natural resources are conserved and jobs are created (Tchobanoglous *et al*., 1993; Buchholz, 1998).

In Ghana recycling is more informal than in developed countries. In many situations, people collect waste from dump sites and sell the materials to middlemen to supplement their income. Waste that is recovered and sold for recycling includes lamps, cooking pots and washing pans (Boadi & Kuitunen, 2003).

2.5.4 Storage

Storage of hazardous waste is resorted to only as a final option. The waste is stored in covered facilities that are not close to populated areas and the packaging of the waste must eliminate possible discharges. Constant monitoring of the waste is required to ensure that there is no alteration in the form of the waste, or that there are no further damages to the packaging. Non-toxic waste is seldom stored due to the cost involved (Tchobanoglous *et al*., 1993; Buchholz, 1998).

In Ghana the mining industry has developed storage facilities for hazardous waste that can no longer be used. These facilities are generally located in a warehouse specifically demarcated for the storage of hazardous waste (Personal observation, 2008).

On a national scale Ghana has become a storage place for hazardous and non-hazardous waste from international sources. This waste is dumped in the cities or in landfill sites. Domestic waste is dumped into the Atlantic Ocean off the coast of Ghana (Orloff & Falk, 2003).

2.5.5 Reuse

Ideally, all products should be reused as far as possible before being discarded as waste. Examples of reusable items include glass, metals and plastics. The reuse of waste or other items extends the life of a product, reduces its energy use and reduces the polluting impact that the item will have on the environment. Packaging is one of the largest components of the waste found in landfill sites as more and more producers opt for disposable packaging (*such as* plastic milk bottle instead of the glass milk bottle). Examples of materials that can be reused include lumber, wooden pallets, drums and furniture (Tchobanoglous *et al*., 1993; Buchholz, 1998).

The reuse of products in Ghana occurs as a result of the high level of domestic poverty which compels people to scavenge from the dumps and reclaim any material that may be reused in future. This material could include amongst other things any discarded domestic appliances, containers of any kind and building material (Boadi & Kuitunen, 2003). Used appliances, considered obsolete, such as television sets, refrigerators and cellphones are specifically imported from developed countries into Ghana for reuse. The final disposal of these products thus becomes the responsibility of the already overloaded waste facility of Ghana (Greenpeace, 2009).

2.6. CHAPTER SUMMARY

This chapter has given a theoretical basis explaining what is required when conducting a LCA. Issues pertaining to cyanide, packaging and waste disposal have also been briefly summarised. The next chapter will deal with the methodology employed in conducting an LCA, following the LCA process as discussed in this chapter.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

At the beginning of any research project a plan that includes all aspects of the research from the very start to the very end should be devised. It should focus on the end product, the logic of the research and the type of data that are to be collected. This is the design phase. The research methodology should be stipulated in the design phase and focus on the entire research process, the tools and procedures that will be used and the individual most objective steps that will be employed (Mouton, 2004).

In this chapter as part of the research design the issues to be measured, the type of study to be conducted and the data to be collected will be presented. The methodology that will be used is the ISO 14040 method recommended for life cycle assessments (LCAs).

Figure 3.1 is a schematic representation of the methodology used to conduct the LCA.

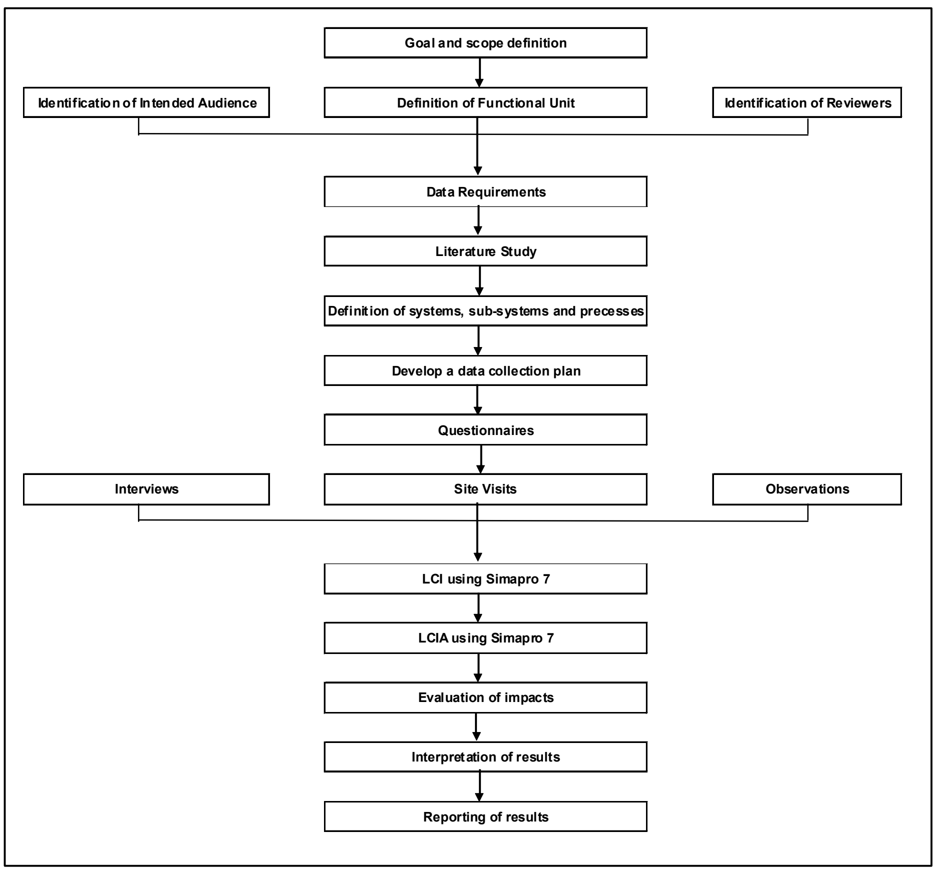

Figure 3.1: General methodology used for this LCA

3.1. BACKGROUND

Research can be conducted in either a quantitative or a qualitative manner depending on the research methodology required for the research in question and the data that are available. Qualitative research focuses on phenomena as they occur in their natural settings and evaluates the studied phenomena in all their complexity. Data are collected either by sampling, observations, or interviews (Denzin & Lincoln, 1994; Leedy & Ormrod, 2005). Often the conclusions drawn during qualitative research serve as questions to be asked in quantitative research. In quantitative research the researcher identifies variables of interest and these are studied in depth to determine the relationships between the variables. These answers are used to explain, predict and control phenomena (Leedy & Ormrod, 2005).

In some forms of research, the two methods (quantitative or qualitative) as defined above can be combined to form mixed methods research. Mixed methods research involves collecting, analysing and mixing qualitative and quantitative approaches in a single study or a series of studies (Creswell, Shope, Clark, & Green, 2006).

This study included both quantitative and qualitative methods of analysis. The initial steps involved the collection of qualitative data by means of questionnaires, participatory research, desktop methods, and fieldwork. Quantitative methods were furthermore employed when the qualitative data were entered into the relevant software (Simapro 7.1). This software generated graphs and tables that were used for further analysis.

3.2. CASE STUDIES

A case study format was employed in the research. Case studies are often used to study situations about which little is known and can focus on individual or multiple units. When focusing on individual units it is known as a single case study, and when multiple units are used it is known as multiple case studies. Embedded cases may also be found within these (Leedy & Ormrod, 2005; Yin, 2009). The main case that was studied in this research is Ghana and the smaller cases within these are the manufacturers, agents and the end-users. In each of these multiple cases an embedded unit in the form of the individual companies or sites is present (e.g. Damang, Obuasi).

Case studies are generally time-intensive and require interaction with the people involved in the process being studied. Data can be collected by making use of a variety of methods when conducting case studies; they include amongst others observations, interviews, questionnaires, participatory research and desktop methods. During the collection of data it is important to obtain information from multiple sources and to apply cross-questioning methods to determine the reliability of the data (Leedy & Ormrod, 2005; Yin, 2009). The methods used for data collection in Ghana included all of those mentioned above. Cross-questioning determined the reliability of the data and multiple sources were used for collection of the data. All the embedded units (agents, end users and manufacturers) were contacted in 2008 for initial data collection, but the process of updating and confirming other data took place throughout 2009.

Case study data are analysed throughout the process of data collection to enable the researcher to identify gaps and from there either to collect more data or analyse the gaps. The analysis of the data consists of examining, categorising, tabulating and testing the evidence obtained. This is done to enable conclusions to be drawn (Leedy & Ormrod, 2005; Yin, 2009). According to Yin (2009) five analytical techniques exist which enable data to be analysed:

- Pattern matching, in which an empirically based pattern is compared with a predicted one
- Explanation building, where an explanation is built around the case
- Time series analysis, in which the case is studied over a period of time
- Logic models, in which cause-and-effect patterns are studied
- Cross-case synthesis, in which multiple cases are studied

This project made use of a cross-case synthesis in which the data for each case were collected, examined, categorised and tabulated. The cases were examined for similarities and differences and from here it was possible to draw conclusions.

In the following sections the selection of the data is discussed. This is followed by the methods of collection and finally the methodology used for the analysis of the data.

3.3. SAMPLE DESIGN AND SAMPLE SELECTION

Sample design involves the selection of the most appropriate method of sampling that should be used in the research. Initial research showed that the project would be based on a case study approach and would involve purposive sampling. In purposive sampling specific units (cases, in this scenario) are chosen with a specific purpose in mind (Leedy & Ormrod, 2005).

The purpose of this research project was linked to the objectives as stated in Chapter 1, and Ghana as the overarching case to be studied.

The first step involved selecting the end-users to be studied. This was done by identifying the major producers of gold in Ghana. Literature, interviews and previous knowledge of the gold mining operations in the country enabled the identification of the end-users. These operations are introduced in section 1.7.3 (Figures 1.3 and 1.5) and are listed here:

- Western Region: Goldfields Ghana Limited Tarkwa (GGL Tarkwa) and Damang (Goldfields Ghana Limited), Wassa and Bogoso / Prestea (Golden Star Resources Limited), Iduapriem (AngloGold-Ashanti)
- Brong Ahafo region: Chirano (Redback Mining Incorporated) and Ahafo (Newmont Ghana Gold Limited)
- Ashanti region: Obuasi (AngloGold-Ashanti)

After the identification of the end-users (section 1.7.2) the agents handling the importing and clearance formalities as well as transportation of the cyanide could be identified. These are:

- Barbex located in Tarkwa (Western Region) with head office in Accra, importing mainly through Takoradi port
- Vehrad Transportation and Haulage with head offices in Accra (Greater Accra region), mainly importing through Takoradi port and sometimes Tema (Accra)

The final step in sample design and selection was the identification of the suppliers of cyanide (section 1.7.2). This was completed by conducting interviews with both the agents and the end-users and these are listed below:

- DuPont (USA)
- Orica (Australia)
- Australian Gold Reagents (Australia)

When all the cases were identified the data collection was initiated.

3.4. DATA COLLECTION

The success of a project lies in the collection of reliable data and this starts with the planning phase prior to obtaining the data. During the planning phase the cases need to be screened for relevance and a case study protocol developed. Case study protocol dictates the manner in which all investigations will be conducted to ensure reliability and consistency. Case study researchers also need to identify which data are required and how to obtain that data effectively. The person collecting the data (researcher) should be adaptable and flexible, ask good questions, be unbiased, understand the topic being studied and be able to interpret the answers effectively (Leedy & Ormrod, 2005; Yin, 2009).

Research was conducted in Ghana to determine which cases would be most relevant to the study. Literature and experts were consulted to understand the whole process involved in the life cycle of cyanide containers in Ghana. The protocol developed included

- contacting relevant parties and obtaining permission for the study;
- obtaining permission for site visits and arranging suitable times and dates;
- requesting the use of a camera and a dictaphone on site visits;
- sending questionnaires to the parties involved before the site visit;
- discussing the questionnaire during or before the site visit.

Where site visits were not possible, the questionnaires were returned via email.

A variety of data were collected from a large number of sources, including the suppliers, the agents, and the end-users, through the use of questionnaires (Appendix A), observations, interviews, fieldwork, and desktop studies. Most of the data collected by means of questionnaires and observations were of a primary nature, meaning that they needed to be collected or had already been collected and were available for use (Mouton, 2004; Leedy & Ormrod, 2005). Primary data were collected by the researcher who was assisted by all persons interviewed. Data collected through the internet, interviews and literature is referred to as secondary data.

The planning revealed that during the LCA the data collected by the means stipulated above would be of a qualitative nature. The analysis of the data would be both qualitative and quantitative.

3.4.1 Desktop study

Desktop methods are relevant and can be applied to any form of research. Desktop study includes all forms of documentation whether it is from books, journals, archival records or the internet. All information used from these sources should be up to date and accurate (Yin, 2009).

Desktop methods were used for obtaining literature pertaining to this study, and sources from the internet, journals and books were used. The information obtained included aspects on manufacture, transportation and disposal of the IBC and was used to compile questionnaires. Input from academic reviewers and professionals working on the gold processing plants refined the documentation of the final questionnaires.

On approval of the final draft the questionnaires were distributed via email to all the parties in the supply chain and these were filled in as hard copies or electronically. The questionnaires were all collected during site visits or returned via email, and the data were captured electronically after receipt thereof.

3.4.2 Questionnaires

Questionnaires can be administered in any type of research, and they are an easy way of obtaining information that is generally unbiased if the person answering the questions can remain anonymous. Questions should be structured in such a way that they do not contain ambiguous or double-barrelled questions. Leading questions should not be included in the questioning. The advantage of using a questionnaire is that it can reach people far away that are willing to take part in the project (Mouton, 2004; Leedy & Ormrod, 2005).

The use of questionnaires was the predominant method used in obtaining information in this LCA. The questions were both open-ended and each questionnaire was tailored specifically for the supplier, agent, or end-user. Issues addressed in the questionnaires are summarised in Table 3.1 below.

Four questionnaires were compiled for the suppliers in which the process ï from the importation of the cyanide into Ghana to the return of the containers to the country of origin, where relevant ï was addressed. These questionnaires were specifically designed to investigate aspects surrounding the transportation and storage of the cyanide and, where applicable, the disposal of the container. Altogether three questionnaires were distributed to the agents. Each end-user was given only one questionnaire (except GGL Tarkwa, which received three) that sought information on the storage, use and disposal of the cyanide containers. Two other questionnaires were compiled, one for the liner supplier and one for the IBC supplier. This was to determine aspects required in the life cycle inventory (LCI) and included questions on the materials used in the manufacture of the respective items and their dimensions. Ten different questionnaires were compiled, but 34 questionnaires were distributed in all. All questionnaires are included in Appendix A.

Table 3.1: Issues addressed in the questionnaires

RESPONDENT	LOCATION	QUESTIONS
Supplier (Eighteen sent, fourteen returned)	Country of manufacture/supply	• IBC origin and manufacture • Origin and manufacture of liners • Manufacturing process of the cyanide • Transportation routes • Methods of disposal
	Supply into Ghana	• Quantification of supply of cyanide to Ghana • Customs process • Transportation routes • Agents used • Disposal, recycling and reuse of the empty container • Specifications of the IBC supplied to Ghana
Agents (Six sent, six returned)	Ghana	• Customs clearance in Ghana • Transportation and storage of the full IBC • Transportation and storage of the empty IBC • Disposal, recycling and reuse of the empty IBC • Sparging
End-users (Ten sent, ten returned)	Ghana	• Transportation, offloading and storage of the full IBC • Disposal, recycling and reuse of the empty IBC and liners • Sparging • Amount of cyanide used • Companies importing cyanide into Ghana • Origin of the cyanide

The liner and IBC questionnaires were distributed to the cyanide suppliers (three of each were distributed). Only one of each was returned; the other four were not returned due to confidentiality restraints. All other questionnaires were returned (88% return rate).

3.4.3 Interviews

Interviews are one of the most important forms of data collection in case studies and can be conducted face-to-face, telephonically or in groups. Interviews in which qualitative data are assembled are generally semi-structured and the tone of these interviews is more informal. When quantitative data are collected the interview is mostly structured with a set of questions that is followed without any deviations. If rapport is established between the interviewee and the interviewer the answers are generally more open and honest (Mouton, 2004; Leedy & Ormrod, 2005; Yin, 2009).

Interviews were scheduled with the end-users (GGL Tarkwa, Damang, Bogoso, Wassa, and Iduapriem) that are in close proximity to Tarkwa. The agent (Barbex) was included in this list as it is also close to Tarkwa. The interviews were mainly structured around the distributed questionnaires, leaving room for discussions where questions or answers were not clear. During the interviews, the responses to the questionnaires were discussed and any other questions arising that appeared relevant, were put to the interviewee. In each case the interview took place in an office and then plant visits were conducted. Barbex was not able to assist with a site tour as a batch of cyanide was being off-loaded and operating procedures prohibited visits during this time. Where it was not possible to interview the end-users (Obuasi, Ahafo and Chirano) due to distance and time constraints email was used to clarify any answers from the respondents.

The Sales Representative of Orica was interviewed in Accra and the responses to the questionnaire were discussed there. The clearing agents forming part of Barbex were interviewed at the port in Sekondi-Takoradi, using the same method as above. A site tour was conducted at the port for familiarisation with the procedure but no photography was permitted at the port. Vehrad Transportation and Haulage was not contacted out of respect of company requests. However, a representative in Australia from Australian Gold Reagents (AGR) answered the questionnaires.

The area manager/representative for Ghana from DuPont was interviewed in his office in Pretoria, South Africa. These discussions were informal, with undocumented questions arising and being answered. DuPont also supplied a considerable amount of information in the form of hand-outs (literature) pertaining to the IBCs and the liners during this session.

3.4.4 Observations

Observations are made in a natural setting of the ócaseô and can be made with the researcher as an outsider or as a participant. During observations photographs can be taken and information not communicated can be noted. In qualitative studies the observations are unstructured, yet every detail should be accurately recorded. Quantitative research requires a more structured type of observation and focuses on a specific aspect (Mouton, 2004; Leedy & Ormrod, 2005; Yin, 2009).

During all discussions/interviews, observations were made to verify the information being provided. On completion of the interview, notes were made on the interview schedule, the computer, or the dictaphone. Photographs were taken where possible and where permission had been granted. The transportation routes were observed whilst travelling to the field sites and documented using photographs when possible.

Areas observed at the gold plants included cyanide storage facilities, cyanide make-up processes, cyanide delivery and off-loading locations and the storage of the empty IBCs. In one situation, where the plant disposed of the IBCs, the incineration facility was investigated. Direct observation of the off-loading, delivery and disposal of the cyanide and IBCs was dependent on whether the any cyanide was being off-loaded, delivered or disposed of during the site visit. The cyanide make-up process was underway at one of the plants and permission was granted for photographs to be taken of the process.

Storage and off-loading facilities, as well as the X-ray facility used for the scanning of the full IBCs, were investigated at the Sekondi-Takoradi Port, but not photographed. A sparging vessel was observed and photographed at the Barbex site.

3.4.5 Fieldwork

Fieldwork entails going into the ófieldô to conduct the research and to cross-examine the information obtained by the above-mentioned methods. It can be seen as the practical component of the research in which site visits are conducted (Mouton, 2004). The fieldwork was still part of the qualitative phase of the research.

The initial scoping study provided the system boundaries for the research. These limits included the use of cameras and dictaphones, proprietary knowledge and suitable times for visiting. From this initial work, it became evident that the most efficacious approach to evaluating the LCA was to assess the key steps in the process of supplying cyanide to Ghana. Broadly speaking, the role-players in this process are the suppliers, the agents and the end-users.

Each of these three units (suppliers, agents, and end-users) was divided into individual case studies to obtain comparable results, thus enabling more holistic conclusions to be drawn. In the following section, each unit will be discussed under one of the headings of supplier, agent or end-user, in the order in which they were visited. A more detailed explanation of each will follow in Chapter 4. In the section that follows the end-user is discussed first as the end-users provided the information needed to identify the supplier and subsequently the agents.

3.4.5.1 End-user

The term œend-userô refers to the identified mine sites studied that make use of cyanide in Ghana. These mine sites were studied as they are the major gold producers in Ghana. These sites are not necessarily the end-users of the IBCs, as the IBCs may be returned to the cyanide suppliers for reuse. Each site was identified through the researchers prior knowledge of the gold mining industry in Ghana. The sites included operations at Goldfields in Tarkwa (GGL Tarkwa) (three plants[1]), Damang, Bogoso, Wassa, Iduapriem, Obuasi, Chirano, and Ahafo (see Figure 1.5). The end-users were visited before any other parties (suppliers, agents) were contacted.

Permission was requested from the operations managers to initiate the study at each processing plant. Following the approvals, people were elected by the site metallurgical manager to provide assistance with the research. The questionnaires (Appendix A) were forwarded by email to each of the persons designated to respond, before the planned field assessment. Of the eight sites, five are relatively close together (GGL Tarkwa, Damang, Bogoso, Wassa, Iduapriem) and these were visited. Due to poor infrastructure and limited timeframes, the other three sites (Chirano, Ahafo, Obuasi) were not visited, although they participated in the research by receiving and completing the questionnaires via email. The end-users all returned their completed questionnaires (10 in total).

[1] Goldfields Ghana Limited (GGL) Tarkwa operations consist of three plants. Two are heap leach operations and the other is a carbon-in-leach operation. The study was conducted at all three plants but the results were tallied to give only one figure. GGL Tarkwa will thus be referred to as only one operation.

Damang was the first site visited because the researcher was familiar with the site and had previously established rapport with the metallurgical manager. In a sense this served as a pilot study as the questionnaires were tested for relevance and then refined to include more applicable questions and exclude those not specific to the study. The interview was very informal and the researcher was allowed to take photographs of the whole process.

During the remaining site visits the responses to the emailed questionnaire were discussed and further questions pertaining to the study posed. After the discussion was completed in an office, the plant was toured and photographs were taken. The interviews and plant tours were all conducted in an informal setting and where questions arose that had not been noted these were asked and taped using a dictaphone.

During the investigation process, safety measures that were in place for handling and storing full and empty IBCs, previous accidents, disposal and recycling of the IBCs and transport routes were examined. The gold plant employees also offered information with regard to the suppliers and agents that were operating in Ghana.

3.4.5.2 Suppliers

Scoping study evaluations, the detailed interviews held with the end-users, and the questionnaires distributed to the agents and the end-users, indicated that the three main suppliers of cyanide into Ghana are Orica, DuPont and Australian Gold Reagents. This information was confirmed by the clearance personnel working at the ports. Permission was granted by all the end-users to contact these suppliers.

To assist with the information/data gathering, questionnaires (Appendix A) were generated for the suppliers. Queries were formulated with regard to the origin of the IBC, transportation to/from the docks, sparging facilities, the recycling, reuse and disposal of the IBC, and handling agents. The questionnaires were sent to all the suppliers via email.

The contact person for Orica is in South Africa and a sales representative is in Accra, Ghana. The Area Manager for DuPont is in South Africa and the area manager for Australian Gold Reagents (AGR) works in Australia. Face-to-face interviews were conducted with the Orica Sales Representative in Ghana and also with the Area Manager for DuPont in Pretoria, South Africa. The questionnaires were discussed and other matters of interest arising from these questions were also addressed.

Australian Gold Reagents was not visited and no interview was conducted due to the distance and time zone constraints. However, the company representative in Australia completed and returned all questionnaires sent to him, as well as the liner and IBC supplier questionnaires.

None of the sites that manufacture the cyanide or the IBC were visited, as they are located in Australia and the USA and therefore it was not logistically and economically feasible to visit them.

The project proved to be largely exploratory: the cases were studied in depth to understand the life cycle process. Observations and questionnaires were the main data collection methods used and each area of interest, which included the suppliers, agents and end-users, was examined as a case study. Desktop studies and fieldwork formed the basis of the research.

3.4.5.3 Agents

Information obtained during the interviews conducted with the relevant end-users and suppliers as well from the completed questionnaires indicated the following:

- Barbex was the main importing agent of cyanide in Ghana, handling importation for six out of the eight sites (75%).
- The remaining two sites, Obuasi and Iduapriem (25%), imported their own cyanide, although all the logistics were handled from their head office (AngloGold Ashanti) in South Africa. Vehrad Transportation and haulage handled most clearance formalities in Ghana and also transported the cyanide to both sites.

The end-users and suppliers granted permission for site visits to the Barbex warehouse and the docks. Since Vehrad does not have a warehouse where cyanide is stored, no site visits were possible as the cyanide is transported directly from the docks to the end-user.

Questionnaires (Appendix A) for the agents were compiled after they had been identified by the end-users. These questions addressed the importation, dock handling procedures, transportation procedures, storage and handling, reuse, recycling and disposal of the IBC. The questionnaires were distributed to all the parties concerned via email. They returned the questionnaires prior to the site visits. The questions and answers in the questionnaires requiring clarification were addressed during these field assignment sessions. All the discussions were recorded with permission of the interviewees.

Port personnel confirmed that all cyanide received at the ports was handled in the same way irrespective of the agent, although different storage zones had been demarcated for each agent. Photographing at the docks and at the agentsô storage facilities was prohibited due to the sensitive nature of cyanide.

3.5. DATA CAPTURING AND DATA EDITING

The data obtained were mainly primary data that were unprocessed and handwritten or typed using the methods stipulated above. The textual qualitative data were tabulated according to key concepts for each supplier, agent or end-user. This tabulation was used to facilitate comparisons and the swift identification of data to be entered into the software. Microsoft Office Word 2003 was used as a word processing program to create tables and capture facts. Quantitative and numerical data were entered into a spreadsheet program (Microsoft Office Excel 2003) to enable calculations to be made with ease. Where possible the raw numeric data were entered directly into the LCA software.

Photographs were downloaded and edited to eliminate white space and unnecessary parts of the images. These cropped images were then compressed to adjust the size of the photographs so that they would be more manageable.

Literature required for the literature review section of the research was sourced in the university library or by accessing electronic journals on the university website. Electronic sources were either printed or saved in folders on the hard drive of the computer. The folders were named according to the literature topic being addressed, for example Ghana, Waste Disposal, etcetera. Hard copies (books) were read and sections typed and saved on the computer in the relevant folders. The authors and other details required for the reference section were noted on the paper and filed along with the printed journal articles.

All the data obtained required processing to enable conclusions to be drawn. The methodology employed in an LCA is prescribed by ISO 14040. This methodology was initiated when qualitative data had been collected and captured and could serve as input for the LCA methodology.

3.6 LIFE CYCLE ASSESSMENT METHODOLOGY

This dissertation uses a Life Cycle Assessment (LCA) as an analytical tool, and attempts to follow the three distinct stages of LCAs as closely as possible (Figure 1.1):

1. Definition of the goal and scope of the study (Stated in Chapter 1 and discussed in Chapter 5)
2. Inventory analysis (discussed in Chapter 5)
3. Impact assessment (presented in Chapter 5)

Each of these stages lends itself to interpretation (Figure 1.1) (discussed in Chapter 6). The methodologies employed in the study are of both a qualitative and a quantitative nature as LCAs have no fixed methodology and generally follow mixed methods of assessment (Clements, 1996).

A faculty licence was granted by Pré-consultants in the Netherlands, who developed the Simapro LCA software, for a period of six months (November 2009 to May 2010). This software makes use of various impact assessment methods and inventory databases that have been developed by independent consultants.

In the Simapro 7.1 a variety of methods exist for the calculation of the inventory list and the life cycle. Eco-indicator 99 (EI99), a method developed by Pré-consultants, was selected as it is one of the most widely used methods. The method uses a damage approach by calculating the effect of the impacts in the characterisation step and separates these into human health, resources, and ecosystem quality damage categories. The database used in EI99 is the ESU-ETH database developed in Zürich, as it is said to be well known and well documented, and focuses on impacts to the European receiving environment (EI99, 2000; Pré, 2008).

The software allows the user to enter the data for different life cycles and then models the impacts around this data. In this LCA the data for the four life cycles was plotted and tabulated to enable comparisons to be made.

The section which follows will briefly give an explanation of how the LCA process was followed according to ISO 14040 using the EI99 method.

3.6.1 Goal and scope definition

Clements (1996) states that a life cycle assessment is started by defining the goals and scope of the study. Furthermore, the product and the intended audience are identified, as well as the data requirements. The critical review that will be conducted is stipulated and the scope of the study is summarised.

As documented in Chapter 1, the goal of the study is to:

> ***Assess the life cycle of intermediate bulk containers (IBCs) of sodium cyanide, as used by the gold mining sector in Ghana.***

The study intended to provide information to manufacturers and end-users, as well as to an academic audience. The data required included qualitative information, documented in questionnaires which were distributed to the relevant parties. Technical aspects were reviewed by a specialist in environmental management and impact assessment and a metallurgical engineer. A specialist in environmental management further reviewed the document for issues of an academic nature.

In defining the scope of the study, the functional units were identified as the reused intermediate bulk container, the incinerated bulk container, the polyethylene liner and the polypropylene liner. Inputs and outputs of these functional units were recorded and from here the boundaries pertaining to the study were established. The main boundaries related to the type of LCA being conducted and to the geographical area involved. Assumptions and limitations were identified and documented.

3.6.2 Life cycle inventory analysis

An LCI requires the capturing of qualitative and quantitative data from which the generation of an inventory list can proceed. As part of the EI99 method used, data are captured in the Simapro 7.1 software to finally generate a complete inventory list. In this phase of the LCA all the inputs and outputs involved in the life cycle are quantified (Curran, 2006).

The LCI phase of the project commenced with the listing of all the processes and systems involved in the life of the IBC. These included raw material requirements, atmospheric emissions, waterborne emissions, and solid waste.

The boundary, as determined above, was then applied to eliminate processes and systems not relevant to the study.

The processes to be evaluated were illustrated in flow diagrams (Figures 5.3 and 5.4), which identified all the inputs and outputs for each stage. These were inputs and outputs to water, air and soil. A data collection plan as described above was drawn up and the relevant arrangements were made for data collection, including the development of questionnaires, interviews, site visits and observations. To conclude this phase of the LCA, the LCI results were documented and reported.

3.6.3 Life cycle impact assessment

During the life cycle impact assessment (LCIA) the impacts identified during the LCI phase are evaluated. This evaluation includes all potential human health and environmental impacts (Curran, 2006).

The steps to be included in the LCIA were decided upon and included the mandatory elements (categorisation, classification, characterisation) and some obligatory elements (normalisation, grouping and weighting). The EI99 method found in the Simapro 7.1 software was used to continue with the LCIA.

3.6.3.1 Categorisation

Ecoindicator 99 uses three damage categories to which the impacts are assigned (EI99, 2000). These categories have been selected based on research conducted within Europe. The impacts identified in the LCI are placed in three damage categories, namely human health, ecosystem quality and resources, according to the effect on the environment.

3.6.3.2 Classification

During classification in EI99 the LCI results are assigned to the impact categories existing within the damage categories according to the following list (e.g. placing carbon dioxide in the climate change impact category):

- Human health
    - Carcinogens
    - Respiratory organics
    - Respiratory inorganics
    - Climate change
    - Ozone layer
    - Radiation
- Ecosystem quality
    - Acidification/eutrophication
    - Ecotoxicity
    - Land use
- Resources
    - Minerals
    - Fossil fuels

In EI99 different procedures are used to place the results from the inventory table into the damage categories. Damage to human health is determined by linking the fate (air, water, soil) of the emission to human exposure and the effect that the emission may have on human health aspects. In ecosystem quality, fate, effect and damage analyses are conducted for acidification/eutrophication and ecotoxicity, whereas land use and land transformation models determine the damage to the land use category. Resource damage is measured by linking effort of extraction to the decreasing levels of the resources (Goedkoop, De Schryver & Oele, 2008a).

A substance can be assigned to more than one class if it has a damaging effect on multiple classes; for example, nitrogen oxide can cause both eutrophication and acidification (Europa, 2009).

3.6.3.3 Characterisation

Characterisation is the aggregation of inventory data within the impact categories to generate impact indicators. It enables the direct comparison of the LCI results with each other in each damage category. This means, for example, that carcinogens and respiratory organics are made comparable to each other in the damage category human health in this quantitative step. In Simapro 7.1 the following equation is typically used to calculate the directly comparable impact indicators (Curran, 2006; Pré, 2008):

$$\text{Inventory Data} \times \text{Characterisation Factor} = \text{Impact Indicators}$$

To illustrate, the characterisation factor for carbon dioxide in the impact category climate change can be equal to one, while the characterisation factor of methane can be 21. This means the release of one kilogram of methane causes the same amount of climate change that 21 kilograms of carbon dioxide do; thus the climate change caused by methane is 21 times more severe than that caused by carbon dioxide (Pré, 2008).

Impact indicators are assigned a unit according to the category to which they are related. Human health is measured in Disability Adjusted Life Years (DALY), ecosystem quality is measured as the Potentially Affected Fraction (PAF m^2yr) or the Potentially Disappeared Fraction (PDF m^2yr) and Resources as surplus energy (MJ surplus) (EI99, 2000). Human health is considered by EI99 (2000) to be a state in which humans exist where they are free of environmentally transmitted diseases, disabilities or premature deaths. Ecosystem quality is the loss of a species over a certain area for a specific time frame and includes the idea that no non-human species should suffer from disruptive changes to their population or geographical distribution. Resources include the idea that natureǿs supply of non-living goods, which are essential to human society, should also be available for future generations (EI99, 2000).

As there are no characterisation factors available for Ghana, the characterisation factors developed for Europe and used by the EI99 method in Simapro 7.1 were used in this study.

3.6.3.4 Normalisation

In the normalisation step a method is used to calculate a dimensionless indicator value. It allows the potential impacts to be expressed in such a way that comparison is possible. For example, after normalisation the global warming impact for carbon dioxide and methane can be compared with each other. Normalised values can only be compared with another normalised value in the same category and not across categories, for example carcinogens cannot be compared to minerals, but respiratory inorganics can be compared to respiratory inorganics (Pré, 2008).

During normalisation a ônormalô value is chosen and the indicator value is divided by this value. A ônormal valueô can be any value but usually the average yearly environmental load in a country or continent, divided by the number of inhabitants is used (Curran, 2006). Eco-indicator 99 as used in this LCA uses the normalisation values developed for Europe. These values are based on the population figures in Europe, with 1993 as the base year and an assumed population of 495 million people (Brent, 2004).

3.6.3.5 Grouping

The damage assessment step in the EI99 method is a grouping procedure. In this step the software determines the sum of impact indicator results (from the characterisation step) for each damage category. It is allowed within damage categories as each impact category included in the damage category will have the same unit (for example PDF). The damage categories are also based on the European level (the damage caused by one European per year), with 1993 as the base year (Brent, 2004).

3.6.3.6 Impact assessment

The final step in the EI99 method is the presentation of the results as an impact assessment. Here the dimensionless results are weighted and then added to give a visual representation of the life cycle that has the biggest impact on the environment. Weighting in this method is based on the European perspective that human health and ecosystem quality are more important than resources, thus the weighted results are calculated using a 40:40:20 ratio (human health:ecosystem quality:resources) (Goedkoop & Spriensma, 2001).

3.6.4 Interpretation

The first step of the interpretation stage of the LCA commenced with the identification of the most important issues. The methods used to identify the significant issues included a contribution analysis, a dominance analysis and an anomaly assessment. In each life cycle the emission contributing the most to environmental degradation was identified as was the impact dominating in the life cycle. Graphs and tables generated in Simapro 7.1 were used to assist with these identifications. Where anomalies were present they were identified in the same way.

The most noteworthy life cycle was then identified by consulting graphs and tables from Simapro 7.1.

In the final phase of the interpretation a completeness, sensitivity and consistency test was performed. During the completeness check a table was drawn in which the completeness of data were evaluated in terms of the LCI and LCIA phases of the LCA. During the sensitivity check input parameters were varied to determine whether the incomplete data identified in the completeness check would bring about notable changes in the LCA. These altered variables were entered as complete life cycles in the software. Consistency between the goal and scope of the study and the study was evaluated in the consistency check by checking data source, data accuracy, data age, temporal representation, geographical representation and the technical level of the data.

On completion of this evaluation, conclusions were drawn and recommendations made.

3.7. DATA ANALYSIS

When more than one case is involved in a study a cross-case synthesis is generally used. During the cross-case synthesis each case is considered individually and then compared or analysed as part of the whole study consisting of the remaining cases (Yin, 2009). In the analysis of data in a case study the following steps are generally followed (Leedy & Ormrod, 2005):

- Organisation of details about the case
- Categorisation of the data
- Interpretation of single instances
- Identification of patterns
- Synthesis and generalisations

All details and data of each case were collected. They are documented in Chapter 4. Tables were compiled in which the data were organised around factors that were considered relevant or according to information required as input for the software.

The software generated inventory lists pertaining to each life cycle (Section 5.2.2). These lists contained data that were uncategorised and specified the emissions to soil, water and air and the use of raw materials. Categorisation was brought about in the LCIA phase of the study in which the software placed each emission in a damage category and an impact category (Sections 5.3.1 and 5.3.2). The quantitative data generated during characterisation were inspected for contribution to each life cycle, dominant factors in the life cycles as well as anomalies by investigating the information obtained in the tables and graphs.

Normalisation allowed for the interpretation of single instances identified. In two instances sparging was used and this was investigated. Other issues were the use of open air burning and reuse of the IBC.

Graphs generated by the software were used to identify patterns regarding each life cycle. This was done to determine which had the biggest negative impact. Within each category the life cycle impacting the most on that category was identified by the use of graphs and tables.

The analysis of data did not take place in isolation for each life cycle or category, as the LCA process is interactive. Often, the answers in one phase needed to be analysed before the next phase started. The answers in each phase were generally used to formulate the questions of the next phase. The data collected initially were qualitative and the qualitative analyses were completed during the LCI phase as well as during categorisation, classification and characterisation in the LCIA. The remaining part of the LCIA phase (normalisation, damage assessment and impact assessment) mainly used quantitative methods of analyses (graphs, tables). The LCIA of the LCA assimilated the data from all the phases. These results were then processed prior to the interpretation phase.

3.8. CHAPTER SUMMARY

This chapter provided a framework of the methodology that was used to complete the study on the IBCs. It is apparent that the methodology could be subdivided. The first division used a more general methodology employing tactics such as sample design, sample selections, data collection and data capturing. This constituted the qualitative phase. Following this general methodology a more structured approach proposed by ISO 14040, the Life Cycle Assessment Methodology, was used to refine the results obtained in the first division. This constituted the quantitative phase.

The chapter concluded by presenting the methods used for data analysis where all the results from both phases were integrated to bring about an explanation and justification for the study. In Chapter 4, the cases from which data were generated will be expounded on to provide an overview of the sites visited as well as of the matters that needed to be addressed.

CHAPTER 4

CASE STUDIES

Creswell (2003) defines a case study as an exploratory process in which a programme, event, activity, process or one or more individuals are studied in depth. He furthermore states that the case or cases should have boundaries in time and activities during which the researchers will collect detailed information by making use of a variety of data collection procedures.

4.1. INTRODUCTION

This chapter aims to present the case boundary (Ghana) with all the units (manufacturers, agents, end-users) and sub-units (individual companies / sites) to provide the reader with an understanding of where and in what context the study was performed. Figure 4.1 (page 65) illustrates the different units researched.

Each of the suppliers, agents and end-users will be introduced with a basic background study and a discussion of the handling procedures that are relevant to the area of study. Information garnered through observations and questionnaires is used in this chapter.

4.2. SUPPLIERS

As mentioned in Chapter 2, cyanide is manufactured in the Far East, Australia, Africa, Europe and North America. No cyanide is manufactured in Ghana. Three manufacturers were identified by the end-users as the suppliers of cyanide to Ghana. They are Orica, DuPont and Australian Gold Reagents (AGR). Each manufacturer has its own policy on the handling of the empty IBCs; some are returned and recycled, while others are incinerated.

In the section below the three manufacturers supplying cyanide to Ghana will be discussed.

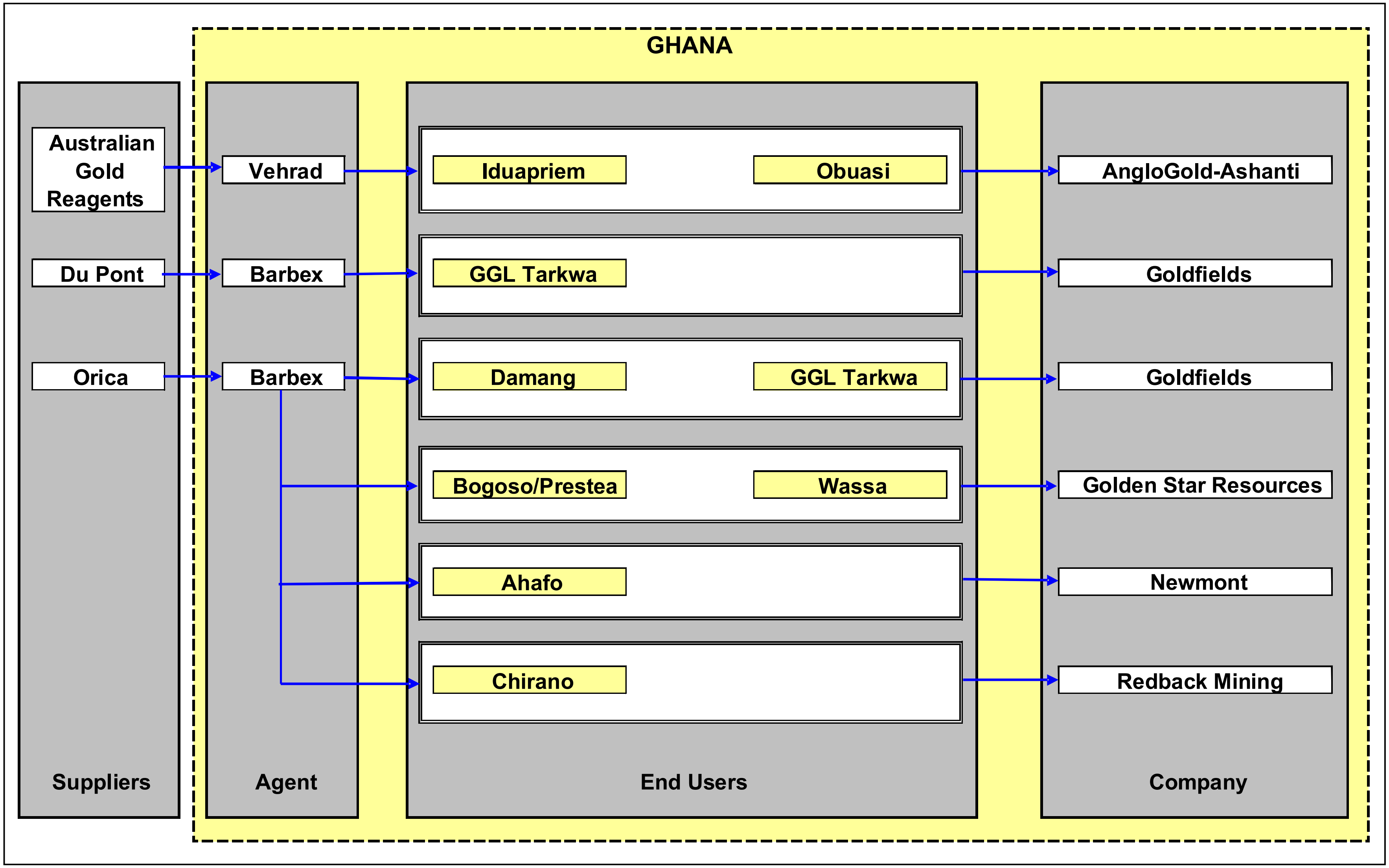

Figure 4.1: Illustration of the embedded case studies and units of study within the framework of Ghana as the bounded case

4.2.1 Australian Gold Reagents

Australian Gold Reagents Pty Ltd (AGR) is a joint venture between Coogee Chemicals, which holds 25 per cent of the company and CSBP Limited, which holds 75 per cent. The manufacturing plant is located at Kwinana in Western Australia, at the chemical and fertilizer complex of CSBP Limited. It was commissioned in 1988 due to the growing need for cyanide resulting from the expansion of the gold mining industry in Western Australia. AGR is now capable of producing 70 000 tons of cyanide per annum and is International Cyanide Management Code (ICMC) compliant (IMO, 2006; CSBP, 2009).

AGR has its own packaging plant for the cyanide briquettes at Kwinana. The packaging that is relevant to this study is the intermediate bulk container (IBC). Each IBC is 1.14 metres long, 1.14 metres wide and 1.09 metres high and has been designed to hold 1 000 kilograms of product. The liners are designed to hold 1 100 kilograms of briquettes. The packaged cyanide is transported throughout Australia or exported worldwide. AGR exports to Ghana, Mali, Guinea, Namibia, Tanzania, Laos, Peru, Indonesia and Burkina Faso (IMO, 2006, CSBP, 2009).

AGR has not employed an agent to attend to clearing formalities in Ghana and either attends to these formalities or makes use of Vehrad Transport and Haulage (Vehrad). Vehrad is also responsible for the transportation of the cyanide to Obuasi or Iduapriem.

No IBCs are returned to the supplier for reuse or recycling. The gold plant remains responsible for the disposal of the IBC as well as of the liners.

4.2.2 DuPont

The sodium cyanide production facilities of DuPont de Nemours International Société Anonyme (DuPont) are located in Memphis, Tennessee and Carlin, Nevada in the USA. The company has refined the manufacturing process that has been in existence since 1953 and now more than 45 000 tons of cyanide are produced per year in Memphis (Jurczyk, 2006) for a variety of uses, including the recovery of gold.

DuPont makes use of the Andrussow process, as described in Chapter 2, to manufacture the chemical. The cyanide is packaged into bulk packaging (IBCs) by Lemms Services Inc. (LSI Packaging) at DuPontôs manufacturing facility in Memphis. The dimensions of these IBCs are 1.14 metres x 1.14 metres x 1.13 metres. At the Carlin Terminal the cyanide is packaged into non-returnable steel drums (50 kilograms and 100 kilograms), and Tuff Paks (Jurczyk, 2006). Only IBCs are freighted to Ghana and it takes approximately three weeks for delivery to the sea-port in Ghana. DuPont makes use of Maersk sea liners to ship the consignment to Ghana.

In Ghana, Barbex Technical Services Limited (Barbex) is the agent responsible for customs clearance, transportation and storage of the full IBCs in the DuPont supply chain. DuPont supplies only Goldfields Ghana Limited (GGL) Tarkwa with cyanide. DuPont does not receive any empty IBCs from Ghana for recycling; they are all returned to and incinerated at Barbex. The liners are also returned to Barbex for incineration.

4.2.3 Orica

Sodium cyanide is manufactured at the Orica Australia Limited (Orica) Yarwun manufacturing facility in Queensland, which has been operating since 1989. Other chemicals such as nitric acid, chlorine, and hydrochloric acid are also manufactured at this plant. The manufacturing facility was audited and was found to be compliant with the ICMC in November 2006 (Golder Associates, 2006).

At Orica the Andrussow process is used to produce sodium cyanide. Orica supplies the cyanide in liquid form to clients within Australia and in a solid briquette form to users further afield (within Australia and beyond its borders). The packaging relevant to this study is the IBC. Each IBC has been designed to hold up to 1 135 kilograms of briquettes. They are 1.14 metres in length, 1.14 metres in breadth and 1.10 metres in height. The solid cyanide is transported to Ghana by sea, using the Mediterranean Sea Company (MSC) as the shippers (OTM, n.d.). The freighting of a consignment from Australia to Ghana takes approximately four weeks.

On arrival in Ghana, Barbex is responsible for the clearance, transportation, and storage of the full sea-containers. After clearance the full IBCs, which are sealed in the sea-containers, are taken to Barbex and distributed to the end-users in Ghana from there. The empty IBCs are returned to Barbex when a new consignment is delivered. Bogoso/Prestea and Ahafo receive the cyanide in an iso-tanker, after the solid cyanide has been emptied into it on the Barbex premises. The IBCs are thus not transported to these sites but remain in the Barbex yard.

When the IBCs are returned by the end-users all are inspected by the Barbex employees, and those in good condition are dismantled and returned in empty sea-containers to Orica. The remaining ‘unusable’ IBCs are dismantled and incinerated along with all the returned plastic liners.

4.3. AGENTS

Ghana is a developing country that relies on developed countries to provide chemicals required for many manufacturing operations. The gold mining industry is no different as chemicals that are required for the effective extraction of the gold are mostly imported. This includes, amongst others, hydrochloric acid, peroxide, carbon and cyanide.

The exporters load the IBCs into the shipping container and seal the shipping container at the manufacturing plant. The sealed shipping container containing the cyanide is sent to Ghana by sea. On arrival in Ghana, Meridan Port Services Stevedores (MPS) unload the containers from the shipping vessels in both Tema and Takoradi and place them in a storage area. These containers are stacked to a maximum of three layers on a concrete floor in the open air. The storage area is situated approximately 15 metres from other storage areas with a maximum capacity for 80 by 20 (80 x 20) foot cubed sea-containers holding 20 IBCs each.

The agents (Vehrad and Barbex) attend to the customs clearance regulations. When clearance has been obtained on the cyanide, the sea-containers are loaded onto flatbed trailers and the port employees use an x-ray machine to scan the sea-containers. Scanning is performed to ascertain whether the container is packed with cyanide as declared. These containers are then transported to the agent or directly to the end-user, depending on company policy, as shown in Table 4.1. The holding time at the port is a maximum of one week, thereafter additional levies are payable.

Table 4.1: Table of the agents and suppliers delivering to the specific sites found in Ghana

User	Supplier	Agent
Iduapriem	AGR	Clearing agent is Vehrad Transport & Haulage or AngloGold Ashanti Port Unit. Transportation is directly to the mine by Vehrad Transport & Haulage.
Obuasi		
GGL Tarkwa	Orica DuPont	Barbex Technical Services is responsible for the clearance, storage and transportation of the cyanide from the port to their warehouses and ultimately to the gold processing plants.
Damang	Orica	
Bogoso/Prestea		
Wassa		
Chirano		
Ahafo		

The agents are responsible for clearance of the goods, transportation to the warehouses and mine sites, the return, and where contractually required, the incineration of the empty IBCs. Barbex returns some IBCs to Orica for reuse. When returned to Barbex, the IBCs are dismantled before being placed in a sea-container for transportation to the harbour. At the harbour the sea-container is inspected and sealed before being shipped to Australia.

4.3.1 Vehrad Transport and Haulage

Vehrad Transport and Haulage (Vehrad) is a trucking company with its main office in Tema, Ghana. It provides logistical management services that include clearing, warehousing, storage, and haulage to various industries. The contract between Vehrad and AngloGold-Ashanti stipulates the handling and clearance of 1 000 containers a year. This equates to 20 000 IBCs. Vehrad transports chemicals and commercial goods throughout Ghana and extends its services into Burkina Faso and Mali. This company was audited by Eagle Environmental and awarded ICMC compliance in 2008 (Eagle Environmental, 2008a; Vehrad, 2009).

As stated above, the sea-containers are received at the harbour in Ghana (Tema or Takoradi) after freighting from AGR in Australia. The clearance formalities are attended to by the

AngloGold-Ashanti Port Unit or Vehrad before storage and subsequent freighting. Vehrad is responsible for the transportation of the cyanide for AngloGold-Ashanti in Ghana (Vehrad, 2009).

After clearance, the sea-containers are loaded onto flatbed trailers by Vehrad and transported to the two AngloGold-Ashanti mine sites (Obuasi and Iduapriem). The trailers have a maximum design capacity of 55 tons, which allows for the transportation of two sealed sea-containers. These sea-containers, sealed at the manufacturing plant with a unique number according to their bill of lading and holding a maximum weight of 25.4 tons each, are individually fixed to the flatbed trailers by twist locks. The haulage takes place in a convoy on pre-approved routes according to the ICMC protocol (Eagle Environmental, 2008a; Vehrad, 2009).

The convoy is made up of the horse and trailers carrying the loaded sea-containers, six 4x4 cars fixed with satellite tracking systems, two-way radios, cellphones and satellite phones. An assistant transport manager, a mechanic, a medical officer, four fire service personnel and two police personnel man the convoy from origin to destination (Eagle Environmental, 2008a; Vehrad, 2009).

In Ghana the roads along which the cyanide is transported are not well maintained. Often the route passes through small villages with open drainage systems, which could pose a problem if there were to be a cyanide spillage. Vehrad is expected to inspect these routes regularly and have contingency plans in place in case of an emergency. The following table (Table 4.2) gives the distances that Vehrad travels when delivering the cyanide

Table 4.2: Distances to mines from Takoradi (AngloGold, 2009)

Company	Mine	Distance from Takoradi to AGA sites
AGA	Iduapriem	70 km
AGA	Iduapriem	204 km

4.3.2 Barbex

Barbex Technical Services (Barbex) established themselves as a logistical support company in 1990. The main office is in Accra, but the other facilities are located in the Western Region of Ghana on the Teberebie Goldfields property near Tarkwa. According to Golder Associates (2007), these Tarkwa facilities consist of the following:

- offices
- cyanide transfer facility
- waste bag strapping facility
- change house
- transport yard
- warehouses (3)
- incinerator that is used for the disposal of waste bags and IBCs

The three warehouses have a storage capacity of approximately 1 200 metres squared. One warehouse is used as an IBC transit store, the other is used as a sparge tanker facility warehouse and the last warehouse is used as a temporary storage area for waste bags. The annex between two of the warehouses is used as an IBC dismantling area. Other chemicals used primarily for mining purposes are also imported by Barbex and stored at the Tarkwa facility. Up to 3 000 tons of cyanide can be housed at the Barbex Tarkwa facility at any one time (Golder Associates, 2007). This facility was audited by Golder Associates in 2007 and awarded compliance with the ICMC.

Barbex acts as the intermediate between Orica and DuPont and various end-users that operate in Ghana. They are responsible for receiving, clearing, transporting, and storing the cyanide before it is delivered to the end-user. The clearance takes place at Takoradi harbour, and then a flatbed trailer is loaded with one sealed shipping sea-container. All sealed sea-containers containing the IBCs are transported in convoy to the Barbex premises where they are stored according to bill of lading and supplier.

The cyanide from Orica, destined for Damang, GGL Tarkwa, Wassa and Chirano are stored in a concrete floored, bunded area, in the sealed sea-containers until directive for delivery has been received. The South Heap Leach plant of GGL Tarkwa, which is located right next to the Barbex facility, does not receive the sealed sea-container ï the IBC is removed from the container and then each IBC is delivered individually. The empty IBCs are returned to the Barbex premises. GGL Tarkwa is the only end-user that is supplied with cyanide from DuPont.

The IBCs destined for Ahafo and Bogoso/Prestea are opened and the cyanide is emptied into the sparge iso-tanker when cyanide is requested from these two end-users. The sparge iso-tanker then transports the solid cyanide to the relevant plant, where it is mixed with water and discharged from the tanker.

In the figure below (Figure 4.2) the first photo depicts a loaded flatbed trailer with one full sea-container ready for transportation to a site. The second photo shows the sparge iso-tanker. The iso-tanker is empty, and so has not been coupled to a horse.

Photo 1

Photo 2

Figure 4.2: Methods of delivery used by Barbex

The routes used by Barbex for the transportation of the cyanide are not always in a good condition. In some cases, the cyanide is transported through villages with very narrow, badly maintained dirt roads. The drainage system in these villages more often than not consists of open drains, into which cyanide could spill in case of an accident. During the rainy season the condition of the roads often deteriorates even more and can become impassable at times. Barbex regularly inspects the roads along which their vehicles travel and have ensured that contingency plans are in place.

The convoy in which the cyanide is transported is made up of the cyanide transporting vehicle and a support vehicle. There are two drivers in each vehicle. These vehicles are fitted with a GPS tracking device, a two-way radio and mobile telephones. The vehicle is not left alone at any point during the journey.

Table 4.3 provides the distances in kilometres that the Barbex vehicles travel to deliver to the relevant sites.

Table 4.3: Distances to mines from Barbex facility (Golder Associates, 2007).

Company	Mine	Distance from Barbex facility located in Tarkwa in kilometres (km)
Goldfields	Tarkwa	14 km on private road
Goldfields	Damang	51 km
Golden Star	Bogoso	62 km
Golden Star	Wassa	70 km
Newmont	Ahafo	320 km
Redback Mining	Chirano	210 km

Barbex unloads a sealed sea-container from the flatbed trailer at the mine site and the end-user breaks the seal. When the sea-container is open the IBCs are removed and placed in a storage area until needed. Where IBCs are delivered directly to GGL Tarkwa South Heap Leach, they are removed from the sea-container by Barbex employees and stored in the Barbex warehouse until delivery to GGL Tarkwa where they are placed in a small storage area. These storage areas have concrete floors, a roof and are bunded.

All end-users empty the cyanide into a cyanide mixing tank after level probes indicate that solution levels are low and mixing is required. The emptied waste-liners are then placed inside the empty IBC. The user has no further use for these items and they are stored separately in an empty sea-container until removed from site. As an additional service, Barbex collects all empty IBCs and liners. The damaged IBCs from Orica are dismantled and are incinerated with the empty liners. The IBCs from Orica that are reusable are dismantled and returned to the cyanide supplier. All IBCs from DuPont and AGR are dismantled and incinerated with their liners.

4.4. END-USERS

The end-users in Ghana comprise the gold mines that use sodium cyanide for the extraction of gold in their processing plants. Although the method of extraction can be by means of a carbon-in-leach or a carbon-in-pulp process, both require cyanide. Five of these mine sites are situated in the Western Region of Ghana: one is in the Ashanti Region and the other two are in the Brong-Ahafo Region (Figure 1.3).

Two methods of delivery exist in Ghana: the conventional method, which involves the delivery of the cyanide in the IBC (mostly sealed in the sea-container) or by means of the sparge iso-tanker.

When the cyanide is delivered in the IBC, the sea container, still sealed with the original consignment inside, is loaded onto a flatbed trailer and transported to the site. Each IBC of the consignment is controlled by a unique number stamped onto the IBC (Figure 4.3: Photo 1) and logged on the bill of lading. Cyanide operators at each plant open the sea-containers and the IBCs are moved to storage areas by means of a forklift or telehandler. Signage indicating the dangers of cyanide is displayed in appropriate places. An example of the signage has been photographed and is shown in Figure 4.3: Photo 2. Printed warnings are generally pasted onto the sides of the IBCs (Figure 4.3: Photo 3).

Photo 1

Photo 2

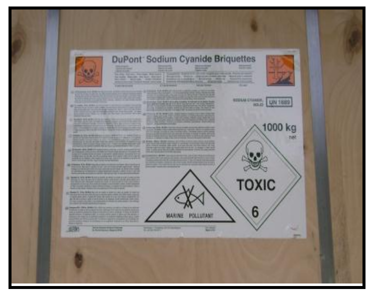

Photo 3

Figure 4.3: Cyanide storage area illustrating notices

When level probes in the cyanide mixing tanks indicate a low level of the liquid chemical, the IBCs are transported to the mixing area and opened manually. This involves the use of pincers, hammers or crowbars. The outer polyethylene liner is slit and a hoist is attached to the straps of the polypropylene liner. The bag is lifted from the IBC into a cutting hood, where it is lowered onto a cutter. The cutter slits the bag and the solid cyanide is emptied into the mixing tank containing pH controlled water (pH>10). The bag is then shaken free of residual cyanide and lowered back into an empty IBC and the empty IBC is stored according to company policy. This policy also dictates who will remove and dispose of the IBC and the liners.

If sparging is used, the company notifies Barbex when cyanide is required. The briquettes are emptied into the sparge iso-tanker at the Barbex facility in the same manner as described above. The iso-tanker is then used to transport the solid cyanide to the relevant site where the iso-tanker is coupled to the mixing tank. Water adjusted to a pH of 10 or above is added in a closed circuit, to dissolve the solid cyanide. On completion the liquid cyanide is discharged into holding tanks. The IBC and the liners remain at the Barbex facility and are disposed of according to the cyanide supplierȏs stipulations.

Table 4.4 tabulates the average amount of cyanide used by each of the end-users discussed in 2008 and the average number of IBCs used to import the cyanide. In this table it is assumed that each IBC contains only one ton of cyanide.

Table 4.4: Cyanide usage in Ghana in 2008

Site name	Approximate usage per annum (ton)	Approximate number of IBCs per annum	% IBC imported per mine site
Iduapriem	2 160	2 160	8.0
Obuasi	4 032	4 032	14.9
Damang	2 172	2 172	8.1
Tarkwa North Heap Leach	6 485	6 485	24.1
Tarkwa South Heap Leach	3 091	3 091	11.5
Tarkwa Gold Plant	1 310	1 310	4.9
Bogoso/Prestea	4 009	4 009	14.9
Wassa	1 558	1 558	5.8
Ahafo	1 630	1 630	6.0
Chirano	484	484	1.8
Totals	**26 931**	**26 931**	**100**

Tabulated below in Table 4.5 is the total number of IBCs incinerated, burnt and returned for 2008. All polyethylene and polypropylene liners were burnt or incinerated.

Table 4.5: IBCs incinerated, burnt or returned for 2008

Manufacturer	IBCs returned	IBCs incinerated	IBCs burnt in open air	Liners incinerated or burnt
AGR			6 192	6 192
DuPont		5 223		5 223
Orica	9 465	6 051		15 516
Total	**9 465**	**11 274**	**6 192**	**26 931**

This table (Table 4.5) assumes that all IBCs are either returned, incinerated or burnt in the open air. The containers that are reused or removed/sold illegally are not accounted for in this study.

4.4.1 AngloGold-Ashanti

AngloGold-Ashanti Limited (AGA) produces gold on an international scale with 21 gold mining operations on four continents. Two of these operations that have been studied are in Ghana, namely Obuasi and Iduapriem (AGA, 2009).

The cyanide supplied to the AGA gold plants is imported to Ghana from AGR. AngloGold-Ashanti makes use of their own clearance agents (AngloGold-Ashanti Port Unit) or Vehrad for customs formalities and then Vehrad Transport and Haulage transports the cyanide to the end-users (Obuasi and Iduapriem). AngloGold-Ashanti does not return any IBCs to Australia for recycling or reuse; all containers are burnt at the mine sites. At both sites the employees indicated that they would consider using the sparging method of transporting cyanide if available.

4.4.1.1 Iduapriem

Iduapriem is located in the western region of Ghana, approximately 70 kilometres north of Takoradi and 10 kilometreses southwest of Tarkwa. It is one of the smallest mines in the AngloGold-Ashanti group (Figures 1.3 and 1.5). It is co-owned by AngloGold-Ashanti (80%) and the International Finance Corporation (20%). Iduapriem is a signatory of the ICMC and it expects to be audited for compliancy in November 2009. The mining method used there is open-pit mining and the metallurgical processing plant is carbon-in-pulp (CIP) (AngloGold, 2009).

Cyanide in IBCs sealed in a sea-container is received from AGR and is used as a lixiviant for the leaching of gold at this plant. On arrival at the plant, the sea-container is offloaded and opened, and the IBCs are taken out and stored in a demarcated part of a shed. The storage area has a concrete floor and a roof, with walls of approximately 0.5 metres separating the different chemicals from each other. A maximum of three boxes are stacked on top of each other until required for mixing. The storage area has the capacity for six monthsô supply of cyanide.

When the mixing of the cyanide is completed as explained above, all IBCs are removed to a secured burning area where they are burned in the open air with other waste. An incinerator for the combustion of cyanide boxes was found in the secured area but was not operational at the time of the observations.

Signage is evident in the plant area and operators were observed to be wearing the relevant personal protective equipment (PPE) when working with cyanide. Log books were kept to control the receipt and use of cyanide, and entry to the storage area was controlled.

4.4.1.2 Obuasi

AngloGold-Ashanti has complete ownership of the Obuasi mine, which is located 80 kilometres from Kumasi in the Ashanti region. A carbon-in-leach (CIL) process is used to extract the gold from the ore. The cyanide used is supplied by AGR and is packaged in IBCs holding 1 000 kilograms of briquettes. The site was not ICMC compliant at the time of the study but they were a signatory to the ICMC and had been gap analysed in August 2008.

Vehrad transports the cyanide in IBCs contained in sealed metal sea-containers by road from Takoradi or Tema to Obuasi. These metal containers are opened at the site and the IBCs unloaded by AGA employees on arrival. The metal sea-containers are then returned to the port in Ghana where they are filled with goods being exported. Obuasi is able to store 1 000 IBCs (1 000 tons of cyanide) in their concrete-floored, roofed storage area. Stacking height does not exceed three boxes on top of each other.

The cyanide mixing procedure is the same as used by the other sites. When the cyanide has been emptied into the mixing tank the liners are shaken free of residual cyanide above the tank, and replaced in the IBC. The IBC containing the liners is transported to an area where it is burnt in the open air. Some of the resulting ashes are tested for cyanide and the rest is thrown into a waste dump facility.

All employees who work with cyanide at the mine are aware of the dangers of cyanide; PPE is always worn when cyanide is handled and signage is evident at all relevant areas. A register exists in which all the cyanide entering the site and used by the site is documented.

4.4.2 Goldfields Ghana Limited

Goldfields Limited, a gold mining house based in South Africa, has a total of nine gold mines located in South Africa, Ghana, Australia and Peru. Two of the sites, namely Damang and GGL Tarkwa, are located in Ghana. Goldfields is one of the worldôs largest producers of gold and is listed on various stock exchanges worldwide (Goldfields, 2009).

Orica and DuPont are the two companies that supply Goldfields with the cyanide they require, and the agent who handles all formalities is Barbex. Both Orica and DuPont import the cyanide to Ghana in IBCs sealed in sea-containers. The cyanide is generally received at the Takoradi seaport, although Tema has been used. All cyanide is transported to the Barbex facility in Tarkwa until required by the mine site and is then delivered to the sites. Sparging is not being considered by either of the Goldfields mine sites.

4.4.2.1 Damang

Damang is situated 30 kilometres north of the town of Tarkwa in south-western Ghana (Figures 1.3 and 1.5). By road it is approximately 300 kilometres west of Accra. Open pit mining, from multiple pits, is the method of mining used and the plant uses a carbon-in-leach (CIL) process (Goldfields, 2009). The cyanide used at Damang is imported from Orica and stored at the Barbex facility at Tarkwa. On request, Barbex delivers the cyanide to the mine site in sealed sea-containers. Damang was awarded with full ICMC compliance following an audit by Eagle Environmental in May 2008 (Eagle Environmental, 2008b).

Barbex has an established transportation route by which the flatbed trailers travel to reach the mine site. The routes take the cyanide through villages on roads that are not always in a good condition; children walk in the roads, and open drains are evident (Figure 4.4).

The cyanide delivered to Damang arrives in a sealed sea-container and is unloaded by the plant personnel. The sealed IBCs are placed in a storage area that has a concrete floor, is bunded and has a roof. This storage area has the capacity to store up to 600 tons of cyanide. The stacking of the IBCs is limited to three on top of each other. After the mixing procedure has been followed, the liners are replaced into their respective IBCs and the IBC transported to the waste IBC area. This area has a cemented floor but no roof. Before Barbex collects the empty IBCs and liners, they are packed into a sea-container and the container is sealed. These sealed sea-containers are then collected by Barbex on delivery of a new consignment. The containers are returned to the Barbex facility where the IBCs are dismantled and incinerated, or dismantled and returned to Orica in Australia.

Figure 4.4: Road conditions on the way to the Damang mine site

Damang employees who handle cyanide maintain a cyanide register into which all IBCs are logged according to their unique numbers. The employees are all aware of the dangers of cyanide and are compelled to wear appropriate PPE when handling the chemical. Signage depicting the dangers of cyanide is clearly displayed at all areas where the cyanide is stored and handled.

4.4.2.2 Goldfields Ghana Limited Tarkwa

The Goldfields Ghana Limited (GGL) Tarkwa gold mine is situated in south-western Ghana, 300 kilometres by road west of Accra. It is four kilometres west of the town of Tarkwa and 60 kilometres northwest of the port of Takoradi. Goldfields Ghana Limited owns 71.1 per cent of the mine, IAMGold 17.9 per cent and the Ghanaian Government owns 10 per cent (Eagle Environmental, 2008c). GGL Tarkwa was awarded with full ICMC compliancy following an audit by Eagle Environmental in May 2008 (Eagle Environmental, 2008c).

The GGL Tarkwa mine obtains its ore from multiple open pits and the extraction of the gold takes place either at one of the two heap leach operations (North and South) or in the CIL plant (Goldfields, 2009). GGL Tarkwa has commissioned both Orica and DuPont to import cyanide for use in the processes, and has the cyanide delivered by Barbex when the stock levels are low. Orica supplies 60 per cent of the cyanide requirement and DuPont supplies 40 per cent. The CIL Gold Plant and the North Heap Leach facility receive the cyanide from Barbex in sealed sea-containers. The individual IBCs, delivered to the South Heap Leach facility, are unloaded from the metal sea-container at the Barbex warehouse prior to delivery. The storage area at the CIL plant has the capacity to store 40 tons of cyanide, the North plant stores between 300 and 500 tons and the South plant stores between 30 and 100 tons of cyanide. The transportation to each of these sites is along well-maintained private mine roads.

The North Heap Leach plant and the CIL gold plant have the metal sea-containers offloaded by Barbex and placed in a secured area. The IBCs are discharged from the container and placed in a bunded area that has concrete floors and a roof. Maximum stacking is three on top of each other. The cyanide from Orica and DuPont are kept separate in the same storage area. When required, the cyanide is mixed using the same process as documented above. GGL Tarkwa differs from Damang in that the empty IBCs are placed directly in a metal sea-container when the cyanide has been removed. These containers are filled with 20 IBCs, sealed and then collected by Barbex.

Every IBC containing cyanide is logged in a cyanide register and the empty IBCs returned to Barbex are also logged. GGL Tarkwa does not sell any of the wood to the community. The chemical is treated as harmful and signs informing the employees about the dangers of cyanide are displayed clearly wherever cyanide is stored or handled. Figure 4.5 depicts the delivery and offloading of the metal sea-containers from Barbex into the secured area at one of the Tarkwa sites.

Figure 4.5: Delivery and offloading of the sea-containers from Barbex at GGL Tarkwa

4.4.3 Golden Star Resources

Golden Star Resources (GSR) is a company based in Canada. It has mining and exploration projects in Ghana, Sierra Leone, Côte dôIvoire, Burkina Faso, Niger, Suriname, French Guiana and Brazil. The two operating mines in Ghana, namely Wassa and Bogoso/Prestea, are situated on the Ashanti Gold Belt. The expected production of gold from these two mines for 2009 was 400 000 ounces (GSR, 2009).

Golden Star Resources has entered into a contract with Orica to supply the two sites with cyanide. In most cases the cyanide is imported into Ghana through Takoradi, although occasionally Tema is used as the port of entry. All the cyanide is stored at Barbex until directive is given for its delivery.

Both plants have signage posted at the relevant areas informing the employees of the dangers of cyanide, and all cyanide handlers are equipped with PPE. A cyanide register controlling the influx and use of cyanide is filled in on delivery of the chemical.

4.4.3.1 Bogoso/Prestea

The Bogoso/Prestea mine, which has mining and exploration concessions, is owned by Golden Star Resources, with a 10 per cent interest in the property by the Government of Ghana. The mine is located in the Western Region of Ghana, 300 kilometres west of Accra. Ore is mined from open pits and then transported to the gold plant where the gold is extracted by means of a combination of gravity concentration, flotation, conventional CIL methods and bio-oxidation (GSR, 2009). When the site visit was conducted Bogoso/Prestea had not been audited for ICMC compliancy, but had been gap audited and was awaiting final auditing in January, 2009.

Cyanide received from Orica in IBCs is stored at Barbex and delivered to Bogoso/Prestea in a sparge iso-tanker as a solid briquette. The mine site has a cyanide sparge plant (Figure 4.6) with two tanks (mixing and storage) and coupling lines. On delivery, the sparge iso-tanker is coupled to the cyanide mixing tank on site and water (pH>10) is circulated through the sparge iso-tanker to dissolve the briquette. The resulting liquid cyanide, with concentration approximately 30 per cent, is then pumped into the storage tank through a closed circuit. Altogether 20 tons of cyanide are delivered to the site three times a week and a cyanide delivery register is kept.

Figure 4.6: Bogoso/Prestea cyanide sparge plant

Advantages noticed by Bogoso/Prestea employees since using the sparging method of delivery include less direct human exposure to the chemical, making the mixing process safer; reduction in IBC waste on site; and time saving.

The transportation route taken by the sparge iso-tanker can be exposed to major challenges, especially during the raining season. The roads are sealed dirt roads that can be affected by heavy rains, and also pass close by and through small villages. Barbex is responsible for the regular inspection of these routes. Some of these challenges are depicted in Figure 4.7.

Figure 4.7: Transportation route to Bogoso/Prestea

4.4.3.2 Wassa

The Wassa processing facility and gold mine is located in the south-western region of Ghana approximately 35 kilometres east of Bogoso/Prestea. It was discovered and developed in the 1990s and initially developed as a heap leach operation. GSR then acquired the mine and added the CIL processing facility. Currently, the ore is mined from open pits and then processed using a traditional carbon-in-leach process. The site was not ICMC compliant at the time of the observations; however, ICMC compliancy auditing was scheduled for January 2009 (GSR, 2009).

When requested by Wassa, Barbex transports sealed sea-containers containing 20 IBCs along most of the same route used to deliver cyanide to Damang. Wassa unloads and stores the IBCs in a cyanide storage shed until required for mixing. The storage area can hold 200 tons of cyanide on a concrete floor, with secondary containment under a roof. Maximum stacking is two high, and the area is secured. Safety information is posted at all relevant points and employees handling the cyanide wear PPE.

After mixing the cyanide, the liners are flushed with clean water, replaced in the IBC and the IBC is transported to the used IBC storage area where they are placed into a sea-container. The waste water is collected in a process water dam and reused in the plant. Barbex collects the full sea-container when a new consignment is delivered.

Wassa previously considered dumping the waste IBC in the waste dump area, but abandoned this plan as they assumed that the wood would be collected and used by surrounding communities.

4.4.4 Newmont – Ahafo

Ahafo, an open pit mine, is owned by Newmont Ghana Gold Limited, a Ghanaian subsidiary of Newmont Ghana Gold Limited. It is located in the Brong-Ahafo region of Ghana about 300 kilometres northwest of Accra (Figures 1.3 and 1.5). Mining started in 2006 and the site was awarded ICMC compliancy following an audit by Golder Associates in 2008 (Golder Associates, 2008).

The gold plant at Ahafo has a conventional cyanide mixing and storage tank, like most of the other end-users described, as well as a sparging facility. The site has never used the conventional system, but has solid cyanide delivered to them in a sparge iso-tanker from Barbex twice a week.

On arrival at the plant, Barbex couples the iso-tanker to the cyanide mixing tank and pH adjusted water ($pH>10$) is pumped into the tanker to dissolve the briquettes. The resulting liquid is then pumped into the storage tank and is ready for use. The circuit through which the liquid cyanide is pumped is closed.

Safety signs are posted at all relevant areas and PPE is used when handling the cyanide or any part of the tanker from which it is pumped. All employees are trained in emergency preparedness, in case of spillage or leaks.

Advantages realised by Ahafo in using sparging instead of the conventional mixing methods include safer handling, limited access to cyanide, and less problems with disposal of IBCs.

4.4.5 Redback Mining – Chirano

Redback Mining is an Australian-owned company, of which Chirano Gold Mines Limited is a Ghanaian subsidiary (Stuart, 2009). Chirano is located in south-western Ghana, 100 kilometres southwest of Kumasi, and 15 kilometres south-southwest of Bibiani, a small township. The production of gold at Chirano commenced in 2005, with the first gold pour in 2005. Currently the ore is mined from open pits, but an underground mine is being developed

(Redback, 2009). The metallurgical process used at Chirano for the extraction of gold is carbon-in-leach; there are no heap leach operations. Chirano is not ICMC compliant and is not a signatory.

All cyanide used at Chirano is ordered from Orica and then delivered by Barbex in IBCs sealed in sea-containers. The IBCs are transferred to a warehouse after removal from the sea-container and stacked on top of each other, the maximum being three boxes. The capacity of the warehouse is to store 200 IBCs on the concrete floor. The store is roofed and is not bunded. Chirano has not considered sparging as they are satisfied with the current system.

The empty cyanide liners are replaced in the IBC after mixing and the IBC is placed in a used packaging area. Barbex removes the waste IBC and liners, that are inside a sealed sea-container, from the plant when a new consignment is delivered.

Chirano has safety signs posted at all relevant cyanide handling and storage zones in the plant and the employees are trained in emergency preparedness. A cyanide register documents all the cyanide received and used on the gold plant and no IBCs are sold to the communities.

4.5. GENERAL OBSERVATIONS

All the cyanide used in Ghana is manufactured outside of its borders. The cyanide is packaged in IBCs and liners at the cyanide manufacturing plant, and shipping vessels freight the cyanide to Ghana in sealed, metal sea-containers containing 20 IBCs. On arrival in Ghana these sea-containers containing the full IBCs are transported on flatbed trailers along poorly maintained roads to the agent (Barbex) or the mine site (Iduapriem and Obuasi).

When delivered to the AGA end-users the sea-container is transported directly to the site where it is unloaded and destuffed. The full IBC is then stored until the cyanide is required for mixing. The end-users who receive their cyanide from Barbex notify the agent when they require cyanide and then it is delivered to the site in a metal sea-container for destuffing and storage. The south heap leach plant at GGL Tarkwa receives IBCs that have been removed from the sea-container.

In the case of sparging, Barbex opens the sea-container and empties the cyanide from the IBC into the sparge tanker. All liners are replaced in the empty IBCs and these are returned to the agent for incineration. If the IBCs from Orica are in a reusable condition they are dismantled and returned to the supplier, but all the used liners are incinerated. On average 61 per cent of IBCs were returned to Orica from Ghana in 2008. In some cases (Obuasi and Iduapriem) the empty IBCs and their liners are burnt at the mine site.

The table below (Table 4.6) summarises the delivery methods, the waste generated and the manner in which the waste is disposed of for each end-user.

Table 4.6: Summary of delivery methods, waste generated and waste disposal methods for each end-user

Supplier	Agent	End-user	Delivery method	Type of waste generated	Waste disposal
AGR	Vehrad	Iduapriem	• Sealed sea container	• IBC • Polyethylene liner • Polypropylene liner	• Open air burning
		Obuasi	• Sealed sea container	• IBC • Polyethylene liner • Polypropylene liner	• Open air burning
DuPont	Barbex	GGL Tarkwa	• Sealed sea container • IBC	• IBC • Polyethylene liner • Polypropylene liner	• Incineration
Orica	Barbex	GGL Tarkwa	• Sealed sea container • IBC	• IBC • Polyethylene liner • Polypropylene liner	• Incineration • Reuse
		Damang	• Sealed sea container	• IBC • Polyethylene liner • Polypropylene liner	• Incineration • Reuse
		Bogoso/Prestea	• Sparge iso-tanker	• IBC • Polyethylene liner • Polypropylene liner	• Incineration • Reuse
		Wassa	• Sealed sea container	• IBC • Polyethylene liner • Polypropylene liner	• Incineration • Reuse
		Ahafo	• Sparge iso-tanker	• IBC • Polyethylene liner • Polypropylene liner	• Incineration • Reuse
		Chirano	• Sealed sea container	• IBC • Polyethylene liner • Polypropylene liner	• Incineration • Reuse

On route to the mine sites temporary structures built from IBCs were observed (Figure 4.8), showing that cyanide containers were previously sold to the community for personal use. The use of the IBCs for building material has been discontinued due to the toxic nature of cyanide and the concern that residual cyanide could poison humans and animals.

Figure 4.8: Temporary structures from IBCs (Personal Collection, 2008)

Also observed on the route were bulk chemical containers that were being used by people for water storage (Figure 4.9).

Figure 4.9: Chemical containers used for holding water (Personal collection, 2008)

Most of the mine sites investigated indicated that these bulk containers and drums were sold to employees. Cyanide is not imported into Ghana in bulk containers or even in drums as all containers need intensive decontamination before they could be considered safe to use.

4.6. CHAPTER SUMMARY

This chapter aimed at presenting a holistic picture of the importing, transporting, use, recycling, reuse or disposal of the IBC and its liners. The boundary demarcated for the study was Ghana and the units and sub-units were identified and discussed in the embedded case study.

The next chapter will endeavour to analyse and discuss the results of the study by using a cross-case analysis in which all results from the units and sub-units are integrated. The final step, in the next chapter, will be to assimilate all the results and present them as an LCA

CHAPTER 5

RESULTS, PRESENTATIONS AND DISCUSSIONS

This chapter presents and analyses the results that were obtained in the study using the ISO 14000 framework, which divides the life cycle assessment (LCA) process into goal and scope definition (ISO14040), life cycle inventory (ISO14041), life cycle impact assessment (ISO14042) and interpretation (ISO14043). The first three sections are discussed individually by examining the sampling profiles, presenting and reviewing the results obtained from the case studies and finally, where relevant, concluding with interpretations of these results. The interpretation stage will be communicated in Chapter 6.

5.1. GOAL DEFINITION AND SCOPE FOR LIFE CYCLE ASSESSMENT

The LCA study commenced with the definition of the goal and scope. These served as a guide to ensure consistency and lay the foundation for the study. In this step objectives are fixed, applications for the study are determined and the future use for the functional unit is established (Curran, 2006; Landu, 2006).

5.1.1 Goal of the study

The goal states the reasoning behind the LCA study, and identifies the intended audience and the type of critical review to be conducted. The goal and objectives of this LCA was stated in Chapter 1, but is repeated here for practical purposes.

The goal of this study is to assess the life cycle ('cradle to grave') of intermediate bulk containers (IBCs) of sodium cyanide, as used by the gold mining sector in Ghana.

The objectives are restated below:

- Determine the origin of the IBC.
- To quantify the number of IBCs imported to Ghana annually.
- Evaluate methods of disposal of the IBC and its liners and the effect thereof on the environment.
- Identify which category in terms of human health, ecosystem quality and resources is impacted on the most by the different life cycles.
- To ascertain whether transportation within Ghana has a noteworthy effect on the environment.

The intended audience, which was identified in Chapter 3, consists of cyanide manufacturers, agents, end-users and an academic audience. The intention in each case is briefly mentioned below.

In the first place, the intention was to make cyanide manufacturers aware of existing alternatives and of the impact that the IBC has on the environment, so that alternatives can be developed. With regard to agents, the intention was to create an awareness of the potential impacts that poor management of IBCs can have on the environment. A further aim was to encourage end-users to manage the use, reuse and recycling of the IBC properly. Finally, the intention was also to encourage the academic audience to identify further research possibilities and to develop education in the use of LCA methodology.

5.1.2 Scope of the study

The scope of this LCA involved the investigation of a wooden intermediate bulk container and the associated liners used for the transportation of cyanide to and within Ghana. The investigation commenced with the entry of the IBCs into the Ghanaian sea-port to the destruction of the IBCs and the liners in Ghana. Those IBCs not incinerated in Ghana were not included as part of the scope of the research as they are returned to the supplier for reuse.

According to Clements (1996), the scope of the LCA gives the parameters of the study by laying out the functions of the systems under study, defining the functional unit, defining the system boundaries, determining the data requirements, expressing the limitations involved, and laying out the assumptions being made. These aspects are discussed in the sections that follow (5.1.2.1 - 5.1.2.6).

5.1.2.1 Laying out the functions of the systems under study

The whole system that was studied is the IBC containing the cyanide, the polyethylene liner and polypropylene liner. The IBC is filled with cyanide at the overseas cyanide manufacturing plant and is imported into Ghana for use in the mining industry in the extraction of gold. After use, the IBC and the liners are disposed of; this may take the form of incineration, in which some IBCs and all liners are incinerated in Ghana. The remaining IBCs are returned to the manufacturer without the liners for reuse.

Within the whole system identified above, smaller units or systems exist in Ghana, as listed below:

- Storage of the full sea container at the Ghanaian sea-port
- Transportation of the full sea container to the agent
- Storage of the full sea container at the agent
- Transportation of the full sea container to the end-user
- Off-loading of the full sea container at the end-user
- Unloading of the full sea container at the end-user
- Unloading of the IBCs into the sparge iso-tanker
- Transportation of the sparge iso-tanker to the end-user
- Mixing of cyanide and transfer of liquid cyanide from the iso-tanker into the cyanide storage tank
- Storage of the full IBC at the end-user
- Discharging of the full IBC
- Storage of the empty IBC at the end-user
- Return of the empty IBC to the agent
- Disposal/reuse of the empty IBC

Figure 5.1 is a simplified illustration of the route followed by the IBC from entry into Ghana until final destruction or return to the origin. The black lines represent the transportation of the IBC.

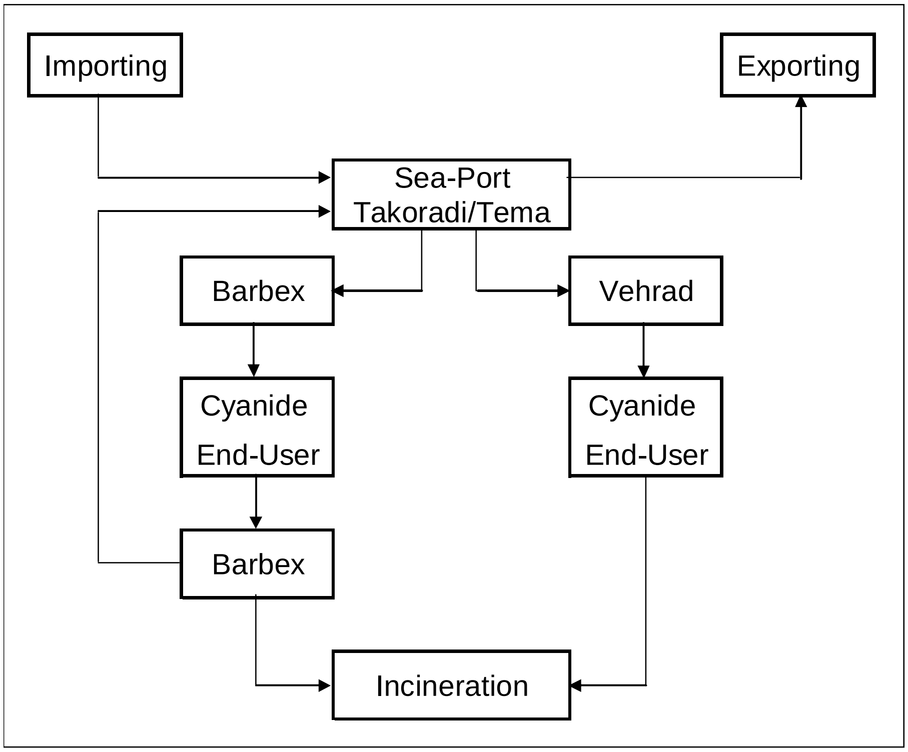

Figure 5.1: Simplified route along which the IBC is transported

5.1.2.2 Defining the functional unit

As defined by Curran (2006) and stated in Chapter 2, the functional unit of an LCA study describes the function of the product or process being studied. The functional unit is identified so that all alternatives can be compared. In this study, it is a wooden IBC used for packaging and transporting one ton of cyanide from the manufacturer to the end-user. The life cycles of both the liners (polyethylene and polypropylene) were included as functional units and these were studied separately to enable comparisons to be made during the LCIA phase.

5.1.2.3 Defining the system boundaries

In defining the system boundaries, the breadth of the study was determined. The origin of the IBC was found to be from either the United States of America (USA) or Australia. The cyanide is imported into Ghana after being shipped by sea from the different suppliers. For practical purposes and to ensure that the LCA did not become too large, the life cycle of the IBC was followed on arrival in Ghana and was terminated on disposal of the IBC. The disposal in this study refers to the incineration of the IBC and its liners by the agent or the end-user, or to the return of the IBC to the supplier for reuse. The incineration step was followed in the LCA but the IBCs that were being returned to the supplier were only studied up to the point where the agent took ownership of the IBC. The study is thus mostly a ógate to graveô assessment, but in some cases can be referred to as a ógate to gateô assessment.

Figure 5.2 (page 94) illustrates the system boundary for this LCA. All highlighted and bolded areas form part of the study.

5.1.2.4 Determining the data requirements

The type of data required for the LCA study is described in Chapter 3, under óData collectionô (Section 3.4). To summarise: it consists of primary and secondary data of both a qualitative and qualitative nature. Primary and secondary data were collected by making use of observations, interviews, questionnaires and desktop methods.

This LCA was conducted in the latter part of 2008 and thus most of the data presented will be from this period.

5.1.2.5 Expressing the limitations involved

The limitations experienced while conducting the research for this study are documented below:

- Confidentiality clauses in supplier contracts limited the availability of data.
- Masses were not provided from all the suppliers with regard to the IBC and its liners.
- LCI results were generated using a model developed for Europe as there is no model in Simapro 7.1 available for Ghana.
- The open air burning process could not be modelled by the software, thus it was included as part of the incineration process.
- The study only focused on the disposal of the IBC and its liners in Ghana.

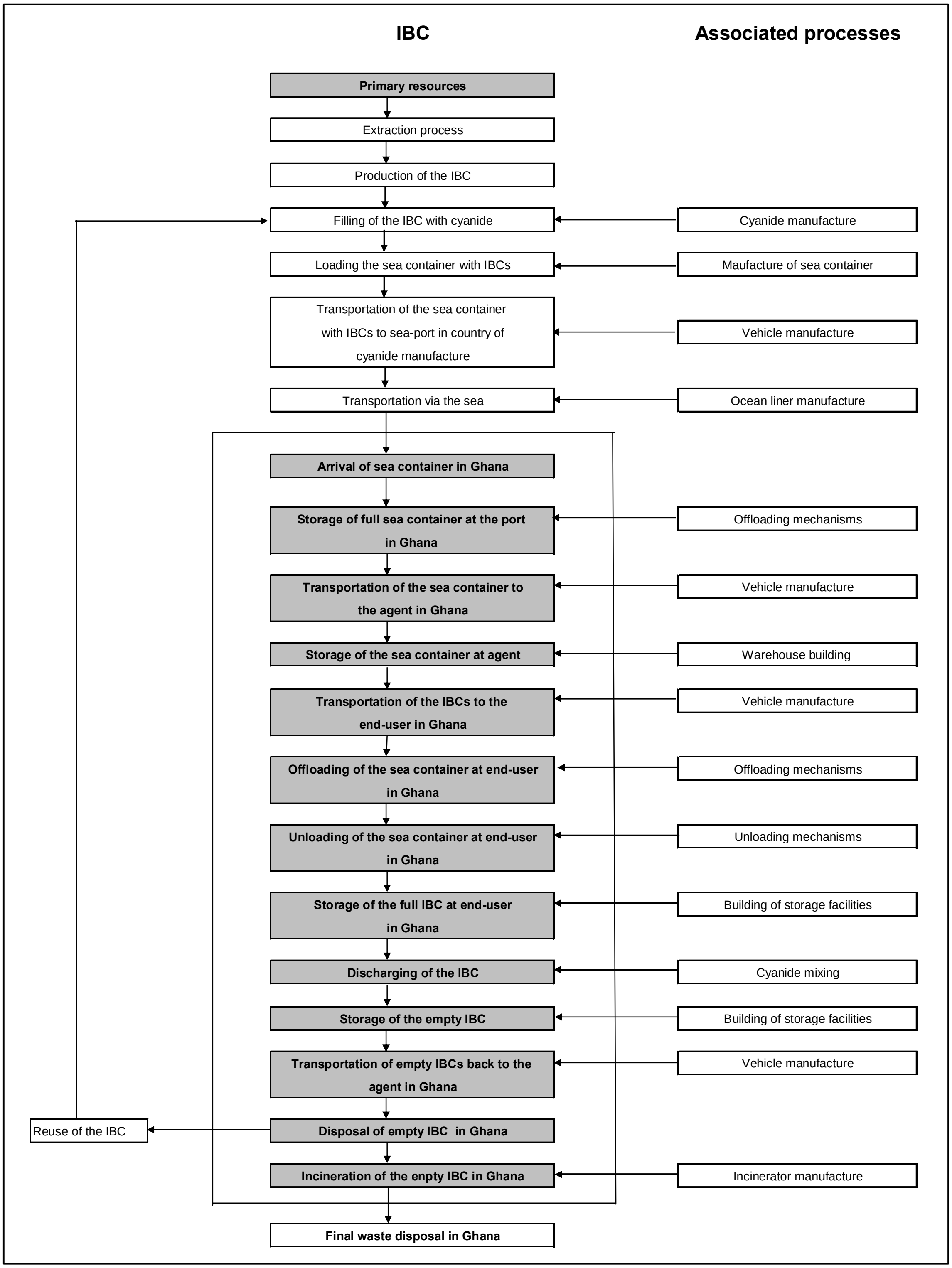

Figure 5.2: System boundaries for the LCA

5.1.2.6 Assumptions being made

In all research projects there are uncertainties involved, thus assumptions need to be made. The assumptions in this study are listed below:

- Mass of the IBC and the liners are the same for all manufacturers.
- The incinerator used in Ghana is powered by electricity.
- Incineration and open air burning have the same effect on the environment.
- An average mass for the sea-container was used because the masses differ for MAERSK and MSC.
- The tonnage of cyanide received for 2008 is representative of the cyanide received for other annual periods.

5.2. LIFE CYCLE INVENTORY

This phase of the project commenced by listing all the processes and systems involved in the life of the IBC. Included were atmospheric emissions, waterborne emissions, and solid waste emissions. Initially the raw materials from which the liners and the IBC were manufactured were identified by literature and interviews. Thereafter the minerals and fossil fuels for each liner and the IBC were identified by databases on the Simapro 7.1 software.

Human resources, manufacture of capital equipment and energy requirements fall outside of the system boundary and were excluded. However, Figure 5.2 above gives a very broad breakdown of the processes within the entire system. This system boundary was simplified to include only the IBC, the polyethylene liner, polypropylene liner and associated inputs and outputs as illustrated in Figures 5.3 and 5.4.

The inputs and outputs represented by the broken lines (Figures 5.3 and 5.4) fall outside of the system boundary and were not included in the research. The solid lines fall within the ambit of the study.

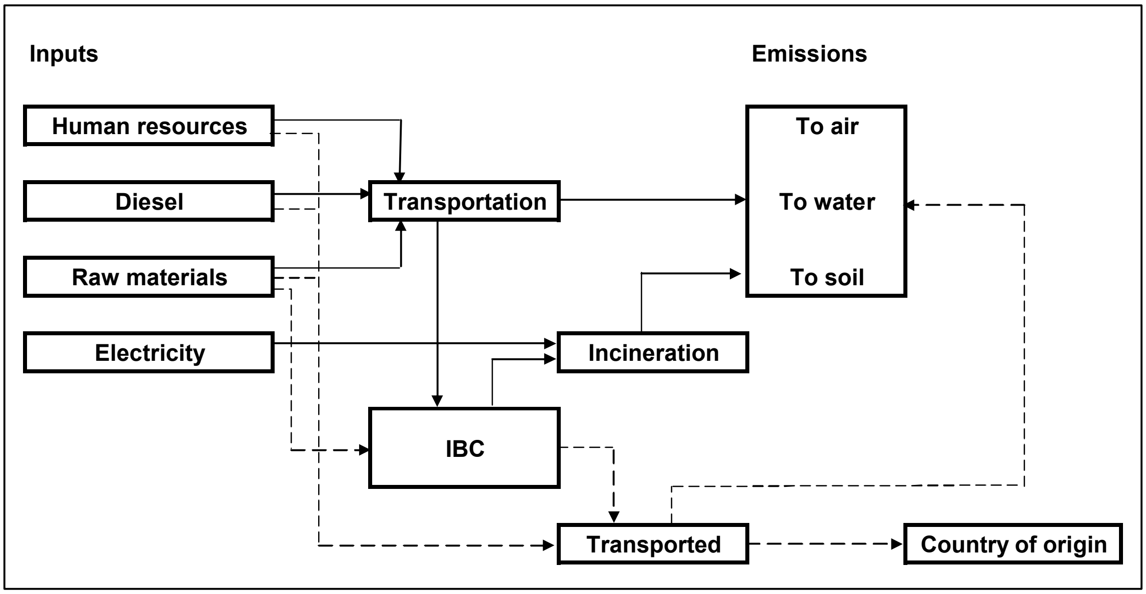

Figure 5.3: Schematic representation of input and output system for the IBC

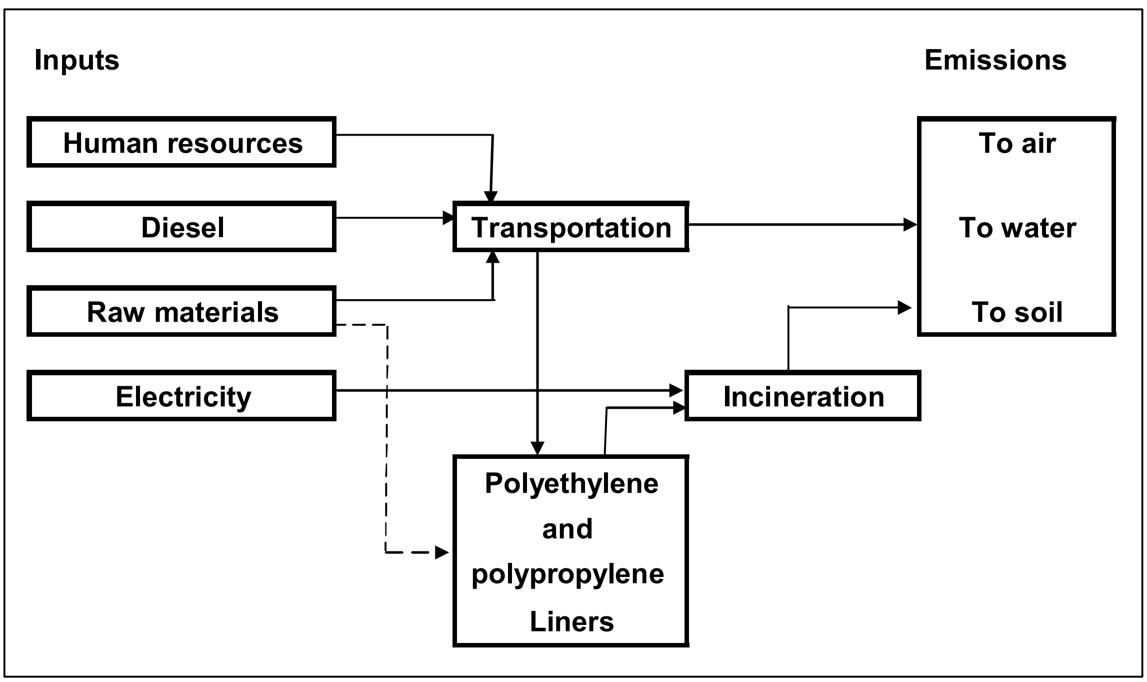

Figure 5.4: Schematic representation of input and output system for the polyethylene and polypropylene liners

5.2.1 Collection of inputs and outputs

The inputs and outputs required to model the system can be divided into foreground systems and background systems. Data from foreground systems describe the product system and are collected from the companies involved in the study, generally by questionnaires and interviews (primary data). Background system data (secondary data) are not collected via questionnaires but can be readily found on the internet, in databases and in literature. All data used, whether foreground or background, should be reliable and complete (Goedkoop *et al.*, 2008a).

Literature from sources such as DuPont provided some inputs. These included the mass and the raw materials from which the IBC and both liners are manufactured; these specifications are tabulated in Table 5.1 below. As no specifications were supplied for the IBCs and liners from Orica and AGR, these data were assumed to be representative of all IBCs and liners in Ghana.

Table 5.1: Mass of IBC and Liners

Item	Material	Approximate mass
IBC	Plywood	88 kg
Polyethylene liner	Polyethylene (LDPE)	1 100 g
Polypropylene liner	Polypropylene (PP)	2 200 g

(Source: DuPont(b), n.d.)

In addition to other general information, the questionnaires (Appendix A) provided information about the number of IBCs incinerated, burnt in the open air, or returned to the manufacturer. The total number of liners incinerated or burnt was also documented in the questionnaires. The relevant percentages were calculated and the results are tabulated below (Table 5.2).

Table 5.2: Waste disposal methods per manufacturer

Company	Open air burning		Incineration		Reuse		Liners incinerated or burnt
	Total	%	Total	%	Total	%	Total
AGR	6 192	22.99					6 192
DuPont			5 223	19.39			5 223
Orica			6 051	22.47	9 465	35.15	15 516
Total	6 192	22.99	11 274	41.86	9 465	35.15	26 931

Using the results in Table 5.2, the waste disposal methods were separated into reuse and incineration. Open air burning was included as a part of the incineration total even though differences do occur between these methods of disposal. This grouping was used to facilitate data use within the application of the Simapro 7.1 software. Incineration accounted for 64.85 per cent of the waste disposal and reuse accounted for 35.15 per cent.

The software required the calculation of the tonnage of waste transported for the total number of kilometres (tkm). In calculating these values, a portion of the mass of the sea-container was calculated and allocated to the cyanide, IBC and its liners (Appendix B). A ratio division of the sea-container was used for the delivery trip in which the sea-container was loaded with cyanide and the packaging, and on the return trip the sea-container was only allocated to the empty packaging, ratio wise (Appendix B).

The empty sea-containers at Barbex are decontaminated and returned to MAERSK or MSC who then use them to export products out of Ghana. The return of the empty sea-containers did not fall within the scope or boundary of the study and was not pursued outside of Barbex.

Appendix B documents and explains how these results were calculated. Although the life cycle of the sea-container was not followed, it was necessary to include it as part of the life cycles of the packaging as it was used as a transport mechanism.

Table 5.3 is a representation of the methods used for disposal of the IBC and the liners. It tabulates the total number of each, the individual masses and also the calculated total mass for each method of disposal.

Table 5.3: Weight of waste and disposal methods

Description	Disposal Method	Number of IBCs	Unit weight in kg	Weight sent to waste in kg
IBC	Reuse	9 465	88	832 920
IBC	Incinerate	17 466	88	1 537 008
Polypropylene Liner	Incinerate	26 31	2.2	59 248.2
Polyethylene Liner	Incinerate	26 931	1.1	29 624.1

The vehicles used to transport the full sea-containers to the mine sites are flatbed trailers that use diesel as fuel and which are capable of transporting a maximum load of 44.6 tons (Eagle Environmental, 2008a). They thus only carry one full sea-container with cyanide at one time and travel in convoys. Only the diesel trailer is considered for the purpose of this study and not the other vehicles travelling in convoy.

5.2.2 Inventory lists

Information from Appendix B and Table 5.3 was used as input data in Simapro 7.1. Transportation was included as a part of each life cycle and was based on the mass of each functional unit transported per kilometre. Simapro 7.1 processed all data and modelled the emissions in terms of raw material used, emissions to soil, emissions to water and emissions to air, and generated a comprehensive inventory list (Appendix C) for each of the liners as well as for the IBC reused and the IBC incinerated.

From these complete inventory lists (Appendix C) generated in Simapro 7.1, inventory tables of selected inputs and outputs to/from the environment (Table 5.4 to Table 5.6) were compiled. A cut-off of two per cent was used to provide a summary of results. In using a cut-off, inputs and outputs that contributed two per cent or less to the overall impacts to the environment were ignored. This was done to make the inventory lists more manageable and thus more readable. Using these summarised inventory lists a comparison could be made of the IBC reused, IBC incinerated, polyethylene liner and polypropylene liner and subsequent deductions of which contributed to the degradation of the environment the most.

Table 5.4: Inventory list of raw material inputs/outputs for individual life cycles

Substance	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Copper, in ground	kg	7.96×10^5	2.71×10^6	1.19×10^5	2.90×10^5
Gas, natural, 35 MJ per m^3, in ground	m^3	3.61×10^8	1.23×10^9	2.06×10^7	5.11×10^7
Land use II-III	m^2a	1.77×10^5	6.04×10^5	3.94×10^4	9.73×10^4
Land use III-IV	m^2a	1.35×10^4	4.59×10^4	2.02×10^3	4.28×10^3
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	kg	1.61×10^5	5.49×10^5	1.83×10^4	3.58×10^4
Oil, crude, 42.6 MJ per kg, in ground	kg	4.02×10^8	1.37×10^9	1.41×10^9	2.90×10^9

Table 5.5: Inventory list of emissions to water for individual life cycles

Substance	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Arsenic, ion	kg	5.24×10^3	1.78×10^4	1.96×10^3	3.65×10^3
Cadmium, ion	kg	2.42×10^2	8.20×10^2	3.84×10^2	6.91×10^2
Cesium-137	kBq	2.25×10^7	7.68×10^7	4.89×10^6	1.21×10^7

Table 5.6 Inventory list of emissions to air for individual life cycles

Substance	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Cadmium	kg	1.37×10^{2}	4.65×10^{2}	4.76×10^{2}	1.04×10^{3}
Carbon dioxide	kg	-1.92×10^{10}	-6.54×10^{10}	2.24×10^{9}	4.96×10^{9}
Carbon dioxide, biogenic	kg	1.15×10^{10}	3.92×10^{10}	1.16×10^{5}	2.08×10^{5}
Carbon dioxide, fossil	kg	1.98×10^{8}	6.16×10^{8}	2.40×10^{9}	4.06×10^{9}
Carbon-14	kBq	3.08×10^{7}	1.05×10^{8}	6.39×10^{6}	1.58×10^{7}
Chromium	kg	9.97×10^{3}	3.40×10^{4}	3.07×10^{2}	6.78×10^{2}
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	3.91×10^{2}	1.33×10^{3}	8.54×10^{1}	2.12×10^{2}
Methane	kg	6.67×10^{6}	2.27×10^{7}	8.23×10^{6}	1.71×10^{7}
Methane, bromotrifluoro-, Halon 1301	kg	1.56×10^{2}	5.33×10^{2}	5.47×10^{2}	1.13×10^{3}
Nickel	kg	3.56×10^{3}	1.21×10^{4}	1.01×10^{4}	2.21×10^{4}
Nitrogen oxides	kg	1.81×10^{7}	6.12×10^{7}	5.81×10^{6}	7.16×10^{7}
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	5.39×10^{6}	1.82×10^{7}	1.08×10^{7}	8.13×10^{7}
Particulates, < 10 εm (stationary)	kg	7.88×10^{6}	2.68×10^{7}	1.02×10^{6}	2.23×10^{6}
Radon-222	kBq	2.58×10^{12}	8.78×10^{12}	5.63×10^{11}	1.40×10^{12}
Sulphur oxides	kg	1.61×10^{7}	5.48×10^{7}	1.60×10^{7}	3.55×10^{7}
Zinc	kg	1.68×10^{4}	5.72×10^{4}	1.07×10^{3}	2.36×10^{3}

5.3. LIFE CYCLE IMPACT ASSESSMENT

On completion of the LCI, the Simapro 7.1 software initiated the life cycle impact assessment (LCIA). In this step, the effects of material consumption and environmental releases identified during the LCI were calculated. During the LCIA, the inventory list was categorised, classified and characterised. These are the mandatory elements of the LCIA. Normalisation was included to generate comparable results, and a damage assessment, a voluntary step in the software, was included to present the damage to the environment.

5.3.1. Selection of impact categories

The impacts generated during the LCI are made up of various inputs and outputs that affect human, animal, plant and overall ecological health. All impacts could be direct, indirect or cumulative on local, regional or global scales. During categorisation, these data were sorted and placed into three broad damage categories (Human health, Ecosystem quality, and Resources), which were subdivided as follows into impact categories according to their effect on the environment:

- Human health
  - Carcinogens
  - Respiratory organics
  - Respiratory inorganics
  - Climate change
  - Radiation
  - Ozone layer
- Ecosystem quality
  - Ecotoxicity
  - Acidification/eutrophication
  - Land use
- Resources
  - Minerals
  - Fossil fuels

5.3.2. Classification of results

During classification, each item in the inventory list was assigned by the Simapro 7.1 software to a specific impact category as stipulated above. In cases where the item contributed to more than one impact category, it was assigned to both. In Table 5.7, the selected inputs and outputs from the inventory list generated during the LCI that were classified by the software, are tabulated.

Table 5.7: Classification of selected inputs/outputs from the life cycle inventory

Damage category	Impact category	Compartment	Input/Output
Human health	Carcinogens	Air	Cadmium ion
	Carcinogens	Water	Arsenic ion
	Carcinogens	Water	Cadmium
	Respiratory organics	Air	NMVOC, non-methane volatile organic compounds, unspecified origin
	Respiratory inorganics	Air	Nitrogen oxides
	Respiratory inorganics	Air	Particulates, < 10 µm (stationary)
	Respiratory inorganics	Air	Sulphur oxides
	Climate change	Air	Carbon dioxide
	Climate change	Air	Carbon dioxide, biogenic
	Climate change	Air	Carbon dioxide, fossil
	Climate change	Air	Methane
	Ozone layer	Air	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114
	Ozone layer	Air	Methane, bromotrifluoro-, Halon 1301
	Radiation	Air	Carbon-14
	Radiation	Air	Radon-222
	Radiation	Water	Cesium-137
Ecosystem quality	Acidification/ Eutrophication	Air	Nitrogen oxide
	Acidification/ Eutrophication	Air	Sulphur oxides
	Ecotoxicity	Air	Chromium
	Ecotoxicity	Air	Nickel
	Ecotoxicity	Air	Zinc

Damage category	Impact category	Compartment	Input/Output
	Land use	Raw Materials	Cesium-137
	Land use	Raw materials	Land use II-III
	Land use	Water	Land use II-IV
Resources	Fossil fuels	Raw materials	Gas, natural, 35 MJ/m^3, in ground
	Fossil fuels	Raw materials	Oil, crude, 42.6 MJ/kg, in ground
	Minerals	Raw materials	Copper, in ground
	Minerals	Raw materials	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground

5.3.3. Characterisation of results

Following the definition of the impact categories, the LCI results were allocated to these 11 categories (see Section 5.3.1 above). The impact categories were quantified in terms of a common unit for that specific category by multiplying the mass value of the relevant emission by its corresponding characterisation factor (discussed in Chapter 3). This generated the impact indicator for each category. Impact indicators allow LCI results to be compared within each damage category for conclusions to be drawn as to which impact category has the largest effect on the environment.

Based on the Eco-indicator 99 method used in the Simapro 7.1 software, the characterisation results generated for the analyses are tabulated in Table 5.8 and are represented graphically in Figure 5.5. The discussion that follows refers to this table and figure.

Table 5.8: Characterisation of separated liners and IBC

Impact category	Unit	Life cycle IBC reused	Life cycle IBC incinerated	Life cycle polyethylene liner	Life cycle polypropylene liner
Carcinogens	DALY	3.99×10^2	1.36×10^3	2.32×10^2	4.51×10^2
Resp. organics	DALY	8.05	2.72×10^1	1.90×10^1	1.06×10^2
Resp. inorganics	DALY	5.64×10^3	1.91×10^4	1.79×10^3	9.17×10^3
Climate change	DALY	-1.52×10^3	-5.18×10^3	1.01×10^3	1.97×10^3
Radiation	DALY	7.35×10^1	2.50×10^2	1.60×10^1	3.96×10^1
Ozone layer	DALY	2.41	8.22	7.64	1.44×10^1
Ecotoxicity	PAF*m^2yr	1.37×10^9	4.66×10^9	9.62×10^8	2.15×10^9

Impact category	Unit	Life cycle IBC reused	Life cycle IBC incinerated	Life cycle polyethylene liner	Life cycle polypropylene liner
Acidification/ Eutrophication	PDF*m^2yr	1.31 x 10^8	4.42 x 10^8	5.00 x 10^7	4.46 x 10^8
Land use	PDF*m^2yr	3.51 x 10^8	1.20 x 10^9	2.47 x 10^7	5.94 x 10^7
Minerals	MJ surplus	3.90 x 10^7	1.33 x 10^8	7.29 x 10^6	1.68 x 10^7
Fossil fuels	MJ surplus	4.84 x 10^9	1.64 x 10^{10}	8.82 x 10^9	1.82 x 10^{10}

Figure 5.5 graphically represents the contribution of each of the life cycles to each impact category. All 11 impact categories are used in this graph to illustrate the fact that within the damage categories there are impacts on these smaller impact categories.

On the y-axis the highest calculated effect score is scaled to 100 per cent and indicates the category impacted on the most (LCIA, 2009). In all, except climate change, the results are positive, showing a negative impact on the environment. In the life cycle for IBC reused and IBC incinerated, climate change has negative values; thus a positive impact is expected.

It becomes obvious when considering each impact category separately that each of the four life cycles contributes to the degradation of the environment to different degrees. However, no conclusive interpretations can be made when consulting the figure as to which life cycle impacts on the environment the most. In essence, characterisation shows which category has been impacted on, whether the impact is positive or negative, and within each category, which life cycle has the greatest effect.

To illustrate this point, it can be seen in the category carcinogens that all four life cycles have a negative impact, that IBC incinerated has the highest impact and the polyethylene liner has the lowest impact.

To simplify this scenario and aid in determining which life cycle has the greatest impact, and on which category, normalisation is applied as stipulated below.

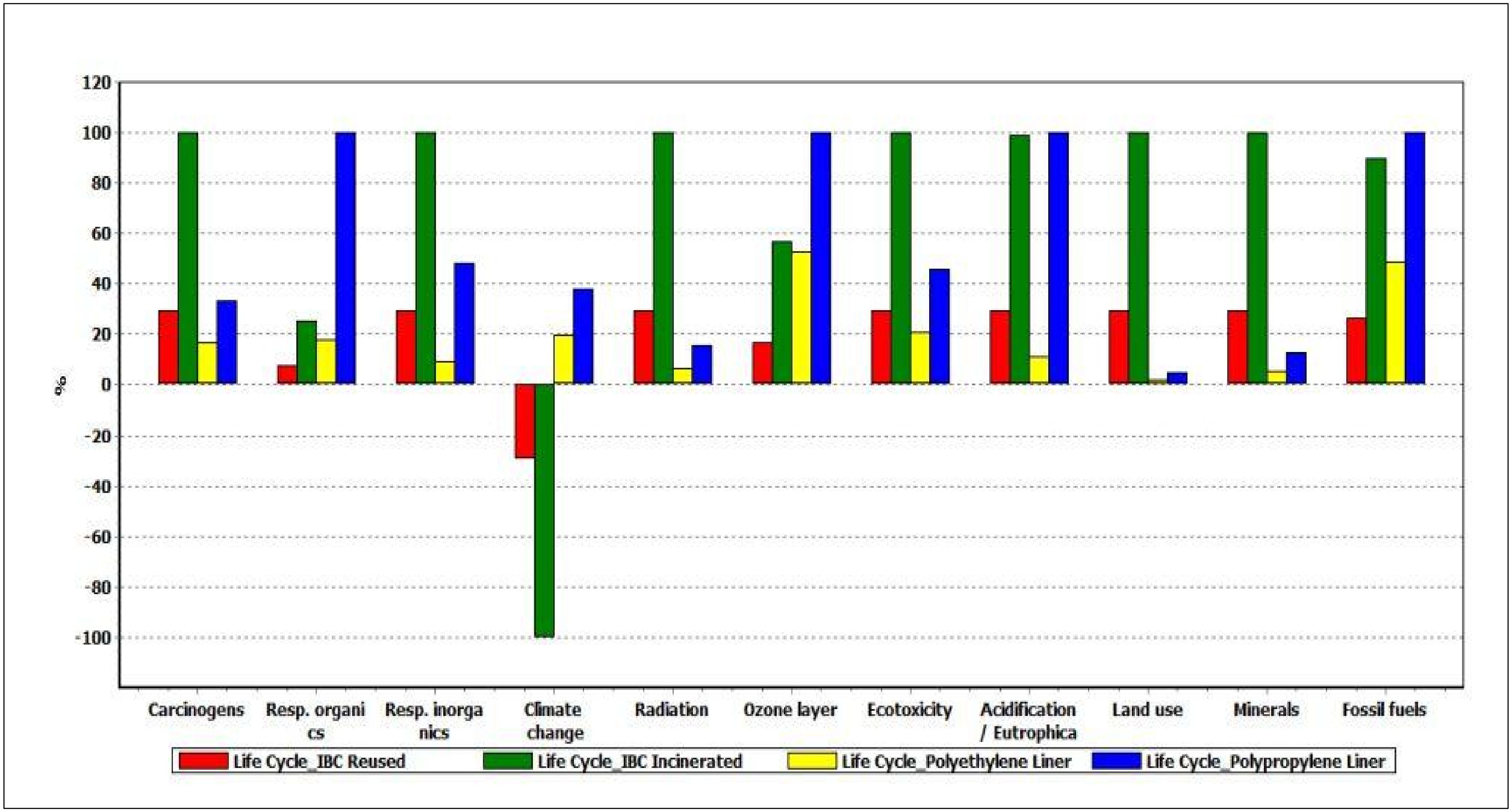

Figure 5.5: Characterisation results of separate life cycles

5.3.4. Normalisation

Normalisation is used to enable the reader to identify the damage category most impacted on by studying the length of the bars in the graph (y-axis). The taller bar represents the impact category most affected by the life cycle. This is brought about by making these impact categories dimensionless by dividing or multiplying by a reference value. The method used most often divides the average yearly environmental load in a country or continent by the number of inhabitants, and this value is then used as the reference (Goedkoop & Spriensma, 2001; Goedkoop, Oele, de Schryver, & Vieira, 2008b).

The graph below (Figure 5.6) represents the normalised results for the full life cycles of the IBC and its associated liners. The impact categories are shown to indicate that within each damage category, the impact categories have different effects. It also demonstrates the variability of the impacts within each damage category.

Here fossil fuels, respiratory inorganics, and climate change are, in order of magnitude, the three impact categories that are affected the most by the four life cycles. This is illustrated by the length of the bars in the graph. The other eight impact categories are all affected to a lesser extent with land use being affected the most by IBC incinerated in these remaining categories.

The effect on land use of the incinerated IBC can be explained as the land that is converted from naturally occurring ecosystems to a cultivated ecosystem in which trees are grown to support the use of wood in the manufacture of the IBC. This alteration of the land will have an effect on the species diversity by altering the ecosystem and changing the size of the land supporting these ecosystems. Man also tends to make use of the best resources first, in this case land, thus affecting the quality of that remaining for future generations (Goedkoop *et al.*, 2008b).

The only perceived positive effect on the environment of the IBC and its liners is shown for climate change, in the life cycle of the IBC incinerated and the life cycle of IBC reused. The negative impacts on the environment caused by the release of carbon dioxide during these life cycles are seemingly negated by the use of carbon dioxide during the growth of the trees. The larger negative value of the IBC incinerated (green bar) shows a bigger positive impact than the IBC reused (red bar). The life cycles of the IBC incinerated and the IBC reused are the

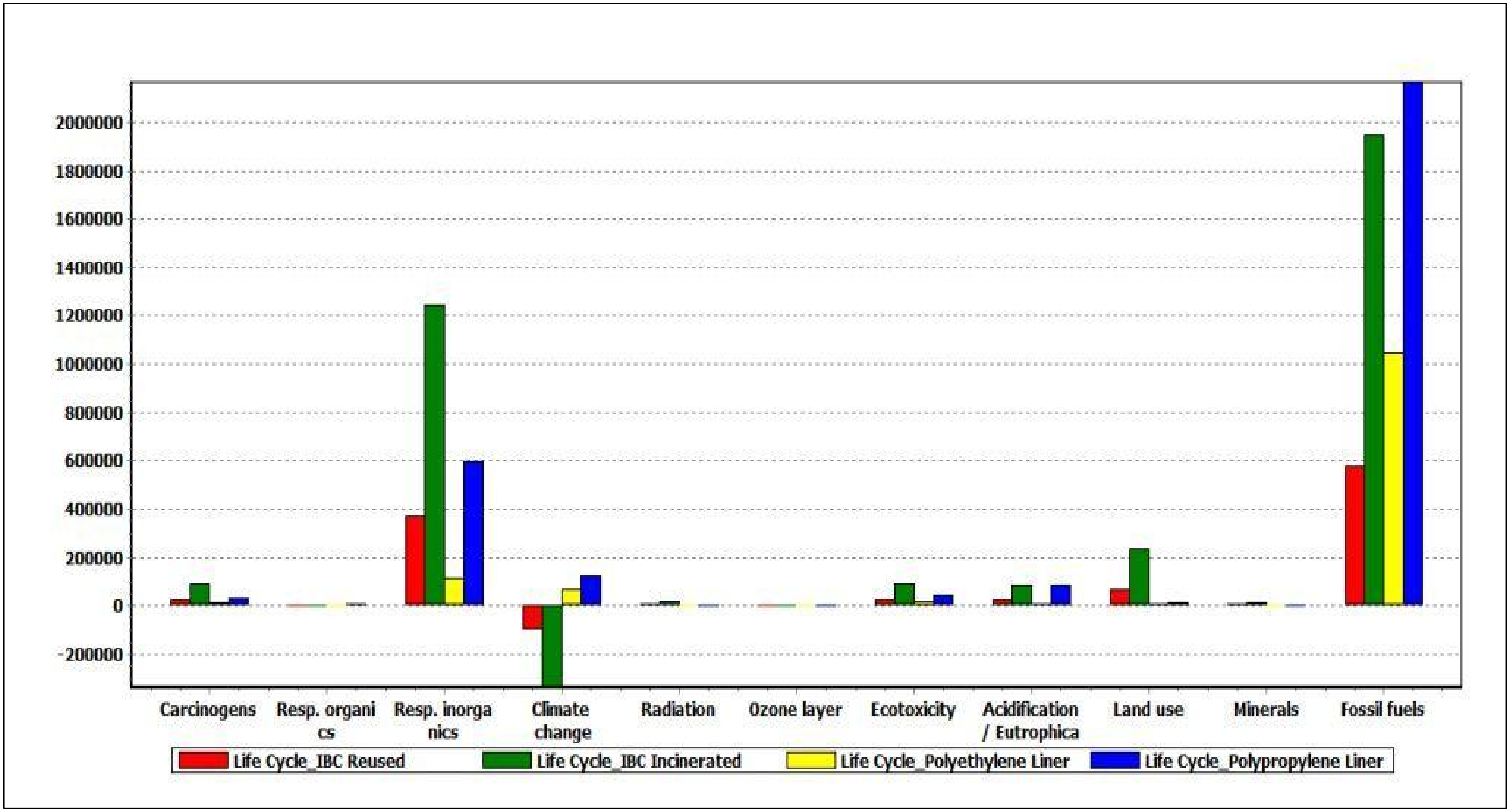

Figure 5.6: Normalisation of separate life cycles

only life cycles that have a positive effect on climate change. A more comprehensive explanation for this is found in Chapter 2 (Literature review).

In summary: it appears that the life cycle of the IBC and liners impacts the most on fossil fuels in the resources category, followed by respiratory inorganics, which affect human health, and then climate change, which forms part of ecosystem quality (Figure 5.6). These damage categories and classifications (impact categories) are generated in the Simapro 7.1 software.

To present results that are more conclusive and even easier to interpret, grouping and ranking is applied by the software. Damage assessment as discussed below is a grouping procedure (Goedkoop & Spriensma, 2001).

5.3.5. Damage assessment

Eco-indicator 99, as used in Simapro 7.1, has an additional damage assessment step. In this step, the impact category indicator results that are calculated in the characterisation step are added to form damage categories. These damage categories show the total damage caused by each life cycle to each damage category (Goedkoop *et al.*, 2008a). Each damage category is represented by different units:

- Damage to human health is measured as the number of years life lost and the number of years lived disabled. Combined, they form the index of Disability Adjusted Life Years (DALY).
- The damage to ecosystem quality is expressed as the loss of species for a certain period, and is measured as the potentially disappeared fraction (PDF m^2yr; m^2 stands for the area size and year (yr) stands for the time) in the case of acidification/eutrophication and land use, also as the potentially affected fraction (PAF m^2yr; m^2 stands for the area size and year (yr) stands for the time) used for ecotoxicity.
- The surplus energy (measured in MJ surplus) needed for the future extraction of minerals and fossil fuels is expressed as the damage to resources and links the lower concentration to increased efforts to extract resources in future (Goedkoop *et al.*, 2008b).

Figure 5.7 is a graphical representation of the damage that the life cycles of the IBC and the liners have on the different damage categories of the environment. The categories represented in this figure are human health, resources and ecosystem quality, but can be expanded to show the damage on each impact category. This representation was chosen as here all the impact categories are summed within a damage category to give a more holistic illustration of which damage category is affected the most. Also, some of the impact categories are impacted on to such a small degree (as seen in Figure 5.6) that the length of the bar is not clear in the graph.

All three damage categories, consisting of the sum of all the relevant impact categories, have four bars of different lengths. These bars symbolise the life cycles of the functional units investigated. Each of these bars represents the sum (y-axis) of all the classified results (impact category values) that are found in that damage category and is scaled to 100 per cent to assist with interpretation.

In the human health damage category the incinerated IBC (green bar) has the highest negative impact, followed by the life cycle of the polypropylene liner (blue bar), showing that human health is impacted on the most by the incinerated IBC when the four life cycles are compared. The characterisation values in Table 5.8 furthermore shows that the category respiratory inorganics affects human health the most in these life cycles. The yellow bar representing the polyethylene liner is the shortest, showing that within this damage category the polyethylene liner has the lowest negative impact on human health.

Ecosystem quality is also affected the most by the incinerated IBC (green bar), followed by the polypropylene liner (blue bar). In this damage category, the polyethylene liner (yellow) also impacts on the quality of the ecosystem the least.

In the damage category representing resources, the polypropylene liner (blue bar) has the greatest negative impact, followed by the incinerated IBC (green bar). The reused IBC (red bar) has the smallest negative impact on resources.

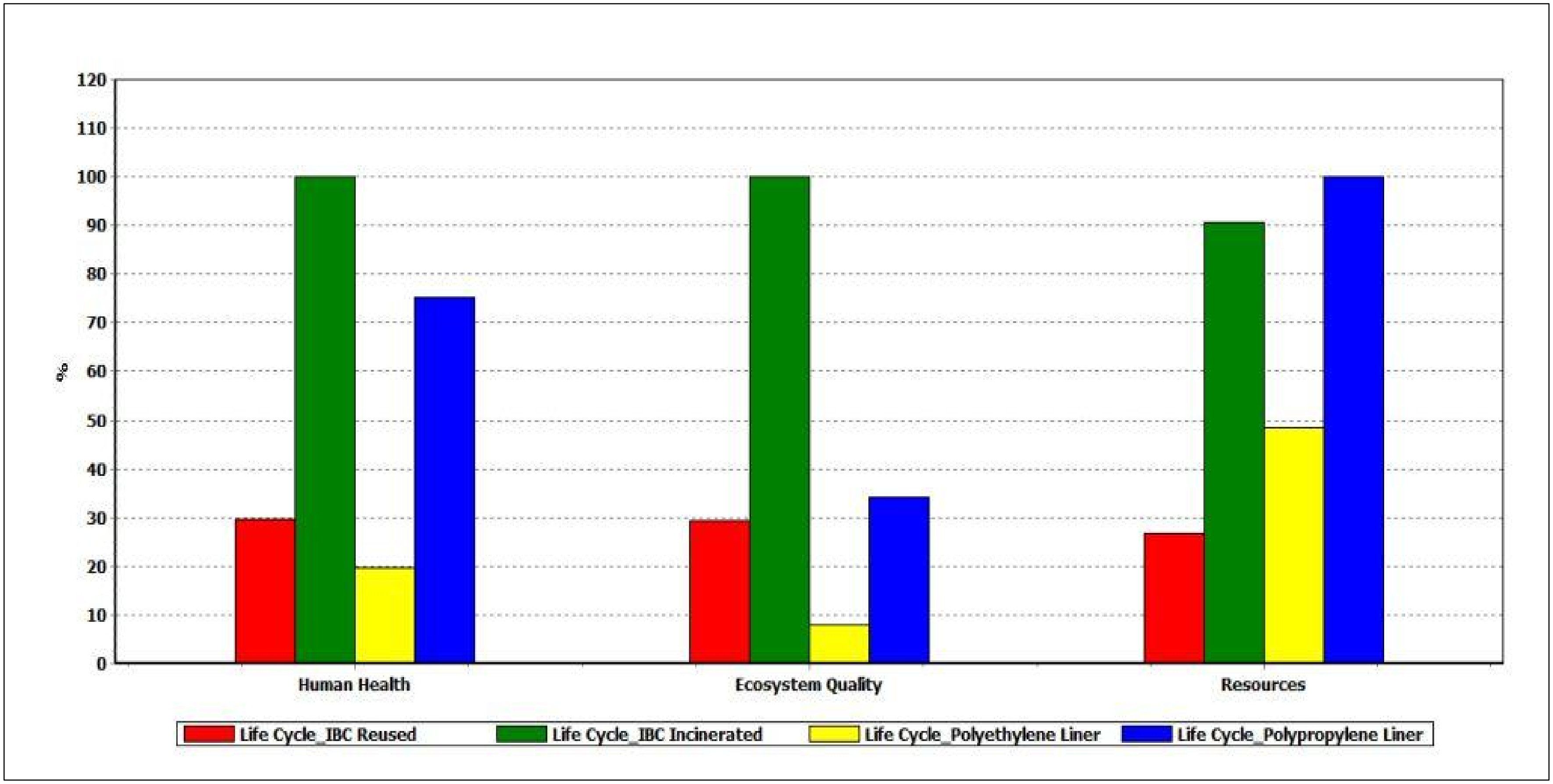

Figure 5.7: Damage assessment of separate life cycles

This graph and the lengths of the green bars (Figure 5.7) show that the incinerated IBC has the largest impact overall, followed by the polypropylene liner, as these bars are the longest in all three categories. The positive impact that climate change has, as observed in Figure 5.6, is outweighed by all the other negative impacts in this category. When these positive effects (climate change) are subtracted from the negative effects a lower overall negative impact is shown. From the graph it is not obvious whether the reused IBC or the polyethylene liner has the largest impact. However, when the percentages from each category of these life cycles are added it appears as though the polyethylene liner (å80%) has a smaller impact than the reused IBC (å90%).

The interpretation of this assessment is further represented and facilitated by a single score impact assessment graph which in effect is a weighting step.

5.3.6. Impact assessment

The following graph (Figure 5.8) summarises the impacts for each impact category in each separate life cycle. It is represented as a single score to enable interpretation at a glance. Single scores are determined by adding the dimensionless weighted values for each impact category in the individual life cycles and then representing them as bars in a graph. These bars are then used as visual tools for interpretation.

The unit on the y-axis is gigapoints (GPt = 1 x10^9 points). The annual emission of one average European inhabitant amounts to approximately 1 000 points. From this the burden of the product is able to be calculated and is represented as people equivalents (Goedkoop & Spriensma, 2001).

5.3.6.1. Life cycle of reused IBC

The total number of points on the y-axis for the life cycle of the reused IBC adds up to 0.325 gigapoints (GPt), which translates to 325 000 people equivalents. This in turn equates to the emissions of 325 000 people in one year, thus the emissions caused by the reused IBC are comparable to the emissions of 325 000 people. For this life cycle, respiratory inorganics have the highest value, followed by fossil fuels. Climate change is positively impacted on in this life cycle.

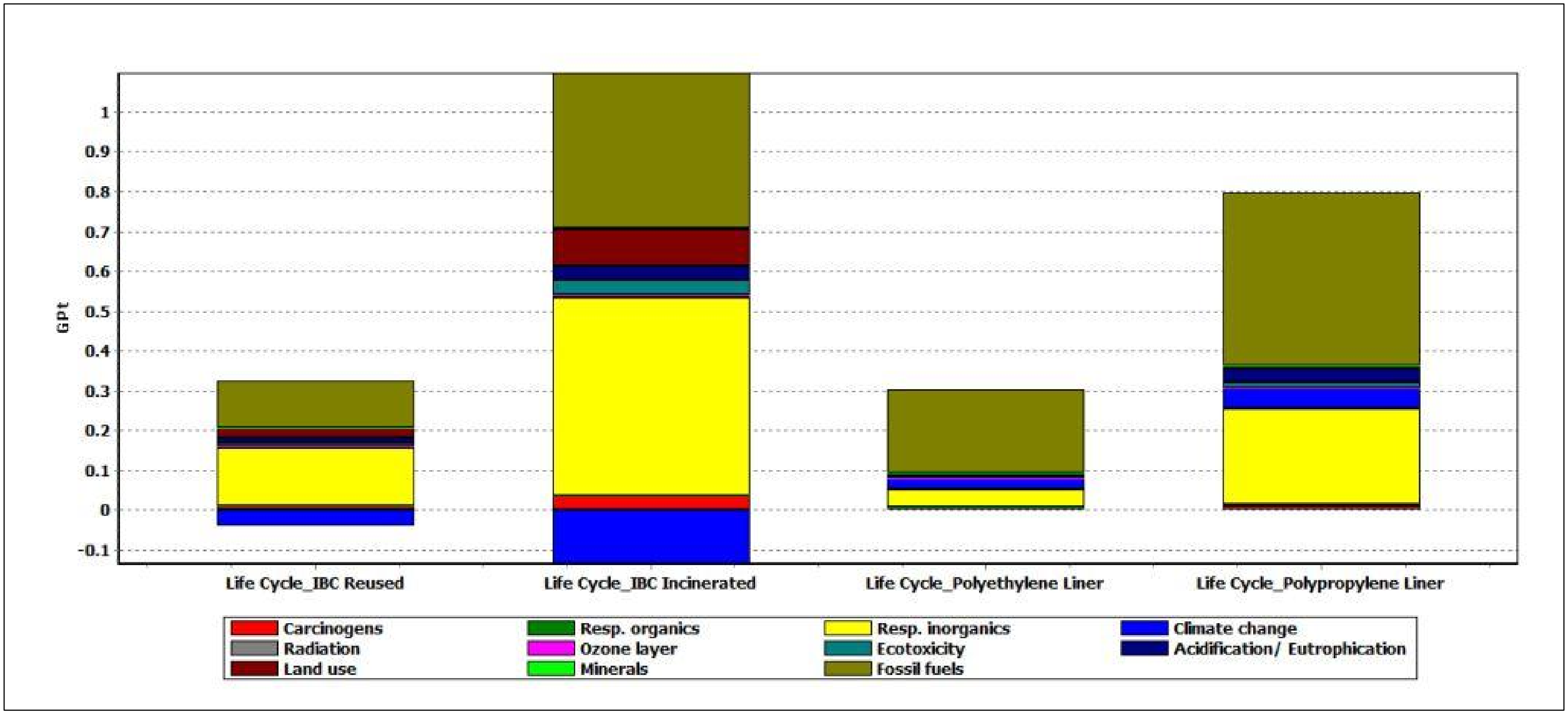

Figure 5.8 Single score impact assessment of the life cycle of the IBC and liners per impact category

As there is no waste disposal in this scenario, it can be assumed that the respiratory inorganics consisting amongst others of non-methane volatile organic compounds (NMVOCs), nitrogen oxides, particulates and sulphur oxides (Table 5.7), are released into the air. These NMVOCs may originate from fuel used for the transportation of the reused IBC. The main fossil fuels that are used as raw materials according to this table (Table 5.7) consist of natural gas and crude oil.

5.3.6.2. Life cycle of incinerated IBC

The impact categories that have the largest negative impact on the environment for the incinerated IBC are arranged from highest to lowest, respiratory inorganics, fossil fuels, land-use, acidification/eutrophication, ecotoxicity, and carcinogens. In this scenario, climate change has a perceived positive impact on the environment, probably caused by the emission of carbon dioxide formed by the burning of biogenic sources (wood) (Table 5.6). The burden of the incinerated IBC amounts to 1.1 gigapoints (Figure 5.8), which is translated to the impact caused by 1 100 000 people equivalents and thus the emissions from the incinerated IBC for this period are comparable to those that are caused by 1 100 000 people.

The respiratory inorganics, as described above, are emissions found in the air and may be caused by the transportation of the IBC as well as by its incineration. The life cycle of the incinerated IBC shows the highest result for respiratory inorganics. Fossil fuels impact on raw materials required for this life cycle and land use impacts on water and raw material use. Acidification/eutrophication and ecotoxicity occur, and carcinogens are emitted into the air and water. Carcinogens and ecotoxicity have the highest impact when the results for these four categories are considered for all four life cycles (Table 5.8).

The life cycle of the incinerated IBC appears to have the largest overall impact on the environment.

5.3.6.3. Life cycle of polyethylene liner

According to the graph (Figure 5.8), the polyethylene liner has the smallest impact on the environment. The total number of people equivalents for this life cycle is 300 000, represented by the 0.3 gigapoints; thus the impact of the polyethylene liner on the environment for 2008 equates to the emissions caused by 300 000 people. Figure 5.8 shows that fossil fuels have the largest impact and climate change and respiratory inorganics both have smaller negative impacts on the receiving environment.

As in the previous life cycles that have been discussed, the category fossil fuels affects raw materials, and respiratory inorganics and climate change impact on the air quality. The raw materials affected in this life cycle are linked to the manufacturing of the polyethylene liner and, to a lesser extent it can be attributed to the raw materials used to manufacture the fuel used for the transportation of the liner.

In this study the cumulative scores in this life cycle (Figure 5.8) show that the polyethylene liner has the smallest impact on the environment.

5.3.6.4. Life cycle of polypropylene liner

In this study, the life cycle of the polypropylene liner demonstrates that it has the second highest impact on the environment, after the incinerated IBC (Figure 5.8). The impact of this product on the environment is comparable to that caused by 800 000 people, as seen in the 0.8 gigapoints in Figure 5.8. Therefore, when this life cycle is related to people it is comparable to the damage caused by 800 000 people (for 2008).

Also evident in Figure 5.8 are the high values obtained for fossil fuels, followed by respiratory inorganics. Climate change and acidification/eutrophication contribute negatively, although the impacts are considerably smaller than for fossil fuels and respiratory inorganics.

As discussed in the previous life cycle (life cycle of polyethylene liner), fossil fuels impact on raw materials, and respiratory inorganics, climate change and acidification/eutrophication impact on the air. All these impacts can be linked to the incineration, transportation and manufacture of the polypropylene liner.

Respiratory inorganics, climate change, acidification/eutrophication and fossil fuels have the highest values for this life cycle when compared to the other three (Table 5.8).

5.4. CHAPTER SUMMARY

In this chapter, the goal and scope of the LCA was revisited, the inventory lists that form part of the LCI were generated and the LCIA was conducted. The methodology used was eco-indicator 99 found in the Simapro 7.1 software. All the results obtained using this method and software were documented and general discussions written with regard to these results. The results will be interpreted in the following chapter (Chapter 6).

CHAPTER 6

INTERPRETATION

In Chapter 5, the results of the life cycle inventory (LCI) and the life cycle impact assessment (LCIA) were presented and discussed according to the ISO 14040 framework. This chapter will use these results to interpret the four different life cycles and identify relevant issues, where applicable. During the interpretation, a completeness check, sensitivity check and consistency check are required to comply with ISO standards; these will also be presented in this chapter.

6.1. IDENTIFICATION OF IMPORTANT ISSUES

During the identification of the most noteworthy issues, all relevant information from the LCI and the LCIA are reviewed to determine which of the products, processes, or services contribute the most to the results, thus impacting on the environment the most. According to Curran (2006), the identification and determination of major issues in a life cycle assessment (LCA) are approached in one of the following ways:

- Contribution analysis: The relevance of each of the life cycles is compared to determine the contribution to the study.
- Dominance analysis: In examining the relevance of the identified important contributions, statistical tools, which include quantitative and qualitative ranking, are used.
- Anomaly assessment: Any unusual or surprising deviations are observed and examined for relevance.

The noteworthy issues in this LCA were identified for each life cycle using the characterisation results from Chapter 5 (Table 5.8), which are reprinted here below (Table 6.1). This table shows to what extent each emission within the life cycles impacts on the individual categories; thus it is a contribution analysis. Anomalies were identified where relevant and are discussed (e.g. climate change in the intermediate bulk container (IBC) life cycle), and the categories are ranked according to the quantitative results obtained.

The most important issue in each life cycle and separate category is highlighted in red; the least important is highlighted in yellow. These results will be discussed under the categories Human health, Resources and Ecosystem quality, and the focus will be on the most important issues identified within each life cycle. Only the most important impact category (ranked first) in each damage category will be discussed and in Human health climate change will be discussed as it is an anomaly. Resources were affected the most for all life cycles, followed by Human health and then finally Ecosystem quality. Where relevant, the issues that have the smallest effect on the environment will be discussed.

The units used in Table 6.1 are disability adjusted life years (DALY) for measuring Human health, the potentially affected fraction (PAF m^2 yr) or the potentially disappeared fraction (PDF m^2yr) for Ecosystem quality, and surplus energy (MJ surplus) for Resources (EI99, 2000).

Table 6.1: Least and most important results

Category	Impact category	Unit	Life cycle IBC reused	Life cycle IBC incinerated	Life cycle polyethylene liner	Life cycle polypropylene liner
Human health	**Carcinogens**	DALY	3.99×10^{2}	1.36×10^{3}	2.32×10^{2}	4.51×10^{2}
	Resp. organics	DALY	8.05	2.72×10^{1}	1.90×10^{1}	1.06×10^{2}
	Resp. inorganics	DALY	**5.64×10^{3}**	**1.91×10^{4}**	**1.79×10^{3}**	**9.17×10^{3}**
	Climate change	DALY	**-1.52×10^{3}**	**-5.18×10^{3}**	1.01×10^{3}	1.97×10^{3}
	Radiation	DALY	7.35×10^{1}	2.50×10^{2}	1.60×10^{1}	3.96×10^{1}
	Ozone layer	DALY	2.41	8.22	**7.64**	**1.44×10^{1}**
Ecosystem quality	**Ecotoxicity**	PAF*m^2yr	**1.37×10^{9}**	**4.66×10^{9}**	**9.62×10^{8}**	**2.15×10^{9}**
	Acidification / Eutrophication	PDF*m^2yr	**1.31×10^{8}**	**4.42×10^{8}**	5.00×10^{7}	4.46×10^{8}
	Land use	PDF*m^2yr	3.51×10^{8}	1.20×10^{9}	**2.47×10^{7}**	**5.94×10^{7}**
Resources	**Minerals**	MJ surplus	**3.90×10^{7}**	**1.33×10^{8}**	**7.29×10^{6}**	**1.68×10^{7}**
	Fossil fuels	MJ surplus	**4.84×10^{9}**	**1.64×10^{10}**	**8.82×10^{9}**	**1.82×10^{10}**

Figure 6.1 summarises the impacts for each category into a single score. These data indicate that the largest overall adverse impact (determined by the length of the bar) is caused by the incinerated IBC followed by the polypropylene liner, then the polyethylene liner, and finally the reused IBC. Figure 6.1 also facilitates the interpretation.

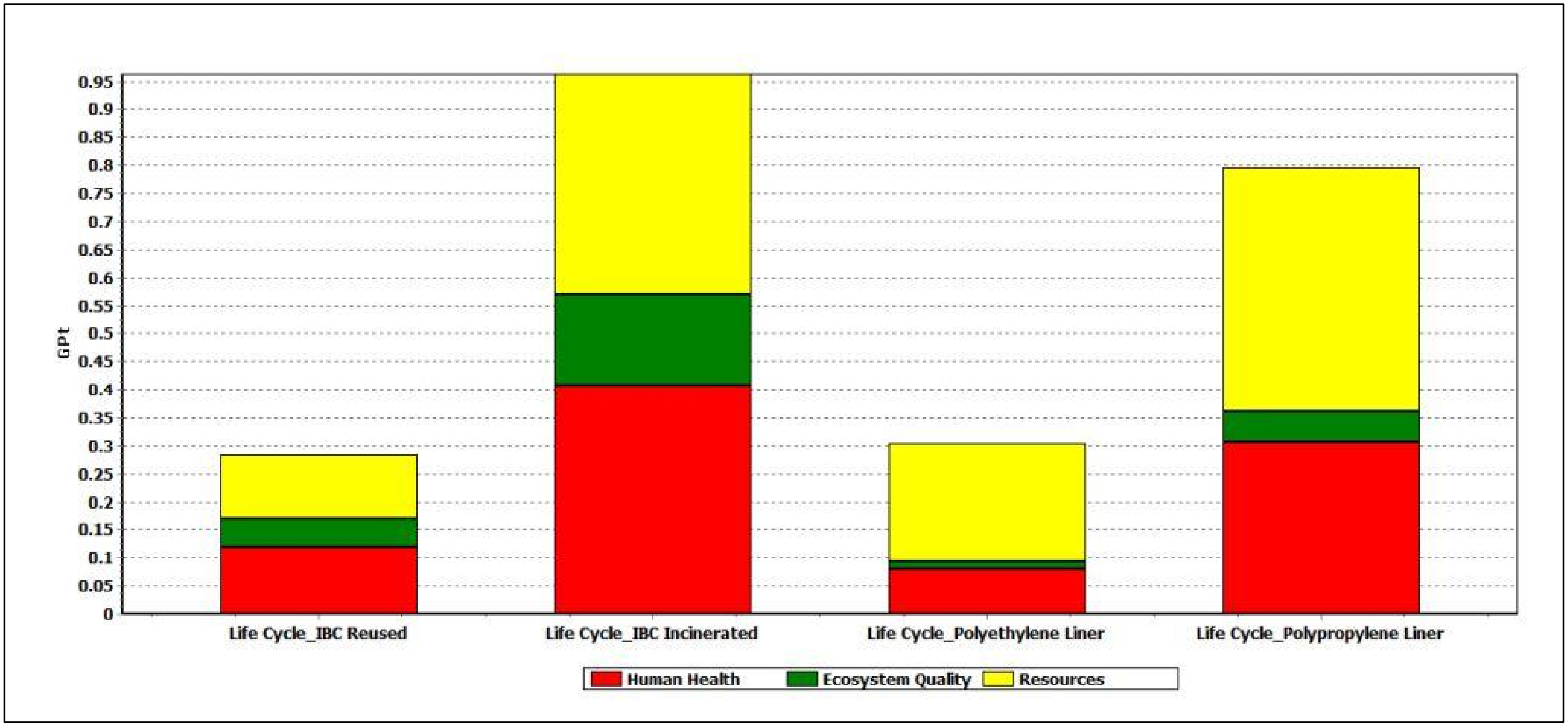

Figure 6.1: Single score presentation of life cycles

6.1.1 Human health

Each human on earth has different levels of tolerance to different chemicals in the environment. Issues such as age, size, acute or chronic exposure, and the concentration of the specific toxins are also major determinants of the effect that the chemicals may have on a human (Wright & Welbourn, 2002). The effect that toxins have on human health is measured in disability adjusted life years (DALY), and can be thought of as one lost year of a healthy life (WHO, 2010) In this scenario, respiratory inorganics exhibit the largest adverse effect on humans for all four life cycles (Table 6.1). The major constituents of the respiratory inorganics emitted into the air in these four life cycles as tabulated in Table 5.7 are nitrogen oxides (NO_x); stationary particulates, less than 10 micrometre (µm) in size; and sulphur oxides (SO_x).

According to Wright and Welbourn (2002), the combustion of fossil fuels is the main source of many atmospheric pollutants, of which sulphur oxides and nitrogen oxides are two.

6.1.1.1 Nitrogen oxides

Nitrogen oxides (commonly known as NO_x) originate mainly from the combustion of hydrocarbons during transportation and may cause photochemical smog at higher concentrations, accelerated weathering of buildings and structures, and respiratory problems. By undergoing several chemical reactions, the smog is converted into ozone, which in turn can cause human health problems and serious crop damage when concentrations are elevated. Nitric acid is another by-product of the chemical reactions in which nitrogen oxides are involved, and combined with sulphuric acid it is responsible for acid deposition.

In humans, epithelial damage of the respiratory tract may occur on exposure to nitrogen oxides suspended in the air (Goudie & Viles, 1998; Wright & Welbourn, 2002). The World Health Organisation (WHO) indicates that there is no threshold above which damage can be expected, as the sensitivities within individuals differ, meaning that the more sensitive an individual is the more likely they are to be adversely affected. An annual mean guideline has been set by the WHO of 40 micrograms per cubic meter ($\varepsilon g/m^3$) for nitrogen dioxide (NO_2) (WHO, 2008).

6.1.1.2 Particulate matter

Particulate matter is released into the air when fuels (which include the IBC and the liners in this scenario) are incompletely burned. This may result in fog formation, soiling of buildings, cancer in humans, and respiratory problems.

Particulate matter that is smaller than 10 micrometer (µm) (PM_{10}) is easily breathed in by humans and is deposited in the lungs and bronchial tubes. These PM_{10}s contribute to bronchitis, respiratory diseases and may even be carcinogenic (Goudie & Viles, 1998). The WHO set guidelines that should not be exceeded (20 $\varepsilon g/m^3$ annual mean) but also states that thresholds are different in all humans (WHO, 2008).

6.1.1.3 Sulphur oxide

Sulphur oxide is produced by the refining of crude oil; it is a precursor of acid deposition and is involved in the formation of ozone. This chemical compound causes damage to crops, corrodes buildings and has human health implications, which include respiratory problems and asthma attacks (Goudie & Viles, 1998; WHO, 2003). A guideline for sulphur dioxide (SO_2) emissions states that the average emission of sulphur dioxide should not exceed 20 microgram per meter cubed ($\varepsilon g/m^3$) in 24 hours (WHO, 2008).

6.1.1.4 Climate change

The least important issue identified in the category Human health from the work on this study is climate change, as found in the life cycle of the reused and the incinerated IBC. In Figure 5.8, it seems as though climate change has a positive impact on human health for these two life cycles. In Chapter 2, Section 5.2, the discussion shows that carbon dioxide from biogenic sources emitted during the burning of the wood is balanced by the carbon dioxide that the trees use during photosynthesis in a developing ecosystem. In this assessment, the positive climate change values should be ignored as the growing of the trees occurs outside of Ghana. However, if the graph presenting the normalised values (Figure 5.7) is considered as though the positive impact occurs in Ghana, it is clear that the other negative impacts on human health are far higher than the supposed positive impact contributed by climate change. Thus, this causes the overall impact on human health to be negative.

Within the category Human health, the incinerated IBC has the greatest negative impact, followed by the impacts caused by the polypropylene liner, the reused IBC and then the polyethylene liner (Figure 5.7, Figure 6.1).

The ranking of the subcategories for each life cycle based on the characterisation values in Table 6.1 are tabulated below (Table 6.2).

Table 6.2: Ranking of human health sub-categories within each life cycle

Position ranked	Life cycle IBC reused	Life cycle IBC incinerated	Life cycle polyethylene liner	Life cycle polypropylene liner
1	Respiratory inorganics	Respiratory inorganics	Respiratory inorganics	Respiratory inorganics
2	Carcinogens	Carcinogens	Climate change	Climate change
3	Radiation	Radiation	Carcinogens	Carcinogens
4	Respiratory organics	Respiratory organics	Respiratory organics	Respiratory organics
5	Ozone layer	Ozone layer	Radiation	Radiation
6	Climate change	Climate change	Ozone layer	Ozone layer

6.1.2 Ecosystem quality

In measuring ecosystem quality, the potentially disappeared fraction (PDF) or the potentially affected fraction (PAF) of the species is determined. The PAF refers to the species that are exposed to the concentration above which there is no observed effect (NOEC). As the concentration increases so does the number of species affected. It can furthermore be interpreted as the toxic stress to a species (Goedkoop & Spriensma; 2001).

The damage category Ecosystem quality can be subdivided into three impact categories, namely ecotoxicity, acidification/eutrophication and land use. For all four life cycles, the most noteworthy impacts were on air quality and occurred in the impact category ecotoxicity (Table 6.1 and Table 5.7). The emissions identified as the most important in the impact category ecotoxicity are chromium, nickel and zinc

6.1.2.1 Chromium

Chromium, a metal, is released into the air through the burning of fossil fuels and the incineration of waste as the hexavalent chromium (Cr^{6+}), which is carcinogenic. According to the WHO, there is no safe threshold for hexavalent chromium in the atmosphere. In humans, chromium can cause mucosal ulcers and cancer, although a recommended limit in the air has been specified of between 0.5 to 1.0 microgram per litre (WHO, 2010; Goedkoop *et al*. 2008a).

In the air, hexavalent chromium is transported via the wind and may deposit in the water and soil by wet or dry deposition (Chen, Wey, Chiang & Hsieh, 1998; WHO, 2010). Hexavalent chromium is highly toxic to aquatic organisms, thus levels in water bodies should be maintained below 20 micrograms per litre (µg/l). Depending on the plant species, hexavalent chromium can be toxic if concentrations in the soil exceed 0.1 milligrams per litre (DWAF, 1996a; DWAF, 1996b, DWAF, 1996c; WHO, 2010; Wright & Welbourn, 2002).

6.1.2.2 Nickel

According to Wright and Welbourn (2002), nickel enters the atmosphere through the burning of fossil fuels and waste incineration, amongst other processes. The nickel released into the atmosphere may occur as nickel sulphate ($NiSO_4$) or nickel oxide (NiO). Both these compounds are water-soluble and may be removed from the atmosphere by wet or dry deposition. Humans and vertebrates primarily inhale nickel, and ingest it via food and water after the nickel is deposited therein. Nickel has been shown to be carcinogenic, affecting the lungs and the nasal passages on inhalation (Wright & Welbourn, 2002).

According to the WHO (2010), there is no safe threshold for nickel in the atmosphere as the risk increases incrementally by 3.8×10^{-4} with each increase of one microgram per cubic meter ($1\ \mu g/m^3$) of nickel. The WHO (2010) recommends that concentrations of 0.026 microgram per cubic meter should not be exceeded in one year. In invertebrates it inhibits growth and reproduction when taken up via ingestion. In aquatic organisms, deposited nickel bioconcentrates cause damage to tissues, influences genotoxicity and decreases growth according to the sensitivity of the organism (WHO, 2010; Wright & Welbourn, 2002). Depending on the type of plant and the sensitivity of the plant to nickel, a concentration of 0.5 milligram per litre can induce toxicity, thereby affecting the growth and the yield of the species (DWAF, 1996a).

6.1.2.3 Zinc

Zinc is emitted into the air through the burning of fossil fuel burning and the incineration of solid waste as zinc (II) (Zn^{2+}); it then deposits into water and onto soil where it may accumulate to lethal concentrations. Although zinc is an essential trace nutrient for both humans and plants, the requirement as trace nutrient varies between species (DWAF, 1996c). Zinc becomes toxic to plants when concentrations in the soil exceed 1.0 milligram per litre, this toxicity is also species dependent (DWAF, 1996a). In humans, excessive concentrations of zinc in the air can cause metal fume fever and aquatic biota are sensitive to zinc when concentrations in the water exceed 2.0 micrograms per litre (DWAF, 1996c; Wright & Welbourn, 2002). Reference exposure levels at which cancer is not expected have been listed as 35 micrograms per cubic meter (Scorecards, 2010).

6.1.2.4 Section summary

In this study, the emission of chromium, nickel and zinc into the air can be attributed to the burning of fossil fuels and the incineration of solid waste. The emissions can then be deposited (wet and dry deposition) into the surrounding soil and water, accumulating in both these mediums and causing indirect impacts. The fossil fuels that are burned are used in the manufacture of the IBC and liners as well as for the manufacture of the fuel used for transporting the cyanide (Table 5.7). The solid waste that is burned includes the IBC, the polyethylene liner and the polypropylene liner, but all four life cycles use diesel for transportation.

It has become evident that the incinerated IBC has the largest effect on ecosystem quality, followed by the polypropylene liner and then the reused IBC. The polyethylene liner has the smallest impact on ecosystem quality (Figure 6.1).

The characterisation values from Table 6.1 were used to facilitate the ranking of the impact categories within the damage category Ecosystem quality. The ranking is presented below in Table 6.3. Only ecotoxicity was discussed above as it is impacted on the most in Ghana by the emissions from the incineration of the functional units and the transportation thereof.

Table 6.3: Ranking of ecosystem characterisation results within each life cycle

Position ranked	Life cycle IBC reused	Life cycle IBC incinerated	Life cycle polyethylene liner	Life cycle polypropylene liner
1	Ecotoxicity	Ecotoxicity	Ecotoxicity	Ecotoxicity
2	Land use	Land use	Acidification/ Eutrophication	Acidification/ Eutrophication
3	Acidification/ Eutrophication	Acidification/ Eutrophication	Land use	Land use

6.1.3 Resources

Mineral and fossil fuels form part of the impact damage category Resources in the eco-indicator 99 method used for this analysis. In manufacturing any item, raw materials are used; these raw materials may be either renewable or non-renewable. Non-renewable resources are resources that occur in nature and, in many instances, take millions of years to form, such as oil. The impact on non-renewable sources is high as these resources cannot be regenerated or regeneration is very slow; both minerals and fossil fuels are considered non-renewable (Press & Siever, 1998). The unit Mega-Joules Surplus (MJ Surplus) indicates the amount of energy required to harvest the depleting reserves. For all four life cycles, the use of fossil fuels as a raw material was impacted on the most in the resources category (Table 6.1). The following raw materials were identified as those important in these life cycles (Table 5.7):

- Natural gas occurring in the ground (35 MJ per m^3)
- Crude oil in the ground (42.6 MJ per kg)

Natural gas and crude oil are both non-renewable sources of fossil fuels. Gas and oil are formed from a large variety of hydrocarbon compounds that have been compacted at high pressures and temperatures for millions of years. Oil is found below gas in a favourable geologic environment. As raw materials, both are used in the manufacture of the IBCs and the liners. The fuel used for transportation is also manufactured from oil (Press & Siever, 1998; Wright & Welbourn, 2002).

Based on the characterisation results (Table 6.1), it can be deduced that within the damage category resources, the reserve of fossil fuels is impacted on the most for all four life cycles, followed by the mineral reserve. Within the impact category Fossil fuels, the use of gas exceeds the use of oil, showing that the manufacture of the functional units impacts the most on oil in the Resources category. In this study the polypropylene liner has the highest impact on resources, followed by the incinerated IBC, the polyethylene liner and finally the reused IBC (Figure 5.6).

6.2. IDENTIFICATION OF MOST NOTEWORTHY LIFE CYCLE

When consulting the figures in Chapters 5 and 6 (Figures 5.5 ï 5.8 and Figure 6.1), it can be seen that the life cycle that has the greatest impact on the environment is the life cycle of the incinerated IBC. Figures 5.7, 5.8 and 6.1 clearly indicate that the incinerated IBC impacts the most on resources, then on human health and finally on ecosystem quality. These figures also show that the polypropylene liner has the highest impact on resources but the second highest overall impact.

The impacts of the reused IBC and the polyethylene liner on the environment are similar, with the polyethylene liner having a slightly higher overall effect. As with the polypropylene liner, the polyethylene liner has a relatively high impact on resources but a smaller impact on the environment.

6.3. EVALUATION OF DATA

To establish confidence in the LCA results, and to determine whether the results are reliable, an evaluation process usually takes place. During this evaluation, a completeness check, sensitivity check, and consistency check are carried out (Curran, 2006). The research conducted included these three checks as part of the evaluation of the data.

6.3.1 Completeness check

The completeness check entails the examination of the data to ascertain whether or not the data are complete. The results for each life cycle are evaluated against the goal and scope of the study (Curran, 2006; Goedkoop *et al.*, 2008a).

The deficiencies identified during the completeness check in this study are arranged according to the LCI and LCIA phase of the LCA, and are tabulated below (Tables 6.4 and 6.5). These deficiencies were not considered to affect the goal and scope of the study adversely.

Table 6.4: Completeness check for LCI phase - aspects, comments and validation

LCA phase	Aspect	Comments	Validation
Life Cycle Inventory	Data required for input of information pertaining to the IBC into the software	One supplier provided information regarding the masses, raw materials and dimensions of the IBC. These were assumed to be representative of all suppliers. The other suppliers were able to supply the dimensions.	The information provided by this supplier was used for the study as the IBCs from the different suppliers are similar in size, shape and holding capacity (Du Pont: 114cm x 114 cm x 113 cm; Orica: 114cm x114cm x 110 cm; AGR: 114 cm x 114 cm x109 cm). Based on these dimensions the life cycles should not be affected considerably by this assumption.
	Data required for input values for the liners	The raw materials used and the masses of the liners were supplied by one supplier. These aspects were assumed to be representative of all the suppliers.	As the liners are manufactured to hold one ton of cyanide and fit into the IBCs with the dimensions as specified above, it was assumed that these masses would not differ extensively and this value was thus considered representative of all the suppliers.
	Confidentiality clauses	Confidentiality clauses prevented suppliers from providing all the required input data.	Confidential data generally pertained to the IBCs and liners. The missing data affected the study because the quantities and types of raw materials used in the manufacturing process were not provided. The software generated a generic list based on the raw material data supplied by one supplier. Future studies could concentrate on determining the exact origin, and the type and quantities of the raw materials used.
	The software used was designed for Europe	The database was designed to generate inventory lists based on European emissions.	As no inventory list was available for Ghana this served to provide the inventory of the raw materials and emissions. As Ghana is situated in the tropics, the emissions data may be inappropriate. The raw material data may also be inappropriate as the source is not of a European nature.
	Open air burning was included as part of incineration	Some of the IBCs and liners were burnt in the open air while others were burnt in an incinerator	Since the incinerators in Ghana do not have mechanisms which allow for the removal of toxic substances and thus allow the emissions to be expelled into the open air, these methods may be considered comparable.
	Incinerator is powered by electricity	The incinerator in Ghana is powered by the national electricity grid.	As the LCI data are based on the European grid, the results obtained may differ if data could be obtained that is based on the Ghanaian national electricity grid. Further studies should address this matter.
	An average mass for the sea containers was used	The masses for the sea containers from MAERSK and MSC shipping liners differ.	An average mass (2 250 kg) was used to simplify the calculations required for inputs into the software. This should not greatly affect the study, as the masses were similar (MSC ï 2 230 kg and MAERSK ï 2 280kg).

Table 6.5: Completeness check for LCIA phase - aspects, comments and validation

LCA phase	Aspect	Comments	Validation
Life Cycle Impact Assessment	Characterisation factors	The characterisation factors used were developed for European models.	The calculations used in the characterisation step were based on the European population and geographical area, as there are none available for Ghana. The software provided options for North America and Europe only and in some cases global characterisation factors were applied by the software.
	Disposal/Reuse	Disposal and reuse percentages may differ year on year.	The use of cyanide fluctuates as the gold ore body changes. Thus the figures supplied this year will not be the same next year. The impact on the environment will differ as these figures change.
	Impact categories	Impact categories such as noise and odour were not included as part of the eco-indicator method used.	The Eco-indicator 99 method does not categorise noise and odour. For future studies a method should be investigated that includes these aspects as part of the impact assessment.
	Emissions from incineration	The incinerator in Ghana does not have any emission purification system such as a scrubber. The emissions are released directly into the ambient air.	Emissions to the air are more controlled in developed countries and therefore it can be assumed that in Europe the incinerators on which the model is based will have emission purification systems (scrubbers). The quantified emissions in this study may thus not be entirely accurate and may be understated, as a Ghanaian model does not exist.
	Quality of diesel used as fuel	The emissions caused by transportation may be higher than those quantified in the LCA.	A study of the diesel used as fuel for transportation has not been conducted. The quality of the diesel may thus differ from that used in Europe where more stringent quality control is exercised. Based on the European model used, the emissions into the Ghanaian atmosphere due to transportation, may be understated.

6.3.2 Sensitivity check

In completing a sensitivity test, the reliability of the results are evaluated to determine whether the issues identified in the completeness check will have an affect on the definition of comparative conclusions. This can be determined by using different parameters on the same life cycles to highlight the data elements that influence the results the most (Curran, 20006; Goedkoop *et al.*, 2008a).

To generate the information, only one parameter is altered along with its dependants; all other independent parameters are kept constant. In this study the following sensitivity testing was concluded by keeping the specified parameter constant:

- The masses of the sea-containers were changed to determine whether the use of an average value would affect the outcome emissions from each life cycle. A minimum value of 2 230 kilograms (MSC container) was used, and a maximum of 2 280 kilograms (MAERSK container). The results obtained were compared to the results of the average mass (2 250 kilograms).
- The masses of the functional units were altered by adjusting the masses upwards by 10 per cent and down by 10 per cent. For example, the masses entered for the IBC were 79 kilograms (-10%), 88 kilograms (as given) and 97 kilograms (+10%).
- The tonnage of cyanide received for 2008 was adjusted using a 10 per cent variance (up and down) as specified above to ascertain to what extent the receiving environment would be impacted on in terms of the increase or decrease in the number of IBCs and liners.

The results (input values for Simapro 7.1, the normalised graphs and the normalised values) are presented in Appendix D and indicate the following:

- By using the minimum and maximum values for the sea containers no real changes in emissions can be expected (all percentages are less than 1%).
- When the masses of the IBCs and liners are altered by an increase or decrease of 10 per cent the change is in the same order (± 10%).
- If the tonnages were to increase or decrease by 10 per cent a change of approximately 20 per cent could be expected both ways.

Taking the above into consideration, it can be assumed that the uncertainties surrounding the issues addressed should not affect the results for this LCA to a large degree. The information provided indicates that the consumption of cyanide is the key driver for the impacts associated with the life cycle, but to a greater degree than just a linear approach. For example, with the commissioning of more mines that use cyanide, the effects associated with the IBCs are expected to increase at a rate greater than the added consumption of cyanide. This is explained by the last bulleted point above. The increase of emissions is approximately double the increase in tonnages of cyanide used.

In future studies, the quality of the diesel used in Ghana should be investigated and the emissions to the air resulting from incineration should be analysed to obtain a more accurate quantification of the emissions. If possible, a model that is based on the Ghanaian environment could be developed and used to enable a more realistic presentation of the effect that the functional units may have.

6.3.3 Consistency check

The assumptions, methods and data used throughout the LCA are tested against the goal and scope of the study for consistency during the consistency check. This check is carried out for each product and/or process evaluated and helps to increase the confidence in the final results. Some inconsistency is deemed acceptable as long as it is documented and its role in the LCA defined. The ISO standards require that the following are checked (Curran, 2006; Landu, 2006):

- Data source
- Data accuracy
- Data age
- Temporal representation
- Geographical representation
- Technical level of the data

6.3.3.1 Data source

Both primary and secondary data were collected. Primary data were obtained directly from cyanide manufactures, agents and end-users by making use of questionnaires, interviews and site visits. The secondary data were accessed from the internet as well as literature resources such as books and journals. Other secondary data included personal communication that was forwarded via email or discussed during the interviews.

The LCI data were obtained from existing databases and software developed for the Dutch Ministry of Housing, Spatial Planning and Environment and used in Simapro 7.1 (Goedkoop

& Spriensma, 2001). These data were then used to generate all other information required for the analyses.

6.3.3.2 Data accuracy

All data obtained from the manufacturers, agents and end-users is believed to be reasonably accurate as these figures are used in the cyanide consumption balances required by the International Cyanide Management Code (ICMC). Questionnaires and interviews were also structured in such a way as to allow for cross-referencing. Personal observations confirmed some of the data received.

6.3.3.3 Data age

All primary data used in the LCA were collected for the year 2008, thus it is deemed recent. Where secondary data were used from journals originating from internet websites and from other literature, the most recent was considered relevant. Inventory data originating from the software database were from 1993 onwards.

6.3.3.4 Temporal representation

The use of cyanide in the extraction of gold is currently the most widely used method for gold recovery where gravity is uneconomical. Ghana makes use of the same transportation methods that are used globally. These methods include sparging and transportation of the cyanide in an IBC. The delivery of liquid cyanide is used internationally as well but was not considered as it is not a viable method of cyanide transportation in Ghana because liquid cyanide is not manufactured or transported in Ghana.

6.3.3.5 Geographical representation

The geographical boundary of the study was Ghana. The raw data obtained from the manufacturers, agents and end-users was within the boundary of the study and are representative of what occurs in Ghana with regard to the cyanide containers.

The LCI databases used were not representative of Ghana, but represented Europe as a whole. No LCI databases were available for Ghana during 2008/9 when the study was conducted and documented. The LCIA method used (Eco-indicator 99) also makes use of European standards. From this it can be concluded that the LCI and LCIA are not entirely representative of Ghana.

6.3.3.6 Technical level of the data

The data used are believed to be sound and technically acceptable for the following reasons:

Most of the manufacturers, agents and end-users have been or are scheduled to be audited for ICMC compliance by an International Cyanide Management Institute (ICMI) auditor. To be awarded with compliance certification all data are required to comply with the high standards set by the ICMI.

Data regarding sizes and weights of the IBC and the liners were obtained from one manufacturer only. This is not deemed to be important as the maximum variance based on calculated volumes (Orica: 1.43 m^3, AGR: 1.42 m^3, DuPont 1.47 m^3) is 3.54%.

In terms of the above categories, the data can be considered consistent with the goal and scope of the LCA. In cases where it is not entirely consistent (geographical representation, technical level), the impact that these differences may have on the LCA is not of much significance. All inconsistencies have been documented.

6.4. CHAPTER SUMMARY

In this chapter the important issues arising from each life cycle were identified and the sub-categories impacted on the most by each life cycle within each category were discussed. Fossil fuels were seen to be impacted on the most in the Resource category, the emission of respiratory inorganics in the Human health category and ecotoxicity in the Ecosystem quality category.

Data presented graphically in Chapter 5 were used in this chapter: The single score graph (see Figure 5.8) was used primarily to identify the life cycle that has the greatest impact on the environment, while Table 5.8 was used in identifying the category impacted on the most. Finally, Table 5.6 was used to rank the emissions/raw materials identified according to magnitude. The life cycles can be ranked in decreasing order of impacts as the life cycle of the incinerated IBC, the polypropylene liner, the reused IBC and finally the polyethylene liner.

The main components contributing to the ranking for each of the units assessed were as follows:

- Incinerated IBC: The category Human health (Table 5.8) was impacted on the most by the inorganic respiratory emissions (Figure 5.8), which consisted of nitrogen oxides, sulphur oxides and particulates, amongst others (Table 5.6), in order of decreasing magnitude. This can be attributed to the incineration of the IBC as well as to the combustion of the fuel used during transportation.
- Polypropylene liner: During the manufacture of the polypropylene liner oil and gas is consumed. In addition, the diesel that is combusted during transportation is manufactured from oil. Within this life cycle the use of fossil fuels, within the Resources category, was affected the most (Table 5.8, Figure 5.8 and Table 5.6).
- Reused IBC: Respiratory inorganics emitted into the air during the combustion of the fuel that is used to return the IBCs to the agents, impacted the most on the environment (Figure 5.8). In order of magnitude nitrogen oxides, sulphur oxides and particulates, although not exclusive (Table 5.6), affect human health the most (Table 5.8).
- Polyethylene liner: As with the polypropylene liner the resources oil and gas, which are both fossil fuels used in the manufacture of the liner, causes the most damage in this life cycle (Table 5.8, Figure 5.8 and Table 5.6).

Completeness, sensitivity and consistency checks were furthermore conducted to determine the relevance and accuracy of the results obtained when related to the goal and scope of the study. In the completeness and sensitivity tests it was found that factors such as incineration and transportation cannot be accurately quantified because the model being used concentrates on Europe and European emission factors, whereas the study was conducted in Ghana. During the consistency check it was seen that the assumptions, methods and data were consistent with the goal and scope of the LCA.

The interpretations provided above will be further discussed in the next chapter (Chapter 7). Finally, conclusions will be drawn and recommendations made.

CHAPTER 7

SYNTHESIS, RECOMMENDATIONS AND CONCLUSION

7.1. INTRODUCTION

In conducting the study, the aim (stated in Chapter 1) was to make use of a life cycle methodology as proposed by the International Standards Organisation (ISO) to assess the life cycle of intermediate bulk containers (IBCs). The study was conducted in Ghana and the focus was on the gold mining sector.

In this chapter, recommendations will be made that focus on the life cycle assessment (LCA) and in the final section of this chapter all the results obtained will be assimilated into each objective so that conclusions may be drawn.

7.2. SYNTHESIS

Before any conclusions can be drawn in a study, all ideas, concepts and objectives need to be fused with the aim of the study (Section 1.8). The aim set out to **determine the impact of cyanide containers on the receiving environment in Ghana by making use of life cycle assessment methodology**. Five objectives were identified around which the research process was designed to achieve the objectives in relation to the aim. In the subsections that follow (7.2.1-7.2.6) each objective will be presented and salient points surrounding them discussed.

7.2.1 Objective 1

Determine the origin of the IBC and the associated liners.

An LCA generally commences with the identification of the origin of a product (or the functional unit) and concludes with the so-called destruction and disposal of the same product. In identifying the origin it then becomes possible to quantify inputs from the environment and outputs to the receiving environment. The origin of the IBC and its liners was found to be outside of Ghana, thus indicating that resources such as raw material extraction and mineral use did not affect the Ghanaian environment.

The qualitative methods used to determine the origin included questionnaires, interviews and desktop studies. Due to confidentiality constraints only one supplier was prepared to supply information regarding quantitative input variables required for the research. Furthermore, confidentiality clauses affected the collection of all relevant information, thus the study appears to commence at the cyanide suppliers in Australia and the United States of America, where, in reality it actually should be extended to the countries in which the raw materials are sourced.

This objective was successfully achieved in terms of determining where the IBC and liners originate from, but in terms of raw material and mineral sourcing it was not successful and this aspect should be explored further.

7.2.2 Objective 2

Quantify the number of IBCs and liners imported to Ghana annually.

The quantification of the functional units in this study is important as the IBC and the liners are foreign to Ghana, thus creating a burden on the Ghanaian environment that originates from international and not local sources. In quantifying the IBCs and liners, it is possible to calculate the emissions to air, water and soil, using software specifically designed for that purpose.

The quantification of the IBCs and the liners was made possible by consulting with the suppliers, agents and end-users. The methods used were questionnaires and interviews. Most of the information and data received was for 2008 and was cross-referenced to determine accuracy and consistency. The identified parties were willing to supply the data at their disposal. All input data were entered into Simapro 7.1 software, which calculated the burdens and presented them as graphs or tables.

The objective was successfully achieved, because the number of IBCs and liners imported to Ghana annually (for 2008) for the parties identified was quantified. The tonnage of cyanide imported to Ghana will vary from year to year as the ore body and number of mines operating change. This, in turn, will affect the number of IBCs and liners that will enter the country and also the emissions.

7.2.3 Objective 3

Evaluate methods of disposal of the IBC and its liners and the effect thereof on the environment.

As identified in the literature review, various methods for the disposal of waste exist. An LCA generally concludes with the disposal of the product being studied. In the research conducted, the methods used in Ghana were identified as incineration, reuse, and rarely recycling, in order of popularity.

The various different methods of disposal were determined by consulting literature sources, such as books and journals, as well as the suppliers and end-users. In Ghana, the dominating forms of disposal of the IBC and liners were established by fieldwork, questionnaires, and interviews.

The burden on the receiving Ghanaian environment was calculated by making use of Simapro 7.1 software. In Objective 1 it was verified that the IBC and liners were manufactured from raw materials and minerals from other countries, thus the burden on the receiving Ghanaian environment from the incineration of the IBC and the liners was caused by products from international sources and not from local sources. The effect on the environment can also be related to the number of IBCs and liners imported.

In terms of reuse, if the IBC was in an acceptable condition, it was returned to the supplier and was not reused in Ghana. The reused IBC affected the Ghanaian environment by releasing respiratory inorganics generated during the combustion of the diesel required for transportation. The full IBC was transported to the end-user and the empty IBC was transported to the agent to be returned to the supplier.

The data regarding the emission of pollutants due to incineration may not be entirely accurate as the model developed for Europe may not be applicable to the Ghanaian situation. In Europe, emissions from incineration are passed through scrubbers or other clarifiers prior to being discharged into the atmosphere. In Ghana, the incinerator allows the emissions to pass into the atmosphere without the same level of clarification. In future studies, the emissions into the air should be analysed for constituents to enable more accurate quantification of these.

Objective 3 was successfully achieved in terms of determining whether incineration or reuse had a greater impact on the receiving environment. The complete life cycle (ócradle to graveô) should, however, be pursued for the reuse of the IBC and should not only entail a ógate to gateô study. Recycling was not quantified and can thus not be considered as having been achieved in this study. Open-air burning was included as part of incineration and should be separated in future studies.

7.2.4 Objective 4

Identify which category in terms of Human health, Ecosystem quality and Resources is impacted on the most by the different life cycles.

The objective was formulated with the intention of determining whether human health, ecosystem quality or resources were impacted on in Ghana and if so, which was impacted on the most for each life cycle.

The initial fieldwork as well as the interviews and questionnaires were employed to collect the numerical data required as input into the Simapro 7.1 software. The software generated information in the form of graphs and tables, which allowed for the identification of the category impacted on the most for the individual life cycles. These results may, however, be biased as they are based on emissions generated in Europe, but are still able to give an indication of the effect of the life cycle, while not predicting the full effect. Resources were identified as being impacted on the most in the life cycle of the polyethylene liner and the polypropylene liner. When related to Ghana and the system boundaries, this is not quite correct, since the use of resources cannot be related to the Ghanaian environment as the minerals and raw materials used in the manufacture of the IBCs and liners are sourced from other countries.

In the life cycles of the incinerated and reused IBC, the respiratory inorganics emitted into the air affected human health the most. If the use of fossil fuels and minerals is discounted in the other two life cycles it can be seen that respiratory inorganics were the biggest contributors to the deterioration of Ghanaian air quality.

This objective was successfully achieved, since the category impacted on the most by each individual life cycle in the LCA was determined.

7.2.5 Objective 5

Ascertain whether transportation within Ghana has a noteworthy effect on the environment.

Transportation makes use of fossil fuels as an energy source and also emits gases that are detrimental to any receiving environment. The use of cyanide by all end-users in Ghana requires transportation over many kilometres on roads that are poorly maintained in most situations.

In this study, the emissions from the transportation of the cyanide were quantified by means of the Simapro 7.1 software after data was collected during fieldwork. Data collection methods used included questionnaires and interviews. The main emissions identified in this study resulting from transportation are nitrogen oxides, sulphur oxides and particulates.

The software generated data on emissions based on the quality of the fuel used in Europe. The fuel from Ghana was not analysed or researched to determine the constituents and quality of the fuel; thus these obtained results could impact on the accurate interpretation of the Ghanaian situation. It is believed that the fuel used in Ghana may contain more impurities than that used in Europe.

This objective was successfully achieved in determining that the emissions generated by transportation had an effect on the Ghanaian environment. The findings were inconclusive in terms of the magnitude of the effect that these emissions may have, as the model was generated based on European fuel and not on the fuel used in Ghana.

7.2.6 Section summary

The general aim in conducting this research was to determine the impact of the IBC and the liners on the Ghanaian environment. This aim was achieved but also delivered surprising results.

The initial view was that the incineration of the IBC and liners would have the most profound impact on the air and, subsequently, on human health. However, the research showed that the *transportation* of the incinerated and reused IBCs impacted the most on human health.

Another preconceived notion is that it is not viable to use the IBC as building material. This view is based on the severity of the potential toxic risk that cyanide poses to humans and animals on exposure. During the literature review, it became obvious that cyanide degenerates in ultra-violet light and thus the IBC could be used if decontaminated properly. Sunlight serves as a source of ultra-violet light, thus decontaminating the cyanide further.

To conclude this section:

- Transportation has the most noteworthy influence on all the life cycles.
- The incinerated IBC affects the environment the most followed by the polypropylene liner.
- Human health is affected the most by respiratory inorganics, probably emitted during the combustion of fuel during transportation or incineration of the functional units.
- The ecosystem quality is affected by toxic emissions, possibly due to incineration and transportation.
- Resources are used as raw materials in the manufacture of the IBC, liners and fuel for transportation. This however does not impact on any resources in Ghana.

7.3. RECOMMENDATIONS

In the course of this study shortcomings became clear and certain questions were not answered. Some of these issues are presented below and relevant recommendations are made.

- The boundary of the study was drawn from the point where the cyanide entered Ghana. The study included a listing of the raw materials (from other countries) used in the IBC as well as in the liners. To conduct a more comprehensive study, the boundary should be extended so that the LCA may commence from the ócradleô (raw material growth and acquisition) and end at the ógraveô (complete incineration/reuse).

- For more accurate results, a region-specific inventory database for the Simapro 7.1 LCA software package should be compiled to accurately determine the impacts of the various constituents used or emitted in that country. For example, if the IBC is manufactured in Indonesia, an Indonesian database should be used for the quantification of raw materials. Furthermore, if the IBC is incinerated in Ghana, a Ghanaian inventory database should be used.

- The research focused on Ghana, but cyanide is used globally in the gold mining industry. Further research could be conducted in developed, transition and developing countries to compare the different manners in which cyanide is transported and the IBCs and liners disposed of.
- Different transportation mechanisms could be investigated for the transportation of the cyanide in Ghana, to ascertain whether there are methods of transportation that do not have such a great impact on the environment. Sparging should be investigated for all sites as an alternative to determine whether or not it is cost-effective.
- Avenues such as the decontamination and reuse of the wood from the IBC as building material could be explored, as it could possibly eliminate the emissions caused by incineration and will reduce the impacts generated by the exporting of the wood back to the supplier.
- Where possible, more data should be collected with regard to the functional units. Confidentiality clauses prevented it in this study. This should include more comprehensive information that includes aspects such as the raw materials used, the masses of raw materials, manufacturing procedures and the generation of energy required for the manufacture of the functional units.
- The life cycle of the IBC incinerated and the IBC reused should not be separated as in this case, but should be examined as a closed-loop life cycle, as essentially it is only one life cycle and not two as presented in this case study. The positive burdens and the negative burdens will then give a better overall indication of the impacts.
- To determine whether the effect of the diesel used in Ghana would be different from that used in Europe, both fuels should be analysed for constituents and emissions on combustion.

7.4. CONCLUSION

The LCA conducted in this research project proved to be effective in identifying the burdens that the IBC and the two liners have on the Ghanaian environment. However, the limitations experienced in the quantification of these burdens, such as the use of European databases and confidentiality clauses, cannot be discounted or underestimated. The study has also generated a base from which future research can be conducted in terms of LCAs, cyanide use, transportation and packaging.

In conducting this study it became apparent that ideally the importation of cyanide into Ghana should be terminated because apart from the toxicity of cyanide, the transportation of the cyanide and the incineration of its packaging impacts negatively on a relatively pristine tropical environment. In reality this is not possible, as the extraction of gold relies on the use of cyanide, and the production of gold makes an important contribution to the Ghanaian economy. This study should therefore be used to improve the management practices relating to the IBC in Ghana to reduce overall impacts.

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APPENDIX A

QUESTIONNAIRES

Cyanide Supplier Questionnaire 1

Cyanide Supplier Questionnaire 2

Cyanide Supplier Questionnaire 3

Cyanide Supplier Questionnaire 4

Liner Supplier Questionnaire

IBC Supplier Questionnaire

Agent Questionnaire 1

Agent Questionnaire 2

Agent Questionnaire 3

End-user Questionnaire

Cyanide Supplier Questionnaire 1

Site: ____

Responsible person(s) & position: ________________________________

Date: ____

Time: ____

Country of origin and general

1. In which country is the cyanide you supply manufactured?
2. What manufacturing process do you make use of (e.g. Andrussow process)?
3. Where is it packaged?
4. Who do you supply with cyanide in Ghana?
5. Do you have an agent handling your cyanide orders in Ghana?
6. If yes, may I have the contact detail?
7. Do you supply sodium, calcium or potassium cyanide to Ghana?
8. In what form do you supply the cyanide ï briquettes, flakes, liquid?
9. What is the density of an individual briquette?
10. In what containers (IBCs, boxes, drums, iso-tainers) do you export to Ghana?
11. Where are the containers manufactured?
12. What control is exercised over the number of containers filled, for example numbering?
13. Are the IBCs/containers recycled to country of origin?
14. What is the life expectancy of the IBC/containers?
15. According to what specifications are the IBCs made?
16. What are the dimensions of the containers in which you export cyanide to Ghana?
17. What is the capacity that can be held by the IBC?
18. What is used for the manufacture of the containers, in terms of paint, steel, wood etc.?
19. Can you give me the contact details of the suppliers of the above-mentioned goods?
20. How many times are the containers that are exported to Ghana, recycled?
21. Do you supply any cyanide to other countries? Please elaborate.
22. Do the procedures differ from developing and developed countries in terms of supply, container reuse, container disposal, etc.?
23. If yes, mention some of the differences.
24. Is the cyanide packaged in liners before being placed in the container?
25. Where are these liners manufactured?
26. From what materials are these liners manufactured?
27. May I have the contact details of the liner manufacturers and the container manufacturers?
28. Are these liners water resistant?
29. What is the size of the polyethylene liner and what is its holding capacity?
30. What is the size of the polypropylene liner and what is its holding capacity?
31. What weight can be supported by these liners without their being damaged when suspended?

32. Who packages the cyanide into the plastic liners?
33. Is it a dangerous process?
34. Is this process carried out under a roof?
35. If not carried out under a roof, where is it done?
36. How does it affect the environment, specifically the surrounding air?
37. Are there possible spillages?
38. What safety mechanisms are in place for protection of employee and environment?
39. How is the IBC/container sealed prior to being placed in the sea-container?
40. How are these IBCs/containers placed into the sea-container?
41. How many IBCs are placed in one sea-container?
42. Who seals this sea-container and in what manner?
43. How is this sea-container transported to the exporting port?
44. Is there vehicle tracking on the vehicle?
45. How many containers are transported at one time?
46. Is there any legislation with regard to this?
47. If there is an accident, is there an accident response plan?
48. If theft occurs how soon will an accident response plan be put into effect?
49. The transport route ï is it well maintained?
50. At the port ï how is the container stored?
51. Do the port authorities have a method of control with regard to the influx and outflux of cyanide?
52. Is an area specially demarcated for the storage of cyanide?
53. How are spillages treated?
54. Are the containers opened at the port?
55. How are they loaded onto the ship?
56. Are the employees on the ship aware of the dangers of cyanide?
57. Is any water able to enter the containers from the sea?
58. Are the containers stored above or below deck?
59. How long is the journey from country of export to country of import?
60. What emergency plans exist for the transport of cyanide by sea?
61. Is there any legislation in the country of origin that prevents the return of used cyanide packaging?
62. If yes, please elaborate.

Cyanide Supplier Questionnaire 2

Site: ____

Responsible Persons/Position: ____

Date: ____

Time: ____

In Ghana

1. Which port in Ghana receives the cyanide?
2. May I have the contact details of the authority in control?
3. Who removes the sea-container from the ship?
4. Are the handlers all aware of the dangers of cyanide?
5. Are the handlers all trained in emergency response plans in case of a spillage?
6. Do the port authorities have a method of control (cyanide balance) with regard to the influx and outflux of cyanide?
7. At the port ï how are the containers stored?
8. Is an area specially demarcated for the storage of cyanide?
9. How are spillages treated here?
10. Are the containers opened at the port?
11. How is this sea-container transported to the agent?
12. Is there vehicle tracking on the vehicle?
13. How many containers are transported at one time?
14. Is there any legislation with regard to this?
15. If there is an accident, is there an accident response plan?
16. If theft occurs how soon will an accident response plan be put into effect?
17. The transport route ï is it well maintained?

At the agent

18. Who are your agents in Ghana?
19. May I have their contact details?
20. Are they ICMC compliant?
21. Have their warehouses been ICMC audited?
22. When were they audited?
23. If not, are they ICMC signatories?
24. Are the unopened sea-containers stored under a roof?
25. Can any possible spillage reach the ground water?
26. Does the agent open any of the sea-containers?
27. If yes, why?
28. Is there a cyanide balance controlling the influx and outflux of cyanide?
29. Is there a separate facility for sparging?
30. If yes, where is this facility?
31. Are the sparging tankers in Ghana your property?

32. How many are in Ghana?
33. To which plants do you supply ósparged ôcyanide?
34. Who empties the cyanide into the tankers?
35. Where is the water added to the cyanide, at the agents or at the mine site?
36. How regularly are these tankers cleaned?
37. How are they cleaned?
38. Is it environmentally safe?
39. Who discharges the cyanide from the sparging tanker?
40. How safe is the procedure?
41. Are the empty containers recycled or disposed of?
42. Whose responsibility is the disposal or recycling of the empty containers?
43. Indicate which is the method of disposal used by your company in Ghana:
    43.1 Incineration ____________________ (If yes, answer question 45.)
    43.2 Mulching _______________________(If yes, answer question 46.)
    43.3 Dismantling _____________________(If yes, answer question 47.)
    43.4 Selling _________________________ (If yes, answer question 48.)
44. Are they incinerated?
    44.1 In the case of incineration, have the fumes expelled been quantized?
    44.2 Are these fumes environmentally acceptable?
    44.3 Do you have any results that I may see?
45. Are they mulched?
    45.1 How is the mulching process carried out?
    45.2 Who carries out the process?
    45.3 What happens to the mulched product?
46. Are they dismantled?
    46.1 If dismantled, what happens to the materials?
47. Are they sold to the community?
    47.1 What materials are sold to the community?
    47.2 What are these materials used for?
    47.3 Are these materials safe for human use?
48. Are they decontaminated?
49. What manner of decontamination is employed?
50. Is this method effective or are there better methods available?
51. Who carries out the above-mentioned processes?
52. What happens to the liners?
53. Are the liners biodegradable?
54. If not, have biodegradable materials been considered for the manufacture of these liners?
55. Are the liners incinerated?
56. If the liners are incinerated, have the fumes been quantized?
57. Are these results available for scrutiny?

<u>Cyanide Supplier Questionnaire 3</u>

Site: ____

Responsible Persons/Position: ______________________________

Date: ____

Time: ____

<u>At the end-user</u>

1. Are the sites that you supply in Ghana ICMC compliant?
2. If not, are they signatories?
3. Have you paid each of these sites a visit?
4. What are your specifications for the storage of cyanide?
5. Do their storage facilities satisfy your specifications?
6. Which site does not satisfy your specifications?
7. Do the sites that do not use sparging receive closed sea containers?
8. If yes, who is responsible for the opening of these containers?
9. Are they stacked satisfactorily?
10. Are safety signs clearly displayed in applicable places?
11. Do you supply cyanide in any container other than a wooden IBC to Ghana?
12. If yes, what other containers are used?
13. How is the cyanide removed from the wooden box?
14. How is the cyanide removed from both the liners?
15. How should these liners be treated after the cyanide is emptied from them?
16. Should the liners be washed clean with water before being replaced inside the box?
17. Should the box be closed when empty?
18. What are the specifications that you require for the storage of the empty IBCs?
19. Who is responsible for the removal of the IBC from site?
20. Where is it removed to?
21. Is the IBC decontaminated?
22. How is it decontaminated?
23. Is this method effective?
24. Are the liners decontaminated in the same manner?
25. If not, explain?
26. Do you recycle the IBCs that are exported into Ghana?
27. If not, why not?
28. Do you recycle the IBCs that are used in the country of manufacture?
29. If yes, how many times are the IBCs reused?
30. Who is responsible for the disposal of the IBCs?
31. What is your preferred method of disposal?
32. What method is used in Ghana?
33. Are you satisfied with the disposal method?

34. Have you ever considered dumping the wooden IBC (not the liner) in the mine dumps, pits or slimes dams?
35. If not, why not?
36. Is this dumping method used in any other country? If yes, please name.
37. Is this an option in Ghana?
38. Is it possible to recycle the polypropylene or polyethylene liners at all?
39. What advantages does sparging have over the conventional delivery method?
40. How much cyanide do you transport per month using the sparging tanker?
41. Who mixes the load with water in the sparging tank?
42. Who discharges the load into the cyanide tanks from the sparging tanker at the client?
43. What is the risk of exposure to cyanide fumes during the discharge process?
44. Are the handlers aware of the dangers to which they may be exposed?
45. Are the handlers trained in emergency response plans?
46. Is sparging economically more feasible for the client?
47. How does the delivery distance influence the economic feasibility?

Cyanide Supplier Questionnaire 4

Site: ____

Responsible Persons/Position: ____

Date: ____

Time ____

At the sparging facility

This questionnaire is only applicable if there is a separate sparging facility.

1. Which companies make use of the sparging facility?
2. Do you have an alternative site where the sparging tanker is prepared?
3. If yes, where is this facility?
4. Is this your facility?
5. If no, who are your agents?
6. Are the sea-containers off-loaded at this facility?
7. Who are your handling agents?
8. Who destuffs the cyanide containers?
9. Are they aware of the dangers of cyanide?
10. Are they trained in emergency preparedness?
11. How many cyanide containers pass through this facility on average per month?
12. How much cyanide passes through this facility per month?
13. Do you have a cyanide balance in place?
14. How are the liners removed from the container?
15. How is the cyanide emptied into the tanker?
16. Are any additives added to the tanker before or during the emptying process?
17. If yes, which additives?
18. If yes to question 16, why are additives added?
19. How much cyanide is emptied into the tanker?
20. What is the holding capacity of this tanker?
21. Is any water added to the tanker prior to the journey?
22. Do these vehicles have tracking devices?
23. Are the drivers trained in emergency preparedness?
24. Is the vehicle left alone at any stage during the journey (e.g. rest stops)?
25. How many drivers are allocated per vehicle?
26. What is the travelling time on average to the mine sites?
27. In what manner are the cyanide containers and their liners disposed of?
28. Are these liners and cyanide containers decontaminated prior to disposal?
29. If yes, what method of decontamination is employed?

Liner Supplier Questionnaire

Site: ____

Responsible Persons/Position: ____

Date: ____

Time: ____

1. For which company do you manufacture liners for cyanide containers?
2. Do you manufacture any other items used for cyanide for this company?
3. Do you manufacture polyethylene and polypropylene liners?
4. In which country are the polyethylene liners manufactured?
   - 4.1 What are the constituents of the polyethylene liner?
   - 4.2 Where do these materials originate from?
   - 4.3 If incinerated will the polyethylene liners give off any noxious/toxic fumes?
   - 4.4 Have these fumes been quantized?
   - 4.5 Are the results available?
   - 4.6 What are the dimensions of the liners?
   - 4.7 What is the holding capacity of these liners?
   - 4.8 What mass can they support if suspended?
   - 4.9 Can any cyanide residue be retained in the pores of the liner?
   - 4.10 Is water sufficient to rinse the liners with as an interim measure before decontamination?
   - 4.11 What is the most effective method of decontamination for these liners?
   - 4.12 How are these liners sealed?
   - 4.13 Describe the process?
   - 4.14 Are these liners biodegradable?
5. In which country are the polypropylene liners manufactured?
   - 5.1 What are the constituents of the polypropylene liners?
   - 5.2 Where do these materials originate from?
   - 5.3 If incinerated will these polypropylene liners give off any noxious/toxic fumes?
   - 5.4 Have these fumes been quantized?
   - 5.5 Are the results available?
   - 5.6 What are the dimensions of the liners?
   - 5.7 What is the holding capacity?
   - 5.8 What mass can they support if suspended?
   - 5.9 Can any cyanide residue be retained in the pores of the liner?
   - 5.10 Is water sufficient to rinse the liners with as an interim measure before decontamination?
   - 5.11 What is the most effective method of decontamination for these liners?
   - 5.12 How are these liners sealed?
   - 5.13 Describe the process.
   - 5.14 Are these liners biodegradable?

6. Where are the straps on the liners manufactured?
    - 6.1 From what raw materials are they manufactured?
    - 6.2 Where do the raw materials originate from?
    - 6.3 If incinerated will they give off any noxious/toxic fumes?
    - 6.4 Have these fumes been quantized?
    - 6.5 Are the results available?
    - 6.6 Can these straps retain any cyanide residue in their pores?
    - 6.7 Is flushing with water an effective interim method prior to decontamination?
    - 6.8 What is the most effective decontamination method for these straps?
    - 6.9 How are these straps attached to the liners?
    - 6.10 What mass can these straps support if suspended?
    - 6.11 Are these straps biodegradable?

IBC Supplier Questionnaire

Site: ____

Responsible Persons/Position: ______________________________

Date: ____

Time: ____

1. In which country are the IBCs manufactured?
2. For which companies do you manufacture IBCs?
3. Do you manufacture any other cyanide containers for this company?
4. From what materials are the IBCs made?
5. Is wood used?
6. What types of wood are used?
7. Where are the trees for the plywood grown?
    - 7.1 What is the plywood used for?
    - 7.2 Are the plywood forests sustainable?
    - 7.3 After how many years is the tree logged?
    - 7.4 Are any trees replanted after logging?
8. Is any hardwood used in the IBC?
    - 8.1 How much hardwood is used per IBC?
    - 8.2 What is the hardwood used for?
    - 8.3 Where does the hardwood originate from?
    - 8.4 After how many years is the tree logged?
    - 8.5 Are any trees replanted after logging?
9. Describe the process of manufacture of the IBC.
10. Is manpower used to cut the wood into sheets?
11. What size are the sheets cut to?
12. Are any fumes generated in the manufacturing process?
13. Are these fumes harmful to the environment?
14. Have these fumes been quantized?
15. Is the wood pre-treated?
16. With what is the wood pre-treated for waterproofing?
17. Is the treatment environmentally friendly?
18. What materials are used to assimilate the wooden sheets: nails, screws or glue etc.?
19. Where are these materials manufactured?
20. If nails/screws are used, approximately how many nails/screws per IBC?
21. What other items are used in manufacturing the IBC?
22. Where do all these raw materials originate from?
23. What are the dimensions of the IBC that you manufacture?
24. What is the holding capacity of the IBC?
25. Is there any legislation pertaining to the manufacturing specifications of an IBC?
26. Is paint used for the labelling of the IBC?

27. If yes, what is the paint manufactured from?
28. Does the paint contain any lead?
29. Is the manufacturing process environmentally friendly?
30. Where do the raw materials for the paint originate from?

Agent Questionnaire 1

Site: ____

Responsible Persons/Position: ____________________________________

Date: ____

Time: ____

1. Who supplies the cyanide to you?
2. Where does the cyanide originate from?
3. How is it transported to Ghana?
4. Who are the transporting companies?
5. Do you have warehouses?
6. What is your maximum storage capacity?
7. How much cyanide do you store here per annum?
8. Do you have a control mechanism (carbon balance) for the influx and outflux of the cyanide?
9. Do you open the sea container at your site?
10. If yes, why?
11. Where are the sea containers stored?
12. Who transports them to the sites?
13. Do you have loose-standing unopened cyanide containers at your site?
14. What type of containers do you receive the cyanide in?
15. What are the dimensions of the cyanide containers?
16. Where are they stored?

15\. Is the area demarcated?

16\. What is the storage capacity of this facility?

17\. Is it under a roof?

18\. Is it bunded?

19\. Do you have emergency response plans in place in the case of spillage?

20\. Can spillage reach the groundwater?

21\. Are safety signs posted?

22\. Are the handlers all aware of the dangers of cyanide?

23\. Is safety equipment worn throughout?

24\. To whom do you supply cyanide?

25\. How is it transported to the users?

26\. Do you supply cyanide in sparging tanks?

27\. Who makes use of the sparging facility?

28\. Where is the sparging tank?

29\. Is the sparging area demarcated?

30\. Is water added to the sparging tank?

31\. How is the cyanide emptied into the sparging tank?

32\. How many end-users make use of sparging?

33\. Who are they?

34. Who disposes of the empty cyanide containers?
35. If you dispose of them, do you have a contract with the supplier for disposal?
36. Who transports the container back to the storage facility?
37. How many containers are loaded onto the vehicle and what vehicle is used?
38. Where are the empty boxes and liners stored?
39. How long are they stored before they are disposed of?
40. What method of disposal do you make use of?
41. Are they decontaminated prior to disposal?
42. If yes, how are they decontaminated?
43. If not, is this an option?
44. Is there an incineration facility available?
45. What is the capacity of this facility?
46. Do you have backup plans in case of downtime and what are they?
47. Have the fumes that are discharged been tested for toxicity?
48. Are any of the IBCs dismantled and sold as building material?
49. Is any of the wood sold as building material before decontamination?
50. Where is the wood used if sold?
51. Is anything built with the IBC wood?
52. If yes, what?
53. Has the IBC wood been tested for residual cyanide?
54. What happens to the liners?
55. Are the liners decontaminated?
56. If the liners are incinerated, are the fumes tested for toxicity?
57. If yes, do you record the results?
58. Are the fume emissions been quantized?
59. If yes, do you record the results?
60. At what temperature are the liners incinerated?
61. At what temperature are the IBCs incinerated?
62. Has the soil been sampled in the vicinity and tested for cyanide?
63. If yes, do you have the results?
64. Are any of the IBCs returned to the supplier?
65. Are there any other cyanide handling agents in Ghana?
66. If yes, may I have their details?

Agent Questionnaire 2

Site: ____

Responsible Persons/Position: ____________________________

Date: ____

Time: ____

Ghana port

1. Is this the only port to which cyanide is imported in Ghana?
2. From which countries is the cyanide imported?
3. Who are the agents that import cyanide to Ghana?
4. For which sites do they import the cyanide?
5. Does the cyanide arrive in Ghana in sealed sea-containers?
6. Are you familiar with the dimensions and type of container that is contained within this sea-container?
7. If yes, please describe?
8. Who unloads the sea-containers from the sea vessel?
9. Where are these containers stored?
10. What is the capacity of your storage facility?
11. Are the containers stacked singly or on top of each other?
12. If they are stacked on top of each other, how many layers are permissible?
13. Is the storage facility under roof?
14. Is it bunded?
15. Are there any safety signs posted?
16. In the case of spillage, can the cyanide reach the groundwater?
17. What emergency plans for cyanide exist at the port in Ghana?
18. How long are the sea-containers stored at the port?
19. Is there a control mechanism (cyanide balance) with regard to the influx and outflux of cyanide into this port?
20. How much cyanide passes through this port on average per month?
21. Are any of the sea containers opened at this port?
22. If yes, who opens them?
23. If yes, why are they opened?
24. Can any cyanide be stolen from the port?
25. Have there ever been any such instances?
26. Is the area in which the containers are stored secured?
27. If yes, who has access to this area?
28. Are you notified prior to the delivery of incoming cyanide?
29. Who collects the cyanide for delivery from this port?
30. Are you aware of where the cyanide will be transported to?
31. Who transports the cyanide from the ports to the agents?
32. Are the handlers of these containers aware of the dangers of cyanide?

33. Have the handlers been trained in an emergency response plan?
34. Do you export any empty cyanide containers?
35. If yes, in what manner are they packaged?
36. For which company do you export these empty cyanide containers?
37. To which countries do you export the empty cyanide containers?

Agent Questionnaire 3

Site: ____

Responsible Persons/Position: ____

Date: ____

Time: ____

Freighting company

To/from the agent

1. For which company do you transport cyanide?
2. Where is the storage facility situated?
3. How are the cyanide containers loaded onto the vehicle in Ghana?
4. What type of container do you upload?
5. What type of vehicle transports the cyanide containers to the agent?
6. If it is a flat-bed trailer, how many containers are placed on the deck?
7. What does legislation stipulate for the loading of the vehicles?
8. Is there vehicle tracking on these vehicles?
9. Has theft of the cyanide in transit ever occurred in Ghana?
10. How would the freighter respond to theft?
11. How would the driver and subsequently the agent be alerted of theft?
12. Is the transport route well maintained?
13. What is the travelling time to the agent?
14. How many drivers are there in the vehicle at one time?
15. Is the vehicle unattended at any one moment, e.g. when the driver needs to stop to eat?
16. Are there emergency plans in the case of an accident?
17. Who is held responsible in the case of an accident ï the freighter or the agent?
18. Have there ever been accidents on route in Ghana?
19. How would the company respond to spillage?
20. Has there ever been an incident of spillage?
21. What is your fuel consumption per month on one of these vehicles?
22. How many kilometres do you travel in total for all your vehicles from the port to the agent per month?

To/from the end-user

23. Who are the end-users that you transport cyanide to?
24. Is there vehicle tracking on these vehicles?
25. Who downloads the containers when they arrive at the site?
26. Has theft ever occurred on route to the end-user?
27. Do you transport any empty containers for the agent/mine site?
28. If yes, how are they transported?
29. Where are these empty containers transported to?
30. Are there any special procedures pertaining to the transport of the empty containers?
31. If yes, describe these procedures.
32. Do you have a cyanide balance that documents the amount of cyanide and containers you transport?
33. What is your fuel consumption per month on one of these vehicles?
34. How many kilometres do you travel in total for all your vehicles from the agent to the mine siteand back to the agent per month?

Sparging tanker

35. Who does the sparging tanker belong to?
36. Where is the sparging facility located?
37. How often are deliveries made with this tanker?
38. Who do you deliver to?
39. Who maintains this vehicle?
40. What is the capacity of this tanker?
41. Where is the water added to the cyanide?
42. Who discharges the tanker?
43. How many drivers are used on route?
44. Is the tanker left alone at any moment, e.g. for rest/lunch stops?
45. How long do you travel to the agent?
46. Are all the drivers trained in emergency response plans?
47. What is your fuel consumption per month on one of these vehicles?
48. How many kilometres do you travel in total for all your vehicles from the agent to the mine site and back to the agent per month?

End-user Questionnaire

Site: ____

Responsible Persons/Position:____

Date: ____

Time ____

1. Is this site ICMC compliant?
2. When were you audited for compliancy?
3. If this site is not ICMC compliant, are you a signatory of the ICMI?
4. Who are your cyanide suppliers
5. From which country does the cyanide you use originate?
6. How much cyanide do you use per month/annum?
7. Do you have a register (cyanide balance) wherein the cyanide influx and use is tabulated and controlled?
8. Do you use calcium or sodium cyanide?
9. Is your process carbon in leach or carbon in pulp?
10. Do you have any heap leach operations? If yes, how many?
11. Which agent delivers to your site?
12. In what form do you receive the cyanide ï granules, briquette, flakes or liquid?
13. In what type of container do you receive your cyanide?
14. Who destuffs the sea container at your site?
15. Where is the full cyanide container stored?
16. What are the dimensions of the cyanide containers you use?
17. How much cyanide do you store on site?
18. Is the storage area demarcated and are the safety signs clearly visible?
19. Is the storage area bunded?
20. What is the size of the storage area and what is its maximum cyanide holding capacity?
21. Is it under a roof?
22. How many IBCs are placed on top of each other?
23. Is there any way that spillage could enter groundwater from the storage area?
24. Can any residual cyanide enter the groundwater in the case of heavy rains?
25. Are the handlers all aware of the dangers of cyanide?
26. Are emergency procedures in place in case of spillage?
27. Is emergency spill equipment readily accessible?
28. What procedures exist for detoxification in the case of a spill?
29. Is personal protective equipment available?
30. Are any safety signs posted in clear view?
31. How is the cyanide container opened?
32. With what are the plastic liners removed from the container?
33. How is the cyanide removed from the liners?
34. Are these liners washed with water prior to disposal?
35. Are the liners replaced in the container?

36. Is there an area demarcated for the empty packaging?
37. Does the mine site dispose of any of the packaging?
38. According to the contract with your supplier, who is responsible for the disposal of the empty containers and liners, if applicable?
39. Who removes the IBCs from the mine site?
40. How are they transported to and from the mine site?
41. Where are they transported to/from?
42. Do you have alternative methods of disposal of the IBCs/containers?
43. Describe these methods.
44. Have you ever considered or practised disposing of the IBCs in your landfill sites, slimes dams or dumps?
45. If yes, have you found it to be effective?
46. Why or why not?
47. Do you know where they source the wood from for the IBC and are these forests sustainable?
48. Have you ever sold these IBCs to the local communities for building material?
49. Have iso-containers ever been used to transport cyanide in Ghana?
50. What other chemicals are transported in iso-containers?
51. Are the iso-containers returned to the supplier?
52. Is any cyanide transported in drums?
53. If yes, who supplies it in drums?
54. How are these drums disposed of?
55. Would you consider sparging?
56. If not, why not?
57. If you are using the sparging process, have you noticed any advantages above your previous method?
58. Mention some of these advantages.
59. Why did you decide to make use of sparging and not the traditional cyanide delivery method?
60. Whose responsibility is the disposal of the empty containers from which your cyanide now originates?
61. Do you receive any cyanide in alternative containers at all?
62. How often does the sparging tank deliver to you site?

APPENDIX B

CALCULATIONS FOR CHAPTER 5

Table B.1: Allocation of mass sea-container to each of the liners, IBC and cyanide on journey to the end-user

Elements	Mass each	Mass in container (mass each x 20 units)	Mass % (mass each/total inside sea-container)	Mass of sea-container allocated to each element
Units	**kilogram (kg)**	**kilogram (kg)**	**%**	**kilogram (kg)**
Polyethylene liner	1.1	22	0.10	2.3
Polypropylene liner	2.2	44	0.20	4.5
IBC	88	1 760	8.06	181.4
Cyanide	1 000	20 000	91.63	2 061.8
Total inside sea-container	1 091.3	21 826	100	
Sea-container	2 250	24 076		

Table B.2: Allocation of mass of the sea-container to each of the liners, IBC and cyanide on journey to agent/waste

Elements	Mass each	Mass in container (mass each x 20 units)	Mass % (mass each/total inside sea-container)	Mass of sea-container allocated to each element
Units	**Kilogram (kg)**	**Kilogram (kg)**	**%**	**Kilogram (kg)**
Polyethylene liner	1.1	22	1.20	27.1
Polypropylene liner	2.2	44	2.41	54.2
IBC	88	1 760	96.39	2 168.7
Cyanide	0	0	0	0
Total inside sea-container	91.3	1 826		
Sea-container	2 250	4 076		

Table B.3: Calculations for polyethylene liners – tonnage transported for every kilometre driven

Name	Number of PE Liners	To Barbex	To Minesite	To waste disposal site	Sea-containers used	Sea-container mass allocated to full PEs	Sea-container mass allocated to empty PEs	PE liner mass	Total mass full PEs transported	Total mass empty PEs transported	Full PE liner to Barbex	Full PE liner to mine site	Empty PE liner to waste
Unit	tons	km	km	km		tons	tons	tons	tons	tons	tkm	tkm	tkm
Iduapriem	2160		70	2	108	0.24	2.93	2.38	2.62	5.30	0.00	183.47	10.61
Obuasi	4032		204	2	202	0.46	5.47	4.44	4.89	9.90	0.00	998.05	19.80
Damang	2172	70	51	51	109	0.25	2.94	2.39	2.64	5.33	184.48	134.41	271.99
Tarkwa North	6485	70	14	14	324	0.74	8.79	7.13	7.87	15.92	550.82	110.16	222.93
Tarkwa South	2980	70	4	4	149	0.34	4.04	3.28	3.62	7.32	253.11	14.46	29.27
Tarkwa South	111	70	14	14	6	0.01	0.15	0.12	0.13	0.27	9.43	1.89	3.82
Tarkwa CIL	1310	70	14	14	66	0.15	1.78	1.44	1.59	3.22	111.27	22.25	45.03
Bogoso/Prestea	4009	70	62	1	200	0.45	5.43	4.41	4.86	9.84	340.52	0.00	0.00
Wassa	1558	70	70	70	78	0.18	2.11	1.71	1.89	3.83	132.33	132.33	267.79
Ahafo	1630	70	320	1	82	0.18	2.21	1.79	1.98	4.00	138.45	0.00	0.00
Chirano	484	70	210	210	24	0.05	0.66	0.53	0.59	1.19	41.11	123.33	249.57
Totals	**26931**				**1347**	**3.05**	**36.50**	**29.62**	**32.68**		**1761.52**	**1720.36**	**1120.80**

Table B.4: Calculations for Polypropylene liners – tonnage transported for every kilometre driven

Name	Number of PP liners	To Barbex	To Mine site	To waste disposal site	Sea-containers used	Sea-container mass allocated to full PPs	Sea-container mass allocated to empty PPs	PP liner mass	Total mass full PPs transported	Total mass empty PPs transported	Full PP liner to Barbex	Full PP liner to mine site	Empty PP liner to waste
Unit	tons	km	km	km		tons	tons	tons	tons	tons	tkm	tkm	tkm
Iduapriem	2160		70	2	108	0.49	5.86	4.75	5.24	10.61	0.00	366.93	21.21
Obuasi	4032		204	2	202	0.91	10.93	8.87	9.78	19.80	0.00	1996.11	39.60
Damang	2172	70	51	51	109	0.49	5.89	4.78	5.27	10.67	368.97	268.82	543.98
Tarkwa North	6485	70	14	14	324	1.47	17.58	14.27	15.74	31.85	1101.64	220.33	445.86
Tarkwa South	2980	70	8	8	149	0.68	8.08	6.56	7.23	14.63	506.23	57.85	117.07
Tarkwa South	111	70	4	4	6	0.03	0.30	0.24	0.27	0.55	18.86	1.08	2.18
Tarkwa CIL	1310	70	14	14	66	0.30	3.55	2.88	3.18	6.43	222.54	44.51	90.06
Bogoso/Prestea	4009	70	62	1	200	0.91	10.87	8.82	9.73	19.69	681.03	0.00	0.00
Wassa	1558	70	70	70	78	0.35	4.22	3.43	3.78	7.65	264.67	264.67	535.58
Ahafo	1630	70	320	1	82	0.37	4.42	3.59	3.96	8.00	276.90	0.00	0.00
Chirano	484	70	210	210	24	0.11	1.31	1.06	1.17	2.38	82.22	246.66	499.14
Totals	**26931**				**1347**	**6.11**	**73.01**	**59.25**	**65.36**	**132.25**	**3523.05**	**3466.95**	**2294.69**

Table B.5 Calculations for IBCs reused – tonnage transported for every kilometre driven

Name	Tonnage/ no of IBC	Reuse	To Barbex	To mine site	To waste disposal site	Sea-containers used	Sea-container mass allocated to full IBC	Sea-container mass allocated to empty IBC	IBC mass	Total mass full IBCs transported	Total mass empty IBCs transported	Full IBC to Barbex	Full IBC to mine site	Empty IBC to waste
Unit	tons	tons	km	km	km		tons	tons	tons	tons	tons	tkm	tkm	tkm
Iduapriem	2160	0		70	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Obuasi	4032	0		204	2	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Damang	2172	590.78	70	51	51	30	5.36	64.06	51.99	57.35	116.05	4014.39	2924.77	5918.55
Tarkwa North	6485	1763.92	70	14	14	88	16.00	191.27	155.22	171.23	346.49	11985.88	2397.18	4850.91
Tarkwa South	2980	810.56	70	8	8	41	7.35	87.89	71.33	78.68	159.22	5507.77	629.46	1273.77
Tarkwa South	111	30.19	70	4	4	2	0.27	3.27	2.66	2.93	5.93	205.16	11.72	23.72
Tarkwa CIL	1310	356.32	70	14	14	18	3.23	38.64	31.36	34.59	69.99	2421.20	484.24	979.91
Bogoso/Prestea	4009	3808.55	70	62	1	190	34.55	0.00	335.15	369.70	0.00	25879.18	22921.56	0.00
Wassa	1558	423.78	70	70	70	21	3.84	45.95	37.29	41.14	83.24	2879.57	2879.57	5827.07
Ahafo	1630	1548.50	70	320	1	77	14.05	0.00	136.27	150.32	0.00	10522.09	48100.99	0.00
Chirano	484	132.40	70	210	210	7	1.20	14.36	11.65	12.85	26.01	899.66	2698.98	5461.64
Totals	**26931**	**9465.002**				**473**	**85.86**	**445.44**	**832.92**	**918.78**	**806.94**	**64314.90**	**83048.47**	**24335.57**

Table B.6 Calculations for IBCs incinerated – tonnage transported for every kilometre driven

Name	Tonnage/ no of IBC	Incinerate	To Barbex	To mine site	To waste disposal site	Sea-containers used	Sea-container mass allocated to full IBC	Sea-container mass allocated to empty IBC	IBC mass	Total mass full IBCs transported	Total mass empty IBCs transported	Full IBC to Barbex	Full IBC to mine site	Empty IBC to waste
Unit	tons	tons	km	km	km		tons	tons	tons	tons	tons	tkm	tkm	tkm
Iduapriem	2160	2160		70	2	108	19.59	0.00	190.08	209.67	0.00	0.00	14677.25	0.00
Obuasi	4032	4032		204	2	202	36.58	0.00	354.82	391.39	0.00	0.00	79844.23	0.00
Damang	2172	1581	70	51	51	79	14.34	171.46	139.15	153.49	310.60	10744.40	7828.06	15840.81
Tarkwa North	6485	4721	70	14	14	236	42.83	511.92	415.46	458.28	927.38	32079.84	6415.97	12983.31
Tarkwa South	2980	2169	70	8	8	108	19.68	235.24	190.91	210.59	426.15	14741.39	1684.73	3409.21
Tarkwa South	111	81	70	4	4	4	0.73	8.76	7.11	7.84	15.87	549.09	31.38	63.49
Tarkwa CIL	1310	954	70	14	14	48	8.65	103.41	83.92	92.58	187.33	6480.28	1296.06	2622.69
Bogoso/Prestea	4009	200	70	62	1	10	1.82	0.00	17.64	19.46	0.00	1362.06	1206.40	0.00
Wassa	1558	1134	70	70	70	57	10.29	122.99	99.81	110.10	222.80	7707.08	7707.08	15595.99
Ahafo	1630	82	70	320	1	4	0.74	0.00	7.17	7.91	0.00	553.79	2531.63	0.00
Chirano	484	352	70	210	210	18	3.19	38.13	30.94	34.13	69.07	2389.13	7167.39	14503.88
Totals	**26931**	**17466**				**873**	**158.45**	**1191.91**	**1537.01**	**1695.45**	**2159.21**	**76607.07**	**130390.17**	**65019.39**

APPENDIX C

COMPLETE INVENTORY LISTS

Inventory list of raw materials

Inventory list of emissions to air

Inventory list of emissions to water

Inventory list of emissions to soil

Raw materials	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Aluminium, 24% in bauxite, 11% in crude ore, in ground	kg	1.9×10^{4}	6.5×10^{4}	3.27	6.01
Anhydrite, in ground	kg	3.92×10^{-1}	1.33	5.91×10^{-1}	1.01
Barite, 15% in crude ore, in ground	kg	4.99×10^{4}	1.69×10^{5}	8.28	1.52×10^{4}
Baryte, in ground	kg	2.31×10^{6}	7.87×10^{6}	6.19×10^{6}	1.28×10^{7}
Basalt, in ground	kg	3.07×10^{3}	1.05×10^{4}	5.30×10^{2}	9.73×10^{2}
Bauxite, in ground	kg	1.64×10^{6}	5.58×10^{6}	2.75×10^{6}	6.70×10^{5}
Borax, in ground	kg	7.62×10^{-2}	2.60×10^{-1}	1.48×10^{-2}	2.67×10^{-2}
Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground	kg	1.51×10^{1}	5.15×10^{1}	2.02	3.83
Calcite, in ground	kg	1.89×10^{7}	6.42×10^{7}	3.55×10^{6}	6.40×10^{6}
Carbon dioxide, in air	kg	4.04×10^{5}	1.38×10^{6}	8.69×10^{4}	1.55×10^{5}
Carbon, in organic matter, in soil	kg	1.94×10^{1}	6.59×10^{1}	2.57	4.86
Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	kg	4.86×10^{4}	1.66×10^{5}	5.59×10^{3}	1.09×10^{4}
Chromium, in ground	kg	7.36×10^{4}	2.51×10^{5}	1.44×10^{4}	3.32×10^{4}
Chrysotile, in ground	kg	7.46×10^{1}	2.54×10^{2}	3.12×10^{1}	5.30×10^{1}
Cinnabar, in ground	kg	6.92	2.36×10^{1}	2.98	5.05
Clay, bentonite, in ground	kg	1.10×10^{6}	3.74×10^{6}	6.16×10^{5}	1.33×10^{6}
Clay, unspecified, in ground	kg	1.18 x 10	4.03×10^{7}	2.40×10^{6}	4.76×10^{6}
Coal, 18 MJ per kg, in ground	kg	5.20×10^{5}	1.77×10^{6}	1.25×10^{5}	3.10×10^{5}
Coal, 26.4 MJ per kg, in ground	kg	6.17×10^{5}	1.80×10^{6}	4.71×10^{4}	9.49×10^{4}
Coal, brown, 8 MJ per kg, in ground	kg	6.25×10^{8}	2.13 x 10	1.51×10^{5}	3.73×10^{5}
Coal, brown, in ground	kg	3.17×10^{6}	1.08×10^{8}	7.32×10^{6}	1.30×10^{6}
Coal, hard, unspecified, in ground	kg	7.86×10^{6}	2.68×10^{7}	1.13×10^{6}	2.12×10^{6}
Cobalt, in ground	kg	3.60×10^{-1}	1.23	8.22×10^{-2}	1.69×10^{-1}
Colemanite, in ground	kg	1.07×10^{2}	3.65×10^{2}	1.69×10^{1}	3.13×10^{1}
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	kg	6.42×10^{2}	2.19×10^{3}	1.35×10^{2}	2.42×10^{2}
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	kg	3.54×10^{3}	1.20×10^{4}	7.35×10^{2}	1.32×10^{3}
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	kg	9.38×10^{2}	3.19×10^{3}	1.95×10^{2}	3.50×10^{2}
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	kg	4.69×10^{3}	1.60×10^{4}	9.76×10^{2}	1.75×10^{3}
Copper, in ground	kg	7.96×10^{5}	2.71×10^{6}	1.19×10^{5}	2.90×10^{5}
Diatomite, in ground	kg	5.68×10^{-3}	1.93×10^{-2}	7.85×10^{-2}	1.48×10^{-3}
Dolomite, in ground	kg	1.62×10^{4}	5.52×10^{4}	1.75×10^{3}	3.45×10^{3}
Energy, gross calorific value, in biomass	kJ	4.06×10^{-3}	1.38×10^{-2}	8.73×10^{-4}	1.56×10^{-3}
Energy, gross calorific value, in biomass, primary forest	kJ	1.34	4.57	1.78×10^{-1}	3.37×10^{-1}
Energy, kinetic (in wind), converted	kJ	1.33×10^{-3}	4.51×10^{-3}	3.04×10^{-4}	5.40×10^{-4}
Energy, potential (in hydropower reservoir), converted	kJ	3.89×10^{-6}	1.33×10^{-5}	6.69×10^{-7}	1.66×10^{-6}
Energy, solar, converted	kJ	2.02×10^{-5}	6.87×10^{-5}	4.54×10^{-6}	8.08×10^{-6}
Feldspar, in ground	kg	4.68×10^{3}	1.59×10^{4}	8.69×10^{2}	1.58×10^{3}
Fluorine, 4.5% in apatite, 1% in crude ore, in ground	kg	1.28×10^{2}	4.37×10^{2}	2.40×10^{1}	4.22×10^{1}
Fluorine, 4.5% in apatite, 3% in crude ore, in ground	kg	5.68×10^{1}	1.93×10^{2}	1.06×10^{1}	1.87×10^{1}
Fluorspar, 92%, in ground	kg	3.25×10^{3}	1.11×10^{4}	6.64×10^{2}	1.15×10^{3}
Gallium, 0.014% in bauxite, in ground	kg	5.73×10^{-5}	1.95×10^{-4}	1.29×10^{-5}	2.29×10^{-5}

Raw materials	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Gas, mine, off-gas, process, coal mining/kg	kg	3.53×10^{9}	1.20×10^{10}	8.54×10^{8}	2.11×10^{9}
Gas, mine, off-gas, process, coal mining/m3	m^3	8.07×10^{4}	2.75×10^{5}	1.18×10^{4}	2.21×10^{4}
Gas, natural, 35 MJ per m3, in ground	m^3	3.61×10^{8}	1.23×10^{9}	2.06×10^{7}	5.11×10^{7}
Gas, natural, 46.8 MJ per kg, in ground	kg	2.52×10^{6}	7.35×10^{6}	1.92×10^{5}	3.87×10^{5}
Gas, natural, in ground	m^3	1.79×10^{7}	6.08×10^{7}	2.06×10^{6}	3.98×10^{6}
Gas, petroleum, 35 MJ per m3, in ground	m^3	2.75×10^{7}	9.37×10^{7}	9.65×10^{7}	1.99×10^{8}
Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	kg	2.57×10^{-2}	8.74×10^{-2}	6.10×10^{-3}	1.08×10^{-2}
Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	kg	4.71×10^{-2}	1.60×10^{-1}	1.12×10^{-2}	1.98×10^{-2}
Gold, Au 1.4E-4%, in ore, in ground	kg	5.64×10^{-2}	1.92×10^{-1}	1.34×10^{-2}	2.37×10^{-2}
Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	kg	8.61×10^{-2}	2.93×10^{-1}	2.05×10^{-2}	3.63×10^{-1}
Gold, Au 4.3E-4%, in ore, in ground	kg	2.13×10^{-2}	7.27×10^{-2}	5.07×10^{-3}	8.99×10^{-3}
Gold, Au 4.9E-5%, in ore, in ground	kg	$5. \times 10^{-2}$	1.74×10^{-1}	1.21×10^{-2}	2.15×10^{-2}
Gold, Au 6.7E-4%, in ore, in ground	kg	7.91×10^{-2}	2.69×10^{-1}	1.88×10^{-2}	3.33×10^{-2}
Gold, Au 7.1E-4%, in ore, in ground	kg	8.92×10^{-2}	3.04×10^{-1}	2.12×10^{-2}	3.76×10^{-2}
Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	5.35×10^{-3}	1.82×10^{-2}	1.27×10^{-3}	2.25×10^{-6}
Granite, in ground	kg	5.00×10^{-5}	1.70×10^{-4}	8.32×10^{-6}	1.53×10^{-5}
Gravel, in ground	kg	4.12×10^{5}	1.40×10^{6}	3.14×10^{4}	6.50×10^{4}
Gypsum, in ground	kg	4.56	1.55×10^{1}	4.60	7.87
Helium, 0.08% in natural gas, in ground	kg	2.89×10^{-7}	9.85×10^{-7}	6.51×10^{-5}	1.16×10^{-4}
Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground	kg	2.55×10^{5}	8.67×10^{5}	3.42×10^{4}	6.49×10^{4}
Iron, 46% in ore, 25% in crude ore, in ground	kg	6.92×10^{6}	2.36×10^{7}	7.46×10^{4}	1.47×10^{6}
Iron, in ground	kg	3.04×10^{7}	1.03×10^{8}	7.97×10^{6}	1.71×10^{7}
Kaolinite, 24% in crude ore, in ground	kg	1.77×10^{2}	6.03×10^{2}	2.56×10^{1}	4.81×10^{1}
Kieserite, 25% in crude ore, in ground	kg	1.73	5.90	2.54×10^{-1}	4.77×10^{-1}
Land use II-III	m^2a	1.77×10^{5}	6.04×10^{5}	3.94×10^{4}	9.73×10^{4}
Land use II-III, sea floor	m^2a	3.71×10^{4}	1.26×10^{5}	9.81×10^{4}	2.04×10^{5}
Land use II-IV	m^2a	2.57×10^{5}	8.75×10^{5}	2.58×10^{3}	5.52×10^{3}
Land use II-IV, sea floor	m^2a	3.82×10^{3}	1.30×10^{4}	1.01×10^{4}	2.11×10^{4}
Land use III-IV	m^2a	1.35×10^{4}	4.59×10	2.02×10^{3}	4.28×10^{3}
Land use IV-IV	m^2a	2.50×10^{4}	8.51×10^{4}	2.58×10^{4}	5.38×10^{4}
Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	kg	1.16×10^{3}	3.96×10^{3}	1.59×10^{2}	3.02×10^{2}
Lead, in ground	kg	1.49×10^{5}	5.07×10^{5}	1.09×10^{4}	2.57×10^{4}
Limestone, in ground	kg	3.58×10^{4}	1.05×10^{5}	2.73×10^{3}	5.51×10^{3}
Magnesite, 60% in crude ore, in ground	kg	9.97×10^{4}	3.39×10^{5}	1.12×10^{4}	2.19×10^{4}
Magnesium, 0.13% in water	kg	2.10×10^{-1}	7.14×10^{-1}	4.72×10^{-2}	8.40×10^{-2}
Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	kg	1.45×10^{3}	4.95×10^{3}	2.54×10^{2}	4.65×10^{2}
Manganese, in ground	kg	2.53×10^{4}	8.62×10^{4}	3.16×10^{3}	7.12×10^{3}
Marl, in ground	kg	3.54×10^{7}	1.21×10^{8}	8.14×10^{6}	1.79×10^{8}
Metamorphous rock, graphite containing, in ground	kg	2.20×10^{1}	7.50×10^{1}	4.01	7.31
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	kg	8.71×10^{1}	2.97×10^{2}	1.81×10^{1}	3.25×10^{1}
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	kg	1.23×10^{1}	4.20×10^{1}	2.56	4.60

Raw materials	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	kg	4.44×10^{2}	1.51×10^{3}	8.22×10^{1}	1.49×10^{2}
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	kg	4.52×10^{1}	1.54×10^{2}	9.39	1.69×10^{1}
Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	kg	8.97×10^{2}	3.05×10^{3}	1.66×10^{2}	3.01×10^{2}
Molybdenum, in ground	kg	5.26×10^{1}	1.79	3.10	6.29
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	kg	1.65×10^{3}	5.62×10^{3}	1.76×10^{2}	3.45×10^{2}
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	kg	1.61×10^{5}	5.49×10^{5}	1.83×10^{4}	3.58×10^{4}
Nickel, in ground	kg	4.38×10^{4}	1.49×10^{5}	9.65×10^{3}	2.25×10^{4}
Occupation, arable, non-irrigated	m^2a	1.58×10^{3}	5.37×10^{63}	2.44×10^{2}	4.54×10^{2}
Occupation, construction site	m^2a	5.95×10^{4}	2.03×10^{5}	1.09×10^{4}	1.98×10^{4}
Occupation, dump site	m^2a	2.19×10^{5}	7.47×10^{5}	5.39×10^{4}	9.47×10^{4}
Occupation, dump site, benthos	m^2a	5.68×10^{3}	1.93×10^{4}	6.60×10^{2}	1.27×10^{3}
Occupation, forest, intensive	m^2a	2.75×10^{4}	9.35 x 104	9.23×10^{3}	1.59×10^{4}
Occupation, forest, intensive, normal	m^2a	5.86×10^{5}	2.00×10^{6}	1.02×10^{5}	1.87×10^{5}
Occupation, forest, intensive, short-cycle	m^2a	3.37×10^{2}	1.15×10^{3}	4.47×10^{1}	8.45×10^{1}
Occupation, industrial area	m^2a	4.94×10^{4}	1.68×10^{5}	6.44×10^{3}	1.23×10^{4}
Occupation, industrial area, benthos	m^2a	5.50×10^{1}	1.87×10^{2}	6.40	1.23×10^{1}
Occupation, industrial area, built up	m^2a	2.67×10^{4}	9.08×10^{5}	2.88×10^{4}	5.68×10^{4}
Occupation, industrial area, vegetation	m^2a	2.26×10^{4}	7.69×10^{4}	3.35×10^{3}	6.26×10^{3}
Occupation, mineral extraction site	m^2a	3.36×10^{5}	1.14×10^{6}	4.42×10^{4}	8.41×10^{4}
Occupation, permanent crop, fruit, intensive	m^2a	4.74×10^{2}	1.61×10^{3}	6.18×10^{1}	1.17×10^{-1}
Occupation, shrub land, sclerophyllous	m^2a	2.70×10^{4}	9.18×10^{4}	7.48×10^{3}	1.30×10^{4}
Occupation, traffic area, rail embankment	m^2a	1.54×10^{4}	5.23×10^{4}	2.94×10^{3}	5.32×10^{3}
Occupation, traffic area, rail network	m^2a	1.70×10^{4}	5.78×10^{4}	3.25×10^{3}	5.88×10^{3}
Occupation, traffic area, road embankment	m^2a	1.74×10^{4}	5.94×10^{4}	2.65×10^{3}	4.94×10^{3}
Occupation, traffic area, road network	m^2a	2.50×10^{5}	8.51×10^{5}	5.50×10^{4}	9.73×10^{4}
Occupation, urban, discontinuously built	m^2a	2.51	8.55	4.11×10^{-1}	7.58×10^{-1}
Occupation, water bodies, artificial	m^2a	9.57×10^{6}	3.26×10^{5}	1.40×10^{1}	2.62×10^{1}
Occupation, water courses, artificial	m^2a	1.72×10^{3}	5.85×10^{4}	3.04×10^{3}	5.54×10^{3}
Oil, crude, 42 MJ per kg, in ground	kg	3.62×10^{7}	1.06×10^{8}	2.76×10^{7}	5.58×10^{6}
Oil, crude, 42.6 MJ per kg, in ground	kg	4.02×10^{8}	1.37×10^{9}	1.41×10^{9}	2.90×10^{9}
Oil, crude, in ground	kg	7.34×10^{6}	2.50×10^{7}	1.07×10^{6}	2.01×10^{6}
Olivine, in ground	kg	1.65×10^{-1}	5.64×10^{-1}	2.09×10^{-1}	3.56×10^{-1}
Palladium, in ground	kg	1.49	5.07	1.30×10^{1}	2.62×10^{1}
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	kg	1.06×10^{-2}	3.60×10^{-2}	1.96×10^{3}	3.55×10^{3}
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	kg	2.54×10^{-2}	8.65×10^{-2}	4.70×10^{-3}	8.54×10^{-2}
Peat, in ground	kg	2.12×10^{2}	7.23×10^{2}	6.25×10^{1}	1.10×10^{2}
Phosphorus, 18% in apatite, 12% in crude ore, in ground	kg	2.28×10^{2}	7.77×10^{2}	4.33×10^{1}	7.61×10^{1}
Phosphorus, 18% in apatite, 4% in crude ore, in ground	kg	5.13×10^{2}	1.75×10^{3}	9.61×10^{1}	1.69×10^{2}
Platinum, in ground	kg	1.68	5.72	1.47×10^{1}	2.95×10^{1}
Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	kg	2.89×10^{-4}	9.85×10^{-4}	5.21×10^{-5}	9.50×10^{-5}
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	kg	1.04×10^{-3}	3.53×10^{-3}	1.87×10^{-4}	3.40×10^{-4}

Raw materials	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	kg	1.44×10^{-4}	4.91×10^{-4}	2.14×10^{-5}	4.00×10^{-5}
Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	kg	4.52×10^{-4}	1.54×10^{-3}	6.71×10^{-5}	1.25×10^{-4}
Rhenium, in crude ore, in ground	kg	2.16×10^{-4}	7.35×10^{-4}	2.94×10^{-5}	5.56×10^{-5}
Rhenium, in ground	kg	1.29	4.38	1.10×10^{1}	2.22×10^{1}
Rhodium, in ground	kg	1.58	5.40	1.39×10^{1}	2.79×10^{1}
Sand, unspecified, in ground	kg	1.06×10^{7}	3.60×10^{7}	2.94×10^{6}	6.33×10^{6}
Shale, in ground	kg	1.11	3.77	1.67	2.85
Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	kg	5.73×10^{-1}	1.95	1.36×10^{-1}	2.41×10^{-1}
Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	kg	4.09×10^{-1}	1.39	9.70×10^{-2}	1.72×10^{-1}
Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	kg	3.77×10^{-2}	1.28×10^{-1}	8.95×10^{-3}	1.59×10^{-2}
Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	kg	8.61×10^{-2}	2.93×10^{-1}	$2.05 \times 10^{+2}$	3.63×10^{-2}
Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	kg	8.44×10^{-2}	2.87×10^{-1}	2.00×10^{-2}	3.55×10^{-2}
Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	5.57×10^{-2}	1.90×10^{-5}	1.32×10^{-2}	2.34×10^{-2}
Silver, in ground	kg	1.26×10^{3}	4.30×10^{3}	4.44×10^{3}	9.16×10^{3}
Sodium chloride, in ground	kg	5.50×10^{6}	1.87×10^{7}	1.57×10^{6}	2.88×10^{6}
Sodium nitrate, in ground	kg	5.05×10^{-5}	1.72×10^{-4}	1.55×10^{-5}	2.73×10^{-5}
Sodium sulphate, various forms, in ground	kg	8.83×10^{2}	3.01×10^{3}	1.80×10^{2}	3.11×10^{2}
Stibnite, in ground	kg	5.90×10^{-4}	2.01×10^{-3}	8.16×10^{-5}	1.54×10^{-4}
Sulfur, in ground	kg	1.76×10^{1}	6.00×10^{1}	2.12×10^{1}	3.61×10^{1}
Sylvite, 25 % in sylvinite, in ground	kg	6.01×10^{1}	2.05×10^{2}	1.20×10^{1}	2.17×10^{1}
Talc, in ground	kg	2.04×10^{1}	6.95×10^{1}	5.12	9.01
Tantalum, 81.9% in tantalite, 1.6E-4% in crude ore, in ground	kg	4.51×10^{-1}	1.54	1.07×10^{-1}	1.90×10^{-1}
Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground	kg	6.13×10^{-2}	2.09×10^{-1}	1.45×10^{-2}	2.58×10^{-2}
Tin, 79% in cassiterite, 0.1% in crude ore, in ground	kg	3.23×10^{1}	1.10×10^{2}	6.38	1.15×10^{1}
Tin, in ground	kg	7.02×10^{2}	2.39×10^{3}	2.47×10^{3}	5.09×10^{3}
TiO_2, 54% in ilmenite, 2.6% in crude ore, in ground	kg	1.46×10^{5}	4.97×10^{5}	1.54×10^{4}	3.01×10^{4}
TiO_2, 95% in rutile, 0.40% in crude ore, in ground	kg	1.07×10^{-2}	3.65×10^{-2}	1.69×10^{-3}	3.14×10^{-3}
Transformation, from arable	m^2	1.48×10^{1}	5.05×10^{1}	2.85	5.16
Transformation, from arable, non-irrigated	m^2	2.91×10^{3}	9.91×10^{3}	4.50×10^{2}	8.38×10^{2}
Transformation, from arable, non-irrigated, fallow	m^2	2.32×10^{1}	7.90×10^{1}	3.97	7.28
Transformation, from dump site, inert material landfill	m^2	1.02×10^{2}	3.46×10^{2}	1.60×10^{1}	2.97×10^{1}
Transformation, from dump site, residual material landfill	m^2	1.85×10^{3}	6.30×10^{3}	5.97×10^{2}	1.02×10^{3}
Transformation, from dump site, sanitary landfill	m^2	1.97×10^{3}	6.72×10^{3}	2.00×10^{2}	4.00×10^{2}
Transformation, from dump site, slag compartment	m^2	1.47×10^{3}	4.99×10^{3}	6.82×10^{2}	1.15×10^{3}
Transformation, from forest	m^2	1.07×10^{4}	3.64×10^{4}	1.36×10^{3}	2.59×10^{3}
Transformation, from forest, extensive	m^2	4.50×10^{3}	1.53×10^{4}	8.31×10^{2}	1.51×10^{3}
Transformation, from forest, intensive, clear-cutting	m^2	1.20×10^{1}	4.09×10^{1}	1.60	3.02
Transformation, from industrial area	m^2	1.01×10^{2}	3.45×10^{2}	1.33×10^{1}	2.51×10^{1}
Transformation, from industrial area, benthos	m^2	5.52	1.88×10^{1}	6.11×10^{-1}	1.19
Transformation, from industrial area, built up	m^2	1.83	6.23	3.43×10^{-1}	6.02×10^{-1}
Transformation, from industrial area, vegetation	m^2	3.12×10^{63}	1.06×10^{4}	5.85×10^{2}	1.03×10^{3}

Raw materials	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Transformation, from mineral extraction site	m^2	9.75×10^6	3.32×10^4	1.29×10^3	2.45×10^3
Transformation, from pasture and meadow	m^2	7.39×10^3	2.52×10^4	2.04×10^3	3.53×10^3
Transformation, from pasture and meadow, intensive	dm^2	2.38×10^2	8.09×10^2	3.67×10^1	6.83×10^1
Transformation, from sea and ocean	m^2	5.68×10^3	1.93×10^4	6.61×10^2	1.28×10^3
Transformation, from shrub land, sclerophyllous	m^2	5.46×10^3	1.86×10^4	1.51×10^3	2.62×10^3
Transformation, from tropical rain forest	m^2	1.20×10^1	4.09×10^1	1.60	3.02
Transformation, from unknown	m^2	5.09×10^4	1.73×10^5	6.52×10^3	1.25×10^4
Transformation, to arable	m^2	1.14×10^3	3.88×10^3	1.49×10^2	2.82×10^2
Transformation, to arable, non-irrigated	m^2	2.92×10^3	9.93×10^3	4.51×10^2	8.38×10^2
Transformation, to arable, non-irrigated, fallow	m^2	2.50×10^1	8.53×10^1	4.62	8.35
Transformation, to dump site	m^2	4.86×10^2	1.66×10^3	7.65×10^1	1.42×10^2
Transformation, to dump site, benthos	m^2	5.68×10^3	1.93×10^4	6.60×10^2	1.27×10^3
Transformation, to dump site, inert material landfill	m^2	1.02×10^2	3.46×10^2	1.60×10^1	2.97×10^1
Transformation, to dump site, residual material landfill	m^2	1.85×10^3	6.30×10^3	5.97×10^2	1.02×10^3
Transformation, to dump site, sanitary landfill	m^2	1.97×10^3	6.72×10^3	2.00×10^2	4.00×10^2
Transformation, to dump site, slag compartment	m^2	1.47×10^3	4.99×10^3	6.82×10^2	1.15×10^3
Transformation, to forest	m^2	1.48×10^4	5.05×10^4	2.72×10^3	4.94×10^3
Transformation, to forest, intensive	m^2	1.83×10^2	6.23×10^2	6.14×10^1	1.06×10^2
Transformation, to forest, intensive, clear-cutting	m^2	1.20×10^1	4.09×10^1	1.60	3.02
Transformation, to forest, intensive, normal	m^2	4.26×10^3	1.45×10^4	7.60×10^2	1.39×10^3
Transformation, to forest, intensive, short-cycle	m^2	1.20×10^1	4.09×10^1	1.60	3.02
Transformation, to heterogeneous, agricultural	m^2	5.53×10^2	1.88×10^3	7.02×10^1	1.34×10^2
Transformation, to industrial area	m^2	8.07×10^2	2.75×10^3	1.06×10^2	2.01×10^2
Transformation, to industrial area, benthos	m^2	3.38	1.15×10^1	5.32×10^{-1}	9.84×10^{-1}
Transformation, to industrial area, built up	m^2	6.54×10^3	2.23×10^4	6.99×10^2	1.38×10^3
Transformation, to industrial area, vegetation	m^2	4.68×10^2	1.60×10^3	6.95×10^1	1.30×10^2
Transformation, to mineral extraction site	m^2	4.41×10^4	1.50×10^5	5.73×10^3	1.09×10^4
Transformation, to pasture and meadow	m^2	8.32×10^1	2.83×10^2	9.49	1.83×10^1
Transformation, to permanent crop, fruit, intensive	m^2	6.67	2.27×10^1	8.70×10^{-1}	1.65
Transformation, to sea and ocean	dm^2	5.52×10^1	1.88×10^2	6.11	1.19×10^1
Transformation, to shrub land, sclerophyllous	m^2	5.39×10^3	1.84×10^4	1.50×10^3	2.60×10^3
Transformation, to traffic area, rail embankment	m^2	3.57×10^1	1.22×10^2	6.84	1.24×10^1
Transformation, to traffic area, rail network	m^2	3.93×10^1	1.34×10^2	7.52	1.36×10^1
Transformation, to traffic area, road embankment	m^2	7.28×10^1	2.48×10^2	1.22×10^1	2.25×10^1
Transformation, to traffic area, road network	m^2	2.09×10^3	7.10×10^3	5.54×10^2	9.60×10^2
Transformation, to unknown	m^2	1.72×10^2	5.86×10^2	3.13×10^1	5.68×10^1
Transformation, to urban, discontinuously built	dm^2	5.00	1.70×10^1	8.19×10^{-1}	1.51
Transformation, to water bodies, artificial	m^2	7.53×10^3	2.56×10^4	9.90×10^2	1.89×10^3
Transformation, to water courses, artificial	m^2	1.90×10^2	6.47×10^2	3.45×10^1	6.28×10^1
Ulexite, in ground	kg	2.64	9.00	6.08×10^{-1}	1.08
Uranium, 2291 GJ per kg, in ground	kg	2.52	7.35	1.92×10^{-1}	3.87×10^{-1}

Raw materials	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Uranium, 560 GJ per kg, in ground	kg	4.68×10^{4}	1.59×10^{5}	1.02×10^{4}	2.54×10^{4}
Uranium, in ground	kg	1.59×10^{2}	5.41×10^{2}	3.46×10^{1}	6.18×10^{1}
Vermiculite, in ground	kg	1.95	6.65	3.24×10^{-1}	5.96×10^{-1}
Volume occupied, final repository for low-active radioactive waste	m^3	3.26×10^{-1}	1.11	7.05×10^{-2}	1.26×10^{-1}
Volume occupied, final repository for radioactive waste	dm^3	8.04×10^{1}	2.74×10^{2}	1.75×10^{1}	3.12×10^{1}
Volume occupied, reservoir	m^3y	8.70×10^{7}	2.96×10^{8}	1.46×10^{7}	3.62×10^{7}
Volume occupied, underground deposit	m^3	2.30	7.83	2.56	4.37
Water, cooling, unspecified natural origin/m3	m^3	5.33×10^{5}	1.81×10^{6}	1.68×10^{5}	2.92×10^{5}
Water, lake	m^3	2.05×10^{3}	6.97×10^{3}	3.41×10^{2}	6.27×10^{2}
Water, river	m^3	8.20×10^{6}	2.79×10^{7}	8.39×10^{5}	1.67×10^{6}
Water, salt, ocean	m^3	2.34×10^{4}	7.96×10^{4}	3.68×10^{3}	6.81×10^{3}
Water, salt, sole	m^3	4.57×10^{3}	1.56×10^{4}	6.18×10^{2}	1.17×10^{3}
Water, turbine use, unspecified natural origin	m^3	1.94×10^{10}	6.62×10^{10}	3.53×10^{9}	8.75×10^{9}
Water, unspecified natural origin/kg	kg	9.38×10^{7}	3.19×10^{7}	2.83×10^{7}	6.73×10^{7}
Water, unspecified natural origin/m3	m^3	3.49×10^{5}	1.19×10^{6}	4.96×10^{4}	9.34×10^{4}
Water, well, in ground	m^3	2.62×10^{4}	8.94×10^{4}	4.82×10^{3}	8.77×10^{3}
Wood and wood waste, 9.5 MJ per kg	ton	2.59×10^{1}	7.58×10^{1}	1.98	3.99
Wood, dry matter	ton	1.66×10^{7}	5.64×10^{7}	1.55×10^{3}	3.81×10^{3}
Wood, hard, standing	m^3	1.24×10^{2}	4.23×10^{2}	2.32×10^{1}	4.21×10^{1}
Wood, primary forest, standing	dm^3	1.24×10^{2}	4.24×10^{2}	1.65×10^{1}	3.13×10^{1}
Wood, soft, standing	m^3	2.64×10^{2}	8.98×10^{2}	6.11×10^{1}	1.08×10^{2}
Wood, unspecified, standing/m3	dm^3	2.06	7.00	4.73	8.03
Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	kg	3.25×10^{3}	1.11×10^{4}	6.40×10^{2}	1.16×10^{3}
Zinc, in ground	kg	2.69×10^{3}	9.15×10^{3}	4.12×10^{2}	8.65×10^{2}
Zirconium, 50% in zircon, 0.39% in crude ore, in ground	kg	6.16×10^{-1}	2.10	1.46×10^{-1}	2.59×10^{-1}

Emissions into the air	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
1-Propanol	kg	2.60×10^{-4}	8.86×10^{-7}	5.86×10^{-5}	1.04×10^{-4}
1,4-Butanediol	kg	1.50×10^{-4}	5.09×10^{-4}	3.55×10^{-5}	6.30×10^{-5}
2-Propanol	kg	2.79	9.50	6.63×10^{-1}	1.18
Acenaphthene	kg	2.24×10^{-5}	7.62×10^{-5}	5.14×10^{-6}	9.14×10^{-6}
Acetaldehyde	kg	5.00×10^{3}	1.70×10^{4}	2.95×10^{2}	6.98×10^{2}
Acetic acid	kg	4.44×10^{3}	1.51×10^{4}	1.27×10^{3}	3.02×10^{3}
Acetone	kg	9.68×10^{2}	3.30×10^{3}	2.76×10^{2}	6.62×10^{2}
Acetonitrile	kg	1.31×10^{-2}	4.45×10^{-2}	1.74×10^{-3}	3.28×10^{-3}
Acrolein	kg	3.89×10^{-1}	1.32	4.72×10^{-2}	9.73×10^{-2}
Acrylic acid	kg	7.22×10^{-3}	2.46×10^{-2}	1.72×10^{-3}	3.04×10^{-3}
Actinides, radioactive, unspecified	Bq	3.01×10^{3}	1.02×10^{4}	6.39×10^{2}	1.14×10^{3}
Aerosols, radioactive, unspecified	kBq	6.31×10^{1}	2.15×10^{2}	1.40×10^{1}	2.50×10^{1}
Aldehydes, unspecified	kg	2.84×10^{4}	8.30×10^{4}	2.17×10^{3}	4.38×10^{3}
Aluminum	kg	3.36×10^{4}	1.15×10^{5}	8.20×10^{3}	1.99×10^{4}
Americium-241	kBq	3.62×10^{2}	1.23×10^{3}	7.87×10^{1}	1.95×10^{2}
Ammonia	kg	6.70×10^{5}	2.28×10^{6}	9.07×10^{3}	1.87×10^{4}
Ammonium carbonate	kg	8.46×10^{-3}	2.88×10^{-2}	3.36×10^{-3}	5.88×10^{-3}
Antimony	kg	3.07×10^{1}	1.04×10^{2}	7.28	1.81×10^{1}
Antimony-124	kBq	5.05	1.72×10^{1}	1.16	2.89
Antimony-125	Bq	1.42×10^{3}	4.85×10^{3}	1.50×10^{2}	3.69×10^{2}
Argon-41	kBq	3.83×10^{7}	1.30×10^{8}	9.18×10^{6}	2.28×10^{7}
Arsenic	kg	1.96×10^{2}	6.66×10^{2}	2.24×10^{2}	4.96×10^{2}
Arsine	kg	8.42×10^{-5}	2.87×10^{-6}	2.00×10^{-5}	3.54×10^{-5}
Barium	kg	5.18×10^{2}	1.76×10^{3}	3.16×10^{2}	6.31×10^{2}
Barium-140	kBq	1.04×10^{2}	3.55×10^{2}	1.67×10^{1}	4.13×10^{1}
Benzal chloride	kg	-	-	1.36×10^{-10}	2.47×10^{-10}
Benzaldehyde	kg	1.27×10^{-1}	4.31×10^{-1}	1.58×10^{-2}	3.25×10^{-2}
Benzene	kg	1.04×10^{5}	3.53×10^{5}	5.15×10^{5}	2.41×10^{4}
Benzene, ethyl-	kg	5.18×10^{3}	1.76×10^{4}	3.18×10^{3}	6.83×10^{3}
Benzene, hexachloro-	kg	7.71	2.63×10^{1}	7.80×10^{-1}	1.56
Benzene, pentachloro-	kg	1.92×10^{1}	6.54×10^{1}	1.94	3.88
Benzo(a)pyrene	kg	3.53×10^{1}	1.20×10^{2}	1.06	2.28
Beryllium	kg	5.59	1.90×10^{1}	1.72	3.95
Boron	kg	2.60×10^{4}	8.84×10^{4}	5.77×10^{3}	1.43×10^{4}
Boron trifluoride	kg	-	-	1.49×10^{-10}	2.65×10^{-10}
Bromine	kg	2.47×10^{3}	8.40×10^{3}	6.14×10^{2}	1.50×10^{3}
Butadiene	kg	8.39×10^{-5}	2.86×10^{-4}	1.98×10^{-5}	3.52×10^{-5}
Butane	kg	4.01×10^{4}	1.37×10^{5}	1.25×10^{5}	2.58×10^{5}
Butanol	kg	4.64×10^{-5}	1.58×10^{-6}	1.10×10^{-7}	1.95×10^{-7}
Butene	kg	2.20×10^{3}	7.50×10^{3}	5.84×10^{4}	5.35×10^{3}

Emissions into the air	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Butyrolactone	kg	4.33×10^{-5}	1.47×10^{-4}	1.03×10^{-5}	1.82×10^{-5}
Cadmium	kg	1.37×10^{2}	4.65×10^{2}	4.76×10^{2}	1.04×10^{3}
Calcium	kg	3.99×10^{4}	1.36×10^{5}	1.42×10^{4}	3.20×10^{4}
Carbon-14	kBq	3.08×10^{7}	1.05×10^{8}	6.39×10^{6}	1.58×10^{7}
Carbon dioxide	kg	-1.92×10^{10}	-6.54×10^{10}	2.24×10^{9}	4.96×10^{9}
Carbon dioxide, biogenic	kg	1.15×10^{10}	3.92×10^{10}	1.16×10^{5}	2.08×10^{5}
Carbon dioxide, fossil	kg	1.98×10^{8}	6.16×10^{8}	2.40×10^{9}	4.06×10^{9}
Carbon dioxide, land transformation	kg	8.27×10^{2}	2.82×10^{3}	1.72×10^{2}	3.09×10^{2}
Carbon disulfide	kg	9.29×10^{1}	3.16×10^{2}	1.77×10^{1}	3.20×10^{1}
Carbon monoxide	kg	4.30×10^{7}	1.46×10^{8}	1.00×10^{6}	2.12×10^{6}
Carbon monoxide, biogenic	kg	1.76×10^{6}	5.99×10^{6}	2.30×10^{2}	4.20×10^{2}
Carbon monoxide, fossil	kg	2.38×10^{5}	8.12×10^{5}	2.06×10^{5}	4.11×10^{5}
Cerium-141	Bq	1.89×10^{3}	6.44×10^{3}	4.27×10^{2}	1.04×10^{3}
Cerium-144	kBq	3.85×10^{3}	1.31×10^{4}	8.38×10^{2}	2.07×10^{3}
Cesium-134	kBq	1.37×10^{4}	4.67×10^{4}	2.99×10^{3}	7.42×10^{3}
Cesium-137	kBq	2.65×10^{4}	9.02×10^{4}	5.77×10^{3}	1.43×10^{4}
Chlorine	kg	8.43×10^{1}	2.83×10^{2}	2.60×10^{1}	4.48×10^{1}
Chloroform	kg	4.33	1.47×10^{1}	2.58×10^{-1}	6.29×10^{-1}
Chlorosilane, trimethyl-	kg	1.30×10^{-4}	4.42×10^{-4}	3.08×10^{-5}	5.46×10^{-5}
Chromium	kg	9.97×10^{3}	3.40×10^{4}	3.07×10^{2}	6.78×10^{2}
Chromium-51	kBq	6.65×10^{1}	2.26×10^{2}	1.48×10^{1}	3.69×10^{1}
Chromium VI	kg	3.83	1.30×10^{1}	4.46×10^{-1}	8.68×10^{-1}
Cobalt	kg	3.33×10^{2}	1.13×10^{3}	5.27×10^{2}	1.17×10^{3}
Cobalt-57	Bq	3.01×10^{1}	1.03×10^{2}	7.25	1.80×10^{1}
Cobalt-58	kBq	5.01×10^{2}	1.70×10^{3}	1.20×10^{2}	2.98×10^{2}
Cobalt-60	kBq	7.89×10^{2}	2.69×10^{3}	1.79×10^{2}	4.44×10^{2}
Copper	kg	2.71×10^{3}	9.23×10^{3}	8.99×10^{2}	1.99×10^{3}
Cumene	kg	4.57	1.56×10^{1}	1.49×10^{1}	2.52×10^{1}
Curium-242	Bq	1.73	5.88	4.15×10^{-1}	1.03
Curium-244	Bq	1.57×10^{1}	5.34×10^{1}	3.77	9.37
Curium alpha	kBq	5.74×10^{2}	1.95×10^{3}	1.24×10^{2}	3.10×10^{2}
Cyanide	kg	7.02×10^{3}	2.39×10^{4}	9.37×10^{2}	1.58×10^{3}
Dinitrogen monoxide	kg	1.80×10^{5}	6.12×10^{5}	3.73×10^{4}	8.40×10^{4}
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	6.54×10^{-2}	2.23×10^{-1}	6.09×10^{-3}	1.22×10^{-2}
Ethane	kg	7.71×10^{4}	2.63×10^{5}	3.00×10^{4}	6.36×10^{4}
Ethane, 1,1-difluoro-, HFC-152a	kg	7.44×10^{-3}	2.53×10^{-4}	1.67×10^{-3}	2.98×10^{-3}
Ethane, 1,1,1-trichloro-, HCFC-140	kg	2.90×10^{-5}	9.89×10^{-5}	6.17×10^{-6}	1.10×10^{-5}
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	7.52×10^{-3}	2.56×10^{-2}	1.64×10^{-3}	2.92×10^{-3}
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	3.43×10^{-4}	1.17×10^{-3}	8.14×10^{-5}	1.44×10^{-4}
Ethane, 1,2-dichloro-	kg	5.91×10^{-1}	2.01	9.22×10^{-1}	1.57
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	3.91×10^{2}	1.33×10^{3}	8.54×10^{1}	2.12×10^{2}

Emissions into the air	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Ethane, dichloro-	kg	1.63×10^{2}	5.56×10^{2}	9.65	2.36×10^{1}
Ethane, hexafluoro-, HFC-116	kg	1.82×10^{1}	6.20×10^{1}	3.06	7.42
Ethanol	kg	1.94×10^{3}	6.60×10^{3}	5.51×10^{2}	1.33×10^{3}
Ethene	kg	6.16×10^{4}	2.10×10^{5}	1.93×10^{6}	3.50×10^{5}
Ethene, chloro-	kg	2.69×10^{1}	9.17×10^{1}	1.80	4.23
Ethene, tetrachloro-	kg	2.19×10^{-2}	6.41×10^{-2}	1.68×10^{-3}	3.39×10^{-3}
Ethene, trichloro-	kg	2.09×10^{-2}	6.10×10^{-2}	1.59×10^{-3}	3.21×10^{-3}
Ethyl acetate	kg	1.30×10^{1}	4.42×10^{1}	3.08	5.46
Ethyl cellulose	kg	2.62×10^{-2}	8.93×10^{-2}	6.23×10^{-3}	1.10×10^{-2}
Ethylene diamine	kg	3.76×10^{-5}	1.28×10^{-4}	5.26×10^{-6}	9.93×10^{-6}
Ethylene oxide	kg	1.12×10^{-1}	3.83×10^{-1}	2.01×10^{-1}	3.42×10^{-1}
Ethyne	kg	5.37×10^{1}	1.83×10^{2}	1.24×10^{1}	2.86×10^{1}
Fluorine	kg	1.35	4.58	1.96×10^{-1}	3.69×10^{-1}
Fluosilicic acid	kg	4.22×10^{-1}	1.44	7.58×10^{-2}	1.38×10^{-1}
Formaldehyde	kg	2.38×10^{4}	8.10×10^{4}	1.76×10^{3}	4.29×10^{3}
Formic acid	kg	1.04×10^{-1}	3.53×10^{-1}	1.55×10^{-2}	2.88×10^{-2}
Furan	kg	2.48×10^{-2}	8.45×10^{-2}	3.30×10^{-3}	6.23×10^{-3}
Heat, waste	PJ	-9.66×10^{1}	-3.29×10^{2}	5.91×10^{1}	1.18×10^{2}
Helium	kg	2.78 x 104	9.46×10^{4}	9.73×10^{4}	2.00×10^{5}
Heptane	kg	7.32×10^{3}	2.49×10^{4}	2.54×10^{4}	5.24×10^{4}
Hexane	kg	1.58×10^{4}	5.37×10^{4}	5.32×10^{4}	1.10×10^{5}
Hydrocarbons, aliphatic, alkanes, cyclic	kg	7.21×10^{-2}	2.45×10^{-2}	2.02×10^{-1}	3.42×10^{-1}
Hydrocarbons, aliphatic, alkanes, unspecified	kg	7.31×10^{4}	2.49×10^{5}	2.92×10^{4}	6.10×10^{4}
Hydrocarbons, aliphatic, alkenes, unspecified	kg	1.87×10^{5}	6.38×10^{5}	7.09×10^{2}	1.76×10^{3}
Hydrocarbons, aliphatic, unsaturated	kg	2.73×10^{1}	9.30×10^{1}	5.38	9.71
Hydrocarbons, aromatic	kg	8.13×10^{2}	2.77×10^{3}	1.83×10^{2}	4.11×10^{2}
Hydrocarbons, chlorinated	kg	4.26×10^{-1}	1.45	7.59×10^{-2}	1.39×10^{-1}
Hydrogen	kg	8.82×10^{2}	3.00×10^{3}	3.60×10^{2}	6.12×10^{2}
Hydrogen-3, Tritium	kBq	2.84×10^{8}	9.66×10^{8}	6.56×10^{7}	1.63×10^{8}
Hydrogen chloride	kg	4.35×10^{5}	1.48×10^{6}	1.09×10^{5}	2.64×10^{5}
Hydrogen fluoride	kg	5.08×10^{4}	1.73×10^{5}	1.37×10^{4}	3.34×10^{4}
Hydrogen peroxide	kg	1.94×10^{-2}	6.62×10^{-2}	4.62×10^{-3}	8.18×10^{-3}
Hydrogen sulfide	kg	8.20×10^{3}	2.79×10^{4}	8.74×10^{2}	1.99×10^{3}
Iodine	kg	1.12×10^{3}	3.82×10^{3}	2.68×10^{2}	6.65×10^{2}
Iodine-129	kBq	1.04×10^{5}	3.53×10^{5}	2.26×10^{4}	5.60×10^{4}
Iodine-131	kBq	3.28×10^{4}	1.12×10^{5}	5.26×10^{3}	1.11×10^{4}
Iodine-133	kBq	5.93×10^{3}	2.02×10^{4}	1.40×10^{3}	3.48×10^{3}
Iodine-135	kBq	8.75×10^{3}	2.98×10^{4}	2.09×10^{3}	5.20×10^{3}
Iron	kg	2.36×10^{4}	8.02×10^{4}	8.0×10^{3}	1.90×10^{4}
Iron-59	kBq	6.83×10^{-1}	2.32	1.64×10^{-1}	4.08×10^{-1}
Isocyanic acid	kg	2.21×10^{-1}	7.51×10^{-1}	4.49×10^{1}-2	8.08×10^{-2}

Emissions into the air	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Isoprene	kg	1.15×10^{-3}	3.92×10^{-3}	1.53×10^{-4}	2.89×10^{-4}
Kerosene	kg	4.75×10^{-1}	1.39	3.62×10^{-2}	7.30×10^{-2}
Krypton-85	kBq	1.78×10^{12}	6.07×10^{12}	3.87×10^{11}	9.61×10^{11}
Krypton-85m	kBq	5.16×10^{6}	1.76×10^{7}	4.60×10^{5}	1.14×10^{6}
Krypton-87	kBq	1.82×10^{6}	6.21×10^{6}	2.05×10^{5}	5.09×10^{5}
Krypton-88	kBq	7.73×10^{7}	2.63×10^{8}	1.83×10^{7}	4.53×10^{7}
Krypton-89	kBq	1.63×10^{6}	5.56×10^{6}	1.44×10^{5}	3.56×10^{5}
Lanthanum	kg	1.49×10^{1}	5.08×10^{1}	3.59	8.91
Lanthanum-140	kBq	4.93×10^{1}	1.68×10^{2}	1.05×10^{1}	2.60×10^{1}
Lead	kg	2.60×10^{3}	8.85×10^{3}	9.99×10^{2}	2.21×10^{3}
Lead-210	kBq	3.02×10^{5}	1.03×10^{6}	6.97×10^{4}	1.73×10^{5}
m-Xylene	kg	2.62×10^{-1}	8.93×10^{-1}	6.07×10^{-2}	1.08×10^{-1}
Magnesium	kg	1.35×10^{4}	4.59×10^{4}	2.84×10^{3}	6.95×10^{3}
Manganese	kg	1.15×10^{4}	3.92×10^{4}	4.13×10^{2}	8.95×10^{2}
Manganese-54	kBq	1.84×10^{1}	6.26×10^{1}	4.29	1.07×10^{1}
Mercury	kg	1.36×10^{2}	4.62×10^{2}	5.09×10^{1}	$1.18 X 10^{2}$
Metals, unspecified	kg	1.19×10^{1}	3.47×10^{1}	9.05×10^{-1}	1.83
Methane	kg	6.67×10^{6}	2.27×10^{7}	8.23×10^{3}	1.71×10^{4}
Methane, biogenic	kg	5.06×10^{4}	1.72×10^{5}	6.12×10^{1}	1.09×10^{2}
Methane, bromochlorodifluoro-, Halon 1211	kg	8.90×10^{-1}	3.03	9.89×10^{-2}	1.92×10^{-1}
Methane, bromotrifluoro-, Halon 1301	kg	1.56×10^{2}	5.33×10^{2}	5.47×10^{2}	1.13×10^{3}
Methane, chlorodifluoro-, HCFC-22	kg	6.64	2.26×10^{1}	1.12	2.59
Methane, chlorotrifluoro-, CFC-13	kg	1.97	6.71	4.37×10^{-1}	1.09
Methane, dichloro-, HCC-30	kg	2.08	7.03	6.01×10^{-1}	1.39
Methane, dichlorodifluoro-, CFC-12	kg	3.14	1.07×10^{1}	6.97×10^{-1}	1.72
Methane, dichlorofluoro-, HCFC-21	kg	4.15×10^{2}	1.41×10^{3}	1.60×10^{4}	3.19×10^{1}
Methane, fossil	kg	1.64×10^{5}	5.58×10^{5}	2.67×10^{4}	5.13×10^{4}
Methane, monochloro-, R-40	kg	7.83×10^{-4}	2.67×10^{-3}	1.66×10^{-4}	2.98×10^{-4}
Methane, tetrachloro-, CFC-10	kg	3.91×10^{1}	1.33×10^{2}	2.49	6.00
Methane, tetrafluoro-, CFC-14	kg	1.64×10^{2}	5.59×10^{2}	2.75×10^{1}	6.66×10^{1}
Methane, trichlorofluoro-, CFC-11	kg	1.46×10^{1}	4.97×10^{1}	3.24	8.04
Methane, trifluoro-, HFC-23	kg	7.44×10^{-4}	2.53×10^{-3}	$1.76 X 10^{-4}$	3.13×10^{-4}
Methanol	kg	2.26×10^{3}	7.71×10^{3}	$6.86 X 10^{2}$	1.59×10^{3}
Methyl acrylate	kg	8.19×10^{-3}	2.79×10^{-2}	1.95×10^{-3}	3.45×10^{-3}
Methyl amine	kg	1.56×10^{-5}	5.31×10^{-5}	3.71×10^{-6}	6.57×10^{-6}
Methyl borate	kg	2.77×10^{-9}	9.42×10^{-9}	6.57×10^{-10}	1.16×10^{-9}
Methyl ethyl ketone	kg	1.30×10^{1}	4.42×10^{1}	3.08	5.46
Methyl formate	kg	3.18×10^{-5}	1.08×10^{-4}	7.55×10^{-6}	1.34×10^{-5}
Molybdenum	kg	1.35×10^{2}	4.59×10^{2}	2.56×10^{2}	5.65×10^{2}
Monoethanolamine	kg	4.46×10^{-1}	1.52	1.01×10^{-1}	1.80×10^{-1}
N-Nitrodimethylamine	kg	4.70×10^{-3}	1.37×10^{-2}	3.58×10^{-4}	7.23×10^{-4}

Emissions into the air	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Naphthalene	kg	3.32×10^{-2}	9.71×10^{-2}	2.53×10^{-3}	5.11×10^{-3}
Neptunium-237	kBq	1.89×10^{-2}	6.44×10^{-2}	4.12×10^{-3}	1.02×10^{-2}
Nickel	kg	3.56×10^{3}	1.21×10^{4}	1.01×10^{4}	2.21×10^{4}
Niobium-95	kBq	3.30	1.13×10^{1}	7.59×10^{-1}	1.88
Nitrate	kg	8.05×10^{-2}	2.74×10^{-1}	1.13×10^{-2}	2.14×10^{-2}
Nitrogen	kg	9.38×10^{4}	3.19×10^{4}	5.63×10^{3}	1.39×10^{4}
Nitrogen oxides	kg	1.81×10^{7}	6.12×10^{7}	5.81×10^{6}	7.16×10^{7}
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	5.39×10^{6}	1.82×10^{7}	1.08×10^{7}	8.13×10^{7}
Noble gases, radioactive, unspecified	kBq	2.63×10^{9}	8.96×10^{9}	5.75×10^{8}	1.03×10^{9}
Organic substances, unspecified	kg	5.52×10^{5}	1.61×10^{6}	4.21×10^{4}	8.49×10^{4}
Ozone	kg	9.15×10^{1}	3.11×10^{2}	2.01×10^{1}	3.59×10^{1}
PAH, polycyclic aromatic hydrocarbons	kg	2.19×10^{2}	7.46×10^{2}	2.15×10^{1}	5.08×10^{1}
Paraffins	kg	1.16×10^{-5}	3.97×10^{-5}	1.96×10^{-6}	3.61×10^{-5}
Particulates, < 10 um	kg	1.41×10^{5}	4.13×10^{5}	1.08×10^{4}	2.18×10^{4}
Particulates, < 10 um (mobile)	kg	6.96×10^{4}	2.37×10^{5}	2.82×10^{4}	5.94×10^{4}
Particulates, < 10 um (stationary)	kg	7.88×10^{6}	2.68×10^{7}	1.02×10^{6}	2.23×10^{6}
Particulates, < 2.5 um	kg	6.58×10^{4}	2.24×10^{5}	7.24×10^{3}	1.42×10^{4}
Particulates, > 10 um	kg	5.36×10^{4}	1.83×10^{5}	6.75×10^{3}	1.30×10^{4}
Particulates, > 10 um (process)	kg	1.14×10^{6}	3.89×10^{6}	2.94×10^{5}	4.69×10^{6}
Particulates, > 2.5 um, and < 10um	kg	3.33×10^{4}	1.13×10^{5}	3.86×10^{3}	7.51×10^{3}
Particulates, unspecified	kg	7.88×10^{3}	2.30×10^{4}	6.01×10^{2}	1.21×10^{3}
Pentane	kg	4.64×10^{4}	1.58×10^{5}	1.36×10^{5}	2.82×10^{5}
Phenol	kg	1.57×10^{3}	5.35×10^{3}	1.14	2.61
Phenol, pentachloro-	kg	2.17	7.38	2.27×10^{-1}	4.51×10^{-1}
Phosphine	mg	6.24	2.13×10^{1}	1.48	2.63
Phosphorus	kg	8.61×10^{2}	2.93×10^{3}	2.31×10^{-1}	4.22×10^{-1}
Phosphorus, total	kg	5.15×10^{2}	1.75×10^{3}	1.52×10^{2}	3.60×10^{2}
Platinum	kg	4.67×10^{-1}	1.59	4.45×10^{-2}	9.25×10^{-2}
Plutonium-238	kBq	3.90×10^{-2}	1.33×10^{-1}	9.34×10^{-3}	2.33×10^{-2}
Plutonium-241	kBq	3.15×10^{4}	1.07×10^{5}	6.87×10^{3}	1.71×10^{4}
Plutonium-alpha	kBq	1.15×10^{3}	3.92×10^{3}	2.50×10^{2}	6.21×10^{2}
Polonium-210	kBq	4.46×10^{5}	1.52×10^{6}	1.04×10^{5}	2.58×10^{5}
Polychlorinated biphenyls	kg	1.11×10^{-1}	3.78×10^{-1}	1.2×10^{-2}	2.37×10^{-2}
Potassium	kg	1.09×10^{4}	3.73×10^{4}	2.36×10^{3}	5.39×10^{3}
Potassium-40	kBq	4.95×10^{4}	1.69×10^{5}	1.19×10^{4}	2.95×10^{4}
Promethium-147	kBq	9.78×10^{3}	3.33×10^{4}	2.12×10^{3}	5.27×10^{3}
Propanal	kg	4.64×10^{-3}	1.58×10^{-2}	9.11×10^{-4}	1.63×10^{-3}
Propane	kg	5.10×10^{4}	1.74×10	1.07×10^{5}	2.22×10^{5}
Propene	kg	5.84×10^{3}	1.99×10^{4}	6.38×10^{3}	1.28×10^{5}
Propionic acid	kg	7.44×10^{1}	2.53×10^{2}	1.58	3.86×10^{1}
Propylene oxide	kg	8.50×10^{-1}	2.89	1.20×10^{-1}	2.26×10^{-1}

Emissions into the air	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Protactinium-234	kBq	1.15×10^{4}	3.91×10^{4}	2.51×10^{3}	6.22×10^{3}
Radioactive species, other beta emitters	kBq	9.12×10^{3}	3.11×10^{4}	1.26×10^{3}	2.38×10^{3}
Radioactive species, unspecified	kBq	3.37×10^{7}	9.85×10^{7}	2.57×10^{6}	5.18×10^{6}
Radium-226	kBq	4.06×10^{5}	1.38×10^{6}	8.94×10^{4}	2.22×10^{5}
Radium-228	kBq	2.46×10^{4}	8.37×10^{4}	5.88×10^{3}	1.45×10^{4}
Radon-220	kBq	2.29×10^{6}	7.80×10^{6}	5.52×10^{5}	1.37×10^{6}
Radon-222	kBq	2.58×10^{12}	8.78×10^{12}	5.63×10^{11}	1.40×10^{12}
Ruthenium-103	kBq	2.30×10^{-1}	7.82×10^{-1}	4.29×10^{-2}	1.06×10^{-1}
Ruthenium-106	kBq	1.15×10^{5}	3.92×10^{5}	2.50×10^{4}	6.21×10^{4}
Scandium	kg	5.00	1.70×10^{1}	1.20	2.98
Selenium	kg	4.13×10^{2}	1.41×10^{3}	2.79×10^{2}	6.29×10^{2}
Silicon	kg	1.16×10^{5}	3.94×10^{5}	2.79×10^{4}	6.92×10^{4}
Silicon tetrafluoride	kg	3.88×10^{-3}	1.32×10^{-2}	7.26×10^{-4}	1.27×10^{-3}
Silver	kg	1.36×10^{-3}	4.65×10^{-3}	2.94×10^{-4}	$5.25 \text{ X } 10^{-4}$
Silver-110	kBq	1.77×10^{1}	6.04×10^{1}	4.23	1.05×10^{1}
Sodium	kg	8.47×10^{-3}	2.88×10^{-2}	2.28×10^{-2}	4.51×10^{-2}
Sodium chlorate	kg	3.85×10^{-2}	1.31×10^{-1}	7.87×10^{-3}	1.37×10^{-2}
Sodium dichromate	kg	6.58×10^{-1}	2.24	8.91×10^{-2}	$1.52 \text{ X } 10^{-1}$
Sodium formate	kg	5.51×10^{-3}	1.88×10^{-2}	2.02×10^{-3}	3.46×10^{-3}
Sodium hydroxide	kg	7.24×10^{-2}	2.47×10^{-1}	1.72×10^{-2}	3.05×10^{-2}
Strontium	kg	5.11×10^{2}	1.74×10^{3}	1.29×10^{2}	3.16×10^{2}
Strontium-89	kBq	3.23×10^{1}	1.10×10^{2}	7.50	1.87×10^{1}
Strontium-90	kBq	1.89×10^{4}	6.44×10^{4}	4.12×10^{3}	1.02×10^{4}
Styrene	kg	7.82×10^{-2}	2.66×10^{-1}	3.80×10^{-2}	6.61×10^{-2}
Sulfate	kg	7.76×10^{2}	2.64×10^{3}	9.82×10^{1}	1.86×10^{2}
Sulfur dioxide	kg	9.65×10^{4}	3.29×10^{5}	1.61×10^{4}	2.96×10^{4}
Sulfur hexafluoride	kg	1.20	4.08	2.77×10^{-1}	4.92×10^{-1}
Sulfur oxides	kg	1.61×10^{7}	5.48×10	1.60×10^{7}	3.55×10^{7}
Sulfuric acid	kg	1.52×10^{-2}	5.17×10^{-2}	3.60×10^{-3}	6.39×10^{-3}
t-Butyl methyl ether	kg	1.02×10^{2}	3.46×10^{2}	7.79×10^{-1}	1.62
Technetium-99	kBq	8.04×10^{-1}	2.74	1.75×10^{-1}	4.34×10^{-1}
Tellurium-123m	kBq	7.84×10^{1}	2.67×10^{2}	1.88×10^{1}	4.69×10^{1}
Terpenes	kg	1.09×10^{-2}	3.71×10^{-2}	1.45×10^{-3}	2.74×10^{-3}
Thallium	kg	3.82	1.30×10^{1}	1.21	2.74
Thorium	kg	9.55	3.25×10^{1}	2.30	5.71
Thorium-228	kBq	2.05×10^{4}	6.98×10^{4}	4.93×10^{3}	1.22×10^{4}
Thorium-230	kBq	1.28×10^{5}	4.35×10^{5}	2.78×10^{4}	6.91×10^{4}
Thorium-232	kBq	1.30×10^{4}	4.44×10^{4}	3.14×10^{3}	7.78×10^{3}
Thorium-234	kBq	1.15×10^{4}	3.91×10^{4}	2.51×10^{3}	6.22×10^{3}
Tin	kg	1.32×10^{1}	4.50×10^{1}	6.95	1.39×10^{1}
Titanium	kg	1.43×10^{3}	4.85×10^{3}	1.11×10^{3}	2.14×10^{3}

Emissions into the air	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Toluene	kg	5.64×10^{4}	1.92×10^{5}	1.68×10^{4}	3.49×10^{4}
Uranium	kg	1.07×10^{1}	3.64×10^{1}	2.57	6.39
Uranium-234	kBq	1.38×10^{5}	4.69×10^{5}	3.00×10^{4}	7.45×10^{4}
Uranium-235	kBq	6.68×10^{3}	2.27×10^{4}	1.46×10^{3}	3.61×10^{3}
Uranium-238	kBq	1.73×10^{5}	5.91×10^{5}	3.86×10^{4}	9.57×10^{4}
Uranium alpha	kBq	4.13×10^{5}	1.41×10^{6}	8.98×10^{4}	2.23×10^{5}
Vanadium	kg	1.22×10^{4}	4.16×10^{4}	3.95×10^{4}	8.63×10^{4}
water	kg	2.75×10^{3}	9.35×10^{3}	3.87×10^{2}	7.29×10^{2}
Xenon-131m	kBq	8.38×10^{6}	2.85×10^{7}	9.45×10^{5}	2.35×10^{6}
Xenon-133	kBq	1.25×10^{9}	4.27×10^{9}	2.79×10^{8}	6.91×10^{8}
Xenon-133m	kBq	5.83×10^{5}	1.98×10^{6}	1.40×10^{5}	3.48×10^{5}
Xenon-135	kBq	2.64×10^{8}	9.00×10^{8}	4.74×10^{7}	1.18×10^{8}
Xenon-135m	kBq	5.00×10^{7}	1.70×10^{8}	4.70×10^{6}	1.17×10^{7}
Xenon-137	kBq	1.10×10^{6}	3.75×10^{6}	1.16×10^{5}	2.90×10^{5}
Xenon-138	kBq	1.38×10^{7}	4.68×10^{7}	1.27×10^{6}	3.15×10^{6}
Xylene	kg	5.32×10^{4}	1.81×10^{5}	1.30×10^{4}	2.79×10^{4}
Zinc	kg	1.68×10^{4}	5.72×10^{4}	1.07×10^{3}	2.36×10^{3}
Zinc-65	kBq	9.38×10^{1}	3.20×10^{2}	1.84×10^{1}	4.58×10^{1}
Zirconium	kg	9.49×10^{-1}	3.23	2.21×10^{-1}	5.08×10^{-1}
Zirconium-95	kBq	1.18	4.00	2.80×10^{-1}	6.93×10^{-1}

Emissions into the water	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
1,4-Butanediol	kg	5.98×10^{-5}	2.04×10^{-4}	1.42×10^{-5}	2.52×10^{-5}
4-Methyl-2-pentanone	kg	4.26×10^{-6}	1.45×10^{-5}	$8.08 \times 10^{-}$	1.46×10^{-6}
Acenaphthene	kg	2.45×10^{-3}	8.34×10^{-3}	3.32×10^{-4}	6.28×10^{-4}
Acenaphthylene	kg	3.45×10^{2}	1.17×10^{3}	6.38×10^{6}	1.08×10^{2}
Acetaldehyde	kg	8.59×10^{-2}	2.93×10^{-1}	2.04×10^{-2}	3.62×10^{-2}
Acetic acid	kg	1.12	3.80	3.16	5.36
Acetone	kg	1.01×10^{-5}	3.46×10^{-5}	1.93×10^{-6}	3.49×10^{-6}
Acidity, unspecified	kg	4.29×10^{-1}	1.44	1.64×10^{-1}	2.88×10^{-1}
Acids, unspecified	kg	2.69×10^{2}	9.15×10^{2}	6.53×10^{1}	1.53×10^{2}
Acrylate, ion	kg	1.71×10^{-5}	5.82×10^{-5}	4.06×10^{-3}	7.20×10^{-3}
Actinides, radioactive, unspecified	kBq	4.43×10^{2}	1.51×10^{3}	9.72×10^{1}	1.73×10^{2}
Aluminum	kg	1.50×10^{6}	5.09×10^{6}	3.99×10^{5}	8.53×10^{5}
Americium-241	kBq	4.76×10^{4}	1.62×10^{5}	1.04×10^{4}	2.57×10^{4}
Ammonia	kg	6.64×10^{1}	1.94×10^{2}	5.07	1.02×10^{1}
Ammonia, as N	kg	7.59×10^{4}	2.59×10^{5}	1.09×10^{5}	2.25×10^{5}
Ammonium, ion	kg	2.08×10^{2}	7.07×10^{2}	6.30×10^{1}	1.09×10^{2}
Antimony	kg	3.19×10^{1}	1.09×10^{2}	7.93×10^{3}	1.34×10^{4}
Antimony-122	kBq	7.97×10^{2}	2.71×10^{3}	5.18×10^{1}	1.28×10^{2}
Antimony-124	kBq	3.93×10^{4}	1.34×10^{5}	7.44×10^{3}	1.85×10^{4}
Antimony-125	kBq	6.59×10^{3}	2.24×10^{4}	4.38×10^{2}	1.08×10^{3}
AOX, Adsorbable Organic Halogen as Cl	kg	7.91×10^{1}	2.69×10^{2}	2.83×10^{2}	5.84×10^{2}
Arsenic, ion	kg	5.24×10^{3}	1.78×10^{4}	1.96×10^{3}	3.65×10^{3}
Barite	kg	4.65×10^{5}	1.58×10^{6}	1.23×10^{6}	2.54×10^{6}
Barium	kg	1.18×10^{5}	4.02×10^{5}	3.65×10^{5}	6.97×10^{5}
Barium-140	kBq	7.98×10^{2}	2.72	5.21×10^{1}	1.29×10^{2}
Benzene	kg	2.92×10^{3}	9.95×10^{3}	1.77×10^{4}	2.65×10^{4}
Benzene, 1,2-dichloro-	kg	2.01×10^{-2}	6.85×10^{-2}	4.78×10^{-3}	8.47×10^{-3}
Benzene, chloro-	kg	4.20×10^{-1}	1.43	2.16×10^{-1}	3.09×10^{-1}
Benzene, ethyl-	kg	5.02×10^{2}	1.71×10^{3}	1.70×10^{3}	1.28×10^{4}
Beryllium	kg	3.00	1.0×10^{1}	3.09×10^{2}	5.22×10^{2}
BOD5, Biological Oxygen Demand	kg	2.58×10^{7}	8.77×10^{7}	5.37×10^{6}	9.06×10^{6}
Boron	kg	1.58×10^{4}	5.37×10^{4}	2.74×10^{3}	5.77×10^{3}
Bromate	kg	3.96×10^{2}	1.35×10^{3}	1.68×10^{2}	2.86×10^{2}
Bromine	kg	3.96×10^{2}	1.35×10^{3}	7.69×10^{3}	1.30×10^{4}
Butanol	kg	4.71×10^{-2}	1.60×10^{-1}	1.12×10^{-2}	1.98×10^{-2}
Butene	kg	4.69×10^{-2}	1.60×10^{-1}	6.59×10^{-3}	1.24×10^{-2}
Butyl acetate	kg	6.12×10^{-2}	2.08×10^{-1}	1.45×10^{-2}	2.58×10^{-2}
Butyrolactone	kg	1.04×10^{-4}	3.54×10^{-4}	2.47×10^{-5}	4.38×10^{-5}
Cadmium-109	kBq	4.62	1.57×10^{4}	2.98×10^{-1}	7.42×10^{-1}
Cadmium, ion	kg	2.42×10^{2}	8.20×10^{2}	3.84×10^{2}	6.91×10^{2}

Emissions into the water	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Calcium, ion	kg	1.10×10^{7}	3.75×10^{7}	5.58×10^{6}	1.09×10^{7}
Carbon-14	kBq	2.41×10^{6}	8.21×10^{6}	5.24×10^{5}	1.30×10^{6}
Carbonate	kg	1.36×10^{1}	4.62×10^{1}	8.88	1.53×10^{1}
Carboxylic acids, unspecified	kg	1.65×10^{3}	5.60×10^{3}	2.22×10^{2}	4.20×10^{2}
Cerium-141	kBq	1.20×10^{2}	4.08×10^{2}	7.87	1.94×10^{1}
Cerium-144	kBq	1.09×10^{6}	3.70×10^{6}	2.37×10^{5}	5.89×10^{5}
Cesium	kg	2.06×10^{1}	7.03×10^{1}	7.07×10^{1}	1.46×10^{2}
Cesium-134	kBq	2.44×10^{6}	8.32×10^{6}	5.30×10^{5}	1.32×10^{6}
Cesium-136	kBq	4.44	1.51×10^{1}	3.03×10^{-1}	7.38×10^{-1}
Cesium-137	kBq	2.25×10^{7}	7.68×10^{7}	4.89×10^{6}	1.21×10^{7}
Chlorate	kg	3.02×10^{3}	1.03×10^{4}	1.29×10^{3}	2.19×10^{3}
Chloride	kg	2.10×10^{7}	7.16×10^{7}	4.08×10^{7}	8.45×10^{7}
Chlorinated solvents, unspecified	kg	4.58	1.56×10^{1}	5.21	1.26×10^{1}
Chlorine	kg	2.18	7.42	4.29×10^{-1}	7.74×10^{-1}
Chloroform	kg	5.22×10^{1}	1.78×10^{2}	3.04	2.47×10^{2}
Chromate	kg	4.65×10^{-1}	1.36	$3.55 \text{ X } 10^{-2}$	7.16×10^{-2}
Chromium	kg	6.17	1.80×10^{1}	4.71×10^{-1}	9.49×10^{-1}
Chromium-51	kBq	1.78×10^{4}	6.05×10^{4}	1.17×10^{3}	2.89×10^{3}
Chromium VI	kg	1.98×10^{3}	6.75×10^{3}	1.53×10^{3}	2.62×10^{3}
Chromium, ion	kg	8.72×10^{3}	2.97×10^{4}	1.47×10^{4}	1.10×10^{5}
Cobalt	kg	2.57×10^{3}	8.76×10^{3}	1.61×10^{3}	3.04×10^{3}
Cobalt-57	kBq	8.25×10^{2}	2.81×10^{3}	5.39×10^{1}	1.33×10^{2}
Cobalt-58	kBq	4.01×10^{5}	1.36×10^{6}	4.51×10^{4}	1.12×10^{5}
Cobalt-60	kBq	1.09×10^{7}	3.70×10^{7}	2.30×10^{6}	5.70×10^{6}
COD, Chemical Oxygen Demand	kg	7.86×10^{7}	2.68×10^{8}	1.72×10^{7}	2.92×10^{7}
Copper, ion	kg	3.11×10^{4}	1.06×10^{5}	2.84×10^{4}	4.79×10^{4}
Cumene	kg	1.10×10^{1}	3.74×10^{1}	3.57×10^{1}	6.05×10^{1}
Curium alpha	kBq	6.31×10^{4}	2.15×10^{5}	1.37×10^{4}	3.41×10^{4}
Cyanide	kg	2.50×10^{2}	8.53×10^{2}	3.32×10^{2}	6.93×10^{2}
Dichromate	kg	2.44	8.32	3.31×10^{-1}	5.64×10^{-1}
DOC, Dissolved Organic Carbon	kg	3.10×10^{7}	1.06×10^{8}	6.43×10^{6}	1.09×10^{7}
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1.17×10^{-1}	4.00×10^{-1}	3.81×10^{3}	9.25×10^{3}
Ethane, 1,2-dichloro-	kg	3.94×10^{-2}	1.34×10^{-1}	9.87×10^{-3}	1.73×10^{-2}
Ethane, dichloro-	kg	8.44×10^{1}	2.87×10^{2}	1.80×10^{2}	1.22×10^{1}
Ethane, hexachloro-	kg	1.87×10^{-3}	6.36×10^{-3}	1.11×10^{-4}	2.71×10^{-4}
Ethanol	kg	1.08×10^{-1}	3.69×10^{-1}	2.57×10^{-2}	4.56×10^{-2}
Ethene	kg	4.24	1.44×10^{1}	1.49×10^{1}	2.52×10^{1}
Ethene, chloro-	kg	6.62×10^{-2}	2.25×10^{-1}	5.06×10^{-3}	1.15×10^{-2}
Ethene, tetrachloro-	kg	2.22×10^{-1}	7.54×10^{-1}	1.32×10^{-2}	3.21×10^{-2}
Ethene, trichloro-	kg	1.40×10^{1}	4.78×10^{1}	8.30×10^{-1}	2.03
Ethyl acetate	kg	7.38×10^{-6}	2.51×10^{-5}	1.75×10^{-6}	3.11×10^{-6}

Emissions into the water	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Ethylene diamine	kg	9.11×10^{-2}	3.10×10^{-1}	1.28×10^{-2}	2.41×10^{-2}
Ethylene oxide	kg	8.19×10^{-3}	2.79×10^{-2}	1.94×10^{-3}	3.44×10^{-3}
Fatty acids as C	kg	1.03×10^{5}	3.51×10^{5}	3.57×10^{5}	7.39×10^{5}
Fluoride	kg	1.72×10^{5}	5.86×10^{5}	2.10×10^{4}	3.93×10^{4}
Fluosilicic acid	kg	7.60×10^{-1}	2.59	1.36×10^{-1}	2.49×10^{-1}
Formaldehyde	kg	9.38×10^{3}	3.19×10^{4}	1.90	3.24
Glutaraldehyde	kg	5.74×10^{1}	1.95×10^{2}	1.52×10^{2}	3.13×10^{2}
Heat, waste	PJ	1.93×10^{1}	6.57×10^{1}	1.02×10^{1}	2.12×10^{1}
Hydrocarbons, aliphatic, alkanes, unspecified	kg	2.73×10^{3}	9.28×10^{3}	9.17×10^{3}	1.90×10^{4}
Hydrocarbons, aliphatic, alkenes, unspecified	kg	2.47×10^{2}	8.42×10^{2}	8.48×10^{2}	1.75×10^{3}
Hydrocarbons, aliphatic, unsaturated	kg	4.72	1.61×10^{1}	6.40×10^{-1}	1.21
Hydrocarbons, aromatic	kg	1.28×10^{4}	4.35×10^{4}	4.23×10^{4}	8.73×10^{4}
Hydrocarbons, unspecified	kg	4.12×10^{2}	1.40×10^{3}	9.08×10^{1}	2.11×10^{2}
Hydrogen-3, Tritium	kBq	7.14×10^{10}	2.43×10^{11}	1.56×10^{10}	3.86×10^{10}
Hydrogen peroxide	kg	1.72×10^{-1}	5.85×10^{-1}	4.02×10^{-2}	7.13×10^{-2}
Hydrogen sulfide	kg	1.43×10^{4}	4.86×10^{4}	1.45×10^{3}	2.91×10^{3}
Hydroxide	kg	5.43×10^{-1}	1.85	1.29×10^{-1}	2.29×10^{-1}
Hypochlorite	kg	6.91×10^{3}	2.35×10^{4}	1.66×10^{3}	4.13×10^{3}
Hypochlorous acid	kg	6.91×10^{3}	2.35×10^{4}	1.66×10^{3}	4.13×10^{3}
Iodide	kg	2.05×10^{3}	6.99×10^{3}	7.06×10^{3}	1.46×10^{4}
Iodine-129	kBq	6.88×10^{6}	2.34×10^{7}	1.50×10^{6}	3.72×10^{6}
Iodine-131	kBq	6.58×10^{3}	2.24×10^{4}	9.93×10^{2}	2.46×10^{3}
Iodine-133	kBq	3.66×10^{3}	1.25×10^{4}	2.36×10^{2}	5.88×10^{2}
Iron	kg	1.28×10^{6}	4.36×10^{6}	3.32×10^{5}	8.13×10^{5}
Iron-59	kBq	1.45×10^{1}	4.93×10^{1}	9.82×10^{-1}	2.38
Iron, ion	kg	1.00×10^{5}	3.41×10^{5}	5.80×10^{5}	9.80×10^{5}
Lanthanum-140	kBq	1.68×10^{2}	5.72×10^{2}	1.11×10^{1}	2.74×10^{1}
Lead	kg	2.25×10^{4}	7.67×10^{4}	3.04×10^{3}	5.83×10^{3}
Lead-210	kBq	1.27×10^{5}	4.31×10^{5}	3.04×10^{4}	7.52×10^{4}
Lithium, ion	kg	1.09	3.72	2.07×10^{-1}	3.76×10^{-1}
m-Xylene	kg	3.08×10^{-5}	1.05×10^{-4}	5.84×10^{-6}	1.06×10^{-5}
Magnesium	kg	2.18×10^{6}	7.42×10^{6}	3.60×10^{5}	7.83×10^{6}
Manganese	kg	3.89×10^{5}	1.33×10^{6}	3.04×10^{4}	5.67×10^{4}
Manganese-54	kBq	1.63×10^{6}	5.54×10^{6}	3.52×10^{5}	8.73×10^{5}
Mercury	kg	1.65×10^{2}	5.60×10^{2}	1.89×10^{1}	8.77
Metallic ions, unspecified	kg	8.54×10^{2}	2.50×10^{3}	6.52×10^{1}	1.31×10^{2}
Methane, dichloro-, HCC-30	kg	2.18×10^{2}	7.42×10^{2}	5.66×10^{2}	1.17×10^{3}
Methane, tetrachloro-, CFC-10	kg	3.38×10^{-1}	1.15	2.00×10^{-2}	4.90×10^{-2}
Methanol	kg	1.24×10^{1}	4.23×10^{1}	1.96	3.65
Methyl acrylate	kg	1.60×10^{-1}	5.45×10^{-1}	3.80×10^{-2}	6.74×10^{-2}
Methyl amine	kg	3.75×10^{-5}	1.28×10^{-4}	8.90×10^{-6}	1.58×10^{-5}

Emissions into the water	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Methyl formate	kg	1.27×10^{-2}	4.32×10^{-2}	3.01×10^{-3}	5.34×10^{-3}
Molybdenum	kg	9.69×10^{3}	3.30×10^{4}	7.97×10^{2}	1.95×10^{3}
Molybdenum-99	kBq	5.66×10^{1}	1.93×10^{2}	3.75	9.22
Neptunium-237	kBq	3.04×10^{3}	1.04×10^{4}	6.61×10^{2}	1.64×10^{3}
Nickel, ion	kg	1.05×10^{4}	3.59×10^{4}	2.20×10^{3}	4.64×10^{3}
Niobium-95	kBq	4.60×10^{2}	1.57×10^{3}	3.08×10^{1}	7.54×10^{1}
Nitrate	kg	4.20×10^{5}	1.43×10^{6}	1.03×10^{5}	1.96×10^{5}
Nitrite	kg	1.86×10^{3}	6.34×10^{3}	4.10×10^{2}	1.01×10^{3}
Nitrogen	kg	5.27×10^{2}	1.79×10^{3}	6.78×10^{1}	1.29×10^{2}
Nitrogen, organic bound	kg	5.30×10^{3}	1.81×10^{4}	2.23×10^{4}	4.55×10^{4}
Nitrogen, total	kg	3.72×10^{4}	1.27×10^{5}	1.42×10^{5}	2.92×10^{5}
o-Xylene	kg	2.24×10^{-5}	7.63×10^{-5}	4.25×10^{-6}	7.71×10^{-6}
Oils, unspecified	kg	5.72×10^{5}	1.95×10^{6}	1.46×10^{6}	2.84×10^{6}
Organic substances, unspecified	kg	4.03×10^{2}	1.18×10^{3}	3.08×10^{1}	6.21×10^{1}
PAH, polycyclic aromatic hydrocarbons	kg	2.78×10^{2}	9.47×10^{2}	9.32×10^{2}	1.94×10^{3}
Paraffins	kg	3.38×10^{-5}	1.15×10^{-4}	5.70×10^{-6}	1.05×10^{-5}
Phenol	kg	3.94×10^{1}	1.33×10^{2}	5.45	1.03×10^{1}
Phenols, unspecified	kg	2.85×10^{3}	9.69×10^{3}	1.04×10^{4}	2.01×10^{4}
Phosphate	kg	1.60×10^{5}	5.45×10^{5}	1.43×10^{4}	3.39×10^{4}
Phosphorus	kg	1.08×10^{1}	3.67×10^{1}	2.74	4.90
Phosphorus compounds, unspecified	kg	1.45×10^{1}	4.94×10^{1}	3.48×10^{1}	7.21×10^{1}
Phthalate, dimethyl tere-	kg	2.20×10^{-1}	7.49×10^{-1}	4.07×10^{3}	6.91×10^{-2}
Phthalate, dioctyl-	kg	8.36×10^{3}	2.85×10^{-2}	4.69×10^{4}	7.02×10^{1}
Phthalate, p-dibutyl-	kg	3.49×10^{-2}	1.19×10^{-1}	6.46×10^{2}	1.10×10^{-2}
Plutonium-241	kBq	4.71×10^{6}	1.60×10^{7}	1.02×10^{6}	2.54×10^{6}
Plutonium-alpha	kBq	1.89×10^{5}	6.44×10^{5}	4.12×10^{4}	1.02×10^{5}
Polonium-210	kBq	1.27×10^{5}	4.34×10^{5}	3.05×10^{4}	7.55×10^{4}
Potassium	kg	3.51×10^{5}	1.19×10^{6}	4.12×10^{5}	8.73×10^{5}
Potassium-40	kBq	1.58×10^{5}	5.37×10^{5}	3.79×10^{4}	9.40×10^{4}
Potassium, ion	kg	5.19×10^{5}	1.77×10^{6}	7.66×10^{2}	1.41×10^{3}
Propene	kg	5.76	1.96×10^{1}	1.34×10^{1}	2.28×10^{1}
Propylene oxide	kg	2.05	6.96	2.88×10^{-1}	5.43×10^{-1}
Protactinium-234	kBq	2.13×10^{5}	7.25×10^{5}	4.64×10^{4}	1.15×10^{5}
Radioactive species, alpha emitters	kBq	1.86×10^{1}	6.34×10^{1}	4.24	9.94
Radioactive species, from fission and activation	kBq	1.29×10^{5}	4.40×10^{5}	3.10×10^{4}	7.71×10^{4}
Radioactive species, Nuclides, unspecified	kBq	2.66×10^{5}	9.06×10^{5}	5.83×10^{4}	1.04×10^{5}
Radium-224	kBq	1.03×10^{6}	3.51×10^{6}	3.54×10^{6}	7.30×10^{6}
Radium-226	kBq	8.77×10^{8}	2.99×10^{9}	1.98×10^{8}	4.89×10^{8}
Radium-228	kBq	2.05×10^{6}	6.99×10^{6}	7.06×10^{6}	1.46×10^{7}
Rubidium	kg	3.96	1.35×10^{1}	5.40×10^{-1}	1.02
Ruthenium	kg	2.02×10^{2}	6.89×10^{2}	7.06×10^{2}	1.46×10^{3}

Emissions into the water	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Ruthenium-103	kBq	2.68×10^{2}	9.13×10^{2}	1.73×10^{1}	4.31×10^{1}
Ruthenium-106	kBq	1.15×10^{7}	3.92×10^{7}	2.50×10^{6}	6.21×10^{6}
Salts, unspecified	kg	2.21×10^{6}	7.52×10^{6}	5.31×10^{5}	1.32×10^{6}
Scandium	kg	3.06	1.04×10^{1}	6.82×10^{-1}	1.22
Selenium	kg	4.31×10^{3}	1.47×10^{4}	2.69×10^{3}	5.36×10^{3}
Silicon	kg	8.83×10^{5}	3.01×10^{6}	2.28×10^{5}	3.96×10^{5}
Silver	kg	1.43×10^{1}	4.86×10^{1}	4.29×10^{1}	8.88×10^{1}
Silver-110	kBq	1.22×10^{5}	4.16×10^{5}	2.90×10^{4}	7.19×10^{4}
Silver, ion	kg	3.92×10^{-1}	1.34	5.43×10^{-2}	1.02×10^{-1}
Sodium-24	kBq	2.46×10^{4}	8.38×10^{4}	1.59×10^{3}	3.96×10^{3}
Sodium formate	kg	1.32×10^{-2}	4.51×10^{-2}	4.86×10^{-3}	8.31×10^{-2}
Sodium, ion	kg	8.88×10^{6}	3.02×10^{7}	2.45×10^{7}	5.02×10^{7}
Solids, inorganic	kg	1.66×10^{4}	5.66×10^{4}	4.22×10^{3}	7.43×10^{3}
Solved solids	kg	1.67×10^{5}	4.89×10^{5}	1.29×10^{4}	2.59×10^{5}
Solved substances	kg	3.52×10^{5}	1.20×10^{6}	8.51×10^{4}	2.10×10^{5}
Strontium	kg	1.33×10^{5}	4.53×10^{5}	4.98×10^{5}	1.00×10^{6}
Strontium-89	kBq	1.82×10^{3}	6.20×10^{3}	1.20×10^{2}	2.96×10^{2}
Strontium-90	kBq	2.63×10^{6}	8.96×10^{6}	5.76×10^{5}	1.38×10^{6}
Sulfate	kton	1.36×10^{1}	4.63×10^{1}	4.60	9.90
Sulfide	kg	6.61×10^{2}	2.25×10^{3}	2.31×10^{3}	4.77×10^{3}
Sulfite	kg	1.44×10^{1}	4.90×10^{1}	3.33	5.91
Sulfur	kg	5.35×10^{1}	1.82×10^{2}	7.10	1.35×10^{1}
Sulfur trioxide	kg	8.44×10^{3}	2.87×10^{4}	1.81×10^{2}	4.45×10^{2}
Sulfuric acid	kg	3.27×10^{1}	9.57×10^{1}	2.50	5.04
Suspended solids, unspecified	kg	1.99×10^{4}	6.59×10^{4}	2.18×10^{3}	4.23×10^{3}
t-Butyl methyl ether	kg	1.27×10^{1}	4.31×10^{1}	1.38×10^{-1}	2.74×10^{-1}
Technetium-99	kBq	1.21×10^{6}	4.11×10^{6}	2.62×10^{5}	6.51×10^{5}
Technetium-99m	kBq	3.95×10^{2}	1.35×10^{3}	2.75×10^{1}	6.63×10^{1}
Tellurium-123m	kBq	4.17×10^{1}	1.42×10^{2}	3.91	8.51
Tellurium-132	kBq	1.38×10^{1}	4.71×10^{1}	9.02×10^{-1}	2.23×10^{-1}
Thallium	kg	8.84	3.01×10^{1}	1.80×10^{2}	3.04×10^{2}
Thorium-228	kBq	4.11×10^{6}	1.40×10^{7}	1.41×10^{7}	2.93×10^{7}
Thorium-230	kBq	3.33×10^{7}	1.13×10^{8}	7.26×10^{6}	1.81×10^{7}
Thorium-232	kBq	2.94×10^{4}	1.00×10^{5}	7.06×10^{3}	1.74×10^{4}
Thorium-234	kBq	2.14×10^{5}	7.30×10^{5}	4.68×10^{4}	1.16×10^{5}
Tin, ion	kg	1.11×10^{2}	3.79×10^{2}	1.54×10^{3}	2.61×10^{3}
Titanium, ion	kg	5.35×10^{4}	1.82×10^{5}	2.41×10^{5}	4.18×10^{5}
TOC, Total Organic Carbon	kg	3.18×10^{7}	1.08×10^{8}	7.49×10^{6}	1.31×10^{7}
Toluene	kg	2.41×10^{3}	8.22×10^{3}	1.49×10^{4}	2.65×10^{4}
Tributyltin	kg	3.41×10^{1}	1.16×10^{2}	6.44×10^{1}	1.35×10^{2}
Tributyltin compounds	kg	8.97×10^{-1}	3.05	1.15×10^{-1}	2.20×10^{-1}

Emissions into the water	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Triethylene glycol	kg	5.33×10^{3}	1.82×10^{4}	3.06×10^{2}	7.57×10^{2}
Tungsten	kg	3.98×10^{1}	1.36×10^{2}	9.58	2.34×10^{1}
Undissolved substances	kg	1.55×10^{6}	5.29×10^{6}	3.83×10^{6}	7.93×10^{6}
Uranium-234	kBq	2.85×10^{5}	9.69×10^{5}	6.20×10^{4}	1.54×10^{5}
Uranium-235	kBq	4.24×10^{5}	1.44×10^{6}	9.29×10^{4}	2.29×10^{5}
Uranium-238	kBq	7.15×10^{5}	2.43×10^{6}	1.57×10^{5}	3.91×10^{5}
Uranium alpha	kBq	1.39×10^{7}	4.73×10^{7}	3.03×10^{6}	7.54×10^{6}
Vanadium, ion	kg	5.43×10^{3}	1.85×10^{4}	3.04×10^{5}	5.14×10^{5}
VOC, volatile organic compounds as C	kg	7.05×10^{3}	2.40×10^{4}	2.47×10^{4}	5.11×10^{4}
VOC, volatile organic compounds, unspecified origin	kg	1.40×10^{2}	4.75×10^{2}	1.91×10^{1}	3.60×10^{1}
Xylene	kg	2.10×10^{3}	7.14×10^{3}	8.33×10^{3}	1.71×10^{4}
Yttrium-90	kBq	9.22×10^{1}	3.14×10^{2}	5.97	1.48×10^{1}
Zinc-65	kBq	5.20×10^{4}	1.77×10^{5}	3.37×10^{3}	8.37×10^{3}
Zinc, ion	kg	1.82×10^{4}	6.20×10^{4}	8.53×10^{3}	1.25×10^{5}
Zirconium-95	kBq	9.79×10^{4}	3.33×10^{5}	2.12×10^{4}	5.27×10^{4}
Waste, solid	kg	6.31×10^{5}	1.85×10^{6}	4.81×10^{4}	9.71×10^{4}

Emissions into the soil	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
2,4-D	kg	4.40×10^{-6}	1.50×10^{-2}	5.85×10^{-4}	1.11×10^{-3}
Aclonifen	kg	5.47×10^{-3}	1.86×10^{-2}	8.24×10^{-4}	1.54×10^{-3}
Aldrin	kg	1.86×10^{-4}	6.32×10^{-4}	4.41×10^{-5}	7.82×10^{-5}
Aluminum	kg	3.04×10^{4}	1.03×10^{5}	8.14×10^{4}	1.68×10^{5}
Antimony	kg	4.56×10^{-5}	1.55×10^{-4}	7.74×10^{-6}	1.42×10^{-5}
Arsenic	kg	1.22×10^{1}	4.14×10^{1}	3.25×10^{1}	6.72×10^{1}
Atrazine	kg	4.87×10^{-5}	1.66×10^{-4}	1.16×10^{-5}	2.05×10^{-5}
Barium	kg	1.14×10^{2}	3.89×10^{2}	1.45×10^{1}	2.77×10^{1}
Benomyl	kg	2.80×10^{-5}	9.52×10^{-5}	3.71×10^{-6}	7.02×10^{-6}
Bentazone	kg	2.79×10^{-3}	9.50×10^{-3}	4.21×10^{-4}	7.86×10^{-4}
Boron	kg	3.41	1.16×10^{1}	4.83×10^{-1}	9.06×10^{-1}
Cadmium	kg	5.99×10^{-1}	2.04	1.40	2.89
Calcium	kg	1.22×10^{5}	4.14×10^{5}	3.25×10^{5}	6.72×10^{5}
Carbetamide	kg	1.05×10^{-3}	3.57×10^{-3}	1.60×10^{-4}	2.98×10^{-4}
Carbofuran	kg	1.53×10^{-2}	5.22×10^{-2}	2.03×10^{-3}	3.85×10^{-3}
Carbon	kg	9.38×10^{4}	3.20×10^{5}	2.52×10^{5}	5.22×10^{5}
Chloride	kg	1.36×10^{4}	4.62×10^{4}	1.80×10^{3}	3.43×10^{3}
Chlorothalonil	kg	6.08×10^{-2}	2.07×10^{-1}	1.09×10^{-2}	1.99×10^{-2}
Chromium	kg	1.52×10^{2}	5.17×10^{2}	4.06×10^{2}	8.41×10^{2}
Chromium VI	kg	6.36	2.17×10^{1}	1.09	1.99
Cobalt	kg	5.57×10^{-1}	1.90	1.93	3.98
Copper	kg	7.88	2.68×10^{1}	1.07×10^{1}	2.18×10^{1}
Cypermethrin	kg	2.19×10^{-3}	7.45×10^{-3}	2.91×10^{-4}	5.51×10^{-4}
Fenpiclonil	kg	2.58×10^{-3}	8.79×10^{-3}	4.58×10^{-4}	8.37×10^{-4}
Fluoride	kg	1.57×10^{1}	5.35×10^{1}	2.19	4.11
Glyphosate	kg	1.37	4.66	2.42×10^{-1}	4.43×10^{-1}
Heat, waste	TJ	2.39×10^{2}	8.14×10^{2}	2.82×10^{1}	6.95×10^{1}
Iron	kg	6.28×10^{4}	2.14×10^{5}	1.63×10^{5}	3.38×10^{5}
Lead	kg	1.31×10^{1}	4.45×10^{1}	4.39×10^{1}	9.08×10^{1}
Linuron	kg	4.22×10^{-2}	1.44×10^{-1}	6.36×10^{-3}	1.19×10^{-2}
Magnesium	kg	1.96×10^{2}	6.66×10^{2}	2.70×10^{1}	5.08×10^{1}
Mancozeb	kg	7.89×10^{-2}	2.69×10^{-1}	1.42×10^{-2}	2.59×10^{-1}
Manganese	kg	1.22×10^{3}	4.16×10^{3}	3.25×10^{3}	6.72×10^{3}
Mercury	kg	7.87×10^{-2}	2.68×10^{-1}	2.65×10^{-1}	5.48×10^{-1}
Metaldehyde	kg	2.13×10^{-4}	7.26×10^{-4}	3.29×10^{-5}	6.13×10^{-5}
Metolachlor	kg	3.05×10^{-1}	1.04	4.60×10^{-2}	8.58×10^{-2}
Metribuzin	kg	2.78×10^{-3}	9.47×10^{-3}	5.00×10^{-4}	9.11×10^{-4}
Molybdenum	kg	4.47×10^{-3}	1.52×10^{-2}	1.67×10^{-3}	2.85×10^{-3}
Napropamide	kg	3.77×10^{-4}	1.28×10^{-3}	5.83×10^{-5}	1.08×10^{-4}
Nickel	kg	4.32	1.47×10^{1}	1.45×10^{1}	2.99×10^{1}

Emissions into the soil	Unit	IBC reused	IBC incinerated	Polyethylene liner incinerated	Polypropylene liner incinerated
Nitrogen	kg	2.35×10^{1}	8.00×10^{1}	7.48×10^{1}	1.55×10^{2}
Oils, biogenic	kg	2.16×10^{5}	7.36×10^{5}	2.76×10^{1}	6.58×10^{1}
Oils, unspecified	kg	3.82×10^{5}	1.30×10^{6}	6.34×10^{4}	1.31×10^{5}
Orbencarb	kg	1.50×10^{-2}	5.11×10^{-2}	2.70×10^{-3}	4.92×10^{-3}
Phosphorus	kg	1.56×10^{3}	5.31×10^{3}	4.16×10^{3}	8.60×10^{3}
Pirimicarb	kg	2.64×10^{-4}	8.99×10^{-4}	3.98×10^{-5}	7.43×10^{-5}
Potassium	kg	9.52×10^{1}	3.24×10^{2}	1.36×10^{1}	2.55×10^{1}
Silicon	kg	6.74×10^{1}	2.30×10^{2}	1.71×10^{1}	3.01×10^{1}
Sodium	kg	5.02×10^{2}	1.71×10^{3}	6.46×10^{1}	1.23×10^{2}
Strontium	kg	2.30	7.82	2.92×10^{-1}	5.56×10^{-1}
Sulfur	kg	1.83×10^{4}	6.23×10^{4}	4.88×10^{4}	1.01×10^{5}
Sulfuric acid	kg	9.36×10^{-3}	3.19×10^{-2}	2.22×10^{-3}	3.94×10^{-3}
Tebutam	kg	8.93×10^{-4}	3.04×10^{-3}	1.38×10^{-4}	2.57×10^{-4}
Teflubenzuron	kg	1.85×10^{-4}	6.31×10^{-4}	3.33×10^{-5}	6.07×10^{-5}
Thiram	kg	4.96×10^{-5}	1.69×10^{-4}	6.58×10^{-6}	1.25×10^{-5}
Tin	kg	1.44×10^{-2}	4.92×10^{-2}	6.01×10^{-3}	1.02×10^{-2}
Titanium	kg	3.86×10^{-1}	1.31	8.78×10^{-2}	1.56×10^{-1}
Vanadium	kg	1.10×10^{-2}	3.76×10^{-2}	2.51×10^{-3}	4.47×10^{-3}
Zinc	kg	5.20×10^{2}	1.77×10^{3}	1.32×10^{3}	2.74×10^{3}

APPENDIX D

SENSITIVITY ANALYSES

Variation around mass of sea-container

Variation around mass of functional unit

Variation around cyanide tonnages imported

The following figures consist of an input table, a normalised graph and a table containing normalised values.

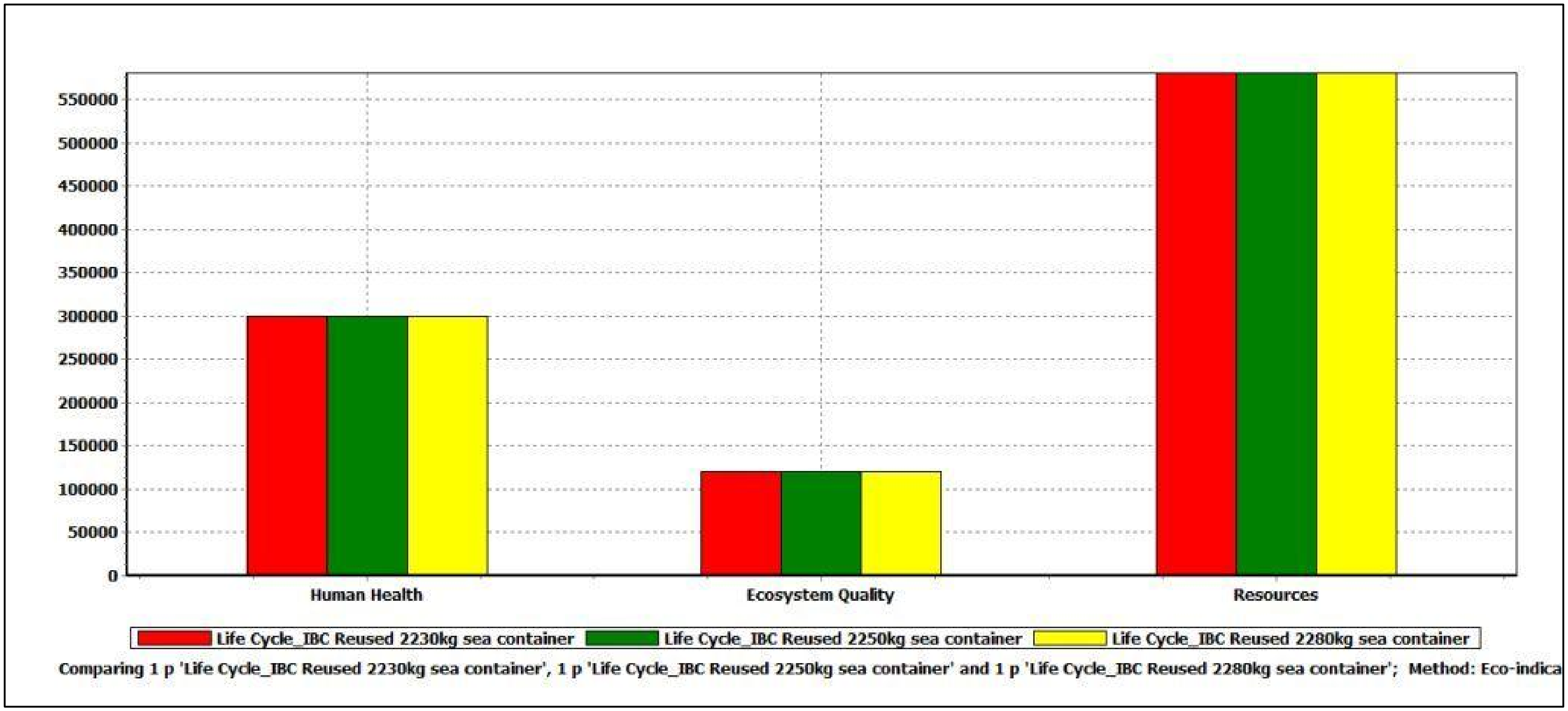
The input table consists of the values that are entered into Simapro 7.1 to generate the normalised graph and tables. Each input table specifies the parameter that is varied (column 1, row 2). In the second column the parameter is adjusted downwards with 10%, the second column reflects the values as received by the supplier and in the last column the value is adjusted with 10% upwards. The input variables that are dependent on the change in the one parameter have been calculated and are presented in the table as well (total mass and tkm).

The normalised graph follows and in this graph the three damage categories are presented. For each category a comparison is made of the variable as is, adjusted upwards and adjusted downwards.

The last presentation in the box is the table containing the normalised values that are used to generate the normalised graph. The categories are tabulated in the rows and the life cycle in which the parameter is varied in the columns. The last two columns (column 5 and 6) present the calculated percentages based on the variation. In column 5 the variation based on a decrease of 10% in the parameter is tabulated and in column 6 a variation based on an increase of 10% is tabulated.

Four figures have been generated for each parameter as the parameter has been varied for each of the functional units. The parameters varied are the masses of the functional units, the masses of the sea-containers and the tonnages (pieces received of each functional unit) of cyanide.

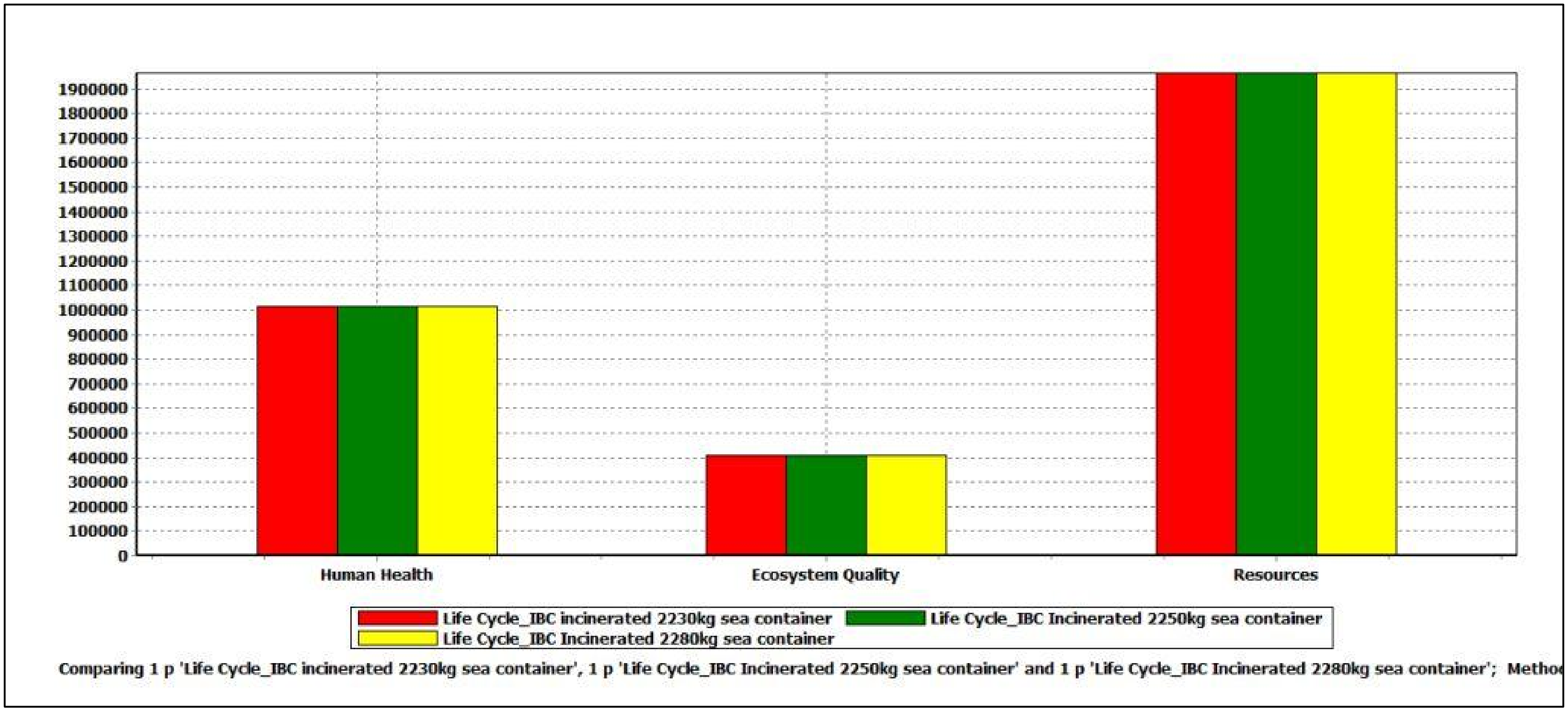
Effect of varied mass of sea containers on the life cycle of the reused IBC



Mass of sea-container (kg)	2230 kg	2250 kg	2280 kg
IBC reused	9 465	9 465	9 465
Item mass (kg)	88	88	88
Total mass (kg)	832 920	832 920	832 920
tkm	171 457.12	171 681.39	172 061.68

Damage category	IBC reused 2 230kg	IBC reused 2 250 kg	IBC reused 2 280 kg	Variance -10%	Variance +10%
Human health	299 787	299 805	299 831	-0.0058	0.0087
Ecosystem quality	120 683	120 684	120 687	-0.0014	0.0022
Resources	580 612	580 652	580 711	-0.0068	0.0102

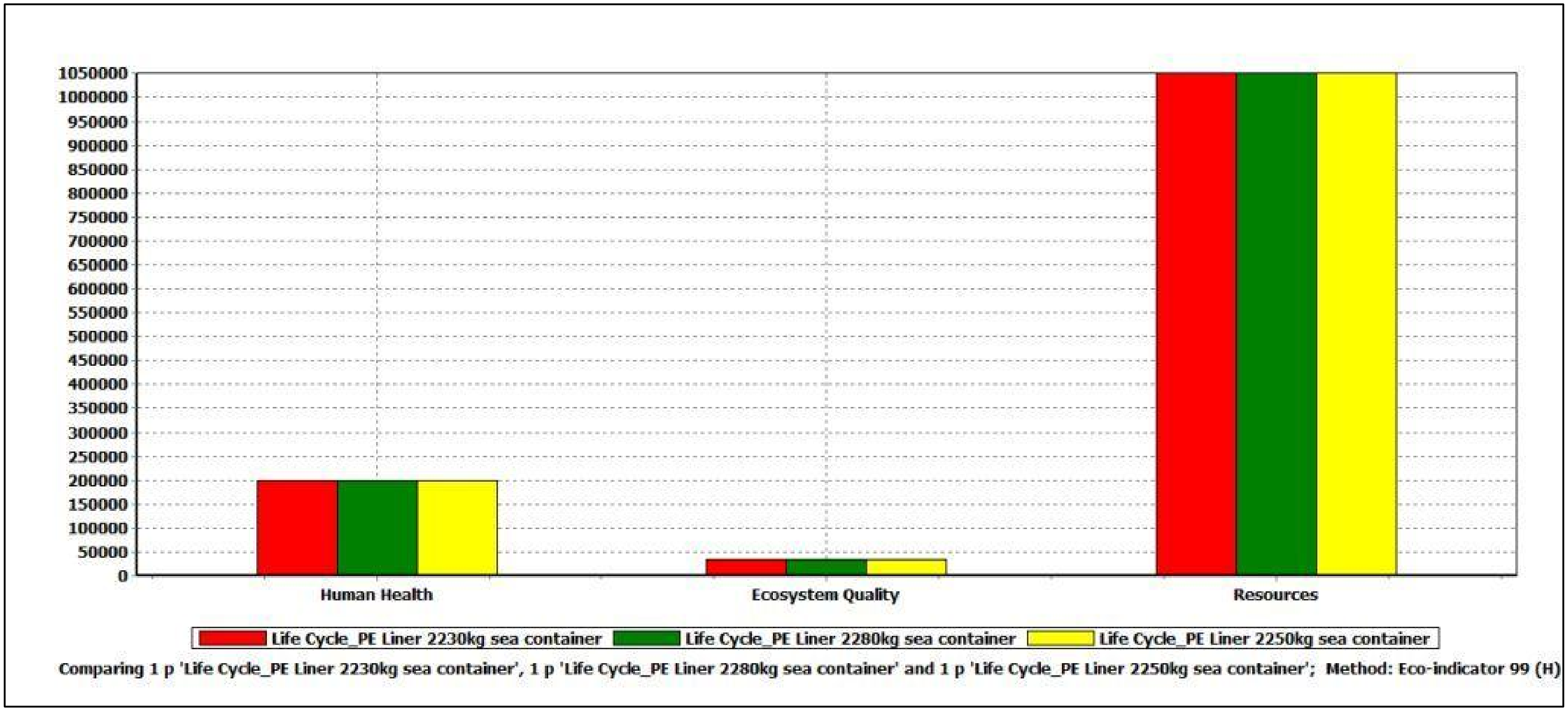
Effect of varied mass of sea-containers on the life cycle of the incinerated IBC



Mass of sea-container (kg)	2 230 kg	2 250 kg	2 280 kg
IBC incinerated	17 466	17 466	17 466
Item mass (kg)	88	88	88
Total mass (kg)	1 537 008	1 537 008	1 537 008
tKm	271 525.64	271 971.49	272 753.11

Damage category	IBC incinerated 2 230kg	IBC incinerated 2 250 kg	IBC incinerated 2 280 kg	Variance -10%	Variance +10%
Human health	1 014 914	1 014 979	1 015 077	-0.0064	0.0096
Ecosystem quality	410 359	410 365	410 375	-0.0016	0.0024
Resources	1 963 530	1 963 678	1 963 901	-0.0076	0.0113

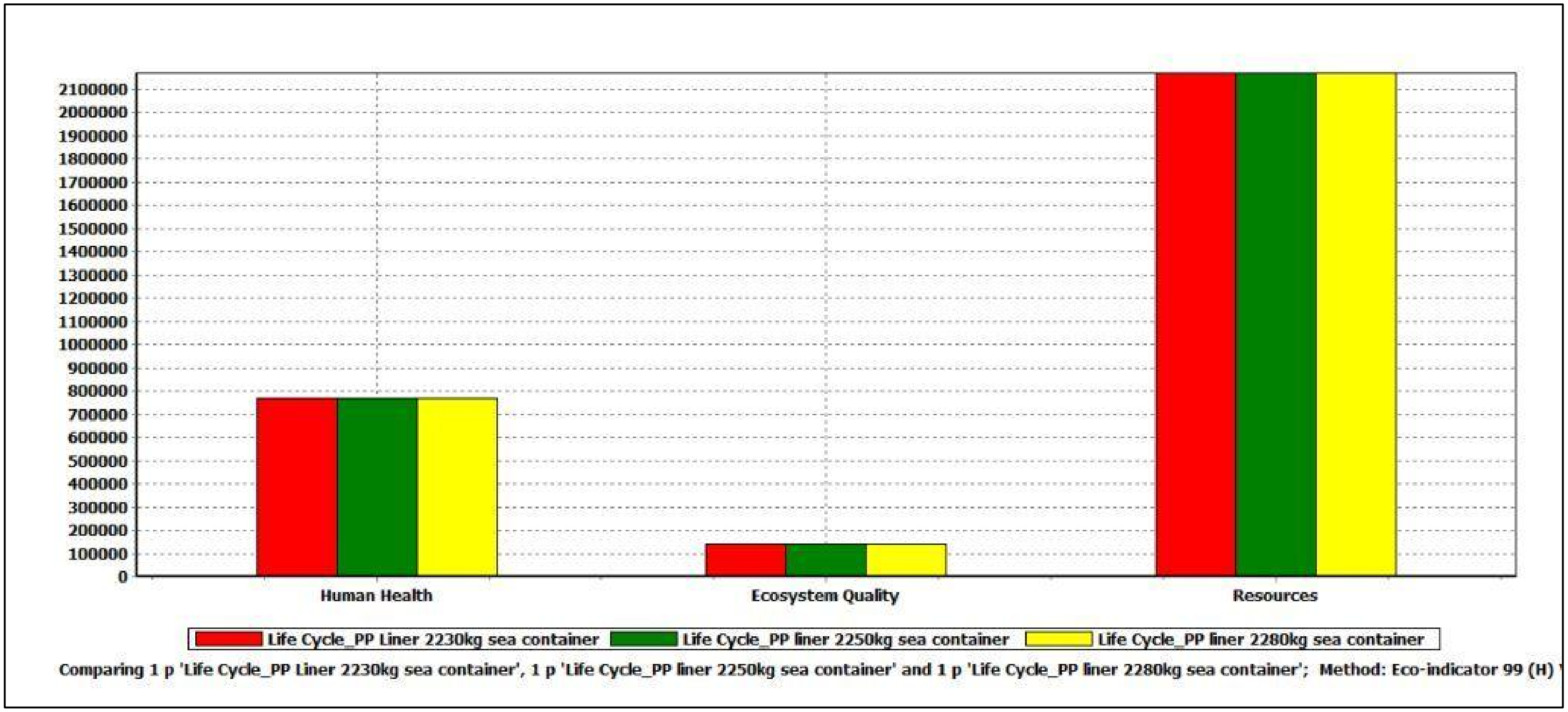
Effect of varied mass of sea-containers on the life cycle of the polyethylene liner



Mass of sea-container (kg)	2230 kg	2250 kg	2280 kg
PE liner	26 931	26 931	26 931
Item mass (kg)	1.1	1.1	1.1
Total mass (kg)	29 624.1	29 24.1	29 624.1
tKm	4 594.29	4 602.68	4 615.27

Damage category	PE liner 2 230kg	PE liner 2 250 kg	PE liner 2 280 kg	Variance -10%	Variance +10%
Human health	200 405	200 406	200 409	-0.0009	0.0013
Ecosystem quality	33 324	33 324	33 324	-0.0005	0.0008
Resources	1 051 035	1 051 039	1 051 044	-0.0004	0.0006

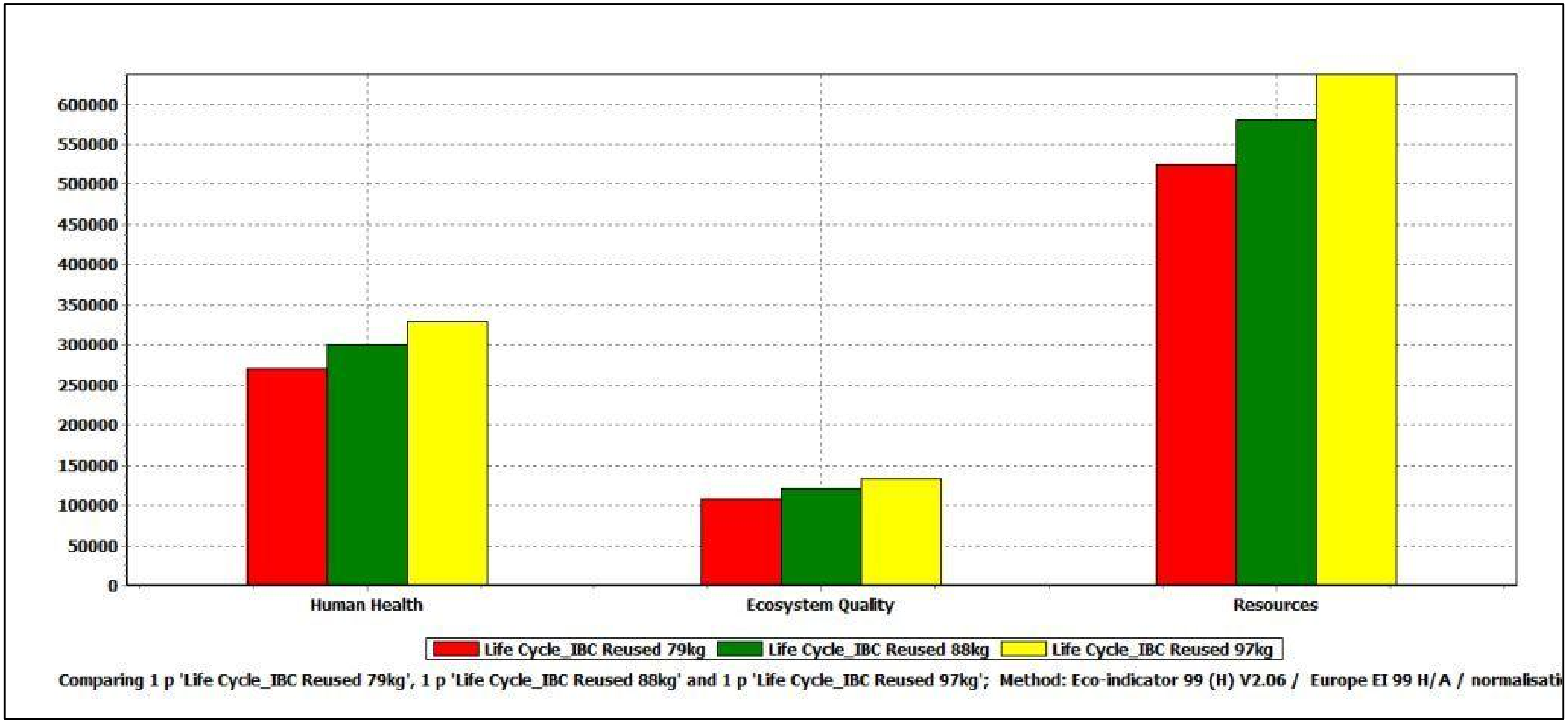
Effect of varied mass of sea containers on the life cycle of the polypropylene liner



Mass of sea-container (kg)	2230 kg	2250 kg	2280 kg
PP liner	26 931	26 931	26 931
Item mass (kg)	2.2	2.2	2.2
Total mass (kg)	59 248.2	59 248.2	59 248.2
tKm	9 267.62	9 284.69	9 310.29

Damage category	PP liner 2 230kg	PP liner 2 250 kg	PP liner 2 280 kg	Variance -10%	Variance +10%
Human health	765 186	765 189	765 195	-0.0005	0.0007
Ecosystem quality	140 616	140 616	140 617	-0.0002	0.0004
Resources	2 167 964	2 167 972	2 167 983	-0.0004	0.0005

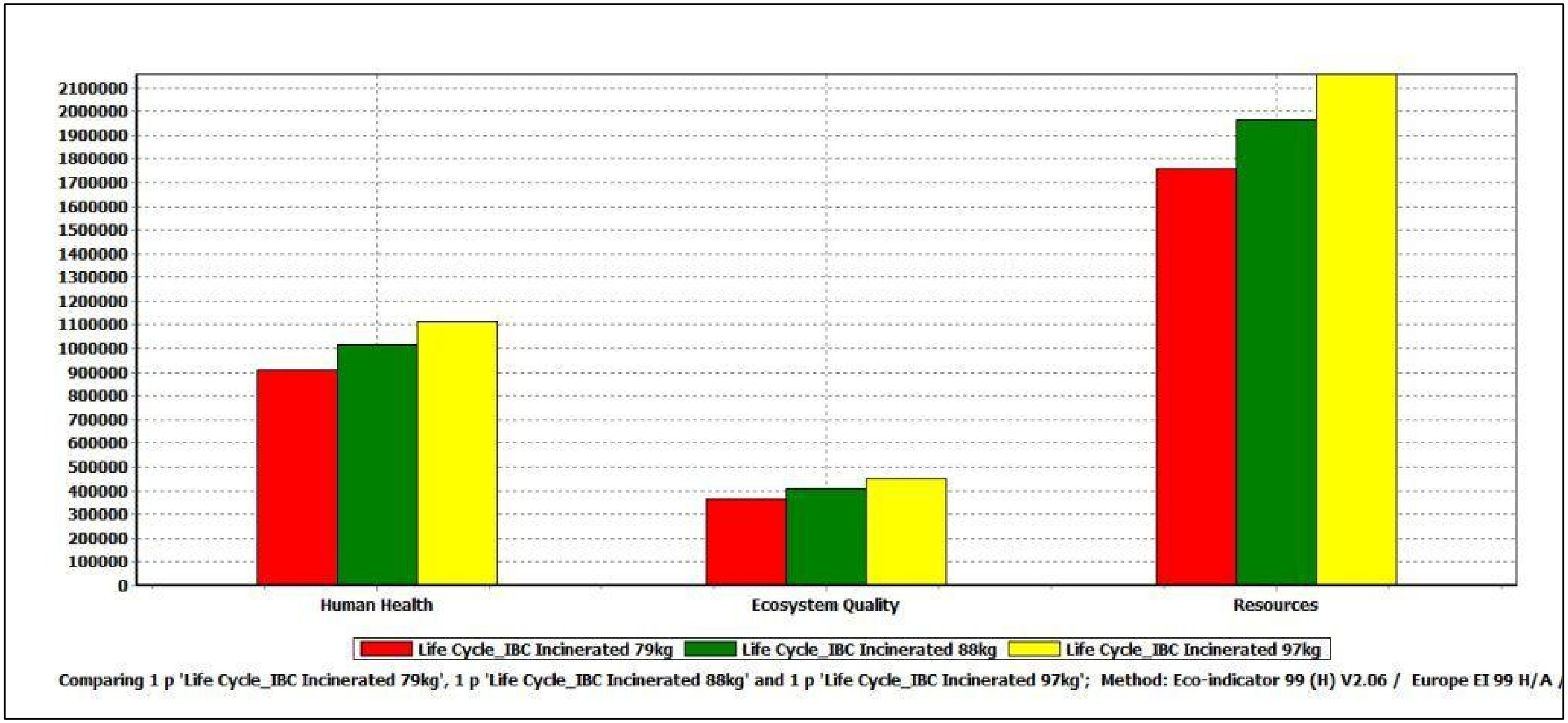
Effect of varied mass of the IBC on the life cycle of the reused IBC



Input	79 kg	88 kg	97 kg
IBC reused	9 465	9 465	9 465
Item mass (kg)	79kg	88kg	97kg
Total mass (kg)	747 735	832 920	918 105
tkm	170 338.19	171 698.94	173 028.45

Damage category	IBC reused 79kg	IBC reused 88 kg	IBC reused 97 kg	Variance -10%	Variance +10%
Human health	270 303	299 805	329304	-9.84	8.96
Ecosystem quality	108 458	120 684	132 911	-10.13	9.20
Resources	523 924	580 652	637 374	-9.77	8.90

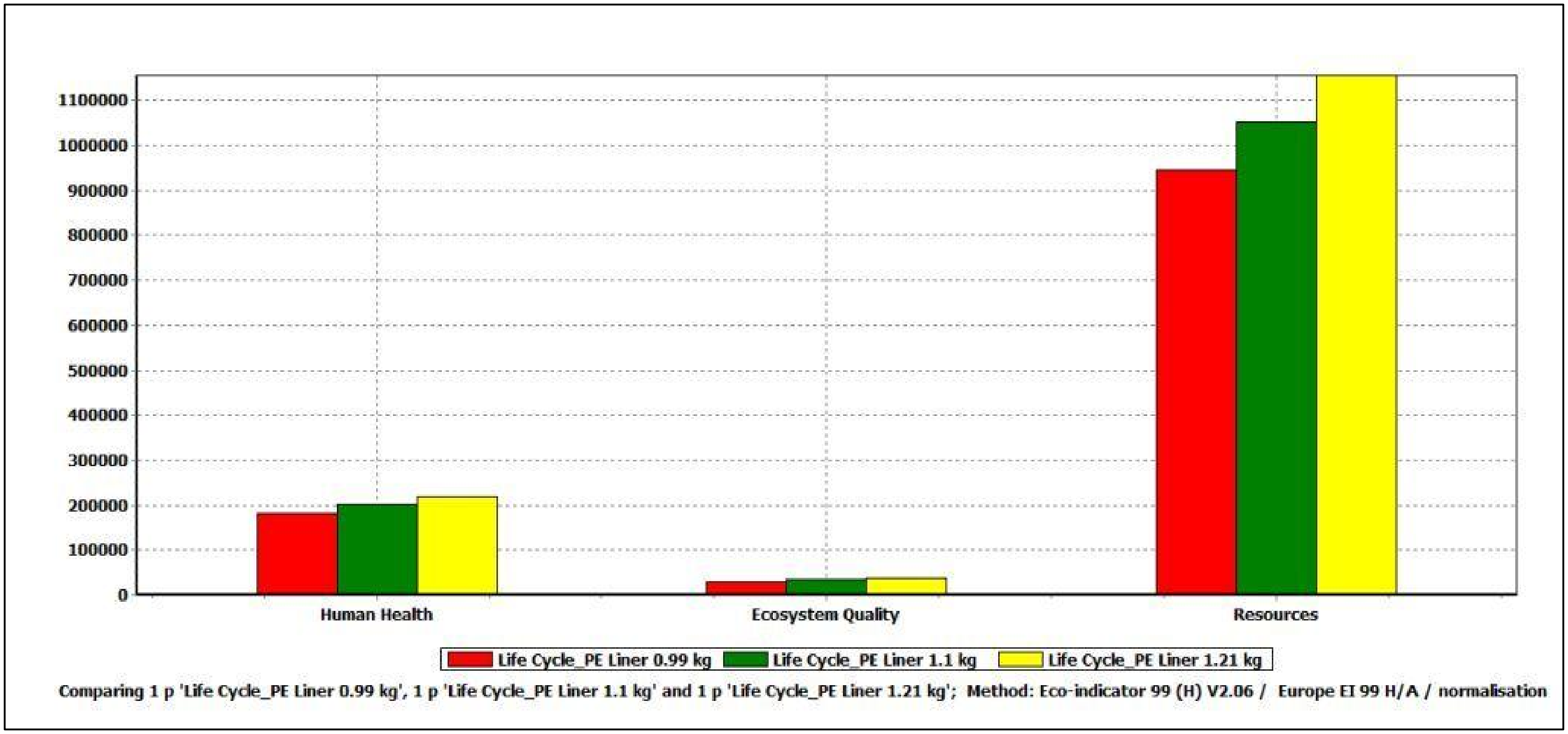
Effect of varied mass of the IBC on the life cycle of the incinerated IBC



Input	79 kg	88 kg	97 kg
IBC incinerated	17 466	17 466	17 466
Item mass (kg)	79kg	88kg	97kg
Total mass	1 379 814	1 537 008	1 694 202
tkm	270 035.41	272 016.63	273 941.42

Damage category	IBC incinerated 79kg	IBC incinerated 88kg	IBC incinerated 97kg	Variance -10%	Variance +10%
Human health	910 321	1 014 979	1 115 362	-10.31	9.00
Ecosystem quality	368 310	410 365	451 992	-10.25	9.21
Resources	1 760 891	1 963 678	2 156 669	-10.33	8.95

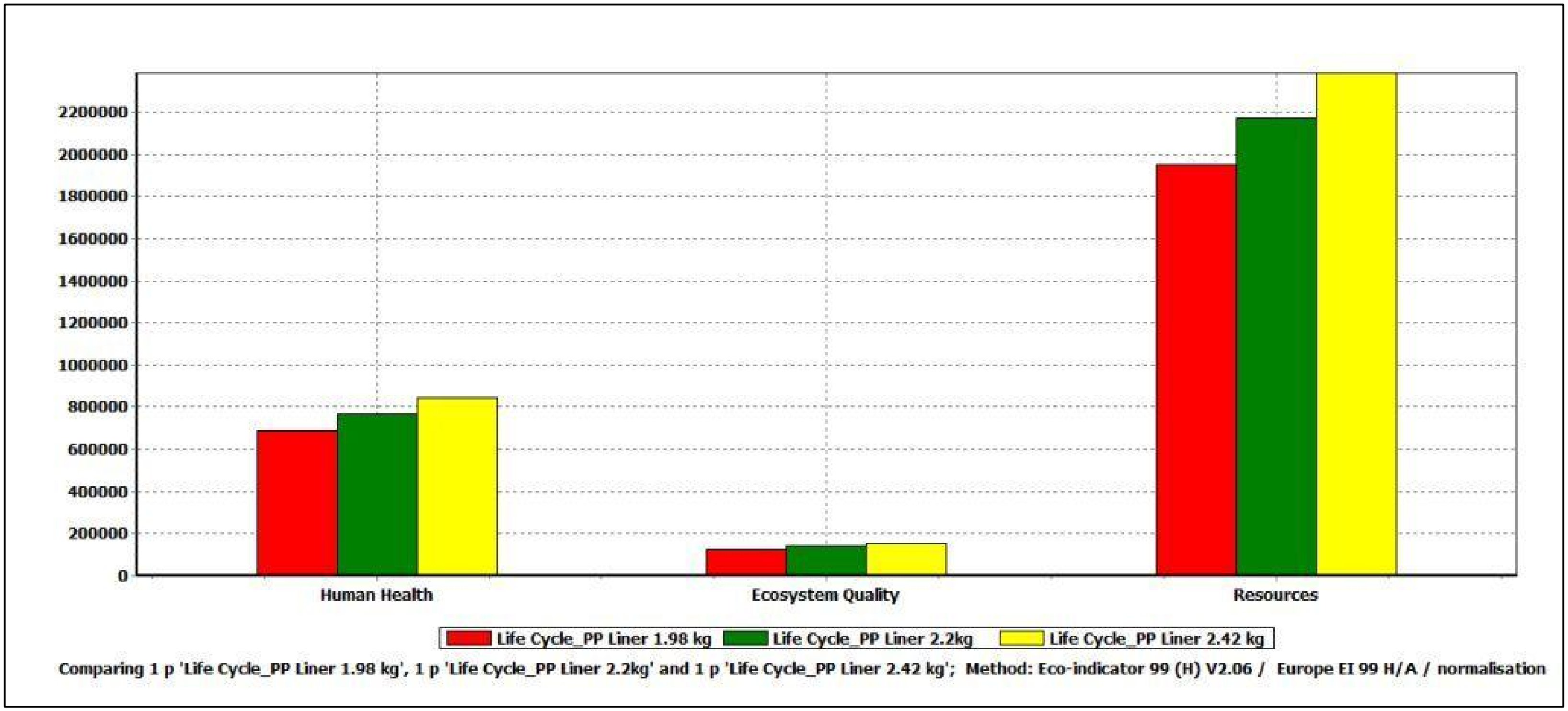
Effect of varied mass of the polyethylene liner on the life cycle of the polyethylene liner



Input	0.99 kg	1.1 kg	1.21 kg
PE liner	26 931	26 931	26 931
Item mass	0.99	1.1	1.21
Total mass	26 661.69	29 624.1	32 586.51
tkm	4 508.98	4 602.69	4 696.24

Damage category	PE liner 0.99 kg	PE liner 1.1 kg	PE liner 1.21 kg	Variance -10%	Variance +10%
Human health	180 440	200 406	220 372	-9.96	9.06
Ecosystem quality	29 999	3 3324	36 649	-9.98	9.07
Resources	946 106	1 051 039	1 155 971	-9.98	9.08

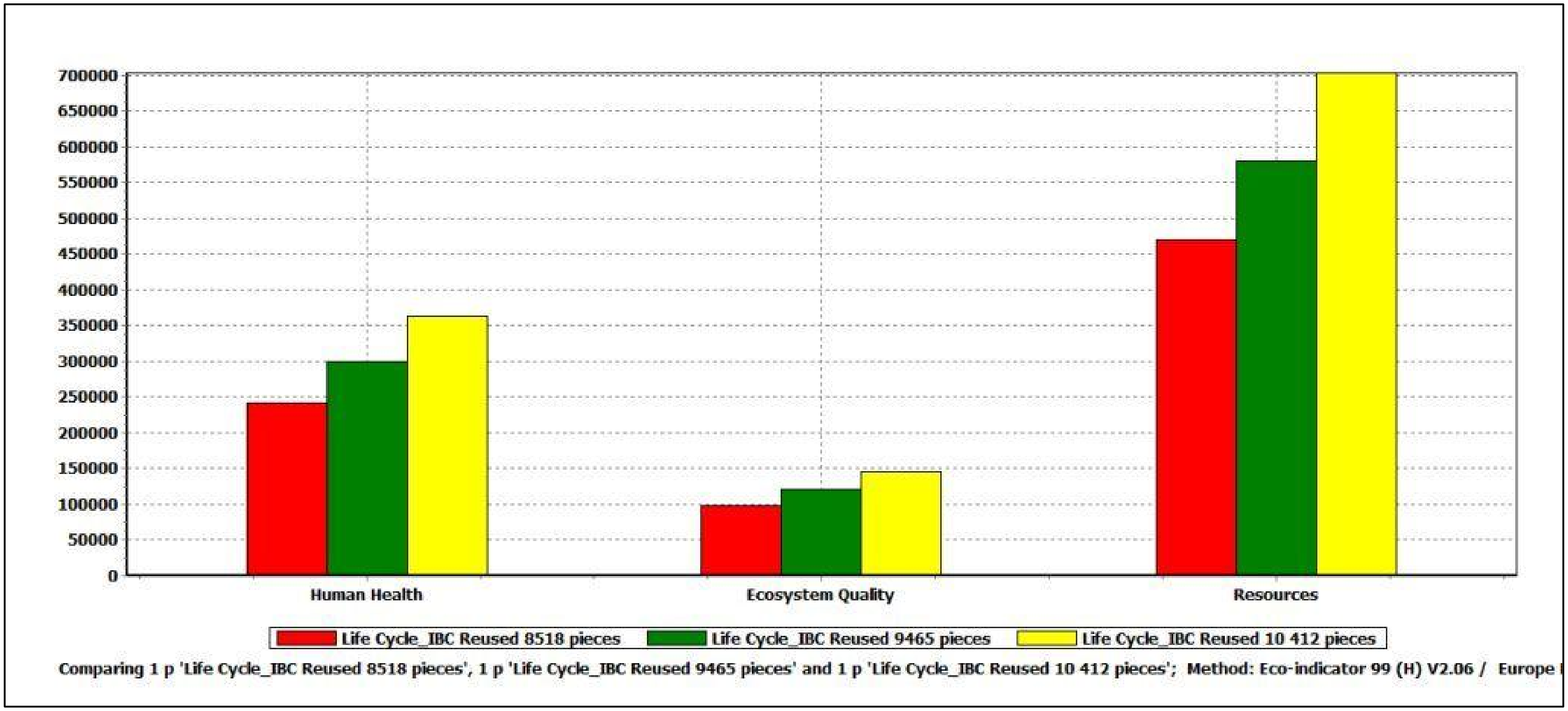
Effect of varied mass of the polypropylene liner on the life cycle of the polypropylene liner



Input	1.98 kg	2.2 kg	2.42 kg
PP liner	26 931	26 931	26 931
Item mass	1.98	2.2	2.42
Total mass	53 323.38	59 248.2	65 173.02
tkm	9 095.57	9 284.69	9 473.19

Damage category	PP liner 1.98 kg	PP liner 2.2 kg	PP liner 2.42 kg	Variance -10%	Variance +10%
Human health	688 821	765 189	841 558	-9.98	9.07
Ecosystem quality	126 570	140 616	154 663	-9.99	9.08
Resources	1 951 520	2 167 972	2 384 423	-9.98	9.08

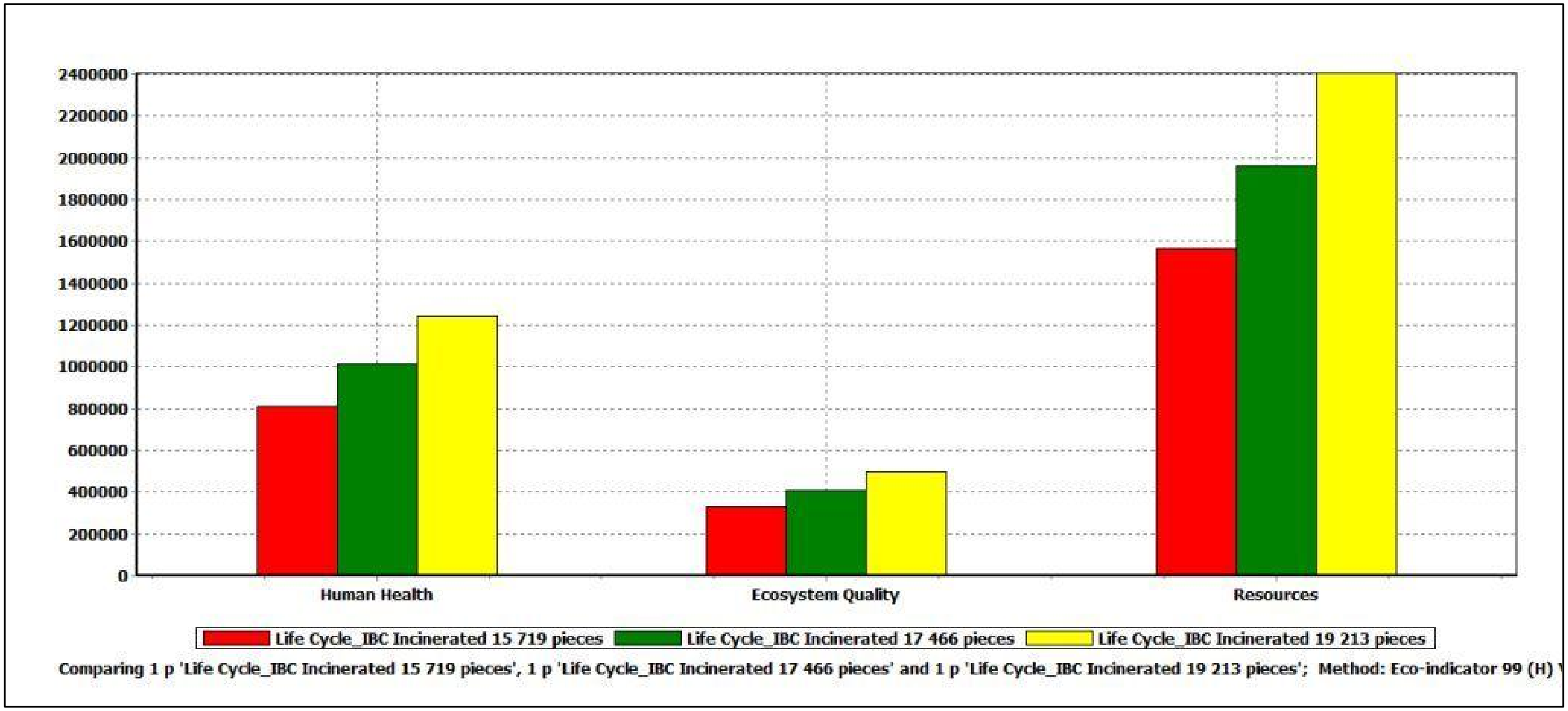
Effect of varied cyanide tonnages (pieces of functional unit) on the life cycle of the reused IBC



Input	8 518 pieces	9 465 pieces	10 412 pieces
IBC reused	8 518	9 465	10 412
Item mass (kg)	88	88	88
Total mass (kg)	749 672	832 920	916 256
tkm	151 088.62	171 698.94	192 309.26

Damage category	IBC reused 8 518 pieces	IBC reused 9 465 pieces	IBC reused 10 412 pieces	Variance - 10%	Variance +10%
Human health	242 620	299 805	363 069	-19.07	17.42
Ecosystem quality	97 732	120 684	146 069	-19.02	17.38
Resources	469 818	580 652	703 275	-19.09	17.44

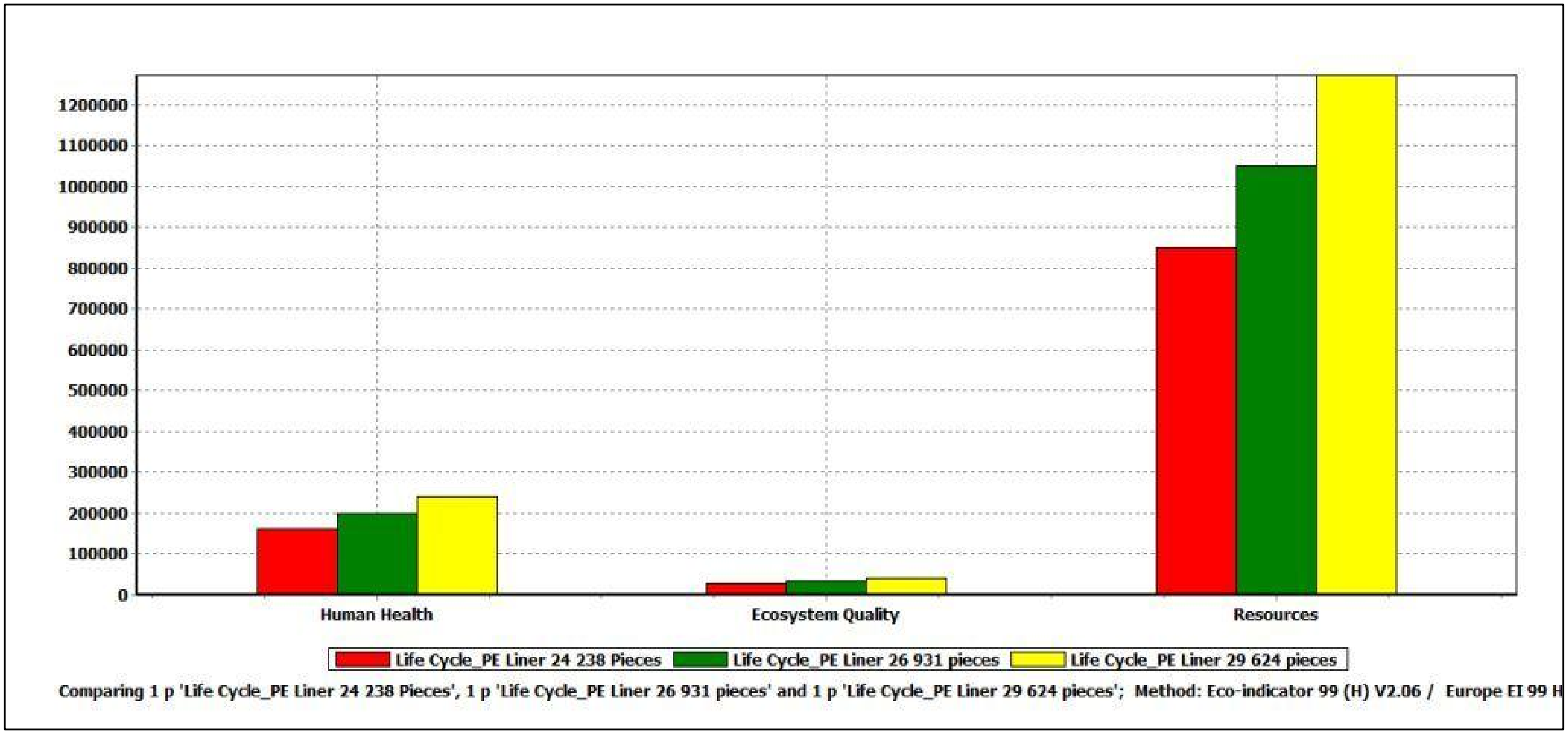
Effect of varied cyanide tonnages (pieces of functional unit) on the life cycle of the incinerated IBC



Input	15 719 pieces	17 466 pieces	19 213 pieces
IBC incinerated	15 719	17 466	19 213
Item mass (kg)	88	88	88
Total mass (kg)	1 383 272	1537008	1690744
tkm	152 467.37	272 016.63	391 565.89

Damage category	IBC incinerated 15 719 pieces	IBC incinerated 17 466 pieces	IBC incinerated 19 213 pieces	Variance -10%	Variance +10%
Human health	811 110	1 014 979	1 241 599	-20.09	18.25
Ecosystem quality	331 280	410 365	497 905	-19.27	17.58
Resources	1 565 338	1 963 678	2 406 902	-20.29	18.41

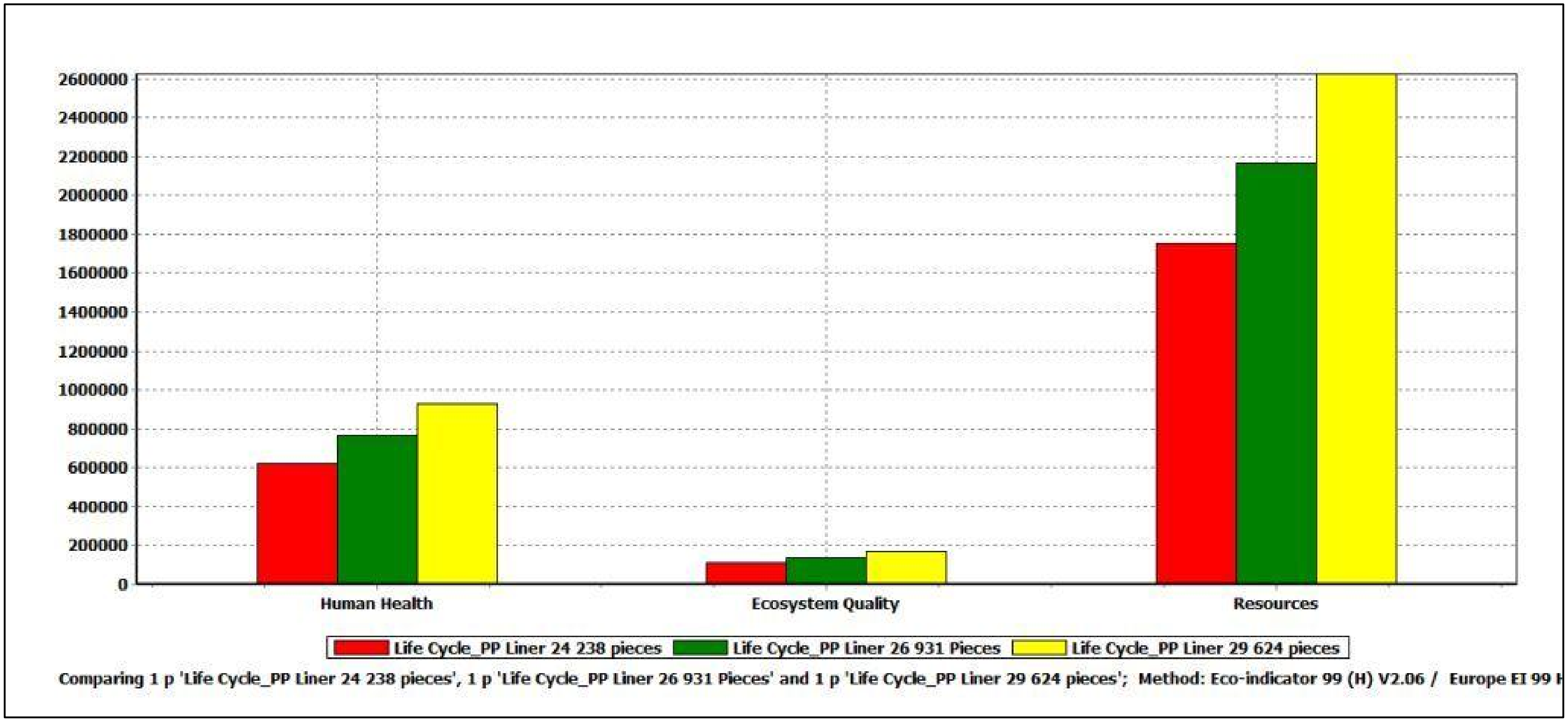
Effect of varied cyanide tonnages (pieces of functional unit) on the life cycle of the polyethylene liner



Input	24 238 pieces	26 931 pieces	29 624 pieces
PE liner	24 238	26 931	29 624
Item mass (kg)	1.1	1.1	1.1
Total mass (kg)	26 661.8	29 624.1	32 586.4
tkm	4 009.47	4 696.24	4 968.20

Damage category	PE liner 24 238 pieces	PE liner 26 931 pieces	PE liner 29 624 pieces	Variance -10%	Variance +10%
Human health	162 306	200 425	242 469	-19.02	17.34
Ecosystem quality	26 990	33 326	40 320	-19.01	17.35
Resources	851 292	1 051 082	1 271 699	-19.01	17.35

Effect of varied cyanide tonnages (pieces of functional unit) on the life cycle of the polypropylene liner



Input	24 238 pieces	26 931 pieces	29 624 pieces
PP liner	24 238	26 931	29 624
Item mass (kg)	2.2	2.2	2.2
Total mass (kg)	53 323.6	59 248.2	65 172.8
tkm	7 923.4	9 283.10	10 642.73

Damage category	PP liner 24 238 pieces	PP liner 26 931 pieces	PP liner 29 624 pieces	Variance -10%	Variance +10%
Ecosystem quality	113 892	140 616	170 154	-19.00	17.36
Human health	619 729	765 189	925 969	-19.01	17.36
Resources	1 755 890	2 167 971	2 623 448	-19.01	17.36