

A platinum Life Cycle Assessment: potential benefits to Anglo Platinum

I. Caddy

Student Number: 21537275

**Mini-dissertation submitted in partial fulfilment of the requirements for the degree Masters in
Environmental Management at the Potchefstroom campus of the North-West University**

Supervisor: Prof. I.J. van der Walt

May 2011

ACKNOWLEDGEMENTS

I would like to thank the following people for their commitment and support:

- Dr Lettie la Grange & Clint Smit from Anglo American Platinum Ltd for their continual support.
- Yolande Muller, for motivating me without fail.
- My supervisor, Prof Kobus van der Walt for his assistance and advice.
- My parents for helping me with the logistics of studying, working and family-life.
- Most importantly, my husband, Syd and my daughter Caz for their unwavering support and understanding.

Table of Contents

ABSTRACT	5
UITTREKSEL	7
LIST OF ABBREVIATIONS:	9
1. INTRODUCTION	1
1.1. HISTORY OF ENVIRONMENTAL MANAGEMENT	10
1.2. LIFE CYCLE ASSESSMENT (LCA).....	13
1.3. BUSINESS CASE OF IMPROVED ENVIRONMENTAL MANAGEMENT.....	15
1.4. ANGLO AMERICAN PLATINUM LTD. (AMPLATS).....	15
1.5. RESEARCH QUESTION	16
1.5.1. Sub-Questions	16
1.6. RESEARCH METHODOLOGY	17
1.7. SECTIONS.....	17
2. A LITERATURE REVIEW OF LIFE CYCLE ASSESSMENT	1
2.1. LIFE CYCLE ASSESSMENT AS AN ENVIRONMENTAL MANAGEMENT TOOL.....	18
2.2. DEFINITION OF LCA	19
2.3. LIFE CYCLE ASSESSMENT PROCESS	19
2.3.1. Goal and scope definition:	21
2.3.2. Inventory Analysis:.....	25
2.3.3. Life Cycle Impact Assessment (LCIA).....	32
2.3.4. Improvement assessment.....	34
2.4. TYPES OF LCA AVAILABLE.....	35
3. LCA CASE STUDIES	1
3.1 INTRODUCTION	37

3.2	CASE STUDIES	37
3.2.1	Use of abridged LCA	37
3.2.2	LCA as comparative tool – production processes	39
3.2.3	LCA as comparative tool – life cycle stages.....	41
3.2.4	LCA as tool to predict long-term impacts	43
3.2.5	Combining LCA with other methodologies	44
3.2.6	The use of LCA as a strategic tool	47
3.2.7	Life Cycle Analysis in the minerals industry	48
3.3	CONCLUSION – LCA CASE STUDIES	51
4.	DOES LCA HAVE SIGNIFICANT BENEFITS FOR THE PLATINUM INDUSTRY?	1
4.1	INTRODUCTION	53
4.2	WHAT BENEFITS AND LEARNINGS DID OTHER INDUSTRIES/COMPANIES REALIZE FROM LCA?	53
4.3	WHAT PROCESS SHOULD BE FOLLOWED TO CONDUCT A LCA FOR THE PLATINUM INDUSTRY?	56
4.4	WHAT ARE THE ANTICIPATED BENEFITS TO THE PLATINUM INDUSTRY OF CONDUCTING A LCA?..	59
4.5	DOES LCA HAVE SIGNIFICANT BENEFITS FOR THE PLATINUM INDUSTRY?.....	61
5	CONCLUSION.....	1
	BIBLIOGRAPHY	65

ABSTRACT

There has been an increased awareness of the inter-dependence between man and the environment since the 1960's. Environmental awareness has evolved from representing fairly radical views opposing all development, to a current emphasis on sustainable development between development and the environment.

Life Cycle Assessment (LCA) is defined as the identification and quantification of the environmental impacts of a product, process or service during the entire life cycle being studied. The life cycle starts at the extraction of raw materials and the production of energy used to create the product through the use and final disposal of the product. LCA therefore considers the production, use and disposal of a product, which constitutes the life cycle of the product.

LCA can be combined with methodologies that study other parameters such as costs in order to optimise the benefits from LCA. It is suggested that cost implications of processes to reduce environmental impacts should be included in a methodology used for a Platinum LCA.

A comment that is consistently raised in the case studies is that the minerals industry regards LCA as an effective tool to determine the impacts of the industry, however extraction & beneficiation of minerals are often grouped together, with accurate data not being available, and databases either not available or not updated.

The case studies indicated several benefits from the various LCA's conducted. A Platinum LCA should clearly define and group the environmental impacts being studied into categories such as greenhouse gas emissions, global warming, acidification, and resource consumption.

A Platinum LCA will be resource- and time intensive due to the large scale of the processes involved. It is suggested that a Platinum LCA firstly focuses on the production phase, i.e. cradle-to-gate, with potential future work done on the use and end-of-life stages.

It is suggested that individual facility-based LCA's for AMPLATS and other platinum producers are conducted in order to get a true reflection of the environmental burden of each company, and then selectively share technological improvements to reduce the environmental burden without disclosing sensitive information.

The benefit of LCA in the case of platinum will be optimised if it can be used to make business decisions, together with consideration of financial and production benefits in addition to anticipated environmental benefits of alterations to processes. It is essential that LCA is seen as a business

tool that will assist the company to make informed business decisions about process improvements, as well as new projects and design of new facilities.

LCA on its own will not determine which product or process is the most cost effective or works best. The information developed in a LCA study should be used as one component of a more comprehensive decision making process assessing the trade-offs with cost and performance. The results from a LCA could be used to make informed decisions about optimisation between costs and reduced environmental impacts.

Key words:

Life Cycle Assessment; LCA; Mining industry; Platinum; PGM; Metals industry

UITTREKSEL

Sedert die 1960's is daar 'n toenemende fokus op die onderlinge afhanklikheid tussen mens en die omgewing. Aanvanklik was omgewingsbewustheid meer radikaal en het alle ontwikkeling teengestaan, maar dit het oor tyd ontwikkel in 'n meer gebalanseerde verhouding tussen volhoubare ontwikkeling en die omgewing.

Lewens-siklus assessering (LCA) word gedefinieer as die identifikasie en kwantifisering van die omgewingsimpakte van 'n produk, proses of diens gedurende die totale lewens-siklus wat bestudeer word. Die lewens-siklus begin by die ontginning van grondstowwe en die produksie van energie wat gebruik word om die produk te vervaardig, en sluit in die gebruik en finale wegdoening van die produk.

LCA kan gekombineer word met metodes wat ander parameters soos koste bestudeer om sodoende die voordele van LCA te optimaliseer. Die studie stel voor dat koste-implikasies van prosesse om omgewingsimpakte te verminder, ingesluit word in 'n Platinum LCA.

Die gevallestudies het uitgewys dat daar nie akkurate data beskikbaar is vir mynbou prosesse nie, en dat databasisse nie opgedateer word nie, of nie beskikbaar is nie. Dit is as gevolg van die feit dat onttrekking en veredeling van metale gewoonlik saam gegroepeer word en daar nie verdere studies op die prosesse gedoen word nie. Ten spyte hiervan beskou die myn industrie LCA as 'n doeltreffende instrument om omgewingsimpakte van die produkte te bestudeer.

Verskeie voordele is geïdentifiseer in die onderskeie gevallestudies. 'n Platinum LCA moet die groepering van omgewingsimpakte duidelik omskryf, byvoorbeeld die vrystelling van kweekhuis gasse, aardverwarming, versuring en verbruik van hulpbronne.

'n Platinum LCA sal tyd- en hulpbron-intensief wees a.g.v. die groot skaal van die prosesse wat betrokke is. Die studie stel voor dat 'n Platinum LCA eerstens fokus op die produksie fase (wieg-tot-hek) met moontlike toekomstige werk wat sal fokus op die gebruik- en einde-van-lewe stadiums van die produk.

Verder word dit voorgestel dat individuele platinum produsente onafhanklike, fasiliteit-gebaseerde LCA studies voltooi. Die resultate van hierdie studies kan dan selektief gedeel word met ander platinum produsente om sodoende tegnologie wat omgewingsimpakte verminder te deel, maar te voorkom dat sensitiewe inligting gedeel word.

Die voordele van 'n Platinum LCA sal optimaal wees indien dit gebruik word om sake-besluite te neem, tesame met die inagneming van finansiële- en produksie voordele. Dit is noodsaaklik dat

LCA gesien word as 'n besigheids hulpmiddel wat sal help om beter besigheids besluite te neem in verband met proses verbeteringe, asook vir nuwe projekte en die ontwerp van nuwe infrastruktuur.

LCA op sy eie sal nie bepaal watter produk of proses die mees koste-effektiewe of mees funksionele sal wees nie. Die inligting ontwikkel in 'n LCA moet gebruik word as 'n komponent van 'n meer omvattende besluitnemingsproses wat ook koste en werkverrigting in ag neem. Die resultate van LCA kan gebruik word om ingeligte besluite te neem om die optimale balans tussen kostes en die minimalisering van omgewingsimpakte te bereik.

LIST OF ABBREVIATIONS:

ABC	Activity-Based Costing
AMPLATS	Anglo American Platinum Ltd.
BEE	Black Economic Empowerment
DEAT	Department of Environmental Affairs and Tourism
EIA	Environmental Impact Assessment
EMS	Environmental Management Systems
EPA	Environmental Protection Agency
IEM	Integrated Environmental Management
ICA	Indoor Climate Assessment
ISO	International Standards Organisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
MEA	Material Emission Assessment
MFA	Material Flow Accounting
PGM	Platinum Group Metals
REPA	Resource and Environmental Profile Analysis
RA	Risk Assessment
SABS	South African Bureau of Standards
SETAC	Society of Environmental Toxicology and Chemistry
UN	United Nations
UNEP	United Nations Environmental Program

CHAPTER 1 – INTRODUCTION

1.1. HISTORY OF ENVIRONMENTAL MANAGEMENT

All human activities impact on the environment in some way. Prior to the industrial revolution this was not significant because the scale of the impact was small compared to the scale of the environment. When populations were small and people had nomadic lifestyles, it was merely a matter of moving to new land when the local capacity of the land to support their activities was exhausted. This process gave the impacted environment the opportunity to regenerate and recover from the impact of human activities.

Colby points out that the scale of the world population doubled (from 2.5 to 5.0 billion) between 1950 and 1986, while the scale of gross world product and world fossil fuel consumption each quadrupled. In the 20th century, world population tripled, and the world economy has expanded to 20 times its size in 1900. *“Human activities are having major effects on the biogeochemical and physical processes that support life on the planet.”* (Colby, 1989:4).

The relationship between man and the environment in the era preceding the 1960's was characterised by the philosophy of “Frontier Economics”. This philosophy is underpinned by the following:

- Man is dominant over nature
- The natural environment is a resource for humans
- The primary goal is material/economic growth for a growing human population
- A belief in ample resource reserves
- High technological progress and solutions.
- Consumerism and a growth in consumption.
- National/centralised community.

According to the USA Environmental Protection Agency (EPA) there was an increased awareness of the limitations of raw materials and energy resources during the 1960's. During this period the first attempts were made to cumulatively account for energy use and to project future resource supplies and use (EPA, 2006:1).

The initial predictive models were developed during the early 1960's to predict the effects of the increasing population on the demand for finite raw materials and energy resources. The picture was one of depleting fossil fuels and climate changes. More detailed calculations of energy use in industrial processes were done as a result of the modelling results, and alternative energy sources and their environmental impacts were studied.

Environmental protection during the 1960's consisted predominantly of ameliorating the effects of human activities, being inherently defensive or remedial. Regulation of pollution was based on the principle of "optimal pollution levels", limiting or cleaning up pollution rather than planning in a manner that will prevent pollution.

Coca-cola initiated a study in 1969 comparing different beverage containers to determine which one has the lowest releases to the environment and least affected the supply of natural resources by quantifying raw materials and fuels used, and environmental loads for each container. Contrary to what was expected, Coca cola showed that plastic bottles were a better environmental choice than glass bottles, using the principles of Life Cycle Assessment. (Freed, 2008) This study formed the foundation for current life cycle inventory analysis, and paved the way for other companies and government departments to follow suit.

The trend to include not only capital and labour resources, but also the interactive supply and demand of natural resources in global systems dynamics models continued into the early 1970's. This period saw an increased awareness of the natural resources becoming scarcer and the negative impact of pollution on these resources.

The USA developed a process known as REPA (Resource and Environmental Profile Analysis) to quantify resource use and environmental releases, with a similar process called Ecobalance implemented in Europe. During the period from 1970 to 1975 several studies were completed as part of these processes, resulting in a protocol for the studies being implemented (Hunt *et al*, 1992, 245).

The problem of environmental disruption was internationalised at the 1972 Stockholm Conference on the Human Environment, hosted by the UN. The conference resulted in the formation of the United Nations Environmental Program (UNEP) to address the issue, however UNEP actions were predominantly remedial in nature. There was a perception that the focus on environmental concerns was elitist in nature. Paradoxically, history has shown

that the poor are harmed more by pollution and resource depletion than the rich (Colby, 1989:15).

The oil embargo imposed by the Arab nations in 1973 resulted in a 70% increase in the oil price, and became a strategic weapon in the Yom Kippur War between Israel and a coalition between Egypt and Syria. The Arab nations unilaterally increased oil prices, forcing the Western world to implement measures to reduce their dependence on these nations for energy. The energy crisis led to increased interest in developing oil fields in America and Alaska, as well as alternative energy sources such as solar energy and wind energy. The West's dependence on gas, coal and nuclear energy also increased as a result of the energy crisis (Wikipedia, 2011).

From 1975 to the early 1980's the influence of the oil crisis subsided, and the focus shifted to hazardous and household waste management. During the 1980's the concept of nature as an infinite supply of raw materials, with infinite capacity to absorb wastes, and therefore being irrelevant to the economy started changing. Technologies developed to this point were focused on enhancing the capability to extract resources from nature. The fundamental flaw is a lack of awareness of the human reliance on ecological balance (Colby, 1989:17).

Systems modelling methodologies and documentation consistently improved during the 1980's, particularly with regard to resource depletion, population pressure and the link to poverty. In the late 1980's it became evident that the consideration of "global commons" issues such as water, the atmosphere and biodiversity were not adequately considered in legal, political and economic structures.

Solid waste became a world-wide issue in 1988. Life Cycle Assessment (LCA) emerged as an environmental management tool to analyse these environmental issues, although at this point LCA was deemed complete at the Inventory step. The need to analyse the impacts of solid waste evolved the LCA methodology beyond the Inventory step to include the Impact Assessment step. (SETAC 1993)

The Brundtland Commission in 1987 (WCED, 1987) introduced the concept of sustainable development, although at that point the definition was vague, causing concern about the sustainability of the concept due to varying interpretations and inconsistency of application. Even though the definition of sustainable development is still not consistent, the concept has endured and remains the aim of environmental interventions and management.

The introduction of the concept of sustainable development heralded a more balanced view of environmental management. Environmental concerns no longer implied being anti-development, but rather taking a balanced approach to ensure sustainability of both the environment and the industry or development in question. The neoclassical imperative of economic growth is still the primary goal of development planning, but criteria of sustainability are viewed as necessary constraints (Colby, 1989:19)

Prior to the 1990's LCA methodology was not yet formalised, since the concept was very much under development. Several companies in the USA used LCA results to make broad marketing claims about their products being environmentally friendly. This resulted in 11 State Attorneys General in the USA denouncing the use of LCA results to promote products until uniform methods for conducting such assessments are developed, and a consensus reached on how this type of environmental comparison can be advertised non-deceptively. As a result of this the International Standards Organisation (ISO) developed LCA standards as part of their environmental management system series (ISO 14000).

Tien *et al* observed that improved environmental performance was generally regarded as a reduction of the environmental impacts of a company, often limited to a reduction or elimination of emissions and wastes at manufacturing sites. They stated the need to look at environmental impacts on a broader scale, such as choice of raw materials, energy consumption, discharge methods and product use. *"A fundamental way to improve environmental performance is to minimise the total impact the product generates in each stage of its life cycle."* Tien *et al* (2002:686)

The Life Cycle Initiative was launched in 2002 by UNEP and the Society of Environmental Toxicology and Chemistry (SETAC). It is an international partnership aiming to put life cycle thinking into practice. It consists of three programs that form the LCA framework, and aims to improve competence in conducting LCA, as well as sharing of relevant information. The three programs are Life Cycle Management (LCM), Life Cycle Inventory (LCI), and Life Cycle Impact Assessment (LCIA) (DEAT, 2004:11).

1.2. LIFE CYCLE ASSESSMENT (LCA)

South Africa's Department of Environmental Affairs and Tourism (DEAT) adopted the Integrated Environmental Management (IEM) approach and subsequently developed several guidelines on various topics and tools related to IEM (DEAT, 2004:4). Multi-national companies and companies that export products have adopted the IEM approach in order to

comply with local and international legislation, as well as requirements of customers and shareholders to demonstrate a responsible approach to environmental impacts of products.

Life Cycle Analysis (LCA) is considered a valuable tool to be used by companies to comply with legislation, meet customer and other stakeholders' requirements and provide valuable information to base strategic decisions regarding products and processes on. Taking cognisance of the fact that the impacts and costs are not limited to a single phase in the life cycle of a product, assists decision-making when considering alternative technologies and materials to be used, which could in turn result in decisions that will also reduce the environmental impacts of a process.

LCA is often referred to as a "Cradle-to-Grave" approach to environmental management (DEAT, 2004:4). The process begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to earth. LCA evaluates all the stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next.

LCA enables the estimation of the cumulative environmental impacts not considered in more traditional analysis (e.g. raw material extraction, material transportation, ultimate product disposal, etc.) By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection (EPA, 2006:2).

LCA can be defined as the calculation and evaluation of environmentally relevant inputs and outputs and the potential environmental impacts of the life cycle of a product, material or service (ISO, 2006). The life cycle consists of the technical system of processes and transport routes used at, or needed for, raw materials extraction, production, use and after-use (waste management or recycling). (DEAT, 2004:4). The process of conducting a LCA includes the development of an Inventory, an Impact Assessment based on a process flow, and an Improvement Assessment, which evaluates the results of the LCA and proposed improvements to the life cycle.

The ultimate aim of environmental management systems and legislative requirements such as Environmental Impact Assessments is to reduce environmental impacts and improve the environmental performance of companies. This improvement doesn't only constitute a reduction in emissions and wastes from sites, but should also include factors such as selection of raw materials, energy consumption, discharge methods and product use (Tien

et al, 2002:686). By limiting the environmental impact at each of the stages in the life cycle of a product the benefits of integrated environmental management are optimized.

1.3. BUSINESS CASE FOR IMPROVED ENVIRONMENTAL MANAGEMENT

Since the energy crisis in the early 1970's and the resource depletion concerns subsequently raised there has been an increased focus on efficient resource management and effective environmental management as an integral part of the overall management of progressive companies. Rising energy costs triggered the need for more systematic and detailed energy usage planning. Legislation governing environmental management has been developed and implemented internationally, with South Africa developing several policies and legislation in order to be aligned with the international requirements and trends.

Earthwatch recognises the fact that business and ecosystem services are inextricably linked, and that corporations not only affect ecosystems but also rely on them. This interdependency poses challenges to companies, such as increased scarcity and cost of raw materials, reputational risk, and the emergence of environmental regulations and taxes on extractive activities (Athanas *et al*, 2006:2).

These challenges can create new business opportunities though, for example developing new technologies and products that will reduce degradation, restore ecosystems or increase efficiency of ecosystem use. However, companies routinely fail to recognise the link between healthy ecosystems and their business interests (Athanas *et al*, 2006:5-9).

LCA is not considered to be an environmental management tool to replace EMS tools such as EIA and product risk assessments. It is rather a complementary system tool that adds a holistic approach to the existing environmental management tools. LCA is considered to be a tool assisting decision-making, whereas EIA is regarded as a decision-making process in itself, and risk assessments tend to focus on a specific component of the overall process (Tukker, 1999:445; Olsen *et al*, 2001:386).

1.4. ANGLO AMERICAN PLATINUM LTD. (AMPLATS)

Anglo American Platinum Ltd. (AMPLATS) is the largest platinum producer in the world, with an annual platinum production of 2.5 million ounces refined platinum, constituting some 40% of the world's newly mined platinum supply. The company consists of 10 underground and opencast mines, six concentrators, three smelting operations, a base metal refinery

and a precious metal refinery. There are also several non-managed Joint Ventures, Black Economic Empowerment (BEE) initiatives and new projects in various phases of development.

All operations in the group have implemented environmental management systems that comply with ISO 14001 requirements and are certified to ISO 14001. Effective management of environmental impacts is high on the list of priorities for the group.

Although various impact assessments and management plans have been developed for segments of the platinum production process, there has not been a holistic analysis of the overall platinum producing process. In addition to these management initiatives, results from a LCA focused on Platinum could be used to set realistic, focused objectives and targets for environmental management plans, thereby improving the effectiveness of existing environmental management plans.

1.5. RESEARCH QUESTION

The potential benefits of a LCA for AMPLATS and the Platinum Industry were assessed by evaluating LCA's that were conducted for other industries, to determine potential benefits gained and problems experienced during the process. The LCA process as defined by the Department of Environmental Affairs and Tourism and the EPA was described, and a preferred approach for Platinum is proposed based on insight gained from the research.

The objective of the research was to evaluate benefits gained by LCA for other industries, and to identify potential benefits of a Life Cycle Assessment (LCA) for AMPLATS, and ultimately the Platinum sector. Problems experienced were discussed in order to develop mitigating controls prior to conducting a LCA. The overall research question is "does LCA have significant benefits for the platinum industry"?

The EPA pointed out that LCA can be resource and time intensive. *"Gathering of data can be problematic, and availability of data can greatly impact the accuracy of the final results."* Therefore, it is essential to weigh the availability of data, the time necessary to conduct the study, and the financial resources required against the projected benefits of the LCA (EPA, 2006:5).

1.5.1. Sub-Questions

In order to answer the main research question, it is necessary to answer the following sub-questions:

- What benefits did other industries realize from LCA?
- What approach should be followed to conduct the LCA for AMPLATS and the platinum industry?
- What are the anticipated benefits to the Platinum industry of conducting an LCA?

1.6. RESEARCH METHODOLOGY

In order to answer the sub-questions, the following research methods will be applied:

- LCA was discussed from literature, including different approaches. This included the history of environmental management, and specifically LCA, and the LCA process as prescribed by local and international government agencies.
- Potential benefits to the Platinum industry were discussed from literature and case studies of LCA studies conducted for other industries. Problems experienced during the conducting of these LCA's were also discussed.
- The platinum extraction and beneficiation processes were compared to the case studies to determine applicability of lessons learnt from the case studies to the platinum industry. In conclusion an opinion was given as to the potential benefits to AMPLATS, and an appropriate LCA approach for the platinum industry.

1.7. SECTIONS

Chapter 1: The first chapter includes a discussion on the history and background of environmental management and LCA, followed by the research question, sub-questions, and research methodology.

Chapter 2: The second chapter, describes existing LCA methodologies and approaches.

Chapter 3: Chapter 3 considers various LCA case studies and discusses lessons learnt and benefits realized by conducting LCA in various industries.

Chapter 4: This chapter summarises business benefits and limitations of LCA from the literature review. The platinum extraction and beneficiation process is discussed, and the applicability of LCA and anticipated benefits for AMPLATS in the context of the literature review are discussed. Findings, conclusions and recommendations are presented in this chapter, as well as a proposed way forward.

CHAPTER 2 – A LITERATURE REVIEW OF LCA

2.1. LIFE CYCLE ASSESSMENT AS AN ENVIRONMENTAL MANAGEMENT TOOL

The previous chapter summarised the history of environmental awareness and the associated increased focus on responsible environmental management practices. Several environmental management tools have been developed to predict potential environmental impacts, identify and quantify actual impacts, and effectively manage controls to mitigate these impacts. The plethora of environmental management tools available, and the specific purpose and benefits of each tool, can be confusing. Where does Life Cycle Assessment (LCA) fit into overall environmental management?

Environmental Impact Assessment (EIA) is generally used as the tool to manage environmental impacts. Manage in this context refers to the identification, quantification and mitigation of potential and actual environmental impacts associated with a product, service or activity. Tukker stated that “*EIA is a procedure rather than a tool, in which LCA certainly may be useful.*” (Tukker, 1999:435)

LCA is a comprehensive study that requires significant investment of resources to complete. Tukker (1999:435) describes the difference between the approach of LCA and EIA as fundamentally relating to the focus on time and location.

The focus of LCA is the entire production chain of a product, assessing the environmental impacts associated with the life-cycle of the product. The emphasis is on a time- and location-independent assessment of potential impacts in relation to an entire production system (Tukker, 1999:436). LCA is a product assessment tool fundamentally non-specific regarding time and site (Olsen *et al*, 2001:397).

EIA, on the other side, is a procedure that supports decision-making with regard to environmental aspects of a much broader range of activities. EIA is often regarded as a local, point-source oriented evaluation of environmental impacts, considering time-related aspects, the specific local geographic situation, and the existing background pressure on the environment Tukker (1999:435). EIA enables decisions to be made, for example, about waste management plans, process installations, and location choices.

Tukker stated that the systematic approach of LCA is a crucial part of EIA, especially strategic and project EIAs where activities upstream and downstream of the production chain should be considered in the process of comparisons of process and abatement alternatives. *“LCA is a specific elaboration of a generic environmental evaluation framework.”* (Tukker, 1999:435) The USA Environmental Protection Agency (EPA) considers LCA a systematic tool used for assessing environmental impacts of a product, to help decision-makers to compare all major environmental impacts caused by products, processes or services when deciding between two or more alternatives (EPA, 2006:3).

2.2. DEFINITION OF LCA

The Department of Environmental Affairs and Tourism (DEAT) defines Life Cycle Assessment (LCA) as the process of *“calculating and evaluating the environmentally relevant inputs and outputs and the potential environmental impacts of the life cycle of a product, material or service”* (DEAT, 2004:2).

The EPA considers LCA to be *“unique because it encompasses all processes and environmental releases beginning with the extraction of raw materials and the production of energy used to create the product through the use and final disposal of the product.”* (EPA, 2006:3). LCA therefore considers the production, use and disposal of a product, which constitutes the life cycle of the product.

The inputs of the life cycle of a product starts at the demand for natural resources, as well as the impacts of the extraction, production and transport of raw resources. Life cycle outputs related to the product should include emission of solid and other waste, as well as disposal or recycling of the product. LCA provides information on the environmental burden at all stages, based on the assumption that all steps in the life cycle are inter-related.

2.3. LIFE CYCLE ASSESSMENT PROCESS

The LCA process is a systematic process to identify and quantify all inputs and outputs, thereby assessing the environmental aspects and potential impacts associated with a process, product or service (Urie & Dagg, 2004:154). The process starts by compiling an inventory of relevant energy and material inputs and environmental releases. Once a comprehensive inventory has been completed, an evaluation is done of the potential environmental impacts associated with identified inputs and releases. Finally the results are interpreted to help decision makers make an informed decision. This approach forms the basis of environmental management systems as defined in the ISO 14000 series.

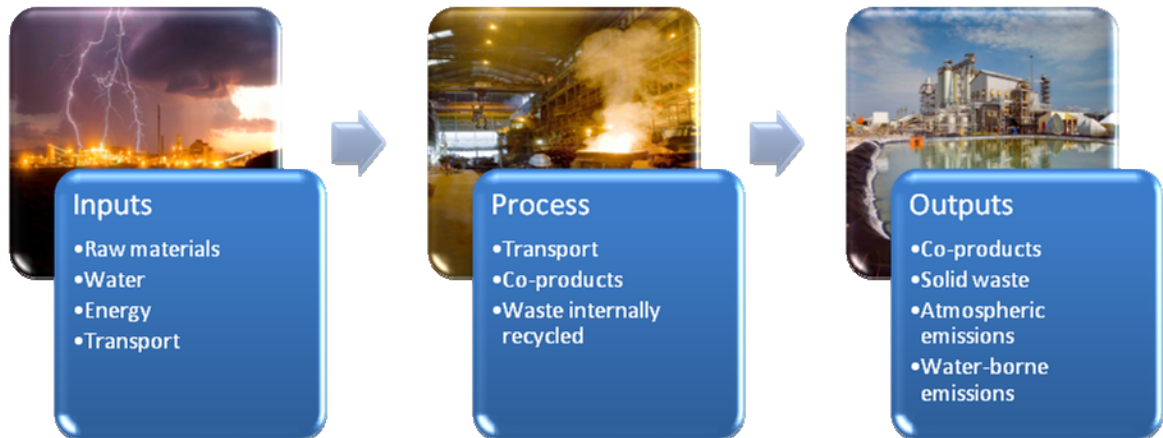


Figure 1: Diagrammatic representation of Inputs, Process and Outputs (EPA, 2006:13)

Both the South African and United States of America's governments define the LCA process as a systematic, phased approach consisting of four components (EPA, 2006:2; DEAT, 2004:4):

1. Goal and scope definition;
2. Inventory analysis;
3. Impact assessment; and
4. Improvement assessment.

The boundaries and limits of the LCA study are defined in the goal and scope definition phase. A full listing and categorisation of the various elements involved in the life cycle being studied, that fall within the pre-defined boundaries, comprise the inventory analysis of the LCA. During the impact assessment all the impacts associated with the elements listed and categorised are described and quantified. Finally, the improvement assessment phase evaluates the results of the impact assessment, forming the basis for improvement of the existing cycle.

Each of these four components will now be discussed in more detail.

2.3.1. Goal and scope definition:

The first phase of LCA is the goal and scope definition. The purpose of the goal and scope definition is that all role players have a clear understanding of the purpose of the study, the product and systems being studied, requirements related to the data and research methodology, and limitations of the study.

The goal and scope have to define the audience and reason for the study, as well as allocation approaches. The context in which the assessment is to be made has to be established, and the boundaries and environmental effects to be reviewed for the assessment have to be defined. Furthermore, the data requirements, data quality requirements, quality assurance of the results, key assumptions, impact assessment method, interpretation method, and type of reporting have to be defined and agreed by all parties (DEAT, 2004:4; EPA, 2006:7; Pehnt, 2001:92).

Norgate and Jahanshahi (2010:68) define LCA as having one of two approaches, problem-oriented (mid-points) or damage-oriented (end points).

The EPA suggests consideration of six questions at the beginning of the LCA process to make effective use of time and resources: (EPA, 2006:7-18)

a. Define the goal or purpose of the project.

Traditionally, LCA is primarily used to provide input into decisions about a preferred product, process or service, in the form of information about potential and actual impacts on the environment and human health and well-being. Information gained from LCA can also be used for business-improvement opportunities toward a net reduction of resources requirements and emissions.

Other potential purposes for LCA could include any of the following:

- *Support wider environmental assessments* – LCA results are valuable in understanding the relative environmental burdens between alternative processes and in comparing the environmental aspects of alternative products that serve the same purpose.
- *Establish baseline information for a process* – LCA establishes a baseline of information on an entire system considering current or predicted practices in the manufacture, use and disposal of the product. This information is valuable for improvement analysis.

- *Rank the relevant contribution of individual steps or processes* – Details regarding aspects and impacts of each process in the overall system being studied highlight processes that contribute the most towards pollution, or require the most energy and resources. This is especially relevant for internal industry studies to support decisions on pollution prevention, resource conservation and waste minimization opportunities.
- *Identify data gaps* – Processes within the system where data is lacking or questionable are disclosed.
- *Provide information and direction to decision-makers* – Industry, government and the public can be informed by LCA on the impacts of alternative processes, products or materials.

b. Determine what type of information is needed to inform the decision-makers

The information required by decision-makers could relate to the quantification of an environmental impact in a particular process, what the overall environmental impact would be if a certain process within the system is altered, or the impact of the process on a specific environmental concern, such as global warming or acid rain. The type of information required to answer these questions has to be determined to ensure appropriate focus is placed on the correct processes.

c. Determine the required specificity

The required level of data accuracy has to be decided based on the use of the final results and the intended audience. Generic, estimated data and best engineering judgment is often adequate for LCA used internally, whereas more detailed information will be required if the intent of the LCA is to support process or product selection by the public or a regulator. Most LCA studies use a suitable combination of generic and accurate information. The level of specificity should be very clearly defined and communicated to enable readers to understand the final results adequately.

d. Determine how the data should be organised and the results displayed.

LCA data is organised in terms of a functional unit that appropriately describes the function of the product or process being studied. When LCA results are used to compare products, the basis of comparison should be equivalent use, i.e. similar amounts of product delivered to the customer.

e. Define the scope of the study

LCA should include all four stages of a product or process life cycle, i.e. raw material acquisition, manufacturing, use/reuse/maintenance and recycle/waste management. The scope should define whether one or all of the stages should be included in the LCA.

Norgate and Jahanshahi (2006:842) divide the life cycle into three stages:

- Cradle to entry gate (raw material extraction and production)
- Entry gate to exit gate (manufacturing of product)
- Exit gate to grave (use of product, recycling and disposal)

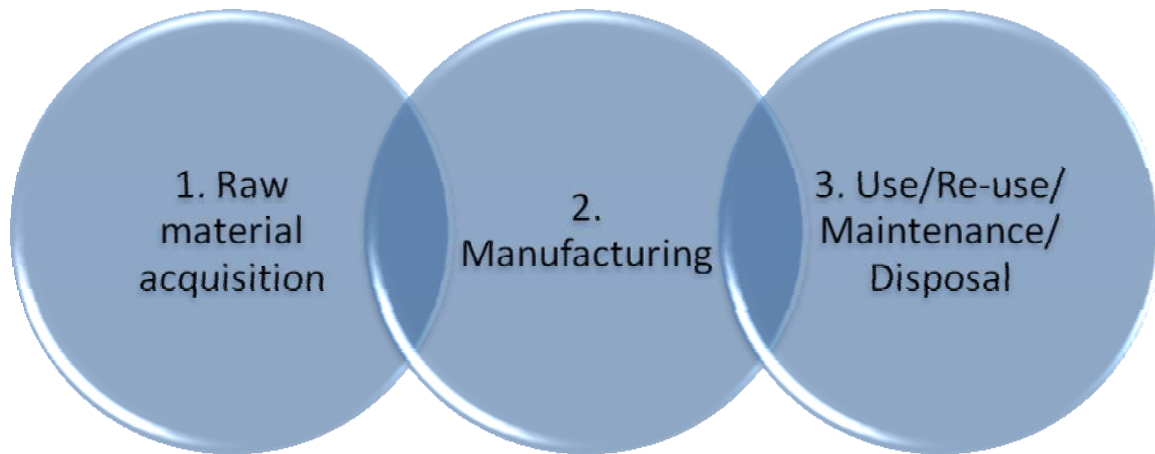


Figure 2: Life Cycle Stages (adapted from Ciambrone, 1997:15)

When defining the processes that constitute the life cycle of a product, the sequence of processes should be broken down into primary and secondary categories. The primary category activities directly contribute to the manufacturing, using or disposing of the product, whereas secondary category activities contribute to materials or processes that in turn form part of the primary category of activities.

Scharnhorst noted that the end of life phase (3 in Figure 2 above) starts with the dismantling of a specific device and ends with the final output of the secondary raw material production and/or final disposal, either by landfilling or incineration, of waste products (Scharnhorst *et al*, 2005:543). The recovery processes that result in the production

of secondary raw material can be sub-divided into pre-separation, dismantling, shredding, fractionation, material recovery and secondary raw material production.

The system boundaries should clearly define where the analysis will be limited and the reasons for the decisions. The following issues should be considered when setting and describing specific system boundaries:

- The required comprehensiveness of the life cycle to be studied should be clearly defined, and decisions to select specific boundaries motivated. Cognisance should be taken of the fact that a complete life cycle system would start with all raw materials and energy sources in the earth and end with all materials back in the earth.
- Supplementary materials or chemicals used to manufacture or package the product, or run the processes, may significantly contribute to demand for raw materials or emissions. In that case, the supplementary materials or chemicals should be included in the study.
- When LCA is used as a comparative study, consideration should be given to the potential that extra materials or processes might be required to allow one product to deliver equivalent performance to the other.

It is of utmost importance that every step be included that could affect the overall interpretation of the analysis to address the issues for which the LCA is being performed.

In the case of very detailed life cycles of products, such as magnesium production, the LCA can be broken down to various cradle-to-gate studies, comparing some clearly defined systems or processes to provide more accurate results. Cherubini *et al* (2008:1095) studied four magnesium production processes in a cradle-to-gate LCA to compare the environmental burdens of the processes used by the most significant magnesium producing countries.

f. Determine the ground rules for performing the work.

The final requirement of the goal and scope definition phase is to define the logistics of the project.

- *Documenting assumptions* – All assumptions and decisions should be reported as part of the final report.
- *Quality assurance procedures* – These procedures ensure that the goal and purpose for performing the LCA are met at the conclusion of the project.

- *Reporting requirements* – The required format and information included in the final report should be defined upfront. This includes how the final results should be documented, the methodology used, as well as the systems analysed and the boundaries that were set. Furthermore any assumptions made should be explained.

2.3.2. Inventory Analysis:

The second step of the LCA process is the Life Cycle Inventory (LCI), which is a quantification of all the system's inputs and outputs to produce a list or inventory of all processes within the life cycle as defined in the scope (Urie & Dagg, 2004:154). During the LCI all relevant data are collected and organised to form the basis to evaluate comparative environmental impacts or potential improvements.

The EPA describes the LCI as the quantification of energy and raw material requirements, atmospheric and waterborne emissions, solid wastes and other releases associated with the entire life cycle of the product, process or activity (EPA, 2006:19). The results can be segregated by life cycle stage, media (air, water and land), specific processes, or any combination thereof.

Similarly, DEAT defines the LCI phase as the collection and interpretation of data, resulting in a flow model of the technical system (DEAT, 2004:4). Emissions, energy requirements and material flows are calculated for each process.

According to the EPA (2006:19) there are four steps to follow in order to complete a comprehensive LCI:

- a. Develop a flow diagram of the processes being evaluated as defined in the scope.
- b. Develop a data collection plan.
- c. Collect the data.
- d. Evaluate and report the results.

a. Develop a flow diagram of the processes being evaluated.

Developing a flow diagram provides the road map for data to be collected. The flow diagram maps the inputs and outputs to a process or system, with unit processes within the system boundaries linking together to form a complete picture of the life cycle being studied. The system boundaries for the flow diagram are based on the boundaries defined in the scoping phase of the LCA. If the LCA is used as a comparative study, the boundaries and level of detail for all alternatives being evaluated have to be the same (EPA, 2006:19).

The level of accuracy required as defined in the scoping phase determines the complexity of the flow diagram. Generally a more complex flow diagram equates to greater accuracy, however this also requires more time and resources.

The system should be divided into a series of sub-systems, each of which is a step or process that forms part of the overall production system. Each stage is broken down to sequentially smaller processes, extending from extracting raw materials to final delivery (Staffel & Ingram, 2010:2492).

Every sub-system has inputs and outputs that contribute to those of the overall system, i.e. inputs of materials and energy, transportation of product produced, and outputs of products, co-products, emissions to the atmosphere, water, solid waste, and other possible releases. These inputs and outputs should be described and quantified. Ultimately this data forms part of the overall quantification of the inputs and outputs of the production system being studied.

Outputs from the system are not limited to the final product and waste emissions only, but also include co-products, which usually have commercial value. When only one product from a suite of products from the same production process is being studied, the inputs and outputs that form part of the production system should be allocated proportionately and objectively to the various co-products. Allocation should allow technically sound inventories to be prepared for products or materials using any particular output of a process independently and without overlap of the other outputs.

Waste or co-products that are re-used within the production system as part of the internal recycling loop are not included in the inventory, because they do not cross the boundaries of the subsystem. Transport of co-products that form part of the internal recycling loop is included though.

If a commercially available software program is used to conduct the LCA, the program will define the quality required of data for input (Staffel & Ingram, 2010:2493).

b. Develop a data collection plan.

A data collection plan specifies the required data sources, types, quality, accuracy, and collection methods. One of the key outputs from the goal definition and scoping phase is the required accuracy of data (EPA, 2006:22). An LCI data collection plan ensures the quality and accuracy of the data meet the expectations of the decision-makers. An effective data collection plan will include the following key elements (EPA, 2006:23):

- **Defining the data quality goals**

The quality goals are closely linked to the overall study goals and will provide a framework for balancing available time and resources against the quality of the data required.

- **Identifying data sources and types.**

The required data sources and types of sources for accurate information pertaining to each stage of the life cycle, sub-process or environmental release have to be specified. Cognisance should be taken of confidential information and the method of reporting this data should be clearly defined to ensure the necessary protection of the information.

- **Identifying data quality indicators.**

As part of the quality assurance process of the study, certain data quality indicators should be defined against which collected data can be measured. The indicators should be appropriate and applicable to the data being evaluated.

- **Developing a data collection worksheet and checklist.**

Developing a spreadsheet that lists all the decision areas and the inter-relation between the various sub-systems is valuable to ensure consistency, accuracy and completeness. Allocating numerical values to the relationships aids the development of proportionality factors that will reflect the relative contributions of the sub-systems to the total system. Including every sub-system and its related components limits the possibility of omissions or double-accounting.

c. Collect data.

Collection of data consists of finding and filling in the flow diagram and worksheets with numerical data. Data are collected by a combination of research, site visits, and direct contact with experts, generating large quantities of data (EPA, 2006:28).

Some of the required data may be difficult or impossible to obtain, and the available data may be difficult to convert to the functional unit needed. Therefore, the system boundaries or data quality goals of the study may have to be refined based on data availability.

Industrial processes are physical, chemical or a combination thereof. Some industrial processes generate multiple output streams in addition to waste streams. The LCI should be modelled in such a way that calculated values of the various environmental burdens reasonably represent actual occurrences (EPA, 2006:37).

The term co-product is used to define all output streams other than the primary product that are not waste streams and that are not used as raw materials elsewhere in the system examined in the inventory (EPA, 2006:21). Co-products should be included only to the point where they no longer affect the primary product being studied. In effect the boundary of the analysis is drawn between the primary product and co-products, with all materials and environmental loadings attributed to co-products being outside the scope of the analysis.

In the case of co-products forming part of the output streams, a decision has to be made about the allocation of environmental burdens across the production process to the various co-products (EPA, 2006:28).

ISO 14041 (2007) requires that allocation is avoided where possible. Allocation is the process of partitioning input and output flows of a process to the product of interest, whilst partitioning the remainder of the input and output flows to the other co-products associated with the process. It is however not always possible to avoid allocation. Proper application of the ISO guidelines in allocation requires a good understanding of the physical relationships between co-products in a process. (ISO 14041: Clause 6.5.3)

In order to appropriately apply allocation, the system is modelled in a manner that reflects the physical relationships between the process inputs and outputs. Sub-systems have to be accurately defined, with data relating to the inputs and outputs of the sub-systems being as detailed as possible (EPA, 2006:29). The sub-system inputs and outputs should be depicted in a manner that reflects the underlying physical relationship between them, and the way these inputs and outputs are impacted by quantitative changes in products and functions within the system.

Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way which reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products. Fthenakis *et al* (2007:495) allocated the emissions from mining of zinc ores to the recovery of saleable zinc to zinc, and the emissions during the purification of the waste stream to extract a by-product, are assigned to the by-product during the study of the LCI for photovoltaic cells.

Every industrial process and LCA will include inputs and outputs specific and often unique to the specific process, however there are certain general inputs and outputs that should be considered as a rule. The EPA (EPA, 2006:29) defines several options available when deciding which raw and intermediate materials to include in a LCI.

- Incorporate all requirements, no matter how minor.
- Within the defined scope of the study, exclude inputs of less than a pre-determined and clearly stated threshold.
- Within the defined scope of the study, exclude inputs determined likely to be negligible, relative to the intended use of the information, on the basis of a sensitivity analysis.
- Within the defined scope, consistently exclude certain classes or types of inputs, such as capital equipment replacement.

Two key inputs to LCI, energy and water, are used to demonstrate the considerations to be included in the LCI, and the fact that inputs are not solely based on the commercial value or impact of the resource, but should take cognisance of the basic source of the resource, and the renewability of the resource (EPA, 2006:31).

Energy:

This includes energy required to operate the system, such as reactors, heat exchangers, stirrers, pumps, blowers and boilers. Transport energy is also included in this category, i.e. energy required to power trucks, trains, ships and pipelines. Energy requirements should be characterised on the basic sources of energy, therefore electricity should be considered based on the basic sources such as coal, nuclear power, hydropower, natural gas and petroleum that produce electricity (EPA, 2006:31).

Water:

Water volume requirements should be included in a life-cycle inventory analysis. The environmental impact of water use is variable based on the geographical location of the process. In some instances alternative water is available, such as sea water that might be used for cooling or other industrial processes where salinity is acceptable. However, when the industry is located far from the coast, water of higher quality might have to be used in the industrial processes (EPA, 2006:34).

Some industrial applications re-use water with little new or makeup water, whereas other applications require tremendous inputs of new water. Availability of water might be seasonal, or readily available in certain areas and scarce in other areas.

In practice, the environmental burden related to water used is stated as net consumptive usage (EPA, 2006:34). Consumptive usage is the fraction of total water withdrawn from

surface or groundwater sources that either is incorporated into the product, co-products (if any), or wastes, or is evaporated. The renewability of the water as a resource is determined in the impact assessment.

Outputs reflected in product Life Cycle Inventory Analysis.

Environmental releases are generally categorised as one of three categories of emissions: atmospheric emissions, waterborne waste, and solid waste (EPA, 2006:34). Most inventories consider environmental releases to be actual discharges (after control devices) of pollutants or other materials from a process or operation under evaluation. Both atmospheric and water borne emissions are reported as unit weight of product output, whereas solid waste is reported by weight. Products and co-products are also quantified.

Grouping the outputs together according to the specific environmental impact that it contributes to, for example Global Warming Potential that will include emissions of greenhouse gases such as CO, CO₂, CH₄ and N₂O, predominantly from production processes such as refineries and smelters, as well as indirect emissions from power plants that supply energy to the production process. Another environmental impact that is often used as a key indicator in LCA is Acidification, measuring oxides of Nitrogen and Sulphur (NO_x and SO_x) (Tan and Khoo, 2005:614).

Atmospheric Emissions

All emissions for which there are obtainable data should be included in the inventory. Cherubini *et al* focused on greenhouse gases emitted from the magnesium production processes, as well as emissions responsible for rain acidification, such as SO₂ and NO_x (Cherubini *et al*, 2008:1095).

Waterborne Wastes

As with atmospheric wastes, waterborne wastes from the production and combustion of fuels (fuel-related emissions), as well as process emissions, are included in the life-cycle inventory (EPA, 2006:35). The effluent values include those amounts still present in the waste stream after the wastewater treatment, and represent actual discharges into receiving waters.

Solid Waste

Solid waste includes all solid material that is disposed from all sources within the system. A distinction is made between industrial solid waste and post-consumer solid waste, as they are generally disposed of in different ways, and at different facilities (EPA, 2006:35).

Industrial solid waste includes waste generated in the actual process, such as waste material not recycled, sludges and solids from emission control devices, as well as fuel-related solid waste that is generated from the production and combustion of fuels required for transport and the operating process. Post-consumer solid waste refers to the product/package once it has met its intended use and is discarded (EPA, 2006:35).

Products

Every sub-system defined as part of the overall systems will have a resulting product, with respect to the entire system. This sub-system product may be considered either a raw material or intermediate material with respect to another sub-system, or the finished product of the system (EPA, 2006:36).

Transportation:

Energy requirements and emissions generated by the transportation requirements among sub-systems for both distribution and disposal of material, products and wastes are included in the LCI. This data is reported as a function of weight of material shipped and distance travelled, taking cognisance of the efficiency of the mode of transport used (EPA, 2006:36).

d. Evaluate and report results.

The key component of the report generated from the inventory analysis is a list containing the quantities of pollutants released to the environment and the amount of energy and materials consumed. The information can be organised by life cycle stage, media (air, water and land), specific process, or any combination thereof that is defined in the “Goal Definition and Scoping” phase, for reporting requirements. The categorisation logic followed could assist in identifying and subsequently controlling certain energy consumption and environmental releases (EPA, 2006:44).

The report should also include a detailed description of the methodology used in the analysis, a clear definition of the boundaries, the systems analysed, and any assumptions should be clearly explained.

2.3.3. Life Cycle Impact Assessment (LCIA)

The Life Cycle Impact Assessment (LCIA) is the third step of the LCA process, following the goal and scope definition, and the inventory analysis, which produces a list of environmental burdens associated with the life cycle of the product being studied. Urie and Dagg (2004:154) describe this stage as follows: *"The huge amount of data generated in the inventory is assessed by grouping the environmental burdens and classifying them into impact categories, followed by characterising them into comparable units."*

During the LCIA the production system is assessed to determine the potential human and ecological impacts, including resource depletion, energy, water and raw material usage, and the environmental releases identified in the inventory. This information will be used in the interpretation phase (DEAT, 2004:9; EPA, 2006:46). The impact assessment phase categorises and aggregates the environmental impacts according to the defined impact categories, such as global warming, and characterisation factors are calculated that determine the contribution of different inputs to the impact category (Pehnt, 2001:92).

Several assessment methods can be applied during the assessment phase of a LCA, because often a single method cannot provide comprehensive information on the environmental impacts, resulting in a LCA that provides only partial indications (Cherubini *et al*, 2008:1095).

It is important to understand the fundamental difference between the LCIA as part of the LCA process, and other types of impact analysis, such as risk assessments (RA). Olsen *et al* (2001:385) describe LCA and RA as two different tools in environmental management. For the purpose of this discussion, Risk Assessment will be compared to LCIA to demonstrate the two extremes on the scale of environmental management tools available. The comparison focuses on similarities and differences between the two tools, and their applications and purpose in environmental management.

LCIA is a relative assessment that does not aim to quantify the specific, actual impacts associated with a product, process or activity, but rather seeks to establish the link between a system and potential impacts associated with the system. Risk assessment, on the other hand, is an absolute assessment, requiring specific and detailed information, narrowly focusing on a single exposure at a specific location. LCIA is considered more universal than risk assessment due to the fundamentally holistic philosophy underpinning LCIA.

The intent of conducting a risk assessment is the detailed modelling of the predicted impacts of, for instance, a chemical on the population exposed and the probability of the

population being impacted by the emission. In the case of LCIA, it is possible that the study will evaluate large quantities of chemical emissions occurring at various locations for their potential impacts on multiple impact categories. LCIA is therefore considered to be a comparative tool, since the environmental impacts of similar products are assessed in relation to each other.

Olsen *et al* (2001:397) argued that both LCA and RA are based on the principle of hazard identification, however due to different uses and aims they result in a relative or comparative assessment for LCA, and an absolute assessment for RA respectively. Even though the conceptual background and the purpose of LCIA and risk assessment are different the two tools complement each other in an overall environmental effort.

LCIA identifies stressors as a result of the hazard identification process, and systematically classifies and characterises the environmental impacts due to these stressors. Stressors are defined as a set of conditions that may lead to an impact.

Due to the fact that LCIA includes a vast number of stressors, at a variety of locations with different environmental burdens, LCIA is not conducted with the same rigour as a risk assessment. LCIA models utilise assumptions and default values that are accepted within the various impact categories. The resulting models that are used within LCIA are suitable for relative comparisons, but not sufficient for absolute predictions of risk (Olsen *et al*, 2001:397).

The intended purpose of the LCIA will determine the approach to be adopted for the study. LCIA specifically assesses the product's contribution to all types of environmental impacts, such as global warming, stratospheric ozone depletion, toxicity, etc, and the use of resources.

At the onset of the LCIA, the impact categories to which the environmental impacts relate have to be classified, and the characterisation where the impact potentials are assessed should be defined, using science-based conversion factors. The assessment of the outputs is based on the fate and effect of the compounds. The impact assessment results in a single or a few impact potentials, which characterise the product's total impact on the individual impact categories (ISO 14042:2000).

ISO 14042 – Life Cycle Impact Assessment (ISO 14042:2000) defines seven key steps to LCIA, of which steps 1-3 and step 7 are mandatory, and the inclusion of steps 4-6 depends on the goal and scope of the study.

Key steps to a LCIA according to ISO 14042:2000:

- a. **Selection and definition of impact categories** – identifying relevant environmental impact categories (e.g. global warming, acidification, terrestrial toxicity)
- b. **Classification** – assigning Life Cycle Inventory (LCI) results to the impact categories (e.g. classifying carbon dioxide emissions to global warming.)
- c. **Characterisation** – modelling LCI impacts within impact categories using science-based conversion factors (e.g. modelling the potential impact of carbon dioxide and methane on global warming)
- d. **Normalisation** – expressing potential impacts in ways that can be compared (e.g. comparing the global warming impact of carbon dioxide and methane for the two options).
- e. **Grouping** – sorting or ranking the indicators (e.g. sorting the indicators by location: local, regional and global)
- f. **Weighting** – emphasising the most important potential impacts.
- g. **Evaluating and reporting LCIA results** – gaining a better understanding of the reliability of the LCIA results.

2.3.4. Improvement assessment

The objective of this phase is to evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results (EPA, 2006:2). DEAT recommends the final phase of the LCA process to analyse the results in relation to the goal and scope definition, reach conclusions, present the limitations of the results and the propose recommendations based on the findings of the preceding phases (DEAT, 2004:4).

The requirements of the final report are defined in the goal and scope definition phase, and the format of the final report has to be aligned with these requirements. Typically the specified requirements will include the documentation of assumptions and decisions made during the study, the quality assurance procedures implemented to ensure the goal and purpose of the LCA are met, the final results, the methodology used, as well as the systems analysed and the boundaries that were set.

Tukker (1999:450) describes the LCA approach as systematic, comparing systems that include the supply and waste treatment processes related to a product. He argues that an LCA-type evaluation approach is relevant when the alternatives concerned have many

indirect influences in an entire production system and affect a large number of impact categories.

2.4. TYPES OF LCA AVAILABLE

Life Cycle Assessment is resource-intensive, involving significant costs, time and expertise. It is therefore essential to start the LCA with a clear understanding what the expectations are in conducting the study. Depending on the anticipated use of the LCA results, a decision can be made related to the type of LCA to be conducted. There are three types of LCA defined by the DEAT (2004:5) in South Africa that companies can select from:

- a. Conceptual LCA – Life Cycle Thinking;
 - b. Simplified LCA; and
 - c. Detailed LCA.
- a. Conceptual LCA (Life Cycle Thinking)** – The Conceptual LCA is used to make an assessment of environmental impacts based upon a limited and often qualitative inventory, rather than using quantitative data. The results are presented using qualitative statements, graphics, flow diagrams or simple scoring systems, indicating which components or materials have the largest environmental impacts and why (DEAT, 2004:5). A conceptual LCA will be used internally only to inform decision-makers on environmental impacts of the product, thereby influencing decision-makers' attitudes.
- b. Simplified LCA** – The Simplified LCA screens the entire life cycle of the product, identifying the important parts of the life cycle, as well as existing gaps using generic data. Further work is focused on the identified important parts or elementary flows by a process referred to as "Simplifying". Finally the reliability of data is assessed to ensure the simplifying process did not significantly reduce the reliability of the overall result.
- c. Detailed LCA** – This involves the full process of LCA and requires extensive and in-depth data collection, specifically focused on the goal of the LCA. If only generic data is available, detailed data must be collected specifically for the product or service under review.

2.5. USES OF LCA

LCA studies are used to provide companies with information to respond to market demands regarding their products and processes, legislative pressure and to explore improved product development and design. The South African Department of Environmental Affairs and Tourism

(DEAT) identifies the following potential uses for LCA in their document on Life Cycle Assessment: (DEAT, 2004:6-7)

Product improvement: Manufacturers prepare LCA's to create a base from which to improve and develop the product or the production processes, by developing a systematic evaluation of the environmental consequences associated with a given product. Information from the LCA is for internal use and kept confidential, and forms a key component of maintaining a competitive edge in the marketplace. The cost of this work is high and the value significant.

Product design: New products are often developed from existing designs and concepts, and the LCA is used to compare existing designs with projections for new products. Results from such a comparative LCA can be used to motivate for capital expenditure on upgrading and replacing infrastructure and technology. A comparative LCA can be completed to compare health and ecological impacts between two or more rival products/processes or identify the impacts of a specific product or process.

Formulation of company policy: LCA's can contribute significantly to the development and modification of company policies in specific areas, such as waste management, raw material selection and increased recycling potential of the product.

Product information: LCA could provide product information that might be required for licensing or legal compliance, such as the quantification of environmental releases to air, water, and land in each life cycle stage and/or major contributing process. The documentary audit trail created by the LCA process can provide evidence in confirming the validity of data used in product-related decisions and choices.

Use in negotiations with authorities: Information from LCA studies can be used by industries when engaging with authorities to ensure achievable, realistic cleaner production targets and requirements are set when permits, authorisations and license conditions are agreed. Information from LCA's can be used to ensure requirements are based on verified data and practicality. LCA is also used to analyze the environmental trade-offs associated with one or more specific products/processes to help gain stakeholder (state, community, etc.) acceptance for a planned action.

The process of completing a LCA is clearly defined, whilst leaving adequate room for customising the study to optimise the results obtained. The following chapter will focus on case studies of industries that are comparable to the mining industry.

CHAPTER 3 – LCA CASE STUDIES

3.1 INTRODUCTION

This chapter will evaluate benefits and problems experienced by industries that completed LCA in order to determine the applicability of LCA to the platinum industry, and to inform an optimised approach for the platinum industry.

Tukker (1999:445) described LCA as a tool designed to evaluate the impacts of the production, use and waste management of goods. An LCA may be performed for the purpose of:

- decisions involved in product and process development;
- decisions on buying;
- structuring and building up information;
- eco-labelling;
- environmental product declarations; and
- decisions on regulations.

LCA is concerned with comparing the impacts related to different products or assessing the dominant environmental problems related to the production of a product (Tukker, 1999:445).

The rest of this chapter investigates processes followed, various applications of LCA, benefits realised and challenges experienced for various industries that conducted LCA's. The focus of LCA is predominantly the environmental impacts of the production process or the product, as defined in the goal and scope phase. The feasibility of combining different methodologies or issues to be studied is discussed.

3.2 CASE STUDIES

3.2.1 Use of abridged LCA

Urie and Dagg (2004:153) proposed an approach focused on life cycle thinking through an abridged LCA approach rather than a detailed inventory compilation, to study the environmental impacts of building products. In this case the abridged LCA is a pragmatic approach, since it considers only three parameters, being resource consumption, energy use and human and ecological impacts. The approach also requires a relative rather than absolute assessment.

A literature review was initially conducted to identify the three major environmental impact categories in the building industry. A matrix is used to plot five life cycle stages against these three impact categories, and a value is assigned to each cell to indicate positive, negative or similar impact as compared to a reference product. (-1; 0; +1). The matrix is completed by a small team in a short period of time. This methodology is subjective, although the information used to populate the matrix might be objective. It is effective for comparison, e.g. bricks made from incinerated sewage sludge vs. clay.

There is a degree of alignment between the building industry and the mining industry, therefore the applicability of an abridged LCA as described in the case study conducted by Urie and Dagg (2004:153) can be extrapolated to the mining industry. An abridged LCA has the potential to be qualitative and quantitative, and could potentially be completed relatively quickly.

One of the benefits of using qualitative data is that non-scientific users are able to easily understand and use the LCA results. Furthermore, an abridged LCA provides a solution for cases where confidentiality issues cause difficulty to collect accurate quantitative data. The abridged LCA excludes some environmental categories or lifecycle stages, resulting in a LCA focused on the included impacts only. This might lead to a small but critical environmental impact being excluded from the study.

Due to the very large scale and complexities of both the construction and mining industries, there are several similarities in LCA requirements for both these industries. The most significant of these are:

- The LCA methodology should be consistent and usable across different assessment teams, providing results that can be replicated and are comparative when different teams study similar areas;
- It should include all stages of the life cycle and all relevant stressors;
- The methodology should be simple enough to allow for relatively quick and inexpensive screening assessments to be made, in order to identify areas that require further in-depth studies.

Urie and Dagg (2004:160) stated that the aim of the abridged LCA is to provide a tool that is attainable, encourages responsible decision-making using life-cycle thinking, is thought-provoking and stimulates the reader to think about environmental issues, and incorporates project-specific issues.

Although the motivation for a streamlined approach is sound, the success depends on a large number of variables being the same. For the purpose of mining, it has a limited use where

alternatives are to be compared, and the variables are known to be constant and similar. For a comprehensive understanding of environmental burdens and the impact of a change on upstream or downstream processes a full LCA has to be conducted, since an abridged LCA will not deliver the same value and information to decision-makers.

3.2.2 LCA as comparative tool – production processes

Cherubini *et al*, (2008:1093) Tan & Khoo (2005:607) and Norgate *et al* (2006:839) evaluated the use of LCA to compare metal production processes to ascertain the sustainability of the various processes. Metal production processes studied include the production of various light-weight as well as heavy metals, including magnesium, aluminium, copper, zinc, nickel, and lead.

The continually increasing interest in sustainable development world-wide has increased attempts to reduce emissions and increase efficiency of resource utilisation. Production processes of metals generally have significant environmental impacts, due to the high energy requirements and chemical processes involved. Metals are not biodegradable, and resources of minerals and metals are usually non-renewable. Recycling of metals is a practice that can significantly improve efficiency of metal processing, however, even with increased recycling, the extraction of metals will increase into the future due to increased demand with the anticipated growth of economies of developing countries (Norgate *et al*, 2006:838).

The environmental impacts of metal production are of particular interest at the moment, especially the use of light-weight metals due to the potential positive impact that utilising lighter metals have on downstream applications of the metals. Both magnesium and aluminium are enjoying increasing attention due to the lighter weight of both metals and high strength-to-weight ratios. Magnesium and aluminium are used in the automobile industry, resulting in improved fuel consumption due to the lighter weight of the vehicles. Other applications are in aerospace, beverage containers and electronics (Cherubini *et al*, 2008:1093; Tan & Khoo, 2005:607).

The production processes of the metals in the case studies are, as for platinum, complex by nature. Due to the fact that the metal production processes involve a large number of feed streams, by-product streams, waste streams and energy inputs it is not a straightforward process to evaluate the environmental impacts of the production processes. The processes are energy intensive, giving rise to growing concerns of atmospheric emissions and high consumption of coal to supply energy to the processes.

Due to the potential positive environmental impacts associated with the increased use of the metals, as well as the existing negative impacts of the production processes, it is essential to

evaluate these processes over the entire life cycle of the metals to get a true reflection of the environmental burden.

The case studies defined specific environmental parameters to use in the comparison of the production processes to each other. These include the impacts of the production processes on greenhouse gas and acid rain gas emissions, solid waste emissions and gross energy consumptions.

The magnesium LCA studied by Cherubini *et al* (2008:1093) the sustainability of the production processes of the major magnesium producing countries in the world, whereas Norgate *et al* (2008:1093) compared new and existing production processes of different metals such as copper, zinc, nickel, aluminium and lead. Tan and Khoo (2005:607) focused their study on the production of the solid waste product known as red mud as part of the aluminium production process. The scopes for the three case studies were all cradle-to-gate, i.e. not considering the use and disposal phases of the metals once production of the metal was complete.

The LCA in each case provided valuable information, with the magnesium production study showing that the process used by China is the least sustainable production chain since it has the highest environmental burdens and material and energy consumption, and the lowest energy efficiency (Cherubini *et al*, 2008:1093). The Chinese production process is therefore more polluting than the other processes studied. The study provides valuable information to international policy makers by raising concerns about the sustainability of the process utilised by the major contributor to the world's magnesium production.

Tan & Khoo demonstrated a correspondence between the reduction of waste and an improved environmental performance, and profitability. The study also showed the benefit of scheduling maintenance stoppages for the machines to optimise the performance of the machines, resulting in improved production with less waste. The LCA results helped pinpoint several tangible strategies to improve the environmental life cycle of primary aluminium, from mining to its final production (Tan & Khoo, 2005:607).

The LCA studied by Norgate *et al* (2006:842) was problem-oriented where the environmental loads as quantified in the inventory analysis were classified into the environmental impacts to which they contribute using appropriate equivalency factors. The authors note that there are many factors associated with a particular metal production process that influence the cradle-to-gate environmental impacts of the process. These include ore grade, electricity energy source, fuel types, material transport and process technology (Norgate *et al*, 2006:844).

The study showed that the cradle-to-gate environmental impacts of the lighter metals were much higher than those for the heavier metals, however, when comparing the environmental impacts of the light and heavy metals, the light metals had lower environmental impacts for the cradle-to-grave life cycle when the high strength-to-weight ratio of the light metals are optimised.

3.2.3 LCA as comparative tool – life cycle stages

Traditionally studies of environmental impacts focus on the production phase of a product. This is the phase where the manufacturer has the most control, enabling changes to the production process to reduce the environmental impacts, thereby enhancing the environmental performance of the manufacturer. The three case studies in the previous section focused only on the production phase, or cradle-to-gate phase of metal production. However, the use and disposal phases of a product usually also have significant environmental impacts, which become more pronounced as the production processes are adapted to reduce the environmental impacts.

Zackrisson (2005:43) stated that the product use and disposal phases result in significant impacts, and therefore there is a need to pay more attention to the environment when designing a product. ISO 14001 doesn't optimise environmental improvement, because the focus is predominantly on the manufacturing phase of the products. The Swedish environmental governance system requires an initial review to be completed before an environmental management system is developed based on ISO 14001. The initial review follows a life cycle approach, tracking activities up- and downstream, including the use and disposal phases of a product. The gate of the production facility is not regarded as the system boundary.

The case studies following have been conducted to determine the life cycle phase that results in the most significant environmental impacts for a specific product. It is not possible to identify one specific life cycle phase that consistently results in the biggest environmental burden, and the significance of the environmental burden of a specific life cycle stage changes as more efficient technologies are implemented, resulting in improvements in processes.

Scharnhorst *et al* (2005:541) studied the relative importance of the end of life phase of a mobile phone network life cycle as compared to the production and use phases of the life cycle. Pehnt (2001:91) evaluated the ecological performance of the production process of polymer electrolyte fuel cell stacks, and compared the environmental impacts of various components and materials to the environmental impacts observed during the “use” phase of the stacks in vehicles. Staffel and Ingram (2010:2491) conducted a LCA on an alkaline fuel cell based domestic combined heat and power system, and comparing the results to the environmental impacts identified in the LCA of other fuel cell technologies, specifically solid oxide and phosphoric acid fuel stacks.

The results of the study conducted by Scharnhorst *et al* (2005:560) showed that the use phase of mobile phone networks have the most significant environmental impacts, whereas the production phase contribute most to the impacts on human health. Ecosystem quality is most significantly impacted by the end of life phase. Recycling of materials, especially precious and rare metals reduce the environmental impacts in both the end of life phase and the production phase.

The LCA for the mobile phone networks resulted in an understanding of the significant impacts of the different life cycle phases, as well as the life cycle phase that contributes most to the environmental impacts. Several suggestions were made about processes that can be optimised, and products and materials that should either be recycled or alternatives found. It was a helpful tool to assist decision-making and ensure focused attention in the areas that will result in the most significant results or improvements.

Pehnt's study of innovative energy systems showed that renewable energy systems, such as the fuel cells, show minimal emissions during the energy conversion phase, therefore the production phase becomes significant with regard to environmental burdens (Pehnt, 2001:92). The study indicated that the environmental impacts of the production phase are significant compared to the environmental impacts of the utilisation phase.

Several improvement potentials were identified related to PGM as a result of the LCA for fuel cells conducted by Pehnt (2001:97). The reduction of impacts related to the use of PGM is economically and ecologically most significant. This study proved to be helpful when new technologies are investigated to reduce a specific environmental impact. It is important to have a thorough understanding of the environmental burdens associated with new technology, and not only to focus on the impacts that will be reduced, such as atmospheric emissions.

The results of the LCA conducted by Staffel and Ingram (2010:2503) showed that the production of the fuel cell stack itself is relatively insignificant compared to the impacts of producing the other components, most notably the production of stainless steel and other structural materials. In order to minimise the environmental impact, recycling of stack components should be improved. Efforts should be focused on reducing the weight of the stacks, and therefore the mass of steel contained. The system should be designed for ease of disassembly and recycling to improve take-back rates, thereby reducing environmental impacts. The greatest benefit will be realised by improving the operating lifetime of the stacks.

Zackrisson concluded that the largest environmental impacts are during the use and disposal phases of a product, and not during the manufacturing phase. The LCA further indicated that the

environmental impact due to staff and duty travel exceed the travel impact of transporting goods. The practice to exclude staff travel from a LCA should be questioned (Zackrisson, 2005:49).

3.2.4 LCA as tool to predict long-term impacts

Life cycle thinking includes consideration of the impacts of the disposal phase for a product. This poses challenges unique to the end-of-life phase of the life cycle, since the expected life of the product often extends to years, and there is no accurate way of predicting what technologies might be available, or future legislative requirements. Furthermore, waste disposal by landfill results in continuous contamination of soil and groundwater. The impacts of this are often not well understood.

By projecting impacts, LCA can be used strategically, using long-term assumptions to enable strategic decisions that will have a long-term impact on production processes. Impacts of decisions can be modelled to give an indication of the impact over several years of technologies selected now.

Benefits from LCA can be optimised by using LCA in the appropriate manner as part of overall environmental management. Tukker suggested that LCA can have a significant role in strategic EIA (SEA). This is due to the fact that SEA and LCA both deal with entire production systems, and similar to LCA, SEA is often location-independent (Tukker, 1999:450). The optimal benefit from any LCA will be if it is used for decision-making.

Dufour *et al* (2010:1205) studied the environmental performance of methane decomposition catalyzed by carbonaceous catalysts using Life Cycle Assessment, comparing it to other decomposition processes and steam methane reforming coupled to carbon capture systems.

The study focused primarily on the emission of greenhouse gases, since climate change is a major concern. Furthermore, the relationship between fossil energy consumed and the energy output is also an important parameter included in the economic profile of the process. This LCA not only focused on current scenarios, but considered energy projections in 2015 and 2030, assuming severe climate change policies, involving a significant reduction in use of coal, and its progressive replacement by gas and renewable energies. The predicted scenario using carbonaceous catalysts as alternative technology showed a significant reduction in the amount of greenhouse gases emitted in 2030, having a positive impact on global warming (Dufour *et al*, 2010:1211).

There is an increasing demand to provide sustainable, best practicable waste management solutions. Obersteiner *et al* (2007:S58) compared different approaches concerning time horizon

and LCI for impacts associated with landfill sites. The focus of the study was exclusively in the LCI step of the overall LCA process, and on a service as opposed to a product.

Ultimately the results of various landfill LCA studies should be combined to be used as a planning tool to optimise the location and design of new landfill sites to minimise the impacts on the environment. These will become strategic tools to evaluate waste management options.

One of the biggest challenges for this LCA was the timeframe of waste management, and the increasing uncertainty as time increases. Short-term impacts are defined as those during the placement of waste, as well as active and passive maintenance. The time horizon for this phase amounts to decades. In the medium-term phase there is no more active maintenance, and external factors and environmental impacts of the landfill site remain more or less constant. This time horizon comes to centuries. Short- and medium-term impacts are considered to be foreseeable. In the long-term phase, the time horizon extends to 10^4 and 10^5 years, and the external factors change. Impacts and developments are not foreseeable. The challenge is to select an appropriate time interval and the time-dependent emission function for the selected time interval (Obersteiner *et al*, 2007:S60).

This study highlighted the fact that the environmental burden is not limited to the production and use of a product, and that the disposal of a product is far from negligible (Obersteiner *et al*, 2007:S69). A comprehensive LCA should include the disposal of a product, and alternatives should be evaluated. Emissions from landfills cannot be accurately quantified, since the emissions are predominantly diffuse emissions manifesting over a long time span. A direct measurement of pollutants over decades is not possible, therefore assumptions have to be made, in the context of the precautionary principle.

3.2.5 Combining LCA with other methodologies

Several studies aim to combine cost-effectiveness and other parameters to be studied with environmental impacts, using various methodologies. The results of these studies are often used to assist policy decisions and decisions pertaining to production efficiency.

Lee and Ding (2000:162-163) conducted a case study on the production of corrugated paperboard, applying a combination of the conventional LCA methodology, and a commercially available weighting and policy-adjustment model. They classified the environmental impacts as pollution and disturbance problems, and further grouped the impacts according to spatial impact, i.e. global, regional and local impacts.

The analysis resulted in the observation that cost-effectiveness and environment-friendliness are found to be competitive, i.e. there is a trade-off between increased production costs and a reduction of the environmental impacts, and *vice-versa*. The study also showed that the cost of reducing environmental impacts increases as the spatial scales of impacts increase, i.e. the reduction of local impacts is found to be the most cost efficient. The results showed that the combination of least strength (i.e. weakest product) cost more and had a more significant environmental impact.

The study showed that LCA can assist decision-makers in increasing production efficiency with regard to both cost-effectiveness and reduced environmental impacts (Lee & Ding, 2000:162-163).

Da Silva and Amaral (2009:1339) proposed a methodology that integrates Life Cycle Assessment (LCA) and Activity-Based Costing (ABC) principles, and tested the methodology on the metallurgical industry in Brazil. The methodology attempts to analyse environmental impacts and related costs simultaneously.

Improving environmental performance has an economic impact on companies. Changes in production processes often require significant capital investment, and even increased running costs. These costs might be offset by reduction in costs due to a reduction in materials and energy consumption. There is a need for a tool that will provide an indication of the balance-point where environmental and economic impacts are optimised, whilst distinguishing between critical and negligible interventions (Da Silva & Amaral, 2009:1343).

The process followed the same process as the usual LCA methodology, with the ABC principles being introduced in the process mapping or Inventory Analysis step. The data gathered in this step include costs, equipment, and availability of labour, products, by-products and wastes.

The actual economic evaluation takes place during the Environmental Impact Assessment phase of the LCA (Da Silva & Amaral, 2009:1341). The environmental evaluation was done using an environmental matrix, based on a risk matrix, showing the extent of the impacts, and the environmental risks.

The extent of the impacts consider the geographical extent (local, regional or global), as well as the toxicity to ensure objective rating of the extent. The environmental risk matrix is completed based on the severity and the frequency of occurrence. The matrix scores the impacts based on the values into pre-defined categories, enabling prioritisation of impacts and interventions to address it. The methodology replaced the LCA steps of classification, characterisation and standardisation with a risk matrix.

The economic evaluation focused on proactive and reactive costs, such as disposal costs and expenditure related to losses of raw materials, as well as associated operational costs and investment performed to prevent environmental problems and process improvements (Da Silva & Amaral, 2009:1343). This enables the identification of the processes that have the highest costs and biggest environmental impact, and compare the costs of proactive and reactive measures.

Cherubini *et al* (2008:1093) took a novel approach to LCA, by integrating Material Flow Accounting (MFA) and energy-based methods, such as Embodied Energy, Exergy Analysis and Emergy Synthesis, complementing these with a detailed description of the environmental hazards associated with emissions from all the different processes of magnesium production. The study compared the different production processes employed by various magnesium-producing countries.

Hellweg *et al* (2003:341) studied the heavy metal contamination of deep soil layers and groundwater, presenting a method to study these impacts. Traditionally LCA focuses on surface water, air, and upper-soil layers, but to determine the time and impact on groundwater a detailed study that includes variables such as mineral composition of the soil is required. Studies like these are generally out of the scope of LCA. The consideration of pollution on groundwater and deep-layer soils is of particular importance when disposal of products are included in the scope of the LCA.

If a methodology to quantify specialised impacts such as this is included in LCA, it tends to involve many assumptions and generalisations. The ideal situation is if detailed, scientific studies were already conducted for specific components of the environmental burden, and to include the results of these studies in the literature review of the LCA to yield more reliable results.

The purpose of conducting a LCA is generally to understand and ultimately minimise the total environmental impact on the external environment and the indoor climate at the same time, but there isn't a proper understanding how a change in one area will impact on the other area. Jonsson (1999:241) investigated the possibility to determine the impact of the indoor climate of buildings on human health whilst conducting an LCA focused on the regional and global external environment.

Jonsson (1999:258) compared three approaches: LCA, Material Emission Assessment (MEA) and Indoor Climate Assessment (ICA) to evaluate the possibility of an integrated approach to determine the impact of indoor climate on human health. He found considerable methodological differences between the three approaches. With regard to the inclusion of indoor climate, the study showed that only impacts that can be predicted and quantified based on available data, could be included in

LCA, which constitutes a very limited portion of indoor climate problems. The conclusion of the study was that methods other than LCA should be used for indoor climate issues.

Frischknecht *et al* (2000:160) studied the damages to human health related to routine releases of radioactive material from nuclear fuel generators. The nuclear industry releases air- and waterborne radionuclides to the environment, and until this study was done, these emissions were seldom considered in LCA studies due to a lack of appropriate models. The study addressed human health damages due to radionuclides emitted by European nuclear fuel cells. Data were generalised to render the assessment site-independent. Disastrous or accidental large emissions were not considered, only routine releases. Occupational exposure was also excluded from the study to ensure consistency. Lastly, the study focused only on human health, and not the environmental or ecological impacts of releases.

This LCA involved very detailed information and data, from specialised disciplines such as nuclear physics and medicine. It underlines the importance of clearly defining the goal and scope of the LCA to ensure the resources are focused on the correct issues and have the same goal. Even though several assumptions were made for this study, it provided a consistent approach for the assessment of radionuclide releases in LCA (Frischknecht *et al*, 2000:187). The study showed that it is not feasible to combine different disciplines requiring detailed studies into a single LCA.

3.2.6 The use of LCA as a strategic tool

The case studies discussed in the chapter have identified areas that manufacturers and industries should focus on to reduce the environmental burden of their projects, whilst remaining cost-effective. LCA results have been used on a larger scale too, assisting policy makers in determining key focus areas.

Tien *et al* (2002:685) investigated Taiwan's industries to identify the characteristics of companies most advanced in environmental design. Five categories of design principles were used: use of raw materials, use of energy, design for recyclability, product life cycle assessment and packaging optimisation. They recognised the fact that the implementation of a management system does not guarantee immediate improved environmental performance.

They found that the larger companies investigated, employing more than 2000 employees, with \$3 billion in capital and/or \$3 billion in annual sales, showed the most advanced implementation of energy reduction measures. Due to the consumption of energy in large companies being a significant contributor to their costs, reducing energy costs had a significant financial benefit for these companies (Tien *et al*, 2002:693).

Seppala *et al* (2002:63) found that even though the Finnish metals industry was well regulated with regard to environmental protection, there were still several areas for continual improvement to further reduce the environmental impacts of the industry. In order to respond to market demands and increased environmental awareness, and to improve the environmental performance of the industry, companies directed their attention to reducing interventions, and towards products and product systems, recognising that sound products are considered key issues in ecologically sustainable development. For these reasons the Finnish environmental administration enhanced the use of life cycle thinking, thereby upgrading the eco-efficiency of the Finnish industry. An extensive project was undertaken using LCA as a tool to manage environmental issues in the Finnish metals industry.

The study found that the collaborative sectoral approach was an effective way to reduce the costs for conducting LCA's and to improve data quality. The company-specific impact assessments conducted in the uniform, consistent methodology facilitated identification of improvement areas for environmental performance in the whole industry sector (Seppala *et al*, 2002:72).

Matsumiya (2005:256) states that in order to progress towards a sustainable society production processes of steel and iron have to reduce their environmental impacts, and even aim to reduce the environmental burden on society. To this extent high-strength steel can reduce the weight of steel products and improved corrosion-resistant steel can lengthen the product's life. This is in line with the life cycle thinking by reducing the use of steel per unit performance of the products.

3.2.7 Life Cycle Analysis in the minerals industry

LCA has proven to be a very attractive tool to assess mining's performance towards sustainability. Several LCA studies for metal production have been conducted, however very little or no emphasis was placed on the extraction of the mineral ore and the consequent waste handling aspects of the industry. The lack of availability of accurate data is a challenge. The most effective way to obtain accurate data is to conduct site-specific or facility-level LCA studies, and ultimately combining the results of these LCA studies to create a reliable database for mining.

Fthenakis *et al* raised a concern that some of the minor metals used in the production of photovoltaics are not fully described in available LCA databases. The contribution of recycling products with these metals was not included, whilst secondary metal production results in significantly lower energy requirements. Significant changes have been made to the production processes and associated emissions of metals such as zinc and copper, and these changes have not yet been incorporated into the LCA databases (Fthenakis *et al*, 2009:494).

Durucan *et al* (2005:1057) observed that it is common practice for mining LCA studies to use a pre-defined set of data to represent mining production systems. Significant activities that are often excluded are exploration, mining method used, production, ore losses, location and the processing methods that govern the nature of the discharges to the environment. The mining system is often represented as a black box, not lending itself to the interpretation of different processes used in minerals production.

Norgate and Jahanshahi (2010:65) took a life-cycle view when investigating the options to extract metals from ore. As lower grade ore is mined, the challenge to extract the metal using an optimal process becomes more critical. The study focused on the extraction of copper and nickel and investigated various alternative processing routes.

Metals extracted for the first time from ore is classified as primary metals, whereas recycled metals re-entering the production line is regarded as secondary metals. Even though the recycling of metals is ever-increasing, continued demand results in a sustained demand for primary metal to be extracted from ore. The grade of available reserves is falling globally, and the characteristics of the orebodies are changing. The lower grades have a significant environmental impact, since it requires additional energy, with associated greenhouse gas emissions, to effectively extract the metals (Norgate and Jahanshahi, 2010:65-66).

The study focused predominantly on energy consumption and greenhouse gas emissions for primary metal production. Both copper and nickel are by-products of the platinum mining process. The LCA compared various extraction methods, based on smelting and leaching, and models were developed that indicated expected impacts with varying ore characteristics, enabling informed decision making and providing a tool that could be useful when selecting a processing methodology for a specific ore-type (Norgate and Jahanshahi, 2010:66).

The study also had to deal with varying qualities of data available, in that extensive, detailed data was available for leaching, but very limited data was available for smelting operations. The study concluded that there is not one specific processing method for low grade ores, but that the optimum method will depend on the mineralogy of the ore in question (Norgate and Jahanshahi, 2010:73).

Suppen *et al* (2006:1101) examined the application of LCA in the mining industry, specifically the Mexican mining industry. Two life cycle approaches were evaluated; a national life cycle inventory for base metals, and an integral life cycle model for the management of mining processes (Suppen *et al*, 2006:1101).

The Mexican mining industry shows similarities to the South African mining industry. The industry is more than 500 years old and significantly contributes to the Mexican economy. Old mining practices and technologies have to be critically evaluated, and it is essential that new technologies are introduced to ensure sustainability.

The Mexican government is showing an increased commitment to sustainability and environmental regulation. The mining sector has implemented environmental management systems and sustainable development strategies, and in recent years LCA was introduced as a useful tool to evaluate environmental impacts, implement eco-design strategies and form the foundation for eco-labels (Suppen *et al*, 2006:1105).

The Latin-American and Caribbean region identified LCA as a key strategy in the area of sustainable consumption and production in 2003. Several life cycle approaches have been introduced since then, among them a national life cycle inventory database, the application of life cycle process modelling for environmental compliance and the LCA evaluation of Mexican products (Suppen *et al*, 2006:1108).

The study showed that LCA is a useful tool for the successful implementation of sustainable development, by not only identifying environmental impacts, but also take into account measures of prevention of incidents such as leakage from or failure of tailings dams. (Suppen *et al*, 2006:1114)

Eckelman (2009:257) presented cradle-to-gate results, which include extraction, production and fabrication of selected nickel and nickel alloy products, based on a facility-level analysis of the life cycle assessment of the global nickel industry. The focus of the LCA is energy use and greenhouse gas implications.

The life-cycle of nickel, as for most metals including platinum, is relatively complicated. There are various grades of metal with varying composition and properties. Production of nickel is energy-intensive, which will add pressure to nickel-producing companies as international policies and focus increase on greenhouse gas emissions, energy use and climate change, in the form of financial, regulatory and public pressure (Eckelman, 2009:257). In the South African context nickel and platinum producing companies experience additional pressure related to the energy requirements of their process due to the inability of Eskom to provide a reliable source of energy.

In an effort to quantify the environmental impacts of nickel specifically, the international Nickel Institute commissioned a series of life-cycle assessment studies in 2000 and 2003. The studies were restricted to facilities that opted to participate in the LCA. There was a high sensitivity to certain parameters that were used across facilities, such as transport energy intensity. Significant

differences emerged between these studies, as additional data were considered and incorporated (Eckelman, 2009:257).

The uncertainty of LCA results can be reduced by incorporating more detailed inventory data. A new study was commissioned, with the purpose to provide an updated and extremely detailed accounting of the energy use and greenhouse gas impacts of nickel production world-wide, covering all major facilities and representing nearly 100% of world production. The study is based on publicly available data, which poses its own challenges and limitations, including out-of-date information, aggregation of process steps, ambiguous treatment of co-products and exclusion of low volume inputs. There is therefore uncertainty about the results of the study (Eckelman, 2009:257).

Challenges for a global LCA of nickel include the varying grades produced by the different producing countries, and the fact that some facilities include mining, smelting and refining, whereas other facilities only focus on one activity and sell their product for additional refining. Joint ownership of many facilities results in a complicated web of material flows as refined nickel producers struggle to ensure consistent supply. All of this makes it difficult to describe an average process for the production of nickel from the perspective of energy use and greenhouse gas emissions. For this reason the nickel LCA accounts for energy use and greenhouse gas emissions on a facility-level instead of using average values (Eckelman, 2009:257).

The results of the LCA showed that smelting and refining are the steps that consume the most energy in the nickel process, with mining of the ore contributing to 7-35% of energy requirements, depending on the composition of the ore. The results will be used in the Nickel industry to manage energy and climate change concerns in the foreseeable future (Eckelman, 2009:262).

3.3 CONCLUSION – LCA CASE STUDIES

The case studies discussed in this chapter showed that the goal and scope definition phase of LCA is critical to ensure that the significant financial and other resources are optimally utilised. The LCA conducted for the industries studied focused on specific environmental impacts, a specific phase of the process, or certain portions of the life cycle of the product, in order to focus the resources on a specific issue.

In order to optimise the LCA process, a readily available database is essential. This will assist in related LCA studies utilising consistent data, with improved reliability of results. The true benefit of LCA is realised when the comprehensive life cycle is considered. However due to the magnitude of such a study the scope of the LCA is often limited to include areas that are easily accessible. Care

should be taken when combining LCA with other research methodologies though, since the focus of a holistic LCA is not always compatible with a detailed scientific study.

The insights gained from the case studies will be used in the next chapter to evaluate the possible benefits and applicability of LCA to the platinum industry.

TOPIC	MAIN FINDINGS	REFERENCE
Abridged LCA	Easy to complete and understand	Urie and Dagg
	Could lead to critical environmental issues being ignored	
	Success depends on a large number of variables being the same	
Metal Production and Strategic issues	Valuable information to international policy makers	Cherubini; Tien; Seppala; Matsumiya
Metal Production	Light metals have a higher “Cradle to Gate” impact, however the heavy metals have a higher “Cradle to Grave” impact	Norgate
Life Cycle Stages	Environmental impact of staff travelling exceeded impact of transporting goods	Zackrisson
Life Cycle Stages	Assisted in decision-making and ensured focused attention	Scharnhorst; Norgate
Life Cycle Stages	LCA useful when new technologies are investigated	Pehnt
Long-term impacts	Strategic decision-making tool with regard to long-term impacts; disposal phase of product is essential for a true reflection of the environmental burden of the product	Dufour; Suppen; Eckelman; Staffell and Ingram; Obersteiner
Include Cost Benefit Analysis	Assist decision-makers to balance cost-effectiveness and reduction of environmental impacts; compare costs of proactive and reactive measures	Lee and Ding; Da Silva and Amaral; Tan and Khoo
Combining methodologies	Combining methodologies could lead to assumptions and generalisations. Include detailed studies in literature review of LCA	Hellweg
Indoor climate	LCA not suitable for indoor climate issues	Jonsson
Minerals industry	Detailed updated database required for mining LCA studies	Fthenakis; Durucan; Eckelman

Table 1: Comparison of findings from LCA case studies

CHAPTER 4 – DOES LCA HAVE SIGNIFICANT BENEFITS FOR THE PLATINUM INDUSTRY?

4.1 INTRODUCTION

The research question posed is "does LCA have significant benefits for the platinum industry"? In order to answer the main research question, it is necessary to answer the following sub-questions:

- What benefits did other industries realize from LCA?
- What approach should be followed to conduct the LCA for AMPLATS and the platinum industry?
- What are the anticipated benefits to the Platinum industry of conducting an LCA?

Mining production systems are commonly represented in LCA as a pre-defined set of data, with the data quality very seldom being improved. As a result essential mining process details that have significant environmental impacts are often not taken into account (Durucan *et al*, 2006:1057). LCA is increasingly being used by the mining industry as the tool to present a comprehensive overview of the environmental impacts attributed to the industry's products.

LCA is a resource-intensive method of collating information that is often already available in various formats, albeit fragmented and not in a single consolidated report. The benefit of LCA can be optimised when used in conjunction with studies that quantify other parameters, especially if the result includes economic indicators. Several case studies discussed in the previous chapter investigated the integration of various methodologies with LCA to optimise the applicability of the results.

The following sections will attempt to answer the research question based on information from the previous chapters.

4.2 WHAT BENEFITS AND LEARNINGS DID OTHER INDUSTRIES/COMPANIES REALIZE FROM LCA?

The literature reviewed highlighted several limitations, learnings and benefits that the various industries obtained from the LCA studies conducted. The relevant limitations and learnings from the case studies, as well as the benefits realised by the industries that conducted the LCA studies are now considered in the context of a Platinum LCA.

The EPA warned that LCA is usually resource- and time intensive. Gathering of data might be problematic, and availability of data can greatly impact the accuracy of the final results. Therefore, it is essential to weigh the availability of data, the time necessary to conduct the study, and the financial resources required against the projected benefits of the LCA. (EPA, 2006:5) A Platinum LCA will be resource- and time intensive due to the large scale and diversity of the processes involved. If the scope of the Platinum LCA includes only AMPLATS as opposed to all platinum producers world-wide, the availability of data will not present a challenge.

The mining industry is highly regulated in South Africa. Regulators often require any number of detailed studies for the various environmental impacts associated with the mining and beneficiation of platinum. Due to this there is ample information available; however it is usually not consolidated to present an overall view of the environmental burden of platinum.

Care should be taken to guard against pre-conceived ideas of the expected results of a LCA, especially when a lot of information is already available. The previous chapter includes several case studies that had unexpected results, such as the case study on corrugated paper conducted by Lee and Ding (2000:162). The study showed that the paper with the lowest cost also had the biggest environmental impact. The results from a LCA could be used to make informed decisions about optimisation between costs and reduced environmental impacts.

Jonsson (2000:244) noted that LCA is generally more effective in focusing on global and regional environmental impacts, whilst predicted local environmental impacts often do not materialise with the same accuracy as the predicted regional and global impacts. He further stated that LCA also does not address events such as accidents, incorrect use of the product being studied, or overuse of it. When defining the scope of a Platinum LCA, cognisance should be taken of these points. The impacts for platinum production identified in the LCA should therefore focus on normal operations, and exclude impacts due to any abnormal circumstances.

Scharnhorst *et al* (2005:541) studied a LCA on second generation mobile phone networks. They noted that although several initiatives have been implemented to reduce the environmental impact of mobile phone networks, there are some significant issues that have not yet been adequately addressed. Issues that also relate to Platinum include the following:

- Regulations on environmentally safe end-of-life treatment methods and emissions caused by treating scrap are not consistent world-wide.
- Environmental impacts related to end of life treatment of entire mobile phone networks are not yet quantified from a life cycle perspective (Scharnhorst *et al*, 2005:541). End-of-life impacts of platinum have not yet been quantified either. Platinum is however recyclable, the

Due to the high value and durability of platinum, and other metals that form part of the PGM grouping, recycling of PGM-containing products should increase significantly as more of these products reach end-of-life. Several initiatives have been implemented by PGM producers to reduce their environmental burden during production, such as reduced stack emissions, maximising the yield of PGM during production and recycling. The area that can be improved most is recycling.

Pehnt (2001:97) stated that there is already an efficient recycling system for automobile exhaust catalysts, but PGM recycling can be further improved by providing an economic incentive and readily available recycling infrastructure. It is foreseen that as the number of vehicles with catalysts reaching end of life increases, the recycling of these catalyst will also increase significantly.

Odiyo *et al* (2005:586) studied the contamination of Thohoyandou roadside soils and sewage and river water of trace metals, including platinum (Pt) and palladium (Pd). The study found increased levels of these metals close to the road, decreasing as the distance from the road increased. Pt and Pd in roadside soils are due to catalytic converters, and although it is low concentrations, as the use of catalytic converters increase over time, this pollution will also increase. The study reported the presence of Pt and Pd in sewage systems, which was not previously the case. It was speculated that it could be due to the increased use and availability of platinum in the form of jewellery, it could also be run-off from road surfaces into sewage drains.

In an effort to quantify the environmental impacts of nickel specifically, the International Nickel Institute commissioned a series of life-cycle assessment studies in 2000. The studies were restricted to facilities that opted to participate in the LCA, resulting in significant uncertainties due to issues such as parameters being shared between facilities, e.g. transport, inconsistent application of the methodology and reluctance to share information from certain facilities (Eckelman, 2009:257). This is a challenge that would be presented to a Platinum LCA as well, and clear mitigation plans to address this should be put in place from the start.

The scope of any LCA, especially on a global scale, such as nickel or platinum, should clearly define whether indirect inputs are included. Indirect inputs are the processes to construct facilities that form part of the production process being studied. In the case of a Platinum LCA, exploration and project phases could be included to determine the impacts of site establishment; however the boundaries of these phases have to be very clearly defined.

Challenges for global LCA for both nickel and platinum include the varying grades produced by the different producing countries, and the fact that some facilities include mining, smelting and refining, whereas other facilities only focus on one activity and sell their product for additional refining. Several facilities are jointly owned, which could pose a challenge with regard to sharing of confidential information. For this reason the nickel LCA accounts for energy use and greenhouse gas emissions on a facility-level instead of using average values (Eckelman, 2009:257). The most effective way to obtain accurate data is to conduct site-specific or facility-level LCA studies, and ultimately combining the results of these LCA studies to create a reliable database for mining.

4.3 WHAT PROCESS SHOULD BE FOLLOWED TO CONDUCT A LCA FOR THE PLATINUM INDUSTRY?

The first step when deciding on a policy for LCA in the platinum industry will be to determine and formulate the objective and anticipated benefits of the LCA. Various industries have conducted LCA for different reasons. The clear definition of the intended benefits and use of the results from the LCA will ensure resources are optimally deployed and benefits of the study are optimised.

According to the United States of America's Environmental Protection Agency (EPA), *"an LCA can help decision-makers select the product or process that result in the least impact to the environment."* (EPA, 2006:3). Results from LCA studies can be used together with other parameters, such as cost and performance data to select a product or process where benefits are optimised.

Due to the inclusive nature of LCA, impacts on all environmental media are presented simultaneously, allowing decision-makers to select a product or process that minimises the overall environmental burden. Single-focus studies might allow for the transfer of impacts from one media to another resulting in a significant impact not being considered when selecting a specific alternative. LCA allows a decision maker to study an entire product system thereby avoiding any sub-optimization that could result if only a single process were the focus of the study. The cradle-to-grave approach to the environmental burden ensures that a balanced view is taken of all environmental impacts and all factors are considered in order to make an informed decision.

According to Da Silva and Amaral (2009:1339) *"most environmental concerns can be related to economic aspects, since the reduction of materials and energy consumption is directly connected with financial benefits, besides environmental improvements."* Companies are increasingly incorporating environmental aspects into the design and operation of industrial processes, usually at significant expense. Benefits are most commonly quantified as reduced use of resources, lower cost of waste management and fewer instances of fines and other impacts due to non-compliance to permit conditions.

LCA on its own will not determine which product or process is the most cost effective or works best. The information developed in an LCA study should be used as one component of a more comprehensive decision making process assessing the trade-offs with cost and performance.

There are limited studies and processes available that analyse environmental impacts and related costs simultaneously. Da Silva and Amaral (2009:1339) proposed an integrated methodology to perform such an evaluation, based on Life Cycle Assessment (LCA) and Activity-Based Costing (ABC) principles. The methodology was applied in a metallurgical industry in Brazil.

The benefit of LCA in the case of platinum should materialise if it can be used to make business decisions, considering financial and production benefits in addition to environmental benefits anticipated by making alterations to the various processes. A Platinum LCA should include a financial component allocated to the various processes.

The proposed goal for a Platinum LCA should include the cradle-to-gate environmental burden of platinum, including the exploration, project development, mining, concentrating, smelting and refining of platinum. A thorough study of the environmental burden of platinum from the exploration phase to refining, with detailed analysis of the impacts at every stage in the process, will be essential for further LCA studies of products utilising platinum.

There is no anticipated benefit in conducting a conceptual or simplified LCA for platinum, since the case studies have highlighted the fact that there are data available for mining and beneficiation processes, there is however a need for detailed information on the various processes resulting in the final product to be further utilised.

The overall process flow of platinum production consists broadly of the following:

- Exploration;
- Various project phases to establish a mine or process plant
 - o Pre-feasibility
 - o Feasibility study
 - o Site establishment
 - o Hand-over
- Mining
- Concentration
- Smelting
- Refining
- Closure

Each of these steps consists of several complex processes, each with their own life cycles that include raw material acquisition, production processes, and products and waste streams resulting from it. Every step therefore becomes a full LCA in itself.

The mining method to extract platinum is hard rock mining, predominantly underground but also opencast. Eckelman observed that electricity requirements for hard rock mining are generally much higher for underground mining than for open-pit mining because of the need for drilling, ventilation, water removal, and hoisting of rock to surface. Open-pit mines generally consume more liquid fuel because of the use of mining trucks to transport rock up from the pit (Eckelman, 2010:258).

Ore beneficiation consists of concentration, smelting and refining. Concentration takes place in concentrators by a process of crushing, grinding, screen separation, and flotation processes. Crushers and ball mills reduce ore to the required particle sizes, these particles are then separated from waste rock in a liquid medium by gravitation or by selective flotation. Flotation is followed by cleaning, thickening and filtering. The concentrates are dewatered, dried and transported by truck to the smelters.

The matte is treated at the smelters in a pyrometallurgical process resulting in significant emissions of SO₂. The refining processes consist of several chemical processes, resulting in the production of the base metals, as well as the PGMs. The most significant environmental impacts during these processes are use of energy, release of gas, liquid and solid emissions, and the use of reagents, water and fuel (Norgate *et al*, 2006:838).

Platinum LCA should ideally consist of various separate LCA's, all using the same methodology to ensure the results could ultimately be combined in a single LCA. A full LCA should be completed for every facility in AMPLATS, i.e. every mine, concentrator, smelter, refinery and project. These should be grouped together according to the step of the platinum process flow described above. If every platinum producing company completes a comprehensive LCA based on the various LCA's for every facility under its control, it would provide a comprehensive overall LCA for the platinum industry.

The results from the site-specific LCA studies for each platinum producing company should be coordinated centrally by a corporate function to provide a comprehensive LCA for the company. The International Platinum Association should coordinate the overall integration of results for a meaningful LCA for the platinum industry. It is evident that it is essential for the various sites and companies to use the same approach to ensure consistent results that can be integrated.

The methodology used for such a LCA should take cognisance of several issues:

- The allocation of emissions to the different PGM products – In SA 1kg of Platinum also yields 0.5kg of palladium, 0.1 kg of rhodium, 300kg nickel and 200kg copper. Emissions from the production process have to be allocated to these products and by-products. Allocation according to the mass of product will not be useful because it does not mirror the motivation to run the mine. In SA, only 0.2 wt% platinum yields 50% of the return. Should ecological impacts therefore be allocated by weight of product, no significant ecological impact will be allocated to the economically attractive product, being platinum. Allocation according to the average market price over a defined period of time is more sensible.
- The country where the LCA is to be conducted should be defined. If the focus is only on AMPLATS, the LCA will be based in SA and Zimbabwe, and platinum produced in Russia and other countries can be disregarded. .
- If the LCA is for the entire platinum industry as opposed to AMPLATS-specific, there will be data gaps due to confidentiality of the processes.

Once these individual LCA's are combined according to their process flow step, an evaluation should be done to determine if there are any processes that were not included yet in the individual LCA's. These processes should then also be studied using the same LCA methodology and included in the overall process flow LCA. Finally all the LCA results for every process flow step should be combined in an overall LCA for platinum.

In future consideration can be given to investigating the environmental burden of the use and disposal of platinum in the various products that it is utilised, with specific focus on the recycling potential.

4.4 WHAT ARE THE ANTICIPATED BENEFITS TO THE PLATINUM INDUSTRY OF CONDUCTING A LCA?

The key decision makers in the platinum industry have all clearly stated their commitment to reduce the environmental footprint of PGMs, and therefore of platinum. Most large companies report on their energy and carbon impacts in their annual reports, and detail plans and programs to improve the sustainability of the metals sector. Now is an opportune time to investigate the feasibility and potential benefits of a Platinum LCA as opposed to other studies aimed at reducing the environmental burden of platinum and PGMs.

AMPLATS is a member of the International Platinum Association, and one of the objectives of this association is to reduce the environmental footprint of PGMs across their lifecycle. The

International Platinum Association is investigating the work required to complete a Platinum LCA that will include all platinum producers world-wide.

Johnson Matthey, an international speciality chemicals company, and the primary client of AMPLATS, formulated a long term strategy to ensure sustainability for the group. A critical component of the strategy is the measurement of some key performance indicators. These include:

- Global warming potential – achieve carbon neutrality;
- Amount of waste to landfill – achieve zero waste to landfill;
- Electricity & natural gas consumption, water use – halve key resources consumed per unit of output.

The objective is to achieve these targets by 2017 (Johnson Matthey, 2010:9).

Many of the applications of Platinum Group Metals (PGM) are aimed at reducing greenhouse gas emissions, such as catalysts for refining processes, auto-catalysts to reduce vehicle emissions and fuel cells that produce energy with fewer CO₂ emissions (Anglo Platinum, 2010:124). Mobile phones use platinum and palladium in contact materials of printed wiring board assemblies (Scharnhorst *et al*, 2005:562).

Even though PGMs are often used in green applications, the processes to produce the PGMs still have significant environmental impacts. Alternatives to platinum and other PGMs are increasingly being considered and studied in an attempt to reduce costs. Platinum is an expensive commodity, and the marketing of platinum as a green product could be beneficial to platinum producers to improve market sentiment towards the metal. Currently platinum recycling rates from auto-catalysts and consumer electronics are only about 50% (Staffel & Ingram, 2010:2495).

It is clear that there is sufficient commitment at senior level from all the major platinum decision makers to support a LCA for platinum. Such a study will provide the industry with a clear indication as to where the most significant environmental impacts are, and where the most benefit can be gained from improving production processes to reduce the environmental burden. If the study is done for the entire industry, it could result in an excellent platform for sharing of best practice, for the collective good of the industry as a whole.

Confidentiality of production processes, especially in the refining processes, could result in a reluctance of role players to share information, casting doubt on the benefit obtained from such a LCA when compared to the financial and other resource required to complete it. It might therefore be more beneficial if AMPLATS completes their own LCA in order to get a true reflection of their

environmental burden, and then selectively share technological improvements that assisted in reducing the environmental burden without disclosing sensitive information.

Due to the scale of Anglo Platinum, and the significant portion of the platinum market it occupies, there is benefit in a detailed LCA for the group, with selective sharing of results to the industry.

The environmental impacts to be studied should be clearly defined, to ensure the benefits from the LCA are optimised. It is essential that LCA is seen as a business tool that will assist the company to make informed business decisions about process improvements, as well as new projects and design of new facilities.

A LCA could furthermore benefit AMPLATS in providing consistent information required for licensing and other regulatory requirements. A comprehensive LCA will provide a database that will enable not only AMPLATS, but also manufacturers of products containing platinum to make informed decisions based on reliable information about improvements that will reduce the environmental impact, whilst making best economic sense.

4.5 DOES LCA HAVE SIGNIFICANT BENEFITS FOR THE PLATINUM INDUSTRY?

Considering the questions above, there are several benefits to the platinum industry in completing a Platinum LCA. There are several valuable lessons learnt from other industries that completed LCA's that are applicable to the platinum industry as a whole, as well as to AMPLATS as a major platinum producer.

The benefits to the industry will be optimised when individual LCA's are completed at facility level, and these results are then combined in a comprehensive LCA for the industry. This will also enable other companies that want to complete LCA's to use information from the various facility-level LCA's as a more accurate and current database for the metal producing industry.

It is essential that a Platinum LCA is used as a strategic decision-making tool to ensure designs are optimised with regard to all factors, including environmental impacts, cost benefits, production optimisation, waste minimisation, legal compliance and sustainability of the industry.

CHAPTER 5 – CONCLUSION

Considering the complexity of the platinum production process and the existence of information and reports that fulfil various environmental requirements, the concept of an abridged or conceptual LCA initially seems like a preferable option. However, the literature review indicated the most significant benefits materialised from comprehensive LCA's, albeit focused on key environmental burdens. The case studies furthermore highlighted the fact that there is generic data available for mining and beneficiation processes, however there is a need for detailed information on the various processes comprising the production of the final product.

Platinum production consists of a variety of processes, each with environmental impact categories particular to the particular stage of the process. The specific environmental impact categories due to the various platinum production processes are defined in existing information with varying quality.

The scope for a Platinum LCA should include the cradle-to-gate environmental burden of platinum, including exploration, project phase, mining, concentrating, smelting and refining of platinum. A Platinum LCA should consist of separate, facility-based studies of the environmental burden of platinum from the exploration phase to refining, with detailed analysis of the environmental impact categories applicable to every stage in the process.

Each of the stages of the platinum production process consists of several complex processes, with their own life cycles that include raw material acquisition, production processes, products and waste streams resulting from the stage. Every stage therefore becomes a full LCA in itself, and should ideally consist of a combination of individual facility-based LCA's that comprise the stages of the process.

The mining method to extract platinum is hard rock mining, predominantly underground but also opencast. Underground mining is characterised by high electricity usage, whereas opencast mining generally consume significant quantities of liquid fuel. Mining also results in waste rock dumps that could pose a significant long-term environmental impact on groundwater.

Ore beneficiation consists of concentration, smelting and refining. The most significant environmental impact categories associated with concentration would be atmospheric emissions, and to a greater extent consumption of reagents and transport-related impacts. Environmental

impacts from smelting are predominantly significant emissions of SO₂ and other greenhouse gases. The refining processes consist of several chemical processes, with the most significant environmental impacts being the use of reagents and release of gas, liquid and solid emissions.

The impact of recycling of platinum-containing products should be included in the LCA model to be used, to determine if it will result in improved environmental performance, as well as potential cost benefits of incorporating recycling into the overall production process of platinum.

A Platinum LCA will be resource- and time intensive due to the large scale of the processes involved. If the scope of the Platinum LCA includes only AMPLATS as opposed to all platinum producers world-wide, the availability of data will not present a challenge.

Confidentiality of production processes, especially in the refining processes, could result in a reluctance of role players to share information if a LCA is conducted that includes all platinum producers, casting doubt on the benefit obtained from such a LCA when compared to the financial and other resource required to complete it.

It will prove to be beneficial to conduct individual LCA's for AMPLATS and other platinum producers in order to get a true reflection of the environmental burden of each company, and then selectively share technological improvements to reduce the environmental burden without disclosing sensitive information. Due to the scale of AMPLATS, and the significant portion of the platinum market it occupies, there is benefit in a detailed LCA for the group, with selective sharing of results to the industry.

The benefit of LCA in the case of platinum will be optimised if it can be used to make business decisions, together with consideration of financial and production benefits in addition to anticipated environmental benefits of alterations to processes. It is essential that LCA is seen as a business tool that will assist the company to make informed business decisions about process improvements, as well as new projects and design of new facilities.

LCA on its own will not determine which product or process is the most cost effective or works best. The information developed in a LCA study should be used as one component of a more comprehensive decision making process assessing the trade-offs with cost and performance. The results from a LCA could be used to make informed decisions about optimisation between costs and reduced environmental impacts.

A LCA could furthermore benefit AMPLATS in providing consistent information required for licensing and other regulatory requirements. A comprehensive LCA will provide a database that will enable not only AMPLATS, but also manufacturers of products containing platinum to make

informed decisions based on reliable information about improvements that will reduce the environmental impact, whilst making best economic sense.

It is essential that a Platinum LCA is used as strategic decision-making tool to ensure designs are optimised with regard to all factors, including environmental impacts, cost benefits, production optimisation, waste minimisation, legal compliance and sustainability of the industry.

Future research could focus on investigating the environmental burden of the use and disposal of platinum in the various products utilises platinum, with specific focus on the recycling potential. The individual LCA's to be conducted for the facilities and stages of the production process could also be future research topics.

BIBLIOGRAPHY

ANGLO PLATINUM LTD. 2010. Annual Sustainable Development Report, Johannesburg

ATHANAS, A., BISHOP, J., CASSARA, A., DONAUBAUER, P., PERCEVAL, C., RAFIQ, M., RANGANATHAN, J. & RISGAARD, P. 2006. Business and ecosystems, Earthwatch Institute, Oxford

CHERUBINI, F., RAUGEI, M., ULGIATI, S. 2008: LCA of magnesium production – Technological overview and worldwide estimation of environmental burdens; *Resources, Conservation and Recycling* 52 (2008): 1093-1100

CIAMBRONE, D.F. 1997. Environmental life cycle analysis, Hughes Aircraft Company, Newport Beach, California : Lewis Publishers.1-42 p.

COLBY, M.E. 1989. The evolution of paradigms of environmental management in development, Strategic Planning and Review Department, The World Bank, Washington DC

DA SILVA, P.R.S. & AMARAL, F.G. 2009. An integrated methodology for environmental impacts and costs evaluation in industrial processes; *Journal of Cleaner Production* 17 (2009):1339-1350

DEAT. 2004. Life Cycle Assessment, Integrated Environmental Management, Information Series 9, Department of Environmental Affairs and Tourism (DEAT), Pretoria.

DUFOUR, J., GALVEZ, D.P., SERRANO, D.P., MORENO, J., MARTINEZ, G. 2010. Life cycle assessment of hydrogen production by methane decomposition using carbonaceous catalysts; *International Journal of Hydrogen Energy* 35 (2010): 1205-1212

DURUCAN, S., KORRE, A. & MUNOZ-MELENDEZ, G. 2005. Mining life cycle modelling: a cradle-to-gate approach to environmental management in the minerals industry; *Journal of Cleaner Production* 14 (2006):1057-1070

ECKELMAN, M.J. 2009. Facility-level energy and greenhouse gas life-cycle assessment of the global nickel industry; *Resources, Conservation and Recycling* 54 (2010): 256-266

ENVIRONMENTAL PROTECTION AGENCY. 2006. Life cycle assessment: principles and practice; Ohio. 1-80 p.

FREED, E.C. 2008. Coca cola dilemma. [Web:] <http://www.ecomii.com/building/coca-cola-dilemma> [Date of access: 4 May 2011]

FRISCHKNECHT, R., BRAUNSCHWEIG, A., HOFSTETTER, P. & SUTER, P. 2000. Human health damages due to ionizing radiation in life cycle impact assessment; *Environmental Impact Assessment Review* 20 (2000): 159-189

- FTHENAKIS, V., WANG, W. & KIM, H.C. 2007: Life cycle inventory analysis of the production of metals used in photovoltaics; *Renewable and Sustainable Energy Reviews* 13 (2009): 493-517
- HELLWEG, S., FISCHER, U., HOFSTETTER, T.B., HUNGERBUHLER, K. 2005. Site-dependent fate assessment in LCA: transport of heavy metals in soil; *Journal of Cleaner Production* 13 (2005): 351-361
- HUNT, R.G., SELLERS, J.D. & FRANKLIN, W.E. 1992. Resource and environmental profile analysis: A life cycle environmental assessment for products and procedures; *Environmental Impact Assessment Review* 12(3):245-269
- ISO 14040. 2006. Environmental management - Life cycle assessment – Principles and framework, International Organisation for Standardisation (ISO), Genève
- ISO 14041. 2007. Environmental management – life cycle assessment – goal and scope definition and inventory analysis, International Organisation for Standardisation (ISO), Genève
- ISO 14042. 2000. Environmental management – life cycle assessment – life cycle impact assessment, International Organisation for Standardisation (ISO), Genève
- JOHNSON MATTHEY. Sustainability Report 2009/2010, 9 p, London
- JONSSON, A. 1999. Is it feasible to address indoor climate issues in LCA?; *Environmental Impact Assessment Review* 20 (2000): 241-259
- LEE, Y.M & DING, C.Y. 2000. Life cycle assessment and production policy: an application to corrugated paperboard manufacture; *Journal of Environmental Management* 59 (2000): 157-165
- MATSUMIYA, T. 2005. Steel research and development in the aspect for a sustainable society; *Scandinavian Journal of Metallurgy* 34 (2005):256-267
- NORGATE, T. & JAHANSHAH, S. 2010. Low grade ores – smelt, leach or concentrate?; *Minerals Engineering* 23 (2010): 65-73
- NORGATE, T., JAHANSHAH, S & RANKIN W.J. 2006. Assessing the environmental impact of metal production processes; *Journal of Cleaner Production* 15 (2007): 838-848
- OBERSTEINER, G., BINNER, E., MOSTBAUER, P. & SALHOFER, S. 2007. Landfill modelling in LCA – A contribution based on empirical data; *Waste Management* 27 (2007): S58-S74
- ODIYO, J.O., BAPELA, H.M., MUGWEDI, R. & CHIMUKA, L. 2005. Metals in environmental media: A study of trace and platinum group metals in Thohoyandou, South Africa; *Water SA* Vol.31 No 4 (2005):581-588
- OLSEN, S.I., CHRISTENSEN, F.M., HAUSCHILD, M., PEDERSEN, F., LARSEN, H.F. & TORSLOV, J. 2001. Life cycle impact assessment and risk assessment of chemicals – a methodological comparison; *Environmental Impact Assessment Review* 21 (2001): 385-404

- PEHNT, M. 2001. Life cycle assessment of fuel cell stacks; International Journal of Hydrogen Energy 26 (2001): 91-101
- SCHARNHORST, W., ALTHAUS, H.J., CLASSEN, M., JOLLIET, O., HILTY, L.M. 2005. The end of life treatment of second generation mobile phone networks: Strategies to reduce the environmental impact; Environmental Impact Assessment Review 25 (2005): 540-566
- SEPPALA, J., KOSKELA, S., MELANEN, M & PALPERI, M. 2002. The Finnish metals industry and the environment; Resources, Conservation and Recycling 35 (2002):61-76
- SOCIETY OF ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY (SETAC), 1993. Guidelines for Life-Cycle Assessment: A Code of Practice. Brussels
- STAFFEL, I. & INGRAM, A. 2010. Life cycle assessment of an alkaline fuel cell CHP system; International Journal of Hydrogen Energy 35 (2010): 2491-2505
- SUPPEN, N., CARRANZA, M., HUERTA, M. & HERNANDEZ, M.A. 2006. Environmental management and life cycle approaches in the Mexican mining industry; Journal of Cleaner Production 14 (2006): 1101-1115
- TAN, R.B.H. & KHOO, H.H. 2005. An LCA study of a primary aluminum supply chain; Journal of Cleaner Production 13 (2005): 607-618
- TIEN, S.W., CHUNG, Y.C. & TSAI, C.H. 2002. Environmental design implementation in Taiwan's industries; Environmental Impact Assessment Review 22 (2002):685-702
- TUKKER, A. 1999. Life cycle assessment as a tool in environmental impact assessment; Environmental Impact Assessment Review 20 (2000):435-456
- URIE, A. & DAGG, S. 2004. Development of a life cycle assessment (LCA) based decision-making tool for the assessment of building products; Journal of Environmental Assessment Policy and Management, Vol. 6, No. 2 (2004):153-175
- WIKIPEDIA. 2011. 1973 Oil crisis. [Web:] http://en.wikipedia.org/wiki/1973_oil_crisis [Date of access: 4 May 2011]
- WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT (WCED) 1987. Our common future, Oxford University Press, Oxford & New York
- ZACKRISSON, M. 2005. Environmental aspects when manufacturing products mainly out of metals and/or polymers; Journal of Cleaner Production 13 (2005): 43-49