Lifecycle Assessment of Steel Balls

Case Study – Craster International

Loice Gudukeya
Mechanical Engineering Dept
University of Johannesburg
Johannesburg, South Africa
University of Zimbabwe,
Harare, Zimbabwe
loicekmg@gmail.com

Charles Mbohwa
Operations Research
University of Johannesburg
Johannesburg, South Africa
cmbohwa@uj.ac.za

Abstract - **Global warming effects have become very apparent in many parts of the world causing governments to force their industries to be environmentally conscious. Small individual contributions will help abate global warming. The steel industry, if left unattended, has great potential of releasing greenhouse gases into the atmosphere. In this paper a life cycle assessment (LCA) for steel balls used as grinding media in mines that are produced at Craster International in Zimbabwe is discussed. Knowing the life cycle environmental impacts of the steel balls is very important since they produce greenhouse gases in their production. The emitted carbon dioxide, sulphur dioxide, nitrous oxides and other trace greenhouse gases have adverse effects on flora, fauna, water bodies and humans. Interviews, questionnaire and direct observation and measurements were used to generate the data. The data is analyzed and a new LCA diagram from the results of the research and recommendations was made.**

I. INTRODUCTION

The ever increasing effects of global warming have pushed governments and non-governmental organizations towards measures that curb global warming. This has in turn put pressure on organizations to assess the impacts of their operations. Life Cycle Assessment (LCA) is one of the tools for evaluating and assessing the impacts of a product or a process to the environment. This assessment was carried out on steel balls used as grinding media in processing of ore in mines. The process used to manufacture the steel ball is energy intense and emits gases to the environment and other various wastes. These steel balls are produced by Craster International.

The company is a Foundry and heavy engineering company based in Harare that manufactures grinding media for mines and other engineering equipment and spares. Of interest are the grinding balls that have been chosen to perform the LCA process. This has been chosen to demonstrate how LCA can be performed at an organizational level. Therefore this initiative has been undertaken to minimize waste, energy, materials resource usage and emissions during processing, transportation and other auxiliary processes.

II. LITERATURE REVIEW

Life Cycle Assessment

Life-Cycle Assessment (LCA) – also called Life-Cycle Analysis –is a process of evaluating environmental load which relates to the entire life periodic system of a product, the technological process or the activity. The entire life periodic system means from the raw material gathering and manufacture to the production, transportation, sale, use, recycle, maintains, circulation use and final disposal. [1] It is a tool for examining the total environmental impact of a product through every step of its life – from obtaining raw materials all the way through making it in a factory, selling it in a store, using it in the workplace or at home, and disposing of it.[2]

According to Mbohwa 2013 [13], LCA is a technique for systematically analysing a product from cradle-to-grave, that is, from resource extraction through manufacture and use to disposal. An inventory phase analyses system inputs of energy and materials along with outputs of emissions and wastes throughout life cycle, usually as quantitative mass loadings. An impact assessment phase then examines these loadings in light of potential environmental issues using a mixed spectrum of qualitative and quantitative methods. The end result is that impact assessment does not measure actual effects of impacts, nor does it calculate the likelihood of an effect or risk. Rather, LCA impact assessment results are largely directional environmental indicators. The accuracy and usefulness of indicators needs to be assessed individually and in a circumstance-specific manner prior to decision making.

The use of LCA provides the practitioner an ability to assess the environmental aspects of a product or process and allows for comparison of the environmental attributes of alternative products. The principles and guidance for performing an LCA are defined by the International Organization for Standardization (ISO) in its 14000 series of standards. The life cycle assessment documents that have been used historically are as follows; [7, 8, 9, 10, 11, and 12]

- ISO 14040: life cycle principle of framework
- ISO 14041: Environmental management-Life cycle assessment-Goal and scope definition and inventory analysis
- ISO 14042: Environmental management –Life cycle assessment-Life cycle impact assessment
- ISO 14043: Environmental management-Life cycle assessment-Life cycle interpretation
- ISO 14048:Environmental management-Life cycle assessment-Life cycle assessment data documentation format
- ISO 14049 :Environmental management-Life cycle assessment-Examples for the application of ISO 14001

According to the ISO 14040 [7] there are four basic stages of conducting an LCA which include: Goal and scope definition, inventory analysis, impact assessment and interpretation as diagrammatically illustrated below

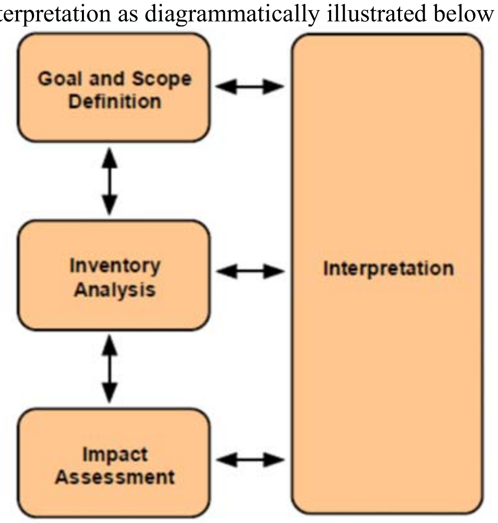

Figure 1. Phases of an LCA - (ISO, 2006)

The University of Taxes (2013) proposed the use of LCA for product development, product improvement, and comparison by manufacturing firms; it can also be used by public policy makers for environmental labeling. *Curran 1996* [1]said many companies have found LCA as a tool which is advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance. *Branz (2012)* outlined several advantages of using LCA highlighting that LCA identifies the environmental liabilities and opportunities to mitigate them through process efficiencies and supply chain changes, whether it's greenhouse gases or full environmental impact. *Comere (2012)* [4] said "to avoid the unintended consequences produced by narrow thinking, a life cycle approach and the intelligence that results from its use can be embedded in product design to yield environmentally superior options. While not a panacea, it is a tool that can prioritize your actions and differentiate your brand on route to a renewing and sustainable future". Having pointed out the merits of using LCA, *CSIRO (2013)* [6] also revealed the limitations of the process. LCA results differ from one company or process which might not apply to other similar companies or processes. During LCA exercise collection of data consumes time and in mostly some of the data requires estimates. *Gregory A (1993)* [3] concurs with the demerits they added that the cost of LCA has to be valued before committing the exercise, financial costs may not be bearable.

Fthenakis V.M., and Kim H.C., 2013 [5] noted that Life Cycle Inventories (LCIs) are necessary for LCA and the availability of such data is often the greatest barrier for conducting LCA. He further went on to say that the LCA experts have put great efforts in gathering and compiling the LCI data. These include detailed inputs and outputs during manufacturing of cell, wafer, module, and balance-of-system (i.e., structural- and electrical- components) that were estimated from actual production and operation facilities.

Life cycle Impact Assessment (LCIA) is one of the systems used to model the relationships between the system and its potential impacts to the environment. *(ISO 14042)* [9] It classifies the LCIA steps as selection of impact categories and their classification, characterization and normalization of the impacts, sorting or ranking the indicators, weighting and finally evaluating and reporting LCIA results.

III. RESEARCH METHODOLOGY

The system boundary has been pulled to cover the major processes required to produce and use the steel balls. This includes raw material and energy used in production including extraction from the earth and further processing and refining. Transportation is also taken into account at every stage

The LCA focused on the raw materials, energy flows, transportation, products and by products directly involved in the manufacture of Ball mill steel balls. The scope did not cover the equipment directly involved in processing and transportation. The material and energy flows of processes involved in the extraction of raw materials (iron) and the production of steel balls are all included. Energy usage was in the form of electricity for production of steel ball, fuel for transportation of raw materials, fuel used in the mining of iron ore and collecting of scrap metal. The processes studied in this LCA were divided into three main subsystems:

- iron/steel production,
- steel ball production and
- steel ball usage.

This is shown in Figure 2.

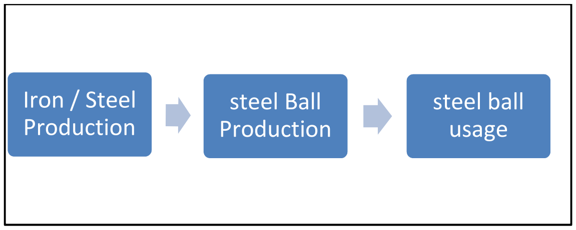

Figure 2: System boundary steel ball production

Material and energy flows were quantified for each process block. Emissions at each subsystem were also noted and quantified. The resources, environmental emissions and energy usage were tracked along the process system from the extraction of iron ore and scrap collection to steel ball production. The study excluded the impacts of the manufacture of equipment for use during mining, manufacture of locomotives and construction of the furnace plant.

The research was carried out as follows:

1. Quantifying space occupied by current wastes (especially slag).
2. Quantifying gaseous emissions per ball.
3. Quantifying the environmental impacts that each emission poses on the environment
4. Carrying out interviews to gather all the relevant data from the following section heads SHE, Foundry Manager, Workshop manager, and Operatives in the production line.

Key personnel were very helpful in the provision of data. The following are the questions that were asked during interviews:

Interview questions for managers

1. What are the sources of the raw materials in the ball production process?
2. What are the quantities of the energy consumption during steel ball production process?
3. What are the types of effluents from the production process?
4. How do you dispose of the waste from the production process?
5. What are your emissions?
6. What are the qualities and quantities of your emissions?
7. Do you have a record of the waste disposal and emissions?
8. On a monthly basis how many incidents and accidents do you record?

Interview questions for employees

1. Do you have any ideas of improving the production process?
2. From your experience as employees have you noticed any effects of the steel ball production process on employees?
3. How is the work environment?
4. How do you dispose of the waste from the production process?

Other questions for end users

1. What is the consumption rate of steel balls?
2. How do you dispose the worn out steel balls?
3. As the end user how can you optimize the consumption of steel balls?

5. Synchronizing the collected data with previous findings in other similar industries
6. Analyzing raw data by plotting appropriate graphs and then studying the effects of varying some input variables to the environment.
7. Identifying areas of improvement In terms of energy consumption per ball, space occupied by waste and gaseous emissions from the results.
8. Evaluating the impacts of emissions and waste.
9. Identifying opportunities for reheating and regenerating energy

A number of problems were faced in carrying out the project. These include:

- Key personnel still had to continue with their daily routine of work so they were not always available for a full interview.
- Many of them knew very little of LCA techniques
- Craster international mainly uses scrap, so information on production of iron and steel from basic elements had to be gathered from elsewhere
- In some cases issues of confidentiality hindered on how the members of staff were able to help

IV. RESULTS AND ANALYSIS

Health and safety risks at Craster International include among other things fumes inhalation related health problems. Small explosions or sparks from furnaces that may jump into the eyes or harm other parts of the body are rare. Since the establishment of the company in the early 1900's there is 1 full furnace explosion on record. There were no injuries or fatalities; however the pipes that make up the cooling system were extensively damaged. The nature of the business requires that furnaces are constantly renewed. In order to alleviate occurrences of accidents at the foundry some of the procedures adopted include the establishment of a health and safety department that includes a clinic that treats minor injuries at workplace. When a person is employed they are not allowed into the foundry or machine shop before he or she has gone through a lecture on safety courtesy of the health and safety department. Safety clothing is provided for all employees including office staff in case they need to go to the foundry for any business. No one is allowed in the foundry even for the shortest time without safety clothing. Those working directly on the furnaces have extra heat resistant clothing that is supplied to them. All this shows that the company is committed to the safety and health of its employees and allowing an LCA to be carried out also shows its commitment to improving its environmental performance.

4.2 - Inventory Analysis

This involves the quantification of all the energy inputs, raw materials, outputs and emissions for the processes involved in the production of steel balls.

Iron and steel production

The table below shows the inputs in making a kg of steel making under blast furnace conditions.

Description	Unit	Sum
Coal (in ground)	kg	0.678
Dolomite (CaCO3, MgCO3, In ground)	kg	0.026
Iron (Fe, ore)	kg	1.485
Limestone (CaCO3, In ground)	kg	0.006
Natural Gas (In ground)	kg	0.059
Oil	kg	0.054
Zinc (Zn, ore)	kg	0.006
Water Used (total)	kg	31.588
Ferrous scrap-total	kg	0.126
E Total Primary Energy	MJ	29.381
E Non Renewable Energy	MJ	28.833
E Renewable Energy	MJ	0.548
E Fuel Energy	MJ	28.976
E Feedstock Energy	MJ	0.406

The table shows out flows from the blast furnace on production of a kg of steel.

Description	Unit	Sum
Carbon Dioxide ($C0_2$, fossil and mineral)	g	2175
Carbon Monoxide (CO)	g	32.141
Nitrogen Oxide (NO_x as NO_2)	g	2.743
Particulate Matters – total	g	1.616
Sulfur Oxides (SO_x as SO_2)	g	3.238
Ammonia (NH_4^+, NH_3, as N)	g	0.114
Chlorides(CI*)	g	0.873
Chromium (Cr III, Cr IV)	g	1.077E-03
COD (Chemical Oxygen Demand)	g	0.276
Cyanides (CN*)	g	0.001
Fluoride (F*)	g	0.023
Iron ($Fe^{++}Fe^{3+}$)	g	0.024
Lead (Pb^{++}, Pb^{4+})	g	5.322E-04
Nickel (Ni^{++}, N^{3+})	g	2.723E-04
Nitrogen-TOTAL (except Ammonium)	g	0.157
Phenol (C_6H_60)	g	8.886E-03
Phosphates ($P04^{3-}$, $HP0^{4-}$, H_2P0^{4-}, H_3P0_4, as P)	g	-0.002
Phosphorus Matter (unspecified as P)	g	0.001
Sulfides (S^-)	g	0.133
Total Suspended Solids (unspecified)	g	0.297
Zinc (Zn^{++})	g	0.005
Water (unspecified)	kg	12.459
Recovered matter (total)	kg	0.082
Waste (total)	kg	0.211

Steel ball Production

The table below shows inflows in steel ball production using an arc furnace.

Description	Unit	Sum
Coal (in ground)	kg	0.088
Dolomite ($CaCO_3$, $MgCO_3$, In ground)	kg	0.001
Iron (Fe, ore)	kg	0.008
Limestone ($CaCO_3$, In ground)	kg	0.0073
Natural Gas (In ground)	kg	0.054
Oil	kg	0.046
Zinc (Zn, ore)	kg	-0.0014
Water Used (total)	kg	8.023
Ferrous Scrap-total	kg	1.118
E Total Primary Energy	MJ	11.509
E Non Renewable Energy	MJ	10.380
E Renewable Energy	MJ	1.125
E Fuel Energy	MJ	10.965
E Feedstock Energy	MJ	0.553

The table shows outflows from steel ball production using the arc furnace.

Description	Unit	Sum
Carbon Dioxide ($C0_2$, fossil and mineral)	g	523.378
Carbon Monoxide (CO)	g	1.654
Nitrogen Oxide (NOx as NO_2)	g	1.398
Particulate Matters – total	g	0.224
Sulfur Oxides (SO_x as SO_2)	g	1.767
Ammonia (NH_4^+, NH_3, as N)	g	0.000
Chlorides (CI*)	g	0.242
Chromium (Cr III, Cr IV)	g	2.18E-05
COD (Chemical Oxygen Demand)	g	0.069
Cyanides (CN*)	g	0.000
Fluoride (F*)	g	0.015
Iron ($Fe^{++}Fe^{3+)}$)	g	0.005
Lead (Pb^{++}, $Pb^{4+)}$)	g	6.33E-05
Nickel (Ni^{++}, N^{3+})	g	6.13E-05
Nitrogen-TOTAL (except Ammonium)	g	-0.001
Phenol (C6H60)	g	5.56E-06
Phosphates ($P04^{3-}$, $HP0^{4-}$, $H2P0^{4-}$, H3P04, as P)	g	9.67E-03
Phosphorus Matter (unspecified, as P)	g	6.67E-02
Sulfides (S^-)	g	0.001
Total Suspended Solids (unspecified)	g	0.057
Zinc (Zn^{++})	g	2.60E-04
Water (unspecified)	kg	7.290
Recovered matter (total)	kg	0.106
Waste (total)	kg	0.067

Steel ball Usage

In usage, steel balls crash ore in wet milling. Electric power drives the ball mill, hence the inflows are linked to power production.

Water used (total)	kg	8.023
Ferrous scrap-total	kg	1.118
E Total Primary Energy	MJ	11.509
E Non Renewable Energy	MJ	10.380
E Renewable Energy	MJ	1.125
E Fuel Energy	MJ	10.965
E Feedstock Energy	MJ	0.553

Out flows from usage of steel balls.

Particulate Matters – total	g	0.224
Sulfur Oxides (SO_x as SO_2)	g	1.767
Ammonia (NH_4^+, NH_3, as N)	g	0.000
Chlorides(CI*)	g	0.242
Chromium (Cr III, Cr IV)	g	21.8E-50
COD (Chemical Oxygen Demand)	g	0.069
Cyanides (CN*)	g	0.000
Fluoride (F*)	g	0.015
Iron ($Fe^{++}Fe^{3+)}$)	g	0.005
Lead (Pb^{++}, $Pb^{4+)}$)	g	6.33E-05
Nickel (Ni^{++}, N^{3+})	g	6.13E-05
Nitrogen-TOTAL (except Ammonium)	g	-0.001
Phenol (C_6H_60)	g	5.56E-06
Phosphates ($P0_4^{3-}$, $HP0^{4-}$, H_2P0^{4-}, H_3P0_4, as P)	g	9.67E-03
Phosphorus Matter (unspecified as P)	g	6.67E-02
Sulfides (S^-)	g	0.001
Total Suspended Solids (unspecified)	g	0.057
Zinc (Zn^{++})	g	2.60E-04
Water (unspecified)	kg	7.290
Recovered matter (total)	kg	0.106
Waste (total)	kg	0.067

4.3 - Impact analysis

The results show that during the making of steel making under blast furnace and the arc furnace conditions per kg the emissions of Carbon dioxide, Carbon monoxide, Sulphur oxides and Nitrogen oxide are the highest emissions. In the usage of the steel balls Sulphur oxides have the highest emissions. Carbon monoxide results from the incomplete combustion of hydrocarbons. It is a highly poisonous, odourless, colourless, tasteless and flammable gas. It is particularly dangerous in that its presence cannot be detected and can be harmful to humans if inhaled.

The results have shown that there are trace elements that are also emitted in all the processes.The environmental impacts presented below are those with at least one contributing substance.

Acidification

Acid Deposition; Substances that contribute to acidification are emitted from almost all of the activities in the studied life cycle. Both emissions to air and water are included. Rainwater normally has a pH close to 5.6 because of the reaction between water and atmospheric carbon dioxide to form carbonic acid. The presence of sulphur oxides and nitrogen oxides, the precursors to sulphuric and nitric acid, as well as chlorides and fluorides, the precursors to hydrochloric and hydrofluoric acids, can lead to rainfall with a pH lower than 5.0. Excess acidity can be harmful to plants. The acidity of the soil may inhibit seed germination and seedling growth in addition to other effects. Calcium, magnesium, and potassium can be leached out of the soil by acid rain. Acidic water may release sufficiently high concentrations of aluminium from minerals in the soil resulting in phototoxic concentrations. High concentrations of aluminium may also reduce the uptake of nutrient cations such as Calcium.

Eco toxicity, aquatic

Eco toxicity in aquatic environment is expressed in cubic meter of polluted water and only emissions to water are considered

Eutrophication

Almost all activities within the life cycle release substances that contribute to eutrophication. The substances could be released either to water or to air. Eutrophication is expressed in kg of NO_x- equivalents.

Resource depletion

Resource depletion is defined as the part of an identified resource that meets minimum physical and chemical criteria to current mining and production practices. Only resources, whose depletion is judged to become, or still be, a problem within the next one hundred years are considered in the characterizations method. Iron (Fe) is the substance that gives the major contribution to the resource depletion category.

Ozone depletion

Ozone depletion is a major challenge, since it shields the earth from short wavelength ultraviolet radiation. A 5% decrease in the amount of stratospheric ozone has been predicted to produce 20% more cases of skin cancer, mostly cell carcinoma, per year in the United States [19]. The main ozone depleting substances contain the chlorine atom, nitric oxide, the hydroxyl radical, and the hydrogen atom.

V. CONCLUSIONS

Life cycle assessment, a directional indicator has been used to note the areas with the greatest environmental burdens within the system boundary. Research findings indicated that most of the environmental impact reduction interventions have to be in the extraction and production of steel balls. Trace elements are in all the processes and their effects have been highlighted.

Employees were also exposed to hazardous emissions during the production of steel and of the steel balls. Accidents affect not only the environment but also can cause human damage. Recommended damage mitigation steps include preventive maintenance of all machinery, regular medical checkups for employees and community and use of sensing and alarm systems.
There is need for further studies such as the ways of mitigating the greenhouse emissions, disposal scenarios of waste and the inclusion of such issues as social issues and economic issues which were not covered in this analysis.

Figure 3 shows the recommended life cycle of the steel balls at Craster International.

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BIOGRAPHY

Loice Gudukeya is a PhD student at the University of Johannesburg, South Africa. She is also a lecturer in the Mechanical Engineering Department at the University of Zimbabwe. She attained her first degree in Industrial and Manufacturing Engineering at NUST (Bulawayo, Zimbabwe) in 2004 and her Masters in Renewable Energy at the University of Zimbabwe in 2012. She is a Board and Corporate member of the Zimbabwe Institution of Engineering. As a corporate member she is part of the subcommittee National Engineering of Student Award Committee. As a board member she is in the displinary committee.
Charles Mbohwa is currently a Full Professor of Sustainability Engineering and Engineering Management at the University Of Johannesburg, South Africa. He did his PhD in Engineering in Environmental Impact Assessment of Information and Communication

Technology, Department of Information, Production and Systems Engineering, Tokyo Metropolitan Institute of Technology, Tokyo, Japan. Graduated in March 2004.

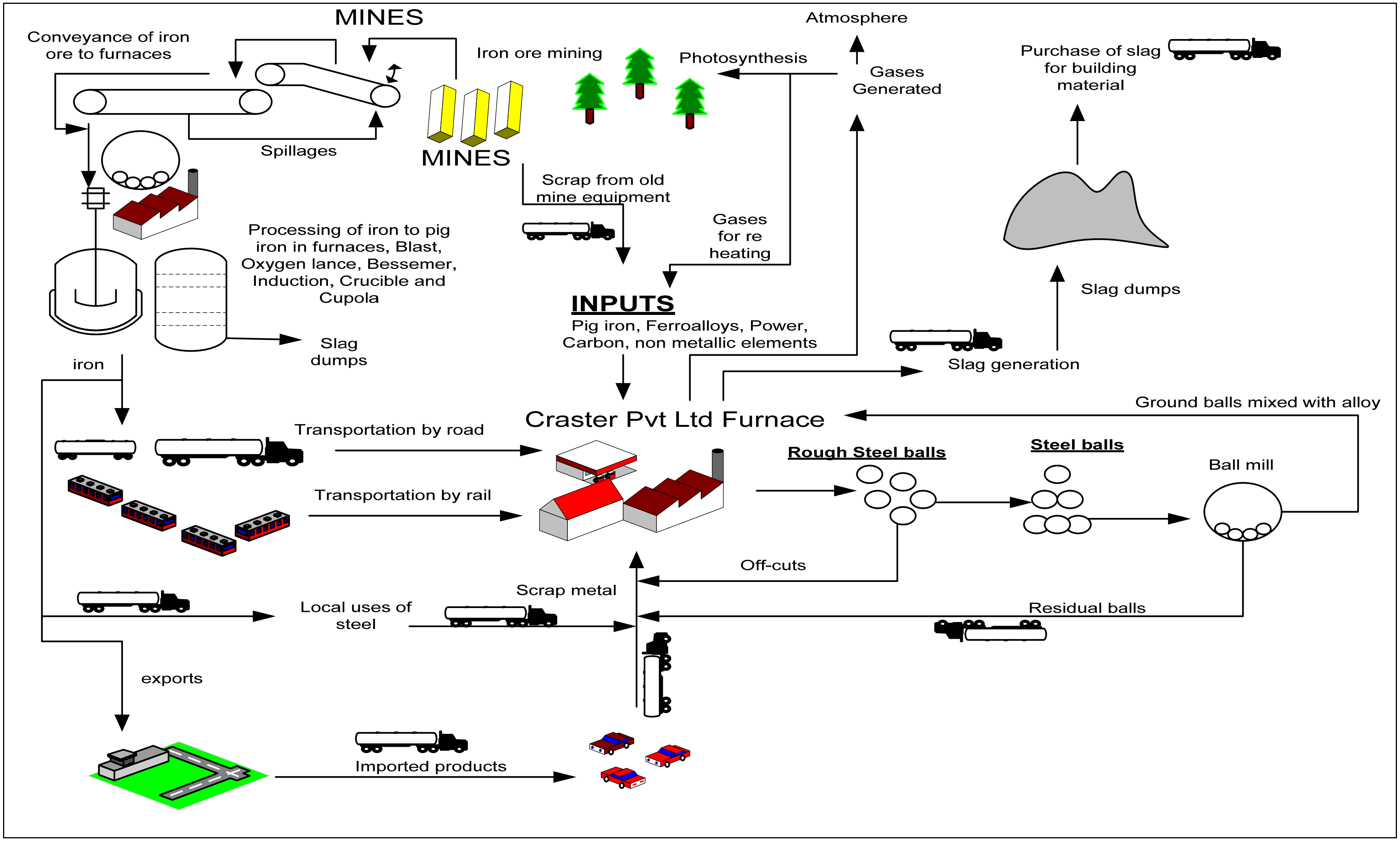

Figure 3: Recommended life cycle of steel balls at Craster International