

# THE CRADLE TO CRADLE LIFE CYCLE ASSESSMENT: A CASE STUDY

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**Abstract**— The growing environmental awareness among the society, customer, stakeholders and tremendous pressure of government bodies to comply with the environmental norms, the industries and professionals are forcing themselves towards the world class environmental management practices.

By taking into account the trend, the work carried out on one of the product 'Deflector Roll'. The roll undergoes heavy wear & tear, high compressive & torsional stresses; as a result it cracks/breaks after certain period of use. The new manufacturing creates environmental & human health burden through various processes performed on it. By taking this gap into account, the life cycle of roll, modelled in an eco-intelligent way so that after the useful life, the material is brought back into the techno sphere without waste. The proposed life cycle model consists of Extraction and Production of Raw Material, Manufacturing, Use, Remanufacturing, Reuse and finally Recycling. This modified framework enables to form the Cradle to Cradle life cycle loop by two ways, viz. while remanufacture/reuse the roll is brought back into the product system and while recycling again around 95% of material is brought back into the techno sphere. Further, in order to evaluate the environmental performance of roll with proposed model, the 'Life Cycle Assessment' tool is chosen. The roll is assessed through all of its life cycle phases. The inputs and outputs during each life cycle phase are collected and recorded. The assessment carried out on the modified life cycle model in one of the reputed LCA software tool 'GaBi 6.' In order to assess the life cycle impacts the 'CML 2001' methodology is adopted which consist of the impact categories like Global warming potential, Acidification, Ozone Layer depletion and many others. Further, the results show that the proposed model creates the negligible impacts during manufacturing, use, remanufacturing and reuse. Also, the two way formation of cradle to cradle loop concludes that the proposed product system model of roll is sustainable.

**Key words**— Cradle to Cradle System, Life Cycle Assessment, Sustainability, LCA software tools, Recycling, Eco-effectiveness, Life cycle impacts, Sustainability Indicators.

## I. LIFE CYCLE ASSESSMENT

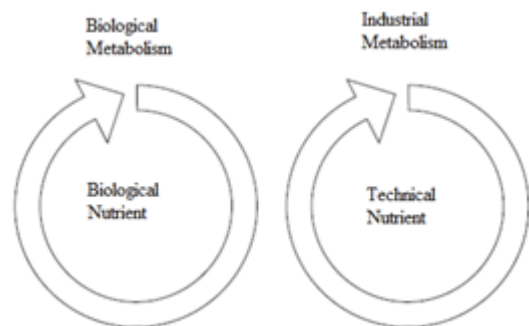
Life cycle assessment is a tool to evaluate the environmental consequences of a Product/Project or activity thoroughly its entire life from extraction of raw material, Use, Disposal and its composition back to the element. The sum of all those phases is the life cycle of a product. LCA allows to track and monitor the environmental impacts of products and services over the entire life and to recognize the factors of environmental impacts (James W. Levis, 2013). It is a systematic analytical method to identify, evaluate and minimize the environmental impacts of a product through every step of its life from transformation of raw materials into useful products and the final disposal of all products and its by-products (Arun Kumar, 2013). Life cycle assessment can be an entrepreneurial tool for firms to achieve sustainable results through of renewed vision about business management and green innovations (Cassiano Moro Piekarski et al. 2013). LCA is a basis for establishing an environmental policy and is

generally used to guide the clean production, development of green production, and the environmental harmonization design (Darko Milanković et al. 2013).

## II. THE CRADLE-TO-CRADLE SYSTEM

William McDonough and Michael Braungart are the key researchers in the field of Cradle-to-Cradle design. William McDonough is an architect, industrial designer, and educator. Michael Braungart is a chemist and an university professor. In 1995 the authors together co-founded McDonough Braungart Design Chemistry, which is a product and process development firm assist the companies for assessment of material, material flows management, and life-cycle design. McDonough and Braungart identified "current human technology is a product of cradle to grave design, we extracts the natural resources from the earth, convert them into a product, use it, and throw it away". Authors in their book "Cradle to Cradle: Remaking the way we make things" in 2002, proposed an totally different strategy of cradle to cradle design which takes the inspiration from nature and states there is no waste on the earth and Waste = Food.

Cradle-to-Cradle is a specific kind of cradle-to-grave assessment, in which recycling or reuse method is employed while disposing the product. Basically, it is a tool to achieve the triple top line growth and eco-effectiveness, aims towards improving the environmental as well as economic values with a large and beneficial ecological footprint.



**Fig. 1: Cradle-to-Cradle Cycle (Source: McDonough and Braungart, 2002)**

The Cradle-to-Cradle concept operates on the principle of nature that, 'there is no waste on the earth' and 'Waste=Food'. The waste of one product/process becomes the food for another which is here called as nutrients. From fig. 1 we can see there are two types of nutrients viz. Biological nutrients and Technical Nutrients. Biological nutrients are organic material where the waste becomes the nutrient for another plants to grow while technical nutrients are those, after the end-of-life of a product/service the same material (Secondary material) is used to recreate the products/goods in a closed loop system. From Industrial perspective, this means developing material,

products/goods, and processes modelled on nature's cradle-to-cradle cycle in which the waste of one product becomes the nutrient for other product/goods with a high quality of secondary material with less environmental and human health impact.

### III. THE CASE STUDY

This study at cold rolling mill manufacturing industry made on life cycle assessment of rolls to assess the life cycle impacts and redesign the life cycle product system in an ecologically intelligent way (Mc Donough Braungart Design Chemistry, 2002) to fit the system in a closed loop cradle to cradle life cycle model with the aim to use the waste material as (technical nutrient) food (Mc Donough & Braungart, 2002).

#### A. The Problem: Current Life Cycle Model

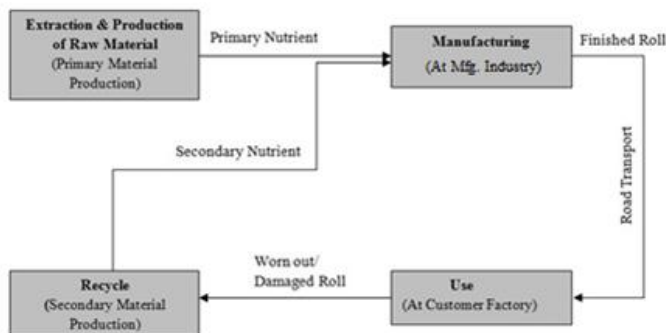


Fig. 2: Current Life Cycle Model of Rolls

From the above fig. 2 we can see, currently the life cycle process of rolls consists of extraction & production of raw material, manufacturing, use phase, recycling and road transportation between all of them. The manufacturing of rolls requires several processes like boring, turning, grinding, cutting etc. The each manufacturing process requires several inputs in the form of material, energy & consumables and emits the outputs in the form of pollutants & Wastes (M. Despeisse et al. 2013). After manufacturing, the rolls are sold to its customers where it undergoes the use phase. The rolls are used at customer factory for drawing the cold rolled steel sheets. During use phase again it requires inputs like the electrical energy to drive the rolls, consumables like rolling oil, grease, cotton wastes and many others, as a result again it emits the outputs in the form of wastes. The average life of rolls is 10,000 tonnes of rolling, after which the rolls gets heavily worn out and becomes useless. Therefore, the rolls are now scraped by customer and sold to the scrap dealer for further recycling.

Now, In order to fulfill the demand by new rolls, requires to extract and produce the fresh raw material, manufacturing, use and again recycling. All those fresh activities create the heavy environmental as well as human health burdens, natural resource depletion and heavy cost. (Jesus Rives et al, 2012)

#### B. The Solution: Cradle to Cradle Life Cycle Model

In order to tackle the situation the study proposed the redesign of product life cycle system in an eco-effective intelligent manner (Mc Donough Braungart Design Chemistry, 2002) to achieve triple top line sustainable growth (Mc Donough & Braungart, 2002) by using the tool 'cradle to cradle life cycle'. For justifying the cradle to cradle principle of "Waste equals food" (McDonough and Braungart, 2002) the life cycle processes are so formed that after the useful life the waste becomes the food in the form of technical nutrient.

From below modified flowchart shown in fig. 3, we can see the life cycle processes of roll now consists of extraction & production of raw material, manufacturing, use phase, remanufacturing, reuse, recycling and road transportation between all of them. From this new perspective the 3R's strategy of Remanufacture, Reuse and Recycle (M.Despeisse et al.2013) is adopted into the life cycle of rolls. In order to carry out remanufacturing, the company can form a policy with its customer according to which, the company can take back its used worn out rolls from its customer (Jeremy Dobbie, 2006) after end of first useful life (which otherwise would have directly scraped and gone for recycling) and send for remanufacturing. In order to accomplish the remanufacturing process of rolls with a standard specification and a comparable quality, the company can have a partner reconditioning company at a nearby distance. After remanufacturing, the rolls again goes for 'reuse' at customer's workplace where again it is subjected to material, energy and waste (MEW) flows in and out of the product (M. Despeisse et al. 2012). After the useful 'reuse life' the rolls gets heavily worn out and its material gets weakened therefore cannot further remanufactured hence, are sent for recycling to bring the material back into the closed loop technical sphere for manufacturing other products.

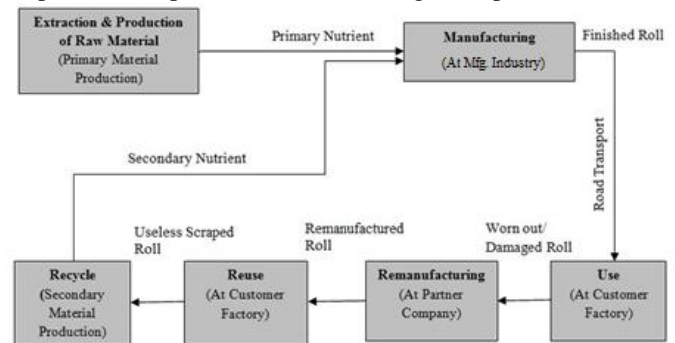


Fig. 3: Proposed Cradle-to Cradle flowchart

The remanufacturing process enables to recondition the roll by using the same material (worn out roll) received after its first useful life. As a result fresh raw material extraction & its production process is eliminated which helps in conservation of natural resources, reducing the environmental & human health burden and saving in material cost (Ken Alston (2008). Also, remanufacturing requires few operations as compared to new manufacturing which again saves the energy and manufacturing cost to a great extent.

The reuse helps to achieve the optimum utilization with total extended life of around 1.8 times of the current life cycle system which gives high value to customer with less cost. The reuse enables to form a closed loop cycle where the waste material of worn out roll comes back into the same product system and form the closed loop cradle to cradle life cycle model.

After reuse, the roll material gets weakened and worn out therefore cannot undergo the remanufacturing again, hence, it has to scrap and send further for recycling. The recycling process helps to bring back around 95% of the scraped material into the closed loop technical sphere as secondary material for further manufacturing, which again achieve 'waste equals food' principle and form the cradle to cradle life cycle model. The remaining around 5% of shortfall material is compensated by primary material.

In this way the couple of closed loops are formed while reusing as well as recycling. By adopting the above processes into the life cycle system the company can get the benefit of improved ecological footprint which helps to gain customer faith, reputation within society, compliance to legislation. Besides, due to reduced cost company can take the competitive advantage by reselling the product at a lower price which further helps to gain higher market share and lead the company to achieve its socio-ecological-economic goals.

### C. Model Development

Based on the exhaustive literature review and innovative ideas, the life cycle processes are so eco-intelligently modelled that after the first useful life, the rolls are sent for remanufacturing in order to take the advantage of reuse and afterwards recycling to bring back the material into techno sphere. Now, in order to check whether such life cycle model is practically possible, the processes are modeled in 'GaBi 6' Education software. The software contains several flows for the standard processes like 'Extraction & Production of Raw Material' and 'Recycling'. The other processes like Manufacturing, Use, Remanufacturing and Reuse has to be

created by own. Their input output flow data was collected by observations and guidance by concerned industrial professionals. The gathered data was evaluated & converted into the suitable quantities and units to form the inventory of input output flows (Jeanette Schwarz, 2002) and put the same in the respective manually formed process in software. Each process of cradle to cradle life cycle system of rolls consists of various inputs and outputs like material, energy, waste, pollutants etc. While developing the model it was ensured that the processes and flows chosen, co-relate each other and are exist in the real world situation, as the 'GaBi 6' do not connects the system processes with each other, in case of wrong and invalid selection of processes & flows. Thus, the GaBi helps not only to assess the environmental impacts during the life cycle phases but also helps to check the feasibility of the innovative system models in practice.

The model developed below fig. 4 shows a life cycle cradle to cradle model of rolls, formed by adopting the applications of 3 R's strategy, cradle to cradle principle of waste equals food, sustainability, and Eco-effectiveness.

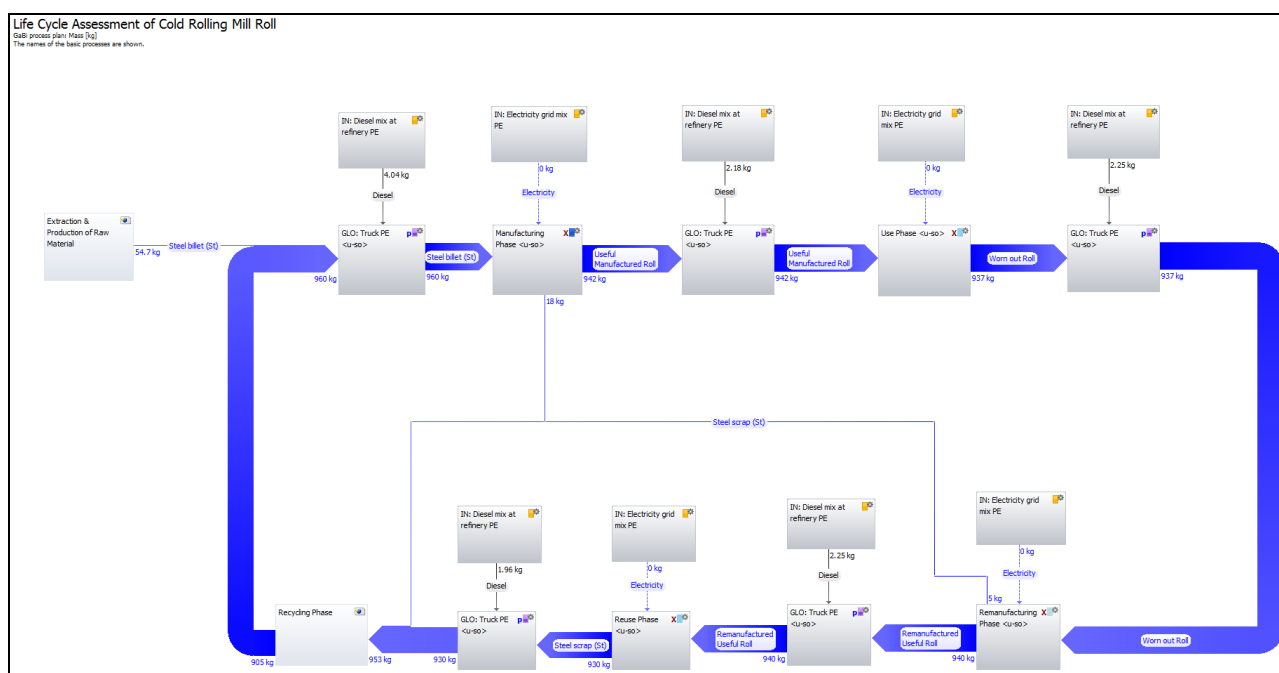


Fig.4: The Input-Output Cradle to Cradle Model

### D. The End of Life System Indicators

The end of life system adopted here is recycling. The indicators for the recycling describe the efficiency of recycling system (Tom N Lighthart, 2012). The following are the recycling indicators for the roll material,

$$\begin{aligned}
 1. \text{ Collection Rate (\%)} &= \\
 &= \frac{\text{Amount of Scrap Collected}}{\text{Amount of Scrap Produced}} \times 100 \\
 &= \frac{953}{953} \times 100 \\
 &= 100 \%
 \end{aligned}$$

$$\begin{aligned}
 2. \text{ Recovery Rate (\%)} &= \\
 &= \frac{\text{Amount of Scrap Recovered}}{\text{Amount of Scrap Available}} \times 100 \\
 &= \frac{953}{953} \times 100 \\
 &= 100 \%
 \end{aligned}$$

$$\begin{aligned}
 3. \text{ Recycling Efficiency (\%)} &= \\
 &= \frac{\text{Amount of Scrap Reprocessed}}{\text{Amount of Scrap Recovered}} \times 100 \\
 &= \frac{905}{953} \times 100 \\
 &= 94.96 \%
 \end{aligned}$$

$$\begin{aligned}
 4. \text{ Recycling Rate (\%)} &= \\
 &= \frac{\text{Amount of Scrap Reprocessed}}{\text{Amount of Scrap Available}} \times 100 \\
 &= \frac{905}{953} \times 100 \\
 &= 94.96\%
 \end{aligned}$$

$$\begin{aligned}
 5. \text{ Recycled Content (\%)} &= \\
 &= \frac{\text{Amount of Scrap Reprocessed}}{\text{Total Amount of Material}} \times 100 \\
 &= \frac{905}{960} \times 100 \\
 &= 94.27\%
 \end{aligned}$$

From above we get the amount of secondary material which is 94.27 %. i.e.,

$$\begin{aligned}
 &= \frac{94.27}{100} \times 960 \\
 &= 905 \text{ Kg.}
 \end{aligned}$$

Hence, the amount of primary material required to fulfil the requirement is 5.72 % i.e.,

$$\begin{aligned}
 &= \frac{5.72}{100} \times 960 \\
 &= 55 \text{ Kg.}
 \end{aligned}$$

The pie chart fig. 5 below shows the primary and secondary material distribution for the manufacturing of roll.

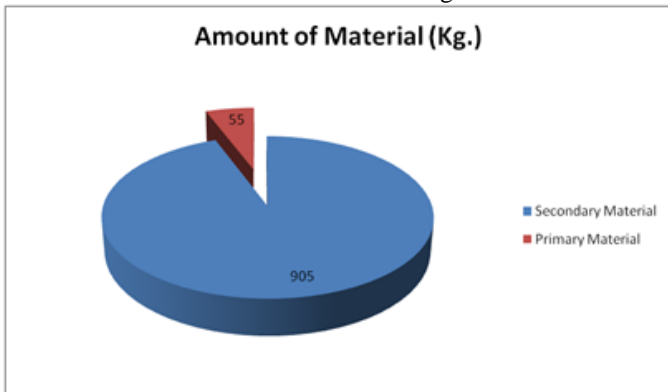


Fig. 5: Primary and Secondary material distribution

#### E. Summary of Results

Sr. No	Flows	Amount of flows (Kg.)
1	Resources	414887010.3
2	Deposited goods	311475.7919
3	Emissions to air	1452303.068
4	Emissions to fresh water	411970784.1
5	Emissions to sea water	1104754.564
6	Emissions to agricultural soil	0.685174844
7	Emissions to industrial soil	0.855017207

Table 1: Results for aggregated Input-Output flows

Sr. No.	Impact Category	Amount of Impact
1	Global Warming Potential (GWP 100 years) [kg CO <sub>2</sub> -Equiv.]	170209.470
2	Acidification Potential (AP) [kg SO <sub>2</sub> -Equiv.]	1517.896
3	Eutrophication Potential (EP) [kg Phosphate-Equiv.]	90.898
4	Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	4.0864E-06
5	Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	0.0062
6	Abiotic Depletion (ADP fossil) [MJ]	1859423.22
7	Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]	478.48
8	Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	60027.83
9	Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	278895394.6
10	Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	75.759
11	Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]	2663.41

Table 2: Results for various Impact Categories

Sr. No	Energy Resource	Amount of Energy (MJ)
1	Primary Energy Demand from Renewable and Non-Renewable Energy Resources (net cal. value)	1.97 x 10 <sup>6</sup>

Table 3: Results for Primary Energy Demand

Sr. No	Type of Technical Nutrient	Amount of Material (Kg)
1	Secondary Material (Recycled Content)	905
2	Primary Material (Fresh extracted material)	55

Table 4: Results for Technical Nutrient Requirement

#### IV. CONCLUSION

The work is practically performed on the Deflector Roll to assess its impacts on the environment as well as on human health throughout the life cycle. In order to perform the life cycle assessment the 'Life Cycle Assessment' (LCA) tool along with the 'GaBi 6' software was selected. The inputs and outputs during each unit process on the product throughout its life cycle was recorded and put into the software to achieve the results. The result gives the aggregated input-output flows, Primary Energy demand and several environmental and human health impacts. Besides, the focus was made to bring back the material into the techno sphere. In order to achieve this, the application of 3 R's strategy (Remanufacturing, Reuse and Recycle), cradle to cradle principle of waste equals food, eco-effectiveness and sustainability was adopted. Accordingly, the processes was so eco-intelligently modelled that after the first

useful life the product is remanufactured to take the advantage of reuse and finally recycling to bring back the material into the techno sphere in the form of secondary material. By doing so, the cradle to cradle model formed and material after the end of life became the food (Technical Nutrient) for same or another product system without waste.

The following are the major contributions of this work,

- The cradle to cradle model of waste equals food is formed in two way viz, while remanufacturing & reusing, the material came back into the same product system without waste, Similarly while recycling, the material again came back into the techno sphere which can again utilised in the same or any other product system.
- The reuse and recycling helped to prevent the natural material and energy resource depletion. Also, minimized the environmental impacts which would have occurred during extraction of fresh raw material and further processing.
- The study identified the several environmental impacts of roll throughout its life cycle phases, which not only helps the manufacturer but also to mining industry, customer who actually uses the product, remanufacturing industry and transportation organisations to understand their environmental performance.
- The company can sell the rolls at a lower price, as the remanufacturing consists of fewer operations which cuts down the manufacturing cost; also utilisation of same material saves the material cost. As a result the company can take the competitive advantage and gain higher market share which helps to achieve the economic goals of company.
- The reuse strategy adopted in the study enables the customer to take the advantage of extended life of roll (i.e. 1.8 Times) in a less cost which gives high value addition to the customer and hence, helps to gain the customer faith.
- The study proposes the remanufacturing at a partner company. Accordingly, the rolls after first useful life are remanufactured which increases the need of man power hence, more employment opportunities are created at partner company.
- The methodology of the proposed study helps the concerned industries to carry out their activities of Environmental Management System like,
  - I. Regularly monitoring and measurement of the operations & activities that have the significant environmental impact.
  - II. Periodically evaluating the compliances with applicable legal requirements and keeping the records of the results of the periodic evaluations.
  - III. Identifying and correcting non-conformities and taking action to mitigate their environmental impacts.
  - IV. Maintaining the environmental records to demonstrate the achievement of specified objectives & targets and effective operation of EMS.
- From the obtained results it was observed that the rolls manufactured by manufacturer, create very negligible environmental impact during Manufacturing, Use, Remanufacturing and Reuse. Thus, the operations are safe for

the employees of company as well as of customer, society and environment. Hence, the company can gain high reputation within society, stakeholders, customers and government bodies.

From all above we came to conclusion that the Ecological, Equity, and Economical goals are fulfilled, as the material after the end of use is brought back into the techno sphere with less cost and with negligible environmental impacts. Hence, we conclude that the product system modelled here is cradle to cradle and sustainable.

#### V.SCOPE FOR FUTURE WORK

The work can be carried out to assess the environmental performance of whole operational system at this rolling mill manufacturing industry as well as at any other industry by aggregating all activities and by adopting the same methodology.

The work can be extended towards achieving industrial ecology at factory level with the aim to make the whole operational system as 'cradle to cradle system' where there is no waste and the waste becomes food for another product/system. Further, the work can be carried out to obtain the cradle to cradle certification.

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