CHAPTER III
EXPERIMENTAL

3.1 Materials and Equipment

3.1.1 Equipment

- Desktop computer (Pentium IV, RAM 1 GB, Window XP and Microsoft Office 2003)

3.1.2 Software

- SimaPro version 7.0

3.2 Methodology

3.2.1 Preparation

a.) Study and review background of bioplastic production including raw materials, process, technology, and manufacturers, and conduct literature survey on LCA studies on the environmental impacts.

b.) Contact manufacturers/companies to explain about the importance and scope of this work through telephone conversation and meetings and also ask for their corporations.

c.) Develop the process and flow diagrams.

d.) Design data templates and distribute to the company for collecting data as shown in Table 3.1.

Table 3.1 Template of data collection for production of bioplastic product

Production of Bioplastic Product							
Input Inventory				**Output Inventory**			
Description	**Unit**	**Amount**	**Remark**	**Description**	**Unit**	**Amount**	**Remark**
Resources				***Products***			
Virgin PLA resin	kg			Product	kg		
Recycle PLA resin	kg			Scrap	kg		
...				....			
Utilities				***Emissions***			
Electricity	kWh			CO_2	kg		
...							

3.2.2 Goal, Scope, Functional Unit, and System Boundary

a.) Formulate and specify goal of the LCA study.

The goal of this LCA study is to assess the environmental impacts of bioplastic resins (PLA and PBS) and their products (2 products each). At present, film bioplastic product has already been selected. The inventory data collection will be compiled by using SimaPro 7.0 software and the environmental impacts of the bioplastic will be evaluated using Eco-Indicator 95 and CML 2 baseline 2000.

b.) Identify Functional Unit (FU) of the study.

In this research, the functional unit is set to be one kg of plastic resin, and one piece or one kg of plastic product.

c.) Determine scope and system boundaries of that bioplastic production and make assumptions based on the goal definition.

The scope of this research covers data collection of bioplastic products produced from PLA and PBS, evaluation of the environmental impacts of the bioplastic products, and comparison of the bioplastic products with the same products produced from conventional plastics. The system boundary includes bioplastic resin production, production of bioplastic product, use of products, waste management of bioplastic products, and transportation at all stages as shown in Figure 3.1.

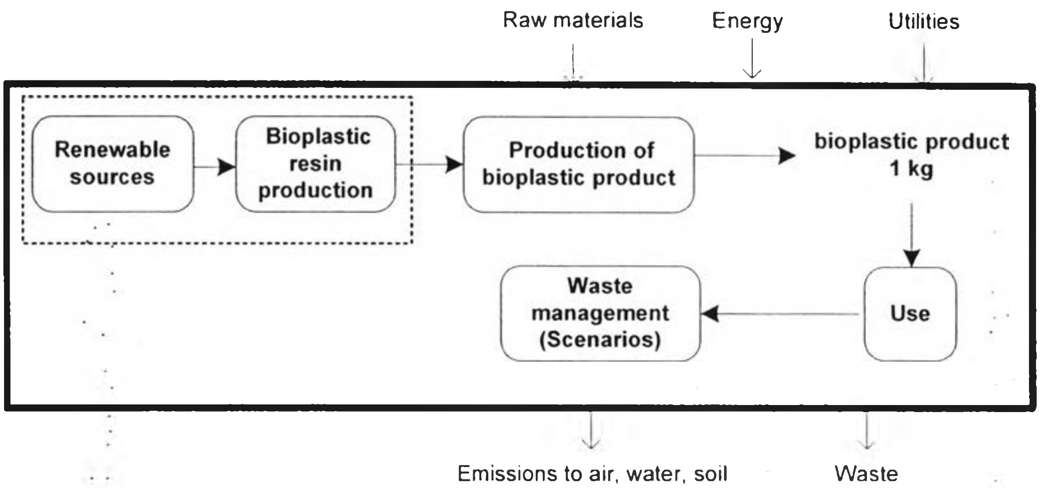


Figure 3.1 System boundary of the LCA bioplastic study.

For transportation phase. PLA plant is located at Rayong province and plastic production plants are located at Nakhon Pathom. The distance of PLA resin transportation between Rayong and Nakhon Pathom about 235 km by using trailer 25 tons. In case of PLA product transportation, majority of customers is customers in Bangkok so the distance or transportation is approximated 56 km by using truck 12 tons.

The goal of disposal phase was to evaluate the environmental impact of bio-plastic treated, which is PLA and PBS. The functional unit of this study was set as 1 kg of bio-plastic treated. Scope of this work is only end of life disposal included transportation bio-plastic waste from household to disposal site by different technology such as landfill, incineration, composting, and recycling. The System boundary is shown in Figure 3.2.

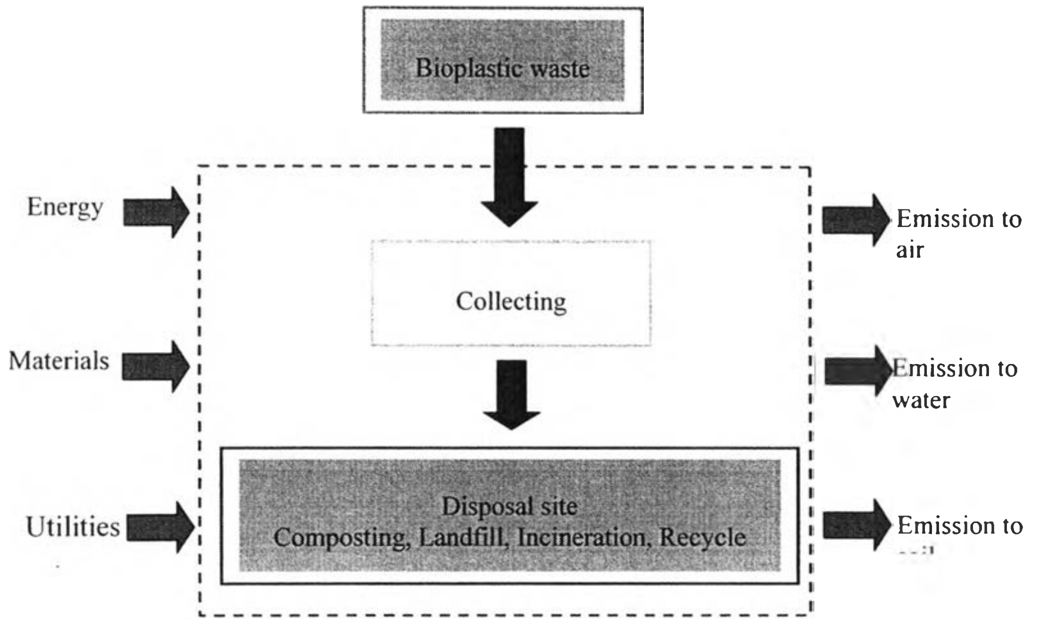


Figure 3.2 The scope of disposal phase.

For disposal phase, different waste management scenarios were created and compared based on the MSW management systems of Bangkok Metropolitan as shown in Table 3.2. Four different scenarios were considered in addition to the base case scenario.

Base case: 12% of bio-plastic wastes are collected and sent to composting plant at Onnut. The remaining 88% are collected and sent to landfill sites at Panomsarakam (gas collection and electricity generation system) based on Bangkok Metropolitan Area (BMA).

Scenario S1: 100% composting.

Scenario S2: 30% composting 30% landfill and 40% incineration based on Master Plan of Bangkok Metropolitan Area (BMA).

Scenario S3: 10% recycle 30% composting 30% landfill and 30% incineration as proposed by PTT Research and Technology Institute (RTI).

Table 3.2 Scenarios for waste management

Scenarios	% Composting	% Landfill	% Incineration	% Recycle
Base case	12	88 (without energy recovery)	0	0
S1	100	0	0	0
S2	30	30	40	0
S3	30	30	30	10

Allocation factor

Plastic wastes from household are considered as 100% of bioplastic waste, which are sent to transfer station for sorting the process. Finally, plastic wastes are sent to disposal facilities. Allocation by mass was used to allocate the burden of energy and utilities used in disposal phase. There is one of the most critical issues in the life cycle assessment and energy analysis.

a.) Assumptions and limitations

- For use phase, it is assumed that the user uses the product only once before it is disposed.
- Average distance of bioplastic waste collection from household to disposal site is equal to 35 km.
- Emission from vehicles operation in fuel transportation are calculated based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
- The carbon content of PLA is 54.6%wt (Iovino *et al.*, 2008).
- PBS is considered to come from succinic acid (SA) (bio-base) 53.03% and 1,4 butanediol (BD) (petroleum-based) 46.97%.
- The carbon contents (as equivalent CO_2 emissions) of BD and SA (expressed in sugar cane) are 1.953 and 0.482 t/t, respectively (Patel *et al.*, 2006).

Landfill

Calculation for Landfill of PLA and PBS

Equation of anaerobic digestion

$$C \longrightarrow CO_2 + CH_4 \quad (1)$$

PLA would be converted to methane in the landfill, but 10% of that methane is either chemically oxidized or converted by bacteria to carbon dioxide based on Bohhmann (2004). Of the remaining 90%, 45% is recovered and combusted to generate electricity and the other 45% escapes to the atmosphere as following Figure 3.3.

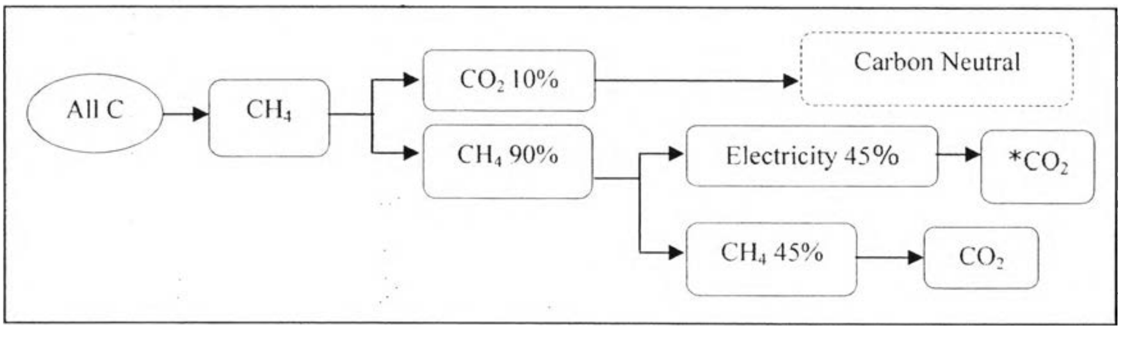


Figure 3.3 PLA landfill.

PBS is consist of (Succinic Acid; SA) 53.03% and (1,4 Butanediol; BDO) 46.97%. PBS would be converted to methane in the landfill, but 10% of that methane is either chemically oxidized or converted by bacteria to carbon dioxide. Of the remaining 90%, 45% is recovered and combusted to generate electricity and the other 45% escapes to the atmosphere as following Figure 3.4.

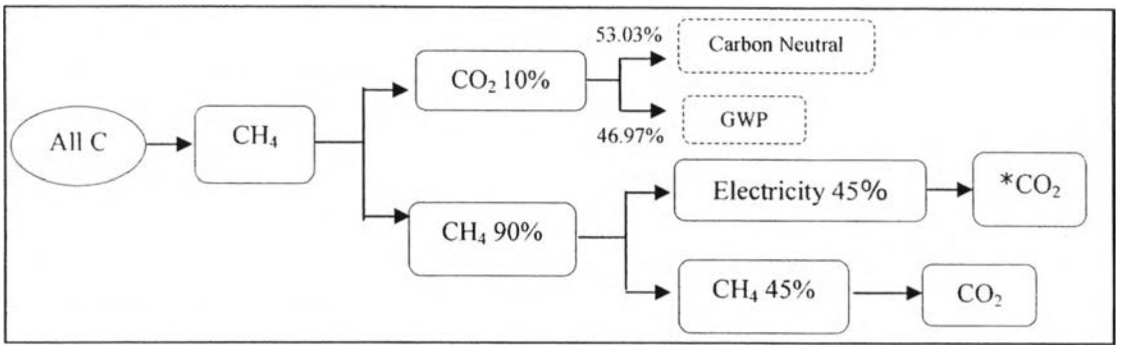


Figure 3.4 PBS landfill.

In case of landfill with energy recovery was used to produce electricity where 45% of CH_4, this is considered to help decrease environmental impact because the electricity generated is considered to compensate the environmental impacts resulting from overall electricity production of EGAT (grid-mixed).

Recycle

The system boundary of bio-plastic recycle consists of collecting, washing, and recycling process as shown in Figure 3.5.

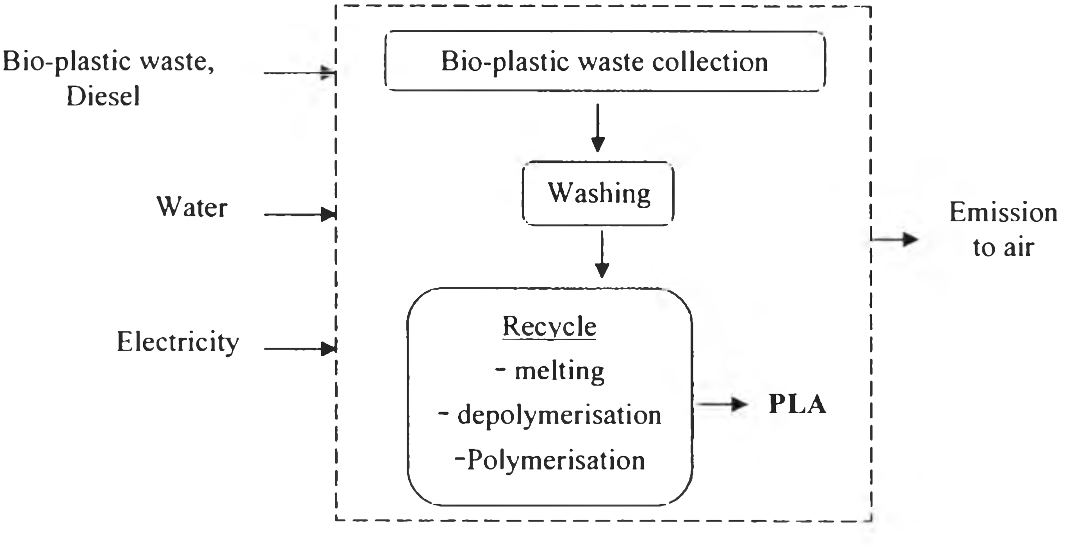


Figure 3.5 The system boundary of recycle bio-plastic waste.

For recycling scenario, recycling of PLA back to monomer (BTM) was considered in this study based on Dornburg *et al.* (2006). PLA is converted into L-LA by a short hydrolysis at low temperatures; about 90% of LA can be recovered by hydrolysis at 250°C and a processing time of 10-20 min. The L-LA is then polymerized to PLA again. PLA production efficiency 0.9 Mg/MgPLA. The energy use for BTM recycling is 0.6 MJ per kg PLA. (Dornburg *et al.*, 2006). Water consumption is 0.005 m^3 per kg recycled plastic (Molgaard, 1995). The recycled PLA is considered as a replacement of virgin material (PLA resin) production.

Compost

Composting is a process at which compostable materials under well controlled circumstances and aerobic condition (presence of oxygen), by means of microorganism, are converted and decomposed. The data used for composting were received from the composting plant at Phang, Chiangmai Province. The system boundary is shown in Figure 3.6.

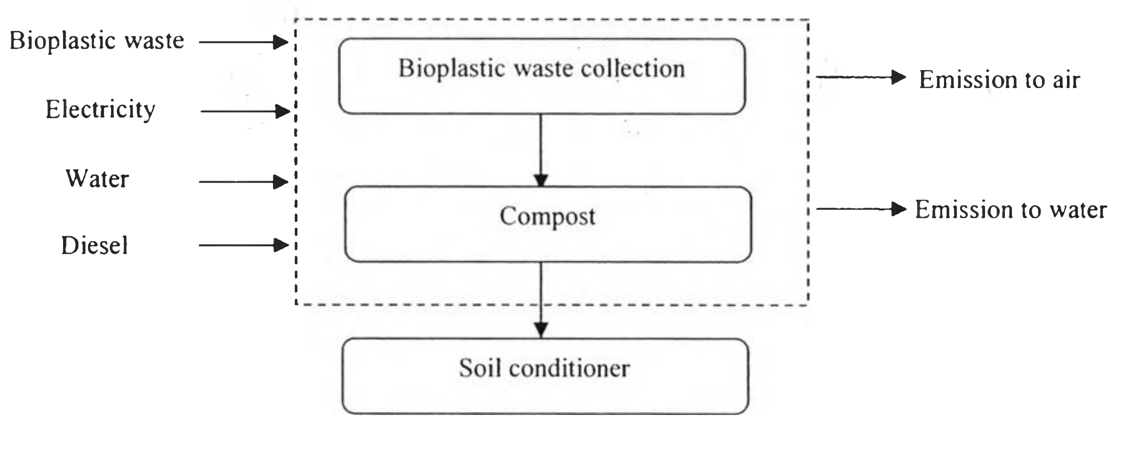


Figure 3.6 The system boundary of composting technology.

Assumption for calculated of composting technology.

- The anaerobic biological treatment, it presumes that CH_4 emission is not generated.

- The biodegradability potential of PLA was 87% of CO_2 evolution and CO_2 from decomposition are carbon neutral as shown in Figure 3.7 (Suwanmanee *et al.*, 2010).
- The biodegradability potential of PBS was 87% of CO_2 evolution and CO_2 from decomposition are carbon neutral as shown in Figure 3.8 as PLA composting.

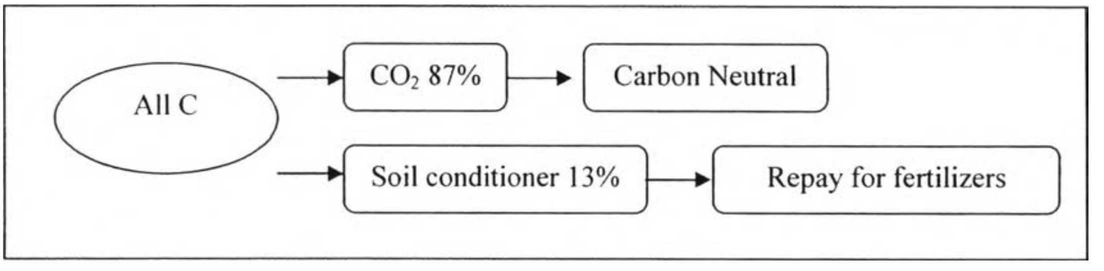


Figure 3.7 Conversion concept of CO_2 in composting process of PLA.

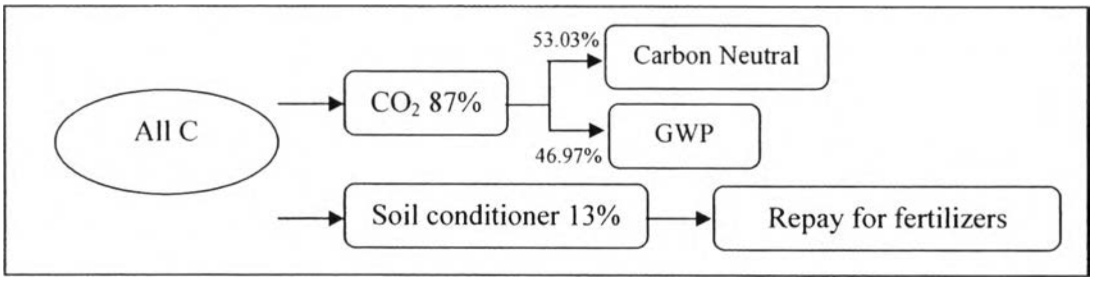


Figure 3.8 Conversion concept of CO_2 in composting process of PBS.

Incineration

Incineration is the thermal destruction of waste. The data used for incineration received from the incineration plant at Phuket Province. The system boundary is shown in Figure 3.9.

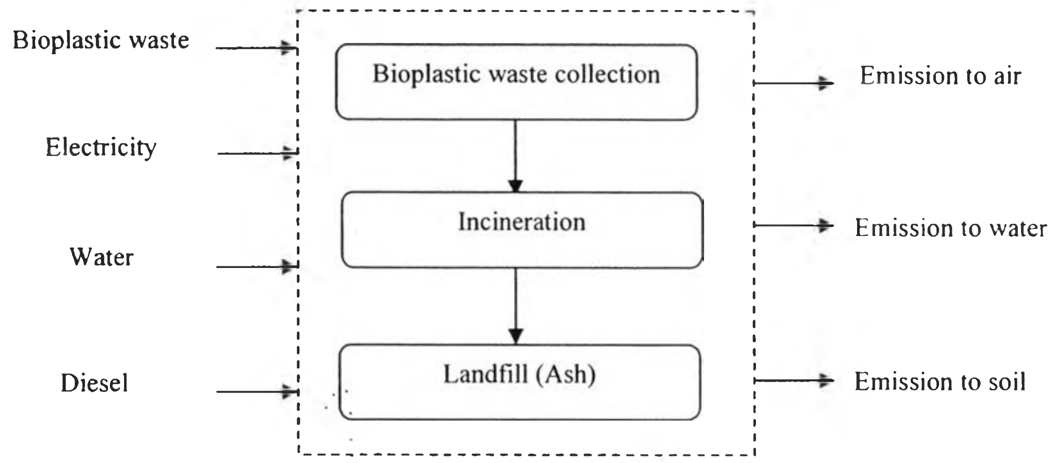


Figure 3.9 The system boundary of incineration technology.

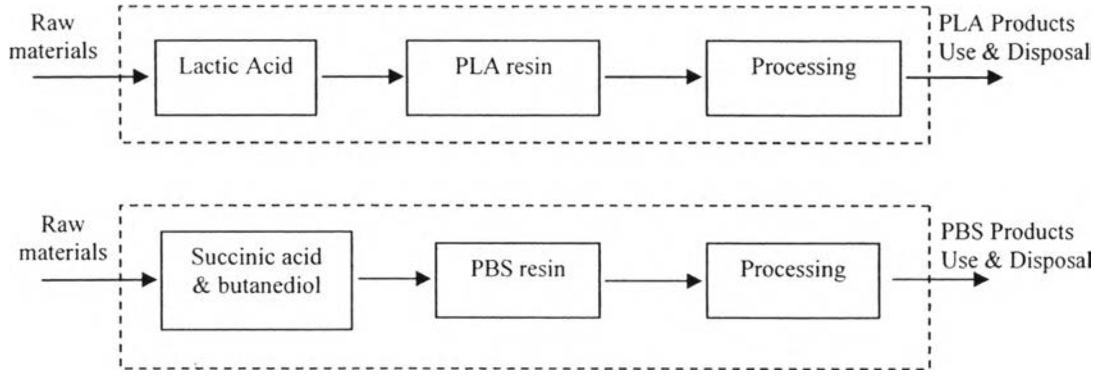
Assumption for calculated of incineration technology.

- Incineration is a process that combusts the waste to generate electricity. Electricity production was calculated with a lower heating value of PLA and electric efficiency of waste incineration plant was estimated to be about 30% (Dornburg *et al.*, 2006).
- CO_2, CH_4, and N_2O emissions from PLA combustion were calculated base on IPCC 2006.
- Heating value of PLA/ PBS is estimated as 18 MJ/kg (Nature work, 2006).

3.2.3 <u>Inventory Analysis</u>

a.) Collect all relevant input-output data within the system boundary for bioplastic production and products which include:

- Raw materials consumption
- Energy consumption
- Utilities consumption
- Product generation
- Air and water emissions
- Waste generation



The sources of input-output data within the system boundary for each phase in the life cycle of bioplastic are shown in Table 3.3.

Table 3.3 Sources of the inventory data used in this study

Phase	Type of data	Data source
Renewable resources	Secondary data	- Cassava cultivation and production - MTEC, JGSEE, KU
Monomer and Resin production	Secondary data	- Literature - Manufacturers' information (Purac, BASF, Nature Works, etc.)
Production of product	Primary data	- Processing manufacturer in Thailand • Thantawan Industry Public Company Limited • Reangwa Standard Industry Co., Ltd. • Thai Plastic Bag Co., Ltd. • etc.
Transportation	Secondary data	- Pollution Control Department (PCD) for truck - PTT - MTEC database

For disposal phase, the data acquirement was carried out by collecting the necessary information from a variety of sources, i.e., on-site survey, domestic research reports, and scientific paper publications. Detailed data source of the study is shown in Table 3.4.

Table 3.4 Data source of disposal phase in this study

Data	Data type	Data source
The amount of waste	2st	Annual report of BMA
Materials & utilities (Water, Electricity, Wire, plastic, Diesel, Emission to water)	1st	On-site data
Emission to air	2st	Calculation, IPCC 1996, 2006

b.) Quantify how much energy and raw materials are used, and how much solid, liquid and gaseous waste is generated at each stage of the product's life based on functional units.

3.2.4 Impact Assessment

a.) Calculate impact potentials based on the LCI results by using software named—SimaPro version 7.0—with Eco-indicator 95 and CML 2 baseline 2000 methods. In part of results, CML 2 baseline 2000 method is only one method, which is shown. Results of Eco-indicator 95 are illustrated in Appendix A

b.) Analyze and compare the impacts on human health and the environment burdens associated with raw material and energy inputs and environmental releases quantified by the inventory, for example:

- Global warming
- Ozone layer depletion
- Acidification
- Eutrophication
- Energy use

3.2.5 Interpretation

This step involves the combination and interpretation of the results of the inventory and impact assessment to provide conclusions and recommendations consistent with the goal and scope of the study.