CHAPTER III
METHODOLOGY

3.1 Software 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 Procedure

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 was to assess the environmental impacts of bioplastic resins (PLA and PBS) and their product (garbage bag). The inventory data collection was compiled by using SimaPro 7.0 software and the environmental impacts of the bioplastic were evaluated using Eco-Indicator 95 and CML 2 baseline 2000.

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

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

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

The scope of this research covered data collection of bioplastic products produced from PLA and PBS, evaluation of the environmental impacts of the bioplastic product, and comparison of the bioplastic product with the same product produced from conventional plastics. The system boundary includes bioplastic resin production, production of bioplastic product, use of product, waste

management of bioplastic product, and transportation at all stages as shown in Figure 3.1.

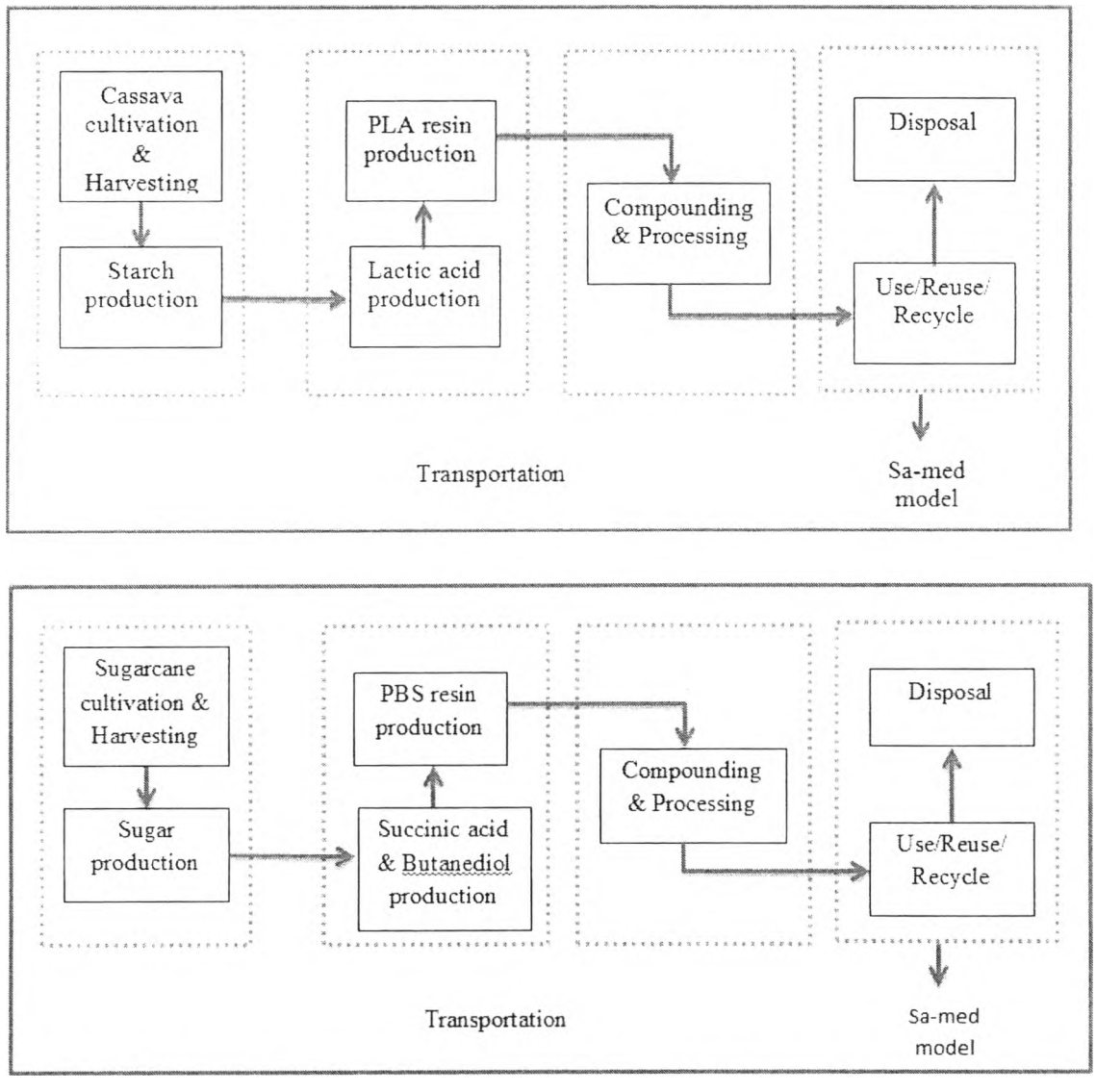

Figure 3.1 System boundary of the LCA bioplastic study.

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 220 km by using 10-wheel truck at full load 16 tons. In case of PLA product transportation, the distance from Nakhon Pathom to Ban Phe, Rayong is approximated 240 km using 10-wheel

truck at full load 16 tons and from Ban Phe to Sa-med island is about 6.5 km using barge.

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 (composting plant at Sa-med) which approximately 10 km by using 6-wheel truck at full load 8.5 tons. The system boundary is shown in Figure 3.2.

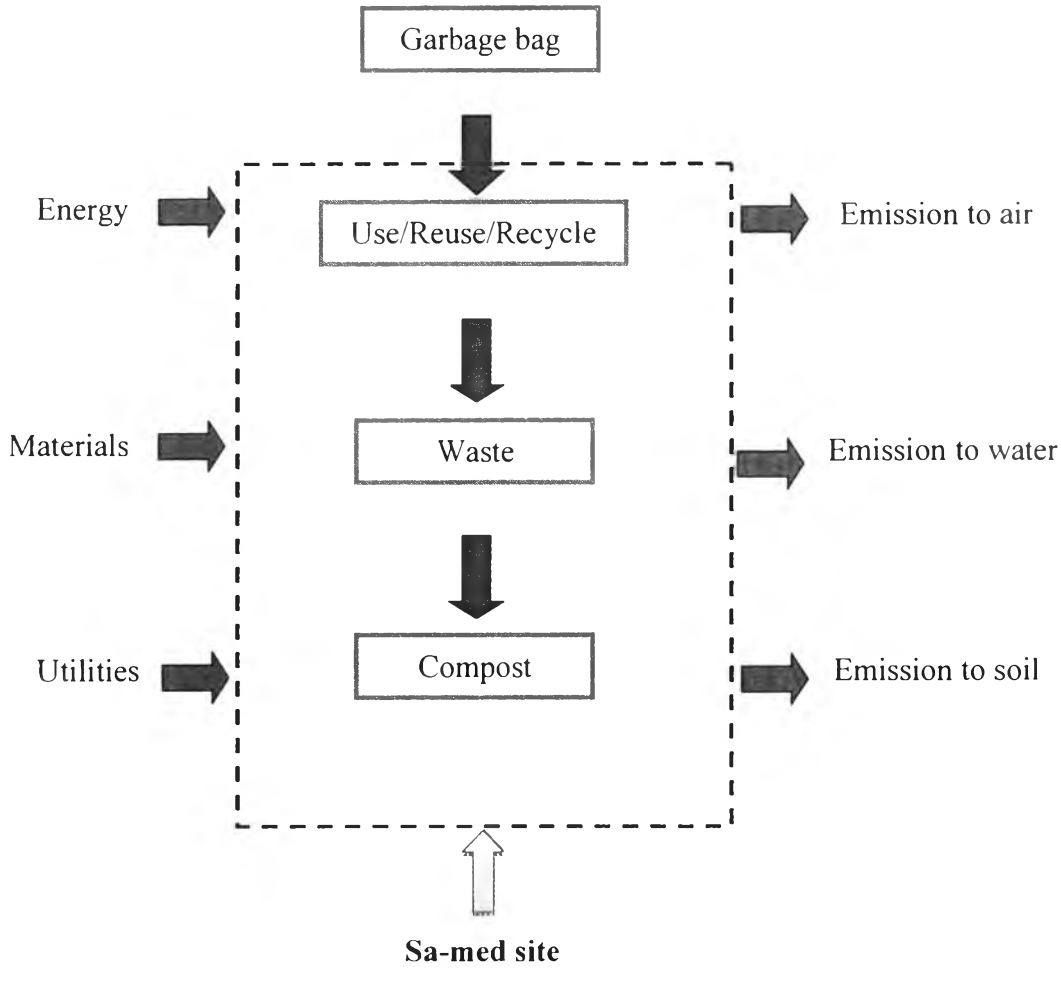

Figure 3.2 The scope of disposal phase.

3.2.3 Inventory Analysis

a.) Collect all relevant input-output data within the system boundary for bioplastic production and product 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 3.2.

Table 3.2 Sources of the inventory data used in this study

Phase		Type of data	Data source
Renewable resources	Cassava cultivation & harvesting	Primary data Secondary data	Kasetsart University Literature
	Sugarcane cultivation & harvesting	Secondary data	MTEC
	Cassava starch production	Primary data Secondary data	Sima Inter Product Co., Ltd. Sanguan Wongse Industries Co., Ltd. Literature
	Sugar production from sugarcane	Secondary data	MTEC
	Sugar production from cassava starch	Primary data	Literature
Monomer and Resin production		Secondary data	Literature Purac's information
Production of product		Primary data	Thai Plastic Bag Co., Ltd.
Use		Primary data	Sa-med site
Disposal phase		Primary data Secondary data	Sa-med site MTEC database Literature
Transportation		Secondary data	Pollution Control Department (PCD) for truck 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 3.3.

Table 3.3 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.

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.

3.3 Model Site: Sa-med

3.3.1 General Information

Sa-med island is located at the east coast of Thailand, about 220 kilometers from Bangkok. It is in the gulf of Thailand. Sa-med is approximately 5.0 square kilometers (3,125 rai) in size (http://en.wikipedia.org/wiki/Ko_Samet), and shaped somewhat like a letter "t". Along the length of the "t" (north-south) the island measures approximately 6.5 km, and measures 2.5 km across the "t" (west-east). Forest remains blanket up to 80% of the total area. Rainy season is during May-September while last month may have a storm of wind and waves. The August, rain is frequent (http://www.kohsamed.org/kohsamed.htm).

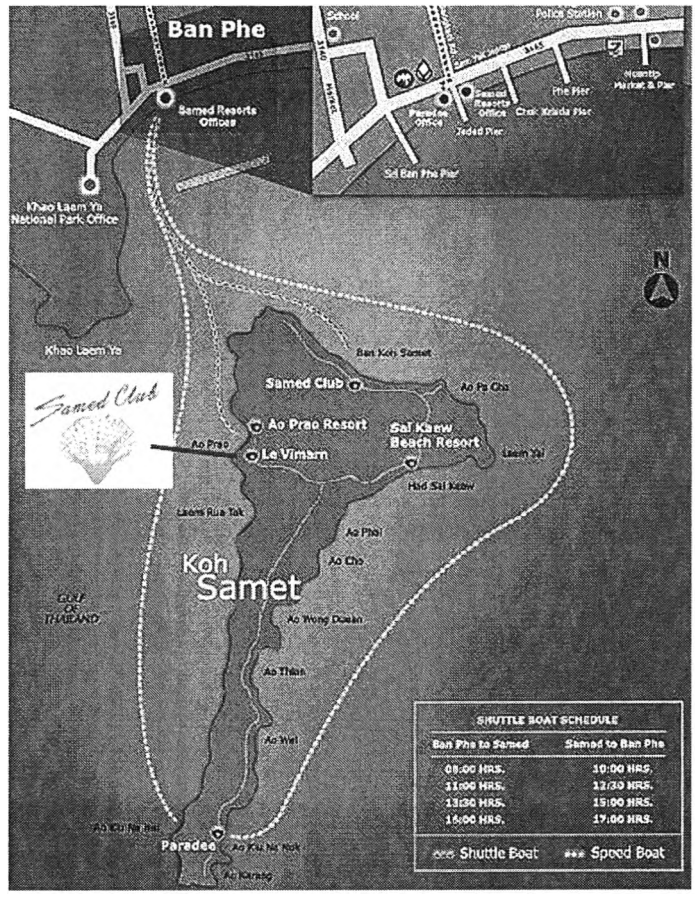

Figure 3.3 Sa-med Island map.
(Source: http://www.roommillion.com/Koh_Samed_Island/Hotel_Map-10146-Location-Samed_Club_Resort-Koh_Samed_Island-Thailand.html).

The island itself is famous among tourists for its interesting destinations and exciting activities. Most of the beaches are on the east side apart from Ao Prao which is located on the west. In 1981 the Royal forest department declared the entire of Sa-med island, A cape of Khao Leam Ya, and 11 km. of Mae Rampeung beach to be a national park. The national park consists of several islands for instance, koh Kudi, koh Kruai, koh Ma Kham, and koh Thalu. Sa-med contains of 18 hidden bays, which offers crystal clear water for year-round. There are five piers which are providing the transportation to Sa-med. There are many boats depart every hour from 8 am to 6 pm to Na Daan pier. The duration of the trip is 30-35 minutes (http://www.limacoco.com/html/map_samed.htm).

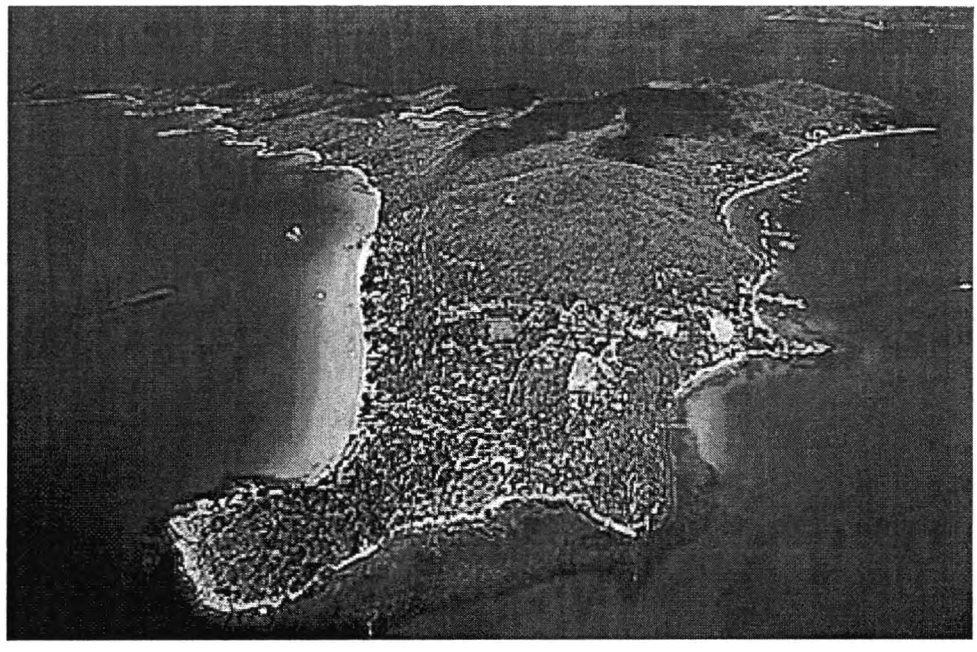

Figure 3.4 Aerial View of Sa-med Island
(Source: http://yaida.web.officelive.com/KohSa-met.aspx).

Sa-med island has Thai population who live on the island of approximately 1,500 people and foreign workers on the island, about 1,000 people (http://en.wikipedia.org/wiki/Ko_Samet). Each year the island has an average annual 300,000 visitors because of natural beauty. Table 3.4 shows the amount of tourists in 2011.

Table 3.4 Tourists statistics on Sa-med island in fiscal 2011 (Oct. 2010 – Sep. 2011)

Month	Number of Tourists		
	Foreign	Thai	Total
October	2,933	15,163	18,096
November	0	11,726	11,726
December	7,105	20,981	28,086
January	10,033	16,847	26,880
February	10,424	26,449	36,873
March	8,315	33,238	41,553
April	7,753	36,779	44,532
May	3,951	31,618	35,569
June	3,628	13,913	17,541
July	5,624	20,905	26,529
August	0	17,962	17,962
September	0	12,058	12,058
Total	59,766	257,639	**317,405**

(Source: http://www.dnp.go.th/NPRD/develop/Stat_Tourist.php)

Sa-med has 6-10 tons of waste per day during weekdays and 10-12 tons during the holiday season (http://www.thaienv.com/content/view/537/39/). In all the waste has organic waste 60 %, 16 % is a waste that can be recycled and 24 % of plastic waste that cannot be recycled (NIA meeting, 2009).

3.3.2 Efforts to Reduce Waste of Sa-med Island

No more foam drinking vessels, packaging or non-biodegradeable plastic bags should be allowed for use in Sa-med Island in order to contain garbage and waste problems of the island resort, according to a locally-based national park official.

During a meeting with the Rayong tourist agents association, Khao Laem Ya National Park chief Sithichai Serisongsaeng proposed that no more foam cups, containers or plastic bags should be permitted for use by tourists, vendors or any others on the island.

Koh Sa-med's five-rai garbage dump site can no longer cope with the ever-increasing amount of such indestructible waste, according to Mr. Sithichai, who

called for more rigorous waste management and disposal, beginning with the reducing the oversupply of the ubiquitous and virtually indestructible contemporary packaging materials (Phuket Gazette, 2007).

3.3.2.1 NIA Pilot Project at Sa-med Island

National Innovation Agency (NIA) in cooperation with PTT Public Company Limited, the Department of National Parks, Wildlife and Plant Conservation (DNP), and Mitsubishi Chemical Corporation (MCC) attended the MOU signing ceremony and press conference of " The use of PBS bioplastic bags in sorting out organic garbage to produce organic fertilizers at Sa-med Island Project" to preserve an environment around the area by using bioplastic garbage bags which are produced from the compound of PLA and PBS with its elasticity that could naturally decompose to help produce organic fertilizers. It is expected that about 100 tons of organic garbage would be eradicate monthly and 1,600 tons of carbons, the cause of global warming, would be reduced yearly (Thai PR, 2010).

Figure 3.5 NIA project at Sa-med Island (Thai PR, 2010).

Mr.Pimook Simarojana, Vice Minister for Natural Resources and Environment stated that "A pilot implementation at Khao Lamya National Park, Sa-med Islands this year is very appropriate as the island is a tourist attraction

receiving a large number of tourists and having around 6 tons of waste per day. In addition, the area is surrounded by sea and limited with area to dispose the waste. As a result, an unsuitable waste treatment such as waste incineration in open space is carried out. The effect on environment is substantial and degrading the tourist attractions very rapidly. At present, the people are informed about waste sorting and people on Sa-med Island have already sorted organic waste to be used as compost and biodiesel for a while. Therefore, this project will support a better waste treatment as well as serves as a case study that can build understanding and information in a concrete manner which will result in environmental measures on waste management in National Parks in the future.

Dr. Wantanee Chongkum, Director, Innovation Department National Innovation Agency (NIA) said that bioplastic is an innovation of material of the future as the new type of plastic is environmentally friendly and will help combat global warming problem in a concrete manner as it will cause at least one time less greenhouse gas than conventional plastic. Because it can be produced from natural raw material which can be replanted such as tapioca or sugarcane. For the past two years, NIA has initiated and coordinated a pilot project to realize the use of bioplastic use in order to create understanding, knowledge and awareness that the use of bioplastic bag in effectively sorting organic waste, in particular, at popular tourist attraction areas for both domestic and international tourists like Sa-med Island. The island is suitable for the type of implementation for better waste treatment and value addition. Furthermore, the communities in the areas are highly ready as they already commenced sorting organic waste for production of compost and biodiesel at a certain degree.

"In implementing this pilot project, NIA has offered academic support with Thai Bioplastic industry Association in producing PBS bioplastic bags and the campaign on community participation process to raise awareness and realization of environmental protection with the Development of Environment and Energy Foundation by using bioplastic bag to sort organic waste to be used as bio fertilizer. It received a fund or four million Baht from PTT Public Company Limited and Mitsubishi Chemical Corporations (MCC) to construct a composting unit to

decompose organic waste to be biofertilizer. A project will be followed-up and data will be continuously collected for the next six months. It is expected that the pilot project will be expanded to become a national policy on organic waste management having effective separation system with the use of bioplastic bag. Doing so, the waste storage and transportation are convenient and hygienic. Not to mention, we will not have to spend money on sorting bag on the process of recovering waste for producing bio fertilizer. This will not only reduce methane gas from degradation of organic waste in open land fill, it will also add value as the bio fertilizer can be used for growing plants." Dr.Wantanee explained (http://www.pttplc.com/en/news-energy-fact-business-social-news-detail.aspx?K=MzQ4MQ==).

3.3.3 Disposal Phase

The past waste management of Sa-med island had three different waste treatment scenarios: landfill without energy recovery, incineration without energy recovery and recycle. After composting plant was built for NIA project, the waste management was changed to new different waste treatment scenarios: composting, incineration without energy recovery and recycle.

Table 3.5 Scenarios for waste management

Waste management scenario	% Landfill without energy recovery	% Composting	% Incineration	% Recycle
Current scenario	40	40	-	20
Scenario with bioplastic	-	40	40	20

3.3.3.1 Transportation for Waste Collection

The transportation bio-plastic waste from household to disposal site (composting plant at Sa-med) is approximately 10 km by using 6-wheel truck at full load 8.5 tons and go through all kind of hardships and difficulties condition.

3.3.3.2 Composting Plant (NIA, 2011)

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 Sa-med, Rayong Province. For composting plant at Sa-med, NIA plans to construct bio-fertilizer plant with capacity 100 tons per month by using technology of Suranaree University of Technology.

The system boundary of composting plant at Sa-med is shown in Figure 3.6.

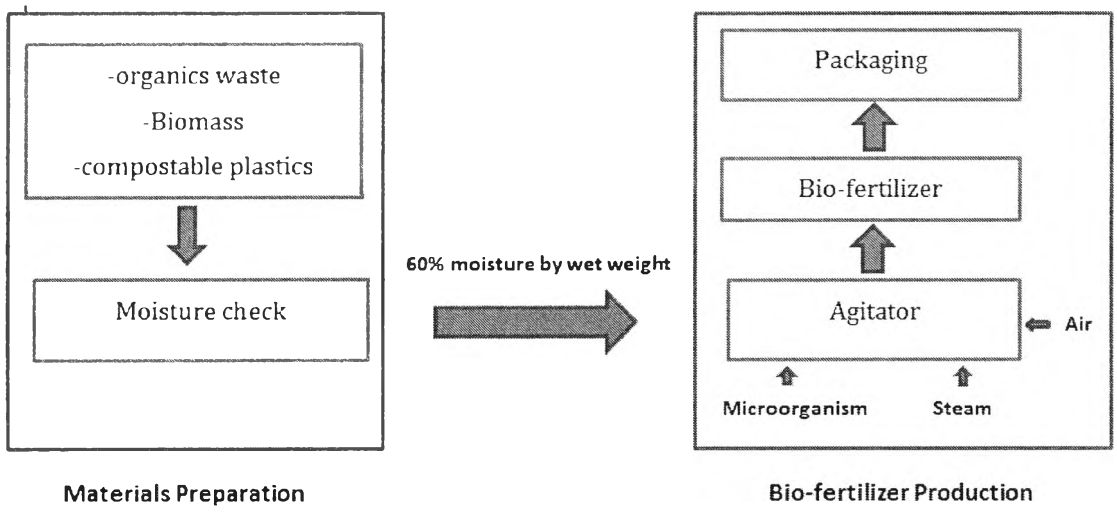

Figure 3.6 The system boundary of composting technology.

The operation of composting plant started with, raw material was loaded into an organic fertilizer production pilot plant (Fig. 3.7). Composting was conducted by mixing raw materials with a screwing operation unit prior to adjusting the moisture content to 60% water-holding capacity. The turning program was operated using the screwing operation unit for 7 hours per day. Aeration was conducted underneath the pile when necessary. Temperature and C/N ratio changes were measured every 7 days. After maturation (27-30 days), 1% (W/W) of each inoculum (*Azotobacter* sp. and *Azospirillum* sp.) was applied to the matured organic fertilizer via pop-up sprinklers.

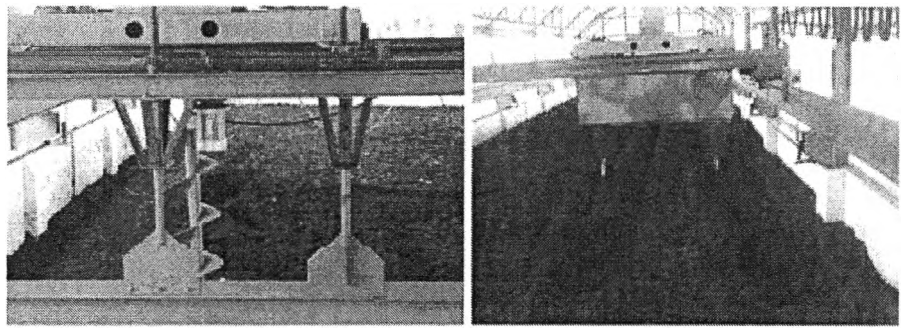

Figure 3.7 The organic fertilizer pilot plant production with two sets of ribbon screws.

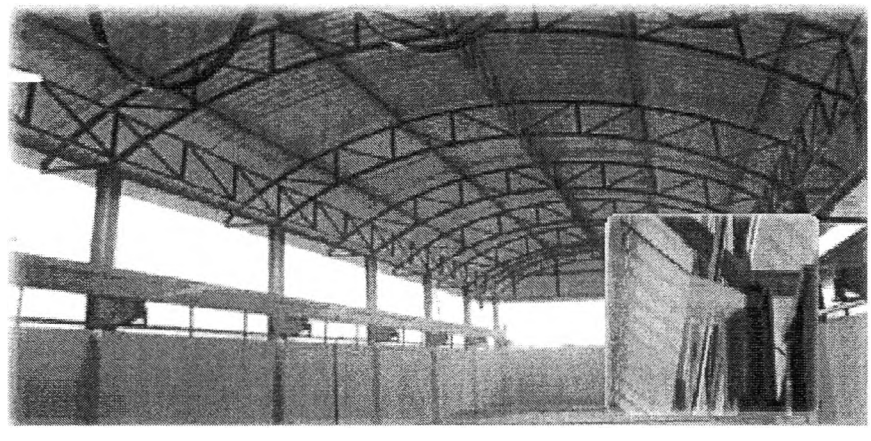

Figure 3.8 The water spray system of the underlying bio-organic fertilizer plant of Suranaree University of Technology.

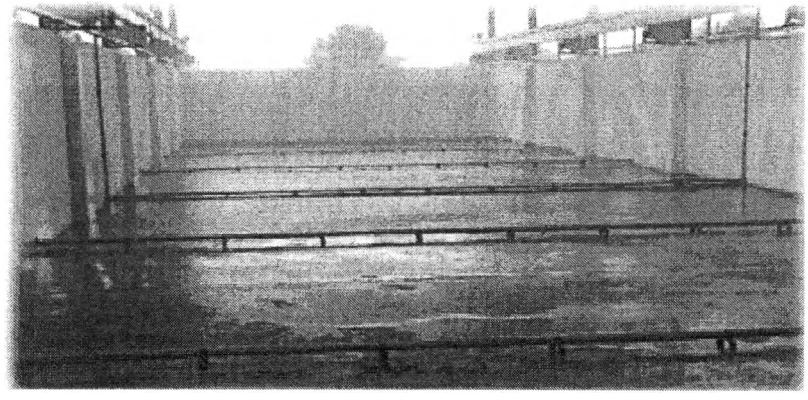

Figure 3.9 Aeration system of the underlying bio-organic fertilizer plant of Suranaree University of Technology.

Figure 3.10 Conveyer system of the underlying bio-organic fertilizer plant of Suranaree University of Technology.

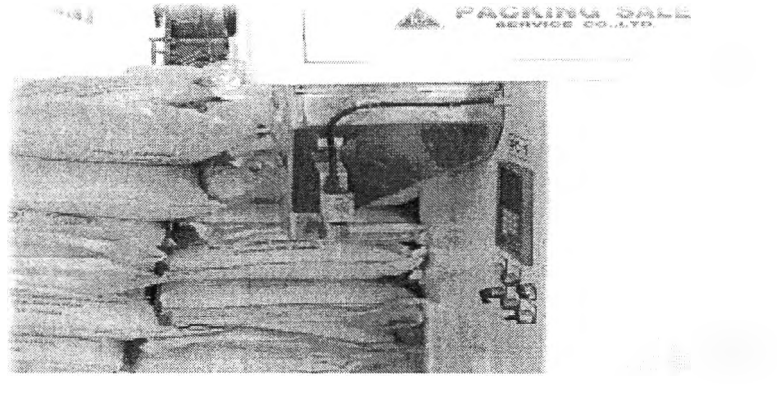

Figure 3.11 Packaging system of the underlying bio-organic fertilizer plant of Suranaree University of Technology.

Assumption for calculated of composting technology.

- In the aerobic 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 3.12 (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 3.13 as PLA composting.

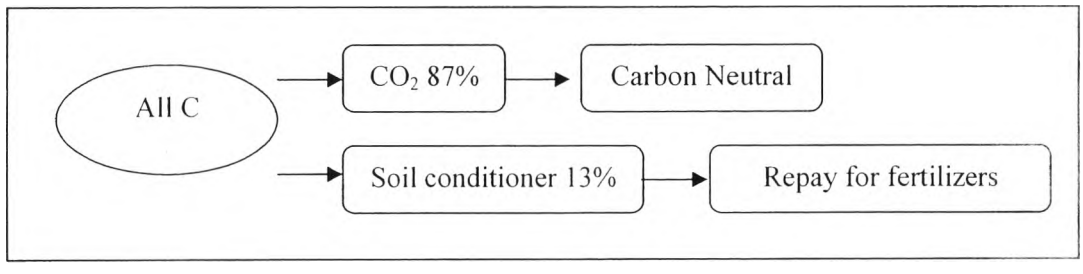

Figure 3.12 Conversion concept of CO_2 in composting process of PLA.

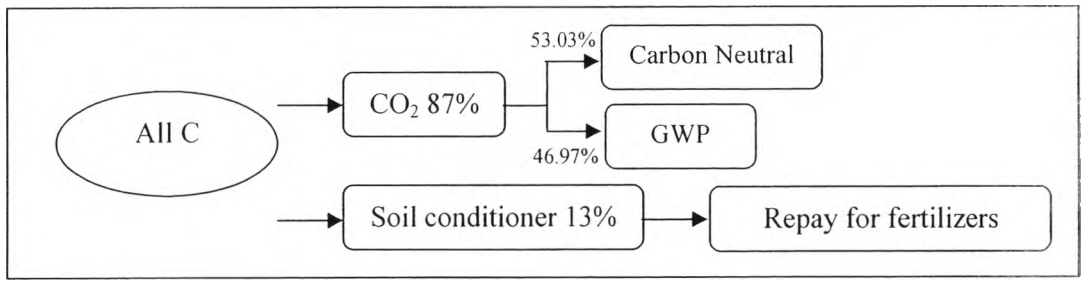

Figure 3.13 Conversion concept of CO_2 in composting process of PBS.

3.4 Assumptions and Limitations in This Research Work

3.4.1 PLA Production

- Use cassava as a raw material.
- Use cassava plantation and production data in Thailand.
- The carbon content of PLA is 54.6%wt (Iovino *et al.*, 2008).

- PLA resin production is based on PURAC Thailand.
- Distance of PLA resin transportation: Rayong to Nakhon Pathom about 220 km.
- Distance of PLA product transportation: Nakhon Pathom to Sa-med island about 246.5 km.

3.4.2 PBS Production

3.4.2.1 PBS-1

- Use sugarcane as a raw material to produce succinic acid.
- Use sugarcane production data in Thailand.
- 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).
- Succinic acid production process is from one of key players of PBS resin production.
- Use 1,4-butanediol from petroleum based as another raw material.
- Distance of PBS resin transportation: Rayong to Nakhon Pathom about 220 km.
- Distance of PBS product transportation: Nakhon Pathom to Sa-med island about 246.5 km.

3.4.2.2 PBS-2

- Use sugarcane as raw material to produce succinic acid and 1,4-butanediol.
- Other assumptions are the same as PBS-1.

3.4.3 Bioplastics Garbage Bag Production

- Mixed bioplastics 1 consist of 65% PBS-1 and 35% PLA.
- Mixed bioplastics 2 consist of 65% PBS-2 and 35% PLA.

3.4.4 Use and Disposal Phase

- 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 shops to disposal site is 10 km.
- Emissions from vehicles operation in fuel transportation are calculated based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.