CHAPTER III
METHODOLOGY

3.1 Materials and Equipment

3.1.1 Equipment

- Desktop computer (Pentium IV, RAM 1 GB, Window XP and Microsoft Office 2007).

3.1.2 Software

- SimaPro version 7.1

3.2 Experimental Procedures

3.2.1 Preparation

Study and review the background of biorefinery including their environmental impact through LCA technique.

3.2.2 Goal, Scope, Functional Unit, and System Boundary

3.2.2.1 Formulate and specify goal and scope of biorefinery in Thailand

The goal of this LCA study was to assess the energy and environmental impacts of the biorefinery model which produces bioethanol, polylactic acid (PLA), electricity and heat using sugarcane and cassava as feedstocks. The methodology used in this study was based on ISO14040 series. The inventory data were collected from secondary data sources (National Thai LCI database, previous works on LCA of biofuels and biopolymers production in Thailand, and selected references) and compiled by using commercial LCA software, SimaPro 7.1, with Eco-Indicator 95 and CML 2 baseline 2000 methods. Various scenarios were created by varying ratio of raw materials (sugarcane, and cassava) and products (bioethanol, and PLA). The energy resource, environmental impacts and generated profit of all scenarios were compared.

For feedstocks transportation phase, we assume the location of biorefinery plant in Nakhon Ratchasima province. Nakhon Ratchasima is the first cassava producer; moreover, this province is in the top five sugarcane production in Thailand. We also assume that biorefinery plant can receive biomass feedstocks (sugarcane and cassava) in 100 km. around the plant by using 10-wheel truck at full load 16 tons.

3.2.2.2 Identify functional unit of the assessment

In this research, the biorefinery model was created while its performance was evaluated in several aspects, including fuel and biopolymer production, raw materials used, and total profit generated.

3.2.2.3 Determine the system boundary of biorefinery and make assumptions based on the goal definition

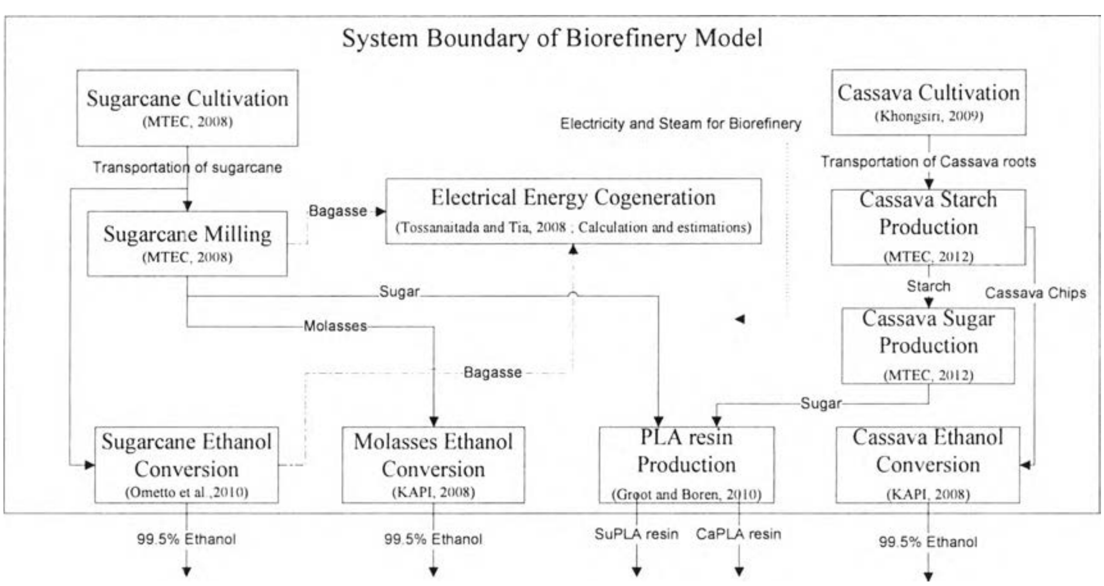

Figure 3.1 The system boundary of biorefinery under study.

The system boundary of biorefinery covers feedstock cultivation, feedstock transportation, feedstock processing, ethanol conversion and PLA resin production as shown in Figure 3.1. The capacities of ethanol and PLA production are 160 ton/day and 300 ton/day, respectively

3.2.2.4 Scenario Analysis

In this research, five scenarios (S1-S5) of biorefinery model, shown in Table 3.1, were created. They were divided into two groups; Group 1 (S1, S2 and S3) was obtained by the varying ratio of the two feedstocks (sugarcane and cassava roots) while Group 2 (S4, S1 and S5) was obtained by varying the ratio of the products (ethanol and PLA) based on assumptions below:

- Biorefinery with max production capacity:
  Ethanol = 160 t/d (from average ethanol plant capacity in Thailand).
  PLA = 300 t/d (from current lactic acid (LA) production in Thailand at 530 t/d which can convert to PLA resin about 500 t/d. Because LA can be used to produce other products, PLA resin capacity was 300 t/d).
- Fix range of capacity for ethanol = 112-160 t/d and PLA = 210-300 t/d (or always operate at least 70% capacity) to be convenient for variations.
- Overall production of ethanol and PLA (combined) at 391 t/d (or 85% capacity) which is a target for optimization between environment and profit.
- Steam production from biomass (bagasse) is sufficient for biorefinery.
- Using high pressure boiler for electricity and steam generation to maximize the benefits from the by-product.
- Profit was calculated based on average price of feedstocks, operating cost, and products in Thailand (Table 3.2).
- Biorefinery plant located in Nakhon Ratchasima. There is the first cassava producer; moreover, this province is in the top five sugarcane production in Thailand. Legal issue is negligible.
- Distance of feedstocks transportation from cultivation area to biorefinery plant about 100 km. by using 10-wheel truck at full load 16 tons.

Table 3.1 Scenarios of biorefinery under study (S1-S5)

Scenarios		S1 (base case)	S2	S3	S4	S5
Feedstock consumption	wt.%	80/20	60/40	40/60	80/20	80/20
Sugarcane/Cassava	t/d	3,081/772	2,085/1,394	1,272/1,902	3,130/765	3,057/765
Products production	wt.%	35/65	35/65	35/65	41/59	29/71
Ethanol/PLA	t/d	136/255	136/255	136/255	160/321	112/279
Sugarcane based ethanol, SuE (t/d)		11	35	55	19	3
Molasses based ethanol, MoE (t/d)		23	12	3	23	24
Cassava based ethanol, CaE (t/d)		102	89	78	118	85
Sugarcane based PLA, SuPLA (t/d)		237	126	35	231	245
Cassava based PLA, CaPLA (t/d)		18	129	220	0	34
Profit (฿/d)		7,814,380	7,070,628	6,464,235	7,425,823	8,220,803

Table 3.2 Average price of the feedstocks, production cost, and products for profit calculation

	Average price (฿/t)	Reference
Feedstock		
Sugarcane	955	Bank of Thailand (2012)
Cassava root	1,960	Bank of Thailand (2012)
Production cost		
SuE	17642	Saibuatrong (2008), Calculations and estimations
MoE	20630	Saibuatrong (2008), Calculations and estimations
CaE	22483	Saibuatrong (2008), Calculations and estimations
SuPLA	71913	National Innovation Agency (2012), Calculations and estimations
CaPLA	79290	National Innovation Agency (2012)
Product		
Ethanol	26,000	Energy Fund Administration Institute Ministry of Energy (2012)
PLA	100,000	PTTPM (2012)
DDGS	5,000	KAPI (2008)
Yeast extract	200,000	KAPI (2008)
Yeast cell wall	80,000	KAPI (2008)

S1 was selected as base case for this study because S1 was created based on current feedstocks production in Thailand in 2011-2012 (97.97 million ton for sugarcane and 24.78 million ton for cassava) (Bank of Thailand, 2012) and actual current biorefinery production capacity (ethanol 160 t/d and PLA 300 t/d). Thus, the raw materials ratio between sugarcane and cassava of base case (S1) would be 80/20 wt. %, and the production ratio between ethanol and PLA of base case (S1) would be 35/65 wt. %

3.2.3. Inventory analysis

3.2.3.1 Collecting information

Collecting information of biorefinery in Thailand related to environment and technical quantities within the system boundaries for all relevant input-output data include raw materials consumption, energy consumption, utilities consumption, product generation, air/water emissions, and waste generations. The sources of input-output data within the system boundary for each phase in the life cycle of biorefinery products are shown in Table 3.2. The details of life cycle inventory (LCI) are shown in appendix A.

Table 3.3 Sources of the inventory data used in this study

Phase	Items	Data source
Cassava cultivation[a]	Fertilizers, diesel, pesticides, lubricant oil, emission from fertilizing, etc.	Thailand LCI database, MTEC (2012).
Sugarcane cultivation[a]	Fertilizers, pesticides, diesel, lubricant oil, emission from fertilizing, etc.	
Transportation	Diesel, emission to air	Thailand LCI database, MTEC (2012).
Chips production	Diesel, emission to air	Silalertruksa and Gheewala (2011), Calculations and estimations.
Cassava starch and sugar production	Energy, chemicals, emission to air, biogas generation	Thailand LCI database, MTEC (2012).
Sugarcane milling	Energy, chemicals, water, emission to air, water and soil	
Electrical energy cogeneration[b]	Electricity and steam generation, emission to air	Tossanaitada and Tia (2008), Calculations and estimations.
PLA resin production	Energy, chemicals, emission to air and water	Groot and Boren (2010), Purac's information, MTEC study.
Cassava ethanol conversion	Energy, water, chemical, emission to air, water and soil, DDGS and biogas generation	Thailand database, KAPI (Kasetsart Agricultural and Agro-Industrial Product Improvement Institute, 2008)
Molasses ethanol conversion	Energy, water, chemical, emission to air, water and soil, biogas generation	Thailand database, KAPI (2008)
Sugarcane ethanol conversion	Energy, water, chemical, emission to water, vinasse generation	Ometto et al. (2010)

[a] Exclude CO_2 uptake
[b] High efficient and high pressure boiler

3.2.3.2 Quantification

Quantify how much energy and raw materials are used, and how much solid, liquid, and gaseous waste is generated of each stage of the production.

3.2.4 Impact assessment

3.2.4.1 Calculate impact potentials

Calculate impact potentials based on the LCI results by using software, SimaPro version 7.1, with Eco-indicator 95 and CML 2 baseline 2000 methods.

3.2.4.2 Analyze and compare

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. Relevant impact categories included in this study are.

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Energy resources

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.