CHAPTER III
METHODOLOGY

3.1 Materials and Equipment

3.1.1 Equipment

- Laptop (Core i7, RAM 4 GB, Window 7, and Microsoft Office 2010).

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 and also previous thesis.

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, biosuccinic acid (BSA), lactic acid (LA), 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 secondary data sources (National Thai LCI database, previous works on LCA of biofuels and biochemicals 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 feedstocks and products (BSA and LA). The energy resource, environmental impacts and generated profit of all scenarios were compared.

For feedstocks transportation phase, the location of biorefinery plant was assumed to be in Nakhon Ratchasima province. Nakhon Ratchasima is the first cassava producer; moreover, this province is in the top five sugarcane production in Thailand. The biorefinery plant was also assumed to 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 biochemicals 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

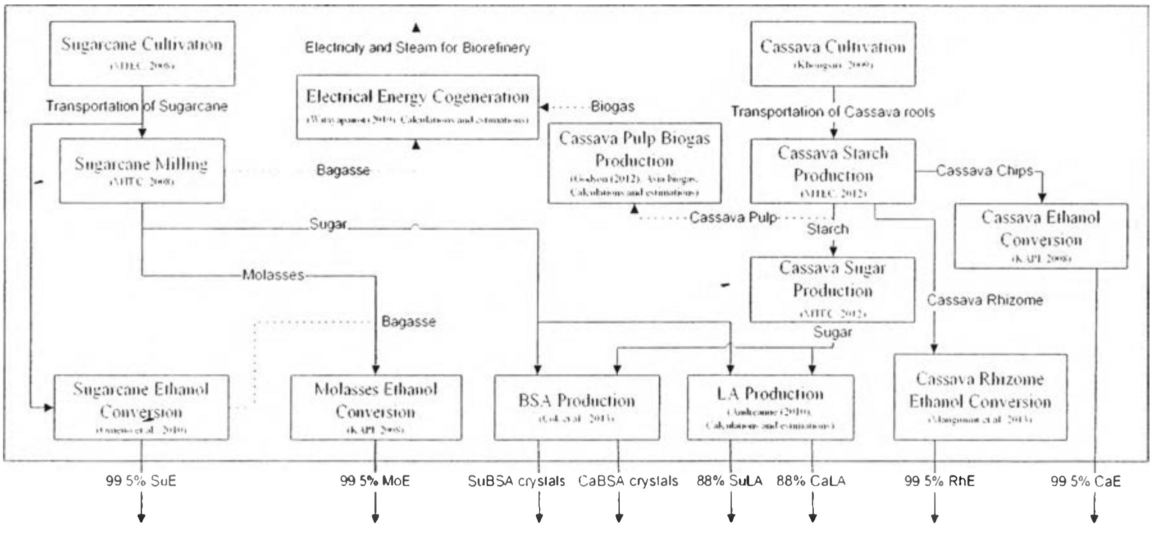

Figure 3.1 The system boundary of biorefinery under study.

The system boundary of biorefinery covers feedstock cultivation, feedstock transportation, feedstock processing, ethanol conversion, LA production and BSA production as illustrated in Figure 5.1. The capacities of ethanol are 160 ton/day and LA and BSA production is 300 ton/day.

3.2.2.4 Scenario Analysis

In this research, 5 different scenarios (S1-S5) of biorefinery model shown in Table 3.1 were created by varying ratio of feedstocks (S1-S3) and products - only BSA and LA - (S1,S4, and S5) based on fixed biorefinery production capacity (ethanol 160 t/d and BSA and LA 300 t/d). It was assumed that the production was always at least 70% of the total capacity in all scenarios studied. This corresponds to overall production of ethanol, BSA and LA of 391 t/d (combined) which is a target for optimization between environment and profit. For profit ($/d), it was calculated based on average price of the feedstocks, utilities and chemicals, and products in Thailand and selected references.

All 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 (BSA and LA) based on assumptions below:

- Biorefinery with max production capacity:
  Ethanol = 160 t/d (from average ethanol plant capacity in Thailand).
  BSA and LA = 300 t/d (from current LA production in Thailand at 100 kt annually which could be approximated to 274 t/d. Because BSA was also produced, BSA and LA capacity was estimated to 300 t/d).
- Fixed range of capacity:
  Ethanol = 112-160 t/d
  BSA and LA = 210-300 t/d (operate at least 70% capacity) to be convenient for variations.
- Overall production of ethanol, BSA, and LA (combined) at 391 t/d (85% capacity) which is a target for optimization between environment and profit.
- All steam and electricity production from biomass (bagasse and biogas) is used for biorefinery.
- Using high pressure boiler for electricity and steam generation to maximize the benefits from the by-product.

- Profit was calculated in biorefinery boundary based on average price of feedstocks, utilities and chemicals, and products in Thailand and selected references (Table 3.2). The installation cost is negligible.
- Biorefinery plant was 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)

Scenario		S1 (base case)	S2	S3	S4	S5
Feedstock consumption	wt.%	75/25	60/40	45/55	75/25	75/25
Sugarcane/Cassava	t/d	2,410/803	1,652/1,101	1,085/1,323	2,403/801	2,415/805
Products production	wt.%	50/50	50/50	50/50	25/75	75/25
BSA/LA	t/d	127.5/127.5	127.5/127.5	127.5/127.5	64/191	192/63
Sugarcane based ethanol, SuE	t/d	75	50	32	75	75
Molasses based ethanol, MoE	t/d	10	7	5	10	10
Sugarcane based BSA, SuBSA	t/d	64	44	31	32	103
Cassava based BSA, CaBSA	t/d	64	83	97	31	88
Sugarcane based LA, SuLA	t/d	61	42	28	92	22
Cassava based LA, CaLA	t/d	67	85	99	100	42
Cassava based ethanol, CaE	t/d	19	35	47	19	19
Cassava rhizome based ethanol, RhE	t/d	32	44	52	32	32
Steam	t/d	-131	-586	-930	-245	-18
Electricity	MWh/d	-123	-182	-226	-14	-230
Profit	฿/d	15,879,422	15,504,861	15,223,488	10,886,959	20,839,428

S1 was selected as base case for this study because S1 was created based on current feedstocks export in Thailand in 2012-2013 (62.52 million tons for sugarcane and 20.27 million tons for cassava) (Office of Agricultural Economics, 2013) and actual current biorefinery production capacity (ethanol 160 t/d and BSA and LA 300 t/d). Thus, the raw materials ratio between sugarcane and cassava of base case (S1) would be 75/25 wt. %, and the production ratio between BSA and LA of base case (S1) would be 50/50 wt. %.

Table 3.2 Average price of the feedstocks, utilities and chemicals, and products for profit calculation

Feedstocks, utilities and chemicals, and products	Average price (฿/kg or ฿/kWh)	References
Feedstock		
Sugarcane	0.91	www.ocsb.go.th (2013)
Cassava root	2.11	www.oae.go.th (2013)
Utilities and chemicals		
Steam	0.73	Chinnawornrungsee R. (2013)
Electricity	2.65	www.egat.co.th (2013)
Water	0.03	www.pwa.co.th (2013)
Diesel	36.05	www.eppo.go.th (2013)
Fuel oil	23.11	www.eppo.go.th (2013)
Sulfuric acid	8.13	www.alibaba.com (2013)
Hydrochloric acid	6.45	www.alibaba.com (2013)
Lime	7.28	www.alibaba.com (2013)
Sulfur	7.62	www.alibaba.com (2013)
Corn steep liquor	13.10	www.alibaba.com (2013)
Sodium hydroxide	13.81	www.alibaba.com (2013)
Ammonia	20.33	www.alibaba.com (2013)
Product		
Ethanol	33.54	Chinnawornrungsee R. (2013) www.oae.go.th (2013) www.alibaba.com (2013)
BSA	104.65	PTTMCC (2013) www.nnfcc.co.uk (2013) www.alibaba.com (2013)
LA	40.93	www.nnfcc.co.uk (2013) www.alibaba.com (2013)
Vinasse	0.25	Sales representative (i1you1@hotmail.com) (2013)
Yeast residue	56.82	Chinnawornrungsee R. (2013)
Cassava peel	0.4	Khongsiri S. (2008)
Sand	0.3	Khongsiri S. (2008)
Gypsum	19.93	Chinnawornrungsee R. (2013) www.ycplywood.com (2013) www.thaicarpenter.com (2013) www.kasetonline.com (2013) www.tthardware.com (2013)
DDGS	5	Chinnawornrungsee R. (2013)

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 including 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 3.3. The details of life cycle inventory (LCI) are shown in appendix A.

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 environmental 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.

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	
Cassva pulp biogas production	Cassava pulp, biogas generation	Godson (2012), Asia biogas, Calculations and estimations.
Electrical energy cogeneration[b]	Electricity and steam generation, diesel, water, emission to air and water, waste	Witayapairot (2010), Calculations and estimations.
BSA production	Energy, water, chemicals, biogas generation, sludge	Cok et al. (2013), Calculations and estimations.
LA production	Energy, water, chemicals, gypsum generation, water emission, sludge	Andreanne (2010), Calculations and estimations.
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)
Cassava rhizome ethanol conversion	Energy, water, chemicals, gypsum generation, air emissions, water emissions, bio waste	Mangnimit et al. (2013)
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), Calculations and estimations.

[a] Exclude CO_2 uptake

[b] High efficient and high pressure boiler