CHAPTER III
EXPERIMENTAL

3.1 Materials and Equipment

3.1.1 Equipment

- Notebook (Pentium Dual-Core, RAM 2 GB, Window 7 and Microsoft Office 2007)

3.1.2 Software

- SimaPro version 7.0
- ProII version 8.2

3.2 Methodology

3.2.1 Preparation

a.) Study and review the background of bio-oil production including raw materials, process, technology, and environmental impact according to LCA concept.

b.) Selecting the literature and collecting all process's inventory cycle.

c.) Study and review the potential of rice straw and *leucaena leucocepphala* which used as feed for bio-oil production.

3.2.2 Goal and Scope, Functional Unit and System Boundary

a.) Defining suitable goal for the LCA study.

The goal of this LCA study was set to assess the environmental performance of bio-oil production from rice straw and *leucaena leucocepphala* based on a life-cycle approach, and to estimate the net energy of rice straw and *leucaena leucocepphala* based bio-oil production in Thailand. The inventory data collection was compiled by using SigmaPro 7.0 software and the environmental impacts of the bio-oil were evaluated using CML 2 baseline 2000.

b.) Identify functional unit of the study

The functional unit (FU) of this study was defined as 1 ton oil equivalent (toe) of bio-oil production.

c.) Determine scope and system boundaries of that bio-oil production and make assumption based on the goal definition.

The scope of this research covered data collection at actual sites for bio-oil produced from rice straw and *leucaena leucocepphala*, evaluation of the energy and environmental performance of the bio-oil products, and comparison of the conventional fuels and biofuels. The system boundary includes the feedstock plantation and harvesting, pyrolysis bio-oil production, upgrading bio-oil, and all transportation activities within the system boundary. Figure 3.1 shows all stages and the system boundary of the bio-oil life cycle.

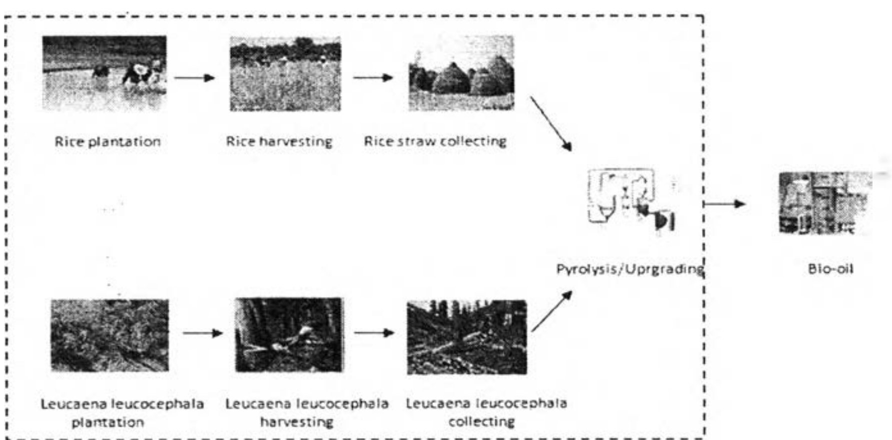

Figure 3.1 The system boundary of the LCA bio-oil.

For rice straw production

The production of rice straw contains activities for rice plantation, rice harvesting and rice straw collecting. For rice plantation, paddy is cultivated in 2 types of areas; irrigated areas could produce 2–3 crops per year, whereas rained area could produce only 1 crop per year during rainy reason without irrigation (Suramaythangkoor and Gheewala, 2010). The rice cultivation and harvesting method were collected from the encyclopedia web site. It said that "The fields are prepared by plowing (typically with simple plows drawn by water buffalo), fertilizing and smoothing (by dragging a log over them). The seedlings are started in seedling beds and, after 30 to 50 days, are transplanted by hand to the fields, which have been flooded by rain or river water. During the growing season, irrigation is maintained by dike-controlled canals or by hand watering. The fields are allowed to drain before cutting". Harvesting is the process of collecting the rice crop from the field and a large quantity of rice straw is also produced. To remove the rice straw for utilization, the rice straw collecting was achieved by tractors for rice straw bailing. Rice straw baling productivity depends on local conditions; the bale size is about 35×47×100 cm, bale weight is 15–20 kg on average.

In this study, rice straw was considered in 2 cases: (1) as a waste and (2) as a by-product of rice production. When rice straw was considered as a waste, rice cultivation was not included in the system boundary. Consequently, this case focuses only on the rice straw harvesting. The rice straw collection data were collected at rice cultivation sites in Nakhon Rachasima province. The system boundary of rice straw production for rice straw as a waste case is shown in Figure 3.2.

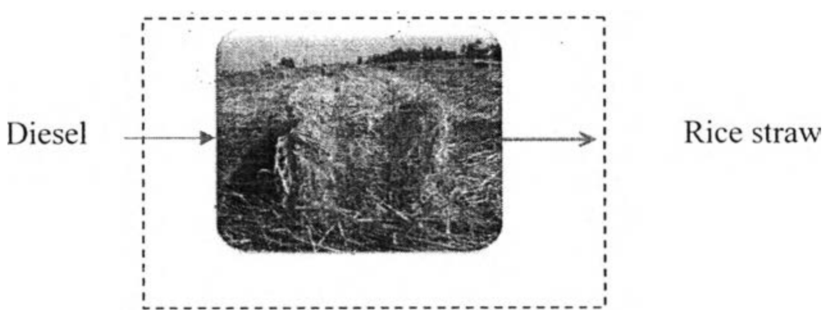

Figure 3.2 The system boundary of rice straw production for rice straw as a waste case.

For rice straw as a by-product case, inventory data covered all agricultural field operations for rice production (soil preparation, rice production, paddy cultivation and harvesting). The inventory data for rice straw production in Thailand was collected from the environmental information databases by Suranaree Environmental Technology Research & Consulting Unit (SENTEC). The subsystem boundaries included the production of process materials such as fertilizers, pesticides and fuel for operating agricultural machinery production. The rice straw collection data used data the same as rice straw as a waste case. The system boundary of rice straw production for by product case is shown in Figure 3.3.

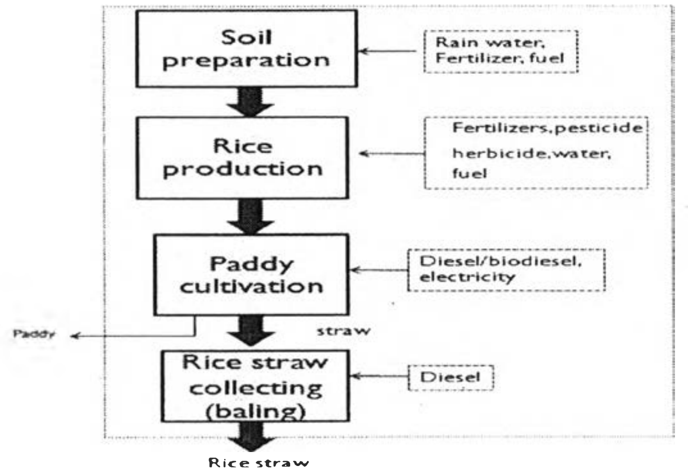

Figure 3.3 The system boundary of rice straw production for rice straw as a by-product case.

For *leucaena leucocephala* production

The *leucaena leucocephala* agricultural production model used test field data collected from PTT research and Technology Institute. The test field was operated in Pakchong district in Nakorn rachasima province in the land of 8 rai. Seed must be soaked before planting with mixture of a suitable *Rhizobium* bacteria and syrup. Then, presses the seed into soil 2 cm deep for generate a young plant. After 2 months, young tree plant was cultivated in the plantation area. There was no used any fertilizer or pesticide in this site production. *Leucaena leucocephala* is a short rotation energy plant. It was harvested every year and cut at 1.5 m of the tree above the ground level. Moreover, it was found that this cutting point of this one crop year harvesting could provide multiple branches and also increase wood yield from the first year plantation.

The system boundary of *leucaena leucocephala* production is shown in Figure 3.4.

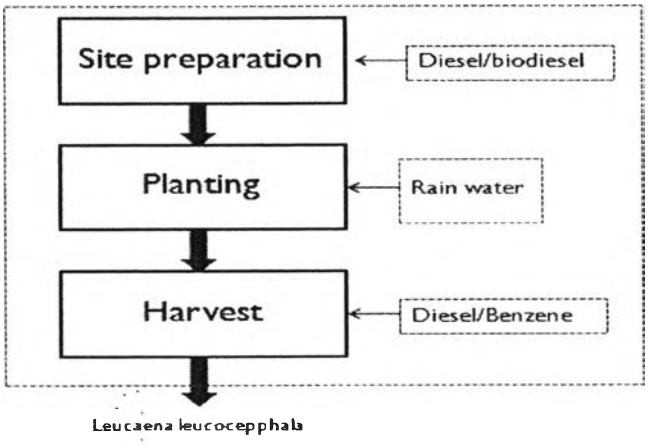

Figure 3.4 The system boundary of *leucaena leucocephala* production.

For transportation phase

The distance of rice straw and *leucaena leucocephala* plantation to pyrolysis plant was assumed to be within a 100 km radius of the pyrolysis plant and mode of transportation was set to be 25 tons truck (diesel oil consumption rate of 2.97 km/liter) (Energy Development and Research Institute). The location of pyrolysis plant and upgrading plant were created and compared in 2 cases as follow;

Case 1: Pyrolysis and upgrading plant were located in Nakorn Sawan and Rayong province, respectively. The transportation of raw bio-oil from pyrolysis plant to upgrading plant was calculated using distance from Muang district, Nakorn Sawan province to Map Ta Phut, Rayong province in a range of 390 km (one-way) and based on 32 tons truck (diesel oil consumption rate of 2.24 km/liter) (Energy Development and Research Institute).

Case 2: Pyrolysis and upgrading plant were assumed to locate in the same area in Rayong province.

For *leucaena leucocephala* transportation, pyrolysis and upgrading plant were assumed to locate in the same area in Rayong province (define as a Case 2).

It can be seen that the upgrading plant was located at Mabtaphut in Rayoung for both cases, this is because the utility (hydrogen) which use in refinery system can also use in upgrading process. Therefore, the energy consumption for the production of hydrogen does not require in this study.

For pyrolysis phase

The system boundary of the pyrolysis system includes feed preparation (drying and size reduction) and pyrolysis process Inputs and outputs in unit processes are linked within the boundaries of the system. The overall of system boundary of pyrolysis system is shown in Figure 3.5.

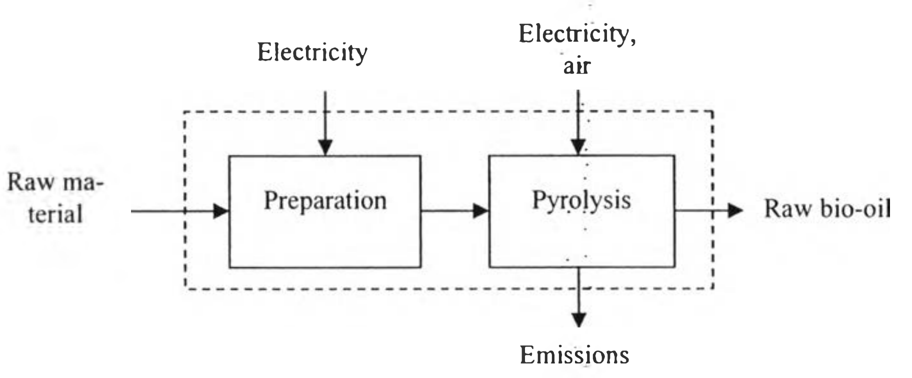

Figure 3.5 The system boundary of pyrolysis system.

In this study, the pyrolysis stage has been separated into 2 processes; feed preparation and pyrolysis process. The feedstock preparation consists of feed drying and size reduction. In the feed drying of rice straw, water in rice straw was minimised to less than 10 % water by sundry, while for *leucaena leucocephala* the feed drying was achieved by sundry (≈30 wt% moisture) and further by boiler oven (≈10 wt% moisture). The energy consumption data for boiler oven was calculated based on the thermodynamic calculation method (Appendix C). For *leucaena leucocephala* size reduction, the primary data in this step was collected from A-PLUS Power Co., Ltd at Nong Moung district in the northern part of Lopburi Province. In this process, 16 kWh of power was supplied for 1 ton of *leucaena leucocephala* chip. Fosr rice straw, the multipurpose shredder machine from Nimut Engineering Company was assumed to use for rice straw size reduction. It was reported that 5.6 kWh of power was supplied for 1 ton of rice straw with 75% efficiency of machine was assumed. The raw materials are needed to be sized into small pieces (<4 mm) for both of rice straw and *leucaena leucocephala*.

For upgrading phase

Upgraded bio-oil was achieved by partial or total elimination of oxygen and hydrogenation of chemical structures. Since there is no commercial plant or any information of this part, process simulation is necessary due to energy consumption is needed. Data for upgrading process simulation was retrieved from Department of Chemical Engineering, University Technology PETRONAS. In this stage, different energy consumption alternatives were created by using process simulation and compared to the base case as shown in Table 3.1.

Table 3.1 Alternatives for upgrading process

Alternatives	Method
Base case	Energy consumption data were calculated based on PETRONAS simulation
Alternative 1 (A1)	Apply heat integration to Base case
Alternative 2 (A2)	Apply heat integration and 75% heat recovery to A1

d.) Assumptions and limitations

- Rice straw ash contains 23 wt% (Garivait *et al.*, 2006) and for *leucaena leucocephala* was assumed to be zero.
- One hundred percent of rice straw, which was collected from rice harvesting, was used as feedstock for bio-oil production.
- Total weight of rice straw transportation per round was assumed to be 75 wt% of 25 tons truck. And A 5% loss of rice straw had been assumed during transportation (Suramaythangkoor and Gheewala, 2010).
- Total weight of *leucaena leucocephala* transportation which used to calculate is 8 dry tons (10 wt% moisture) per round (A PLUS Power Co., Ltd.).

- Since there is no available information concerning the price of the collected rice straw to bio-oil production and therefore, allocation of rice straw had been retrieved from sales revenue at actual site of field in Thailand.
- Emissions from vehicles operation in fuel transportation are calculated based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
- The inventory data for pyrolysis and upgrading system are assumed to use the same data from the literature for both of rice straw and *leucaena leucocephala*.

3.2.3 Inventory Analysis

a.) Collect data related to input and output matter for all main processes including process production, feedstock preparation and within study boundaries unit processes, for example;

- Raw materials, utilities, and energy consumptions
- Air and water emissions
- Waste generations

The sources of inventory data of bio-oil conversion process are shown in Table 3.2.

Table 3.2 Sources of inventory data of bio-oil conversion process

Stage	Rice straw		*Leucaena leucocephala*	
	Type	Source	Type	Source
Plantation & Harvesting	1st, 2nd	SENTEC*, farmers	1st	PTT research and technology Institute
Transportation	1st	PTT research and technology Institute	1st	PTT research and technology Institute
Pyrolysis	2nd	Wellman Process Engineering Ltd.	2nd	Wellman Process Engineering Ltd.
Upgrading process	2nd	PETRONAS	2nd	PETRONAS

*Suranaree Environmental Technology Research & Consulting unit b.) Quantify how much energy and raw materials were used, and how much solid, liquid and gaseous waste was generated, at each stage of the product's life.

3.2.4 Allocation Procedure

Allocation (partitioning of input or output flows of a unit process to the product under study) was one of the most critical issues in life cycle assessment and it was undertaken this study as described below.

In this study, rice straw was considered in 2 cases: (1) as a waste and (2) as a by-product of rice production. When rice straw was considered as a waste, rice cultivation was not included in the system boundary. Therefore, the allocation method can be avoided. For rice straw as a by-product case, in the agricultural system, large amounts of rice straw were generated as a co-product after rice harvesting. Rice straws are obtained and are commonly used for animal feed and fertilizer. Economic allocation was initially applied as baseline in this study. Currently, there is no available information concerning the price of the collected rice straw to bio-oil production and therefore, the price of rice straw came from simulation data. In general case, 1 rai of rice harvesting in Thailand gains amount of rice straw of 1,200 – 1,600 kg and the price of rice straw is 40-50 Bath per rai. Therefore, the price of rice straw 0.03 Bath per 1 kg rice straw. Paddy price in this study is 8.50 Bath per kg according to the Thai Paddy Prices at Central Market on 25 March 2011.

Regarding *leucaena leucocephala*, allocation was not considered because *leucaena leucocephala* was planted to use as a feed for bio-oil production and there was no other products that can be used from this stage.

3.2.5 Impact Assessment

a.) Calculate impact potentials based on the LCI results by using software named—SimaPro version 7.0—with CML 2 baseline 2000 methods.

b.) Analyze and evaluate the influences on the energy consumption and the Net Energy Ratio (NER) from bio-oil production associated with raw material and energy inputs. The energy consumption for bio-oil production is related to the energy required both directly such as petroleum products, electricity and indirectly which used for producing materials including fuel extraction, refining/conversion and delivery in the fuel life cycle. The NER which refers to the ratio between energy output which is the heating value of the fuel bio-oil and total primary energy inputs to produce 1 toe of bio-oil.

c.) Analyze and evaluate the influences on human health and environment performances from bio-oil production associated with raw material and environmental releases quantified by the inventory. In this research, the environmental impacts are evaluated in various categories such as global warming, acidification, eutrophication and human toxicity potential.

3.2.6 Interpretation

a.) Evaluate the net energy ratio, impact assessment and opportunities to reduce energy or environmental impacts at each stage of the product life-cycle.

b.) Analyze an improvement, in which recommendations were made based on the results of the inventory and impact stages.

3.2.7 Comparing

Compare the results between base case and alternatives to confirm that how much the new design is improved. The results are included net energy ration and life cycle impact assessment.