CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

In the present study, we have performed the life-cycle energy and environmental evaluation for bio-oil production from rice straw and *leucaena leucocephala* in Thailand. LCA technique was employed to evaluate the environmental impacts of the design using SimaPro 7.0 with the CML 2 baseline 2000. In order to develop the process to be more sustainable, key indicators from the life cycle analysis and environmental impact analyses were analyzed to provide directions for improvements. The new design alternatives were then generated by process simulation. The simulation process was modeled by using the commercial simulator PRO/II. The new design alternatives were generated with a focus on minimization of the energy consumption in the upgrading stage. All case studies that were conducted in this research are illustrated in Table 5.1.

Table 5.1 Summary of all case studies in this research

Raw materials	Cases		Alternatives		
	Case 1	Case 2	Base case	Alternative 1	Alternative 2
Rice straw • Waste case • By-product case	• Pyrolysis plant: Nakorn Sawan • Upgrading plant: Rayong	• Pyrolysis plant: Rayong • Upgrading plant: Rayong	PETRONAS simulation	Apply heat integration to Base case	Apply heat integration and 75% heat recovery to Alternative 1
Leucaena leucocephala	-				

5.1 Summary of Major Findings

From the energy analysis, net energy ratios (NER) of 1.39 and 1.42 were achieved for rice straw as a waste case for Case 1 and Case 2, respectively, while NER of 1.36 and 1.39 for rice straw as a by-product case for Case 1 and Case 2, respectively. The NER of *leucaena leucocepphala* is 1.35 which is lower than the energy efficiency from the rice straw. Major energy consumption was found to come

from the bio-oil upgrading stage, which accounts for 87.20% and 88.96% of the total energy usage for rice straw as a waste case for Case 1 and Case 2, respectively, 85.50% and 87.11% for rice straw as a by-product case, respectively. For bio-oil production from *leucaena leucocepphala*, energy consumption in upgrading stage accounts for 84.55% of total energy usage. It is the result of intensive use of electricity and steam. In term of energy efficiency from alternative designs, the results showed that the new design alternatives were more energy efficient (higher NER) than the base case, and Alternative-2 is the most energy efficient design with the value of NER is 307% and 332% for rice straw as a waste case for Case 1 and Case 2, respectively, and 284% and 309% for rice straw as a by product case for Case 1 and Case 2, respectively, and 270% for *leucaena leucocepphala*, higher than the base case design.

Bio-oil has shown to have higher energy efficiency than petroleum fuels so it can be substituted for petroleum fuels to reduce oil imports. The results also showed the benefit of bio-oil could be extended replacement of bioethanol from cassava and biodiesel from palm oil.

The results obtained from the LCA study on the base case showed that the major environmental impacts resulted mainly from energy consumption (heating duty) utilized in the upgrading stage, except for bio-oil production from *leucaena leucocepphala* that the highest GWP came from pyrolysis stage due to the electricity consumption for *leucaena leucocepphala* drying.

When comparing the environmental impact among the base case and alternatives, Alternative-2 also showed improvement and achieving a considerable reduction. For global warming. the reduction of 11.59% and 14.44% were achieved from the base case design for rice straw as a waste case for Case 1 and Case 2, respectively, and 11.28% and 13.77% for rice straw as a by-product case for Case 1 and Case 2, respectively. The 10.87% reduction was obtained for bio-oil production from *leucaena leucocephala*. For acidification potential, the reduction of 61.34% and 63.48% reduction from the base case design for rice straw as a waste case for Case 1 and Case 2, respectively, and 59.714% and 60.83% for rice straw as a by-product case for Case 1 and Case 2, respectively. The reduction of 52.24% was obtained for bio-oil production from *leucaena leucocephala*. For eutrophication potential, the

reduction of 81.01% and 82.05% was achieved reduction from the base case design for rice straw as a waste case for Case 1 and Case 2, respectively, and 79.01% and 81.25% for rice straw as a by-product case for Case 1 and Case 2, respectively. The reduction was found to be 72.22% for bio-oil production from *leucaena leucocephala*. For human toxicity potential, the reduction of 91.38% and 96.91% reduction was achieved from the base case design for rice straw as a waste case for Case 1 and Case 2, respectively, and 89.50% and 94.85% for rice straw as a by-product case for Case 1 and Case 2, respectively. The reduction was found to be 94.98% for bio-oil production from *leucaena leucocephala*.

5.2 Recommendations

1. The economic evaluation should be considered for the new investment in case of changing from the base case to alternatives.

2. Future technology in upgrading stage can be applied to reduce the energy consumption especially electricity usage.

3. Further studies should include the comparative study on bio-oil production from pyrolysis technology and other technologies in order to make comparison of energy used and impacts assessment.