# CHAPTER V
# CONCLUSIONS AND RECOMMENDATIONS

In this research, the bioethanol production from cassava rhizome, a potential lignocellulosic material in Thailand, was modeled and simulated though the PRO/II 9.1 process simulator. A systematic sustainable design methodology was then applied through the use of several sustainability analysis tools, SustainPro, ECON program for economic evaluation, and lastly LCA technique in order to evaluate the environmental impacts of the design by using a commercial program called SimaPro 7.1 with the CML 2 baseline 2000 method. Targeting to improve the more sustainable process, the study used sustainability analysis to generate new alternatives design having potential for improvements. These new alternative designs were then compared with the base case design in energy and water consumption, environmental aspects (mainly global warming potential or GWP as $CO_2$ equivalent) and profitability of the designs. The capacity for bioethanol production from cassava rhizome is about 150,000 liters/day which about 1.30 % of total demand of ethanol in Thailand, required the quantity of cassava rhizome about 310,000 tons/year which about 12.13 % of total available unused cassava in Thailand. Nakhonratchasima province is the most appropriate location for places bioethanol production from cassava rhizome plant.

After performing the calculations for sustainability metrics, the indicators were calculated and used to identify points or streams in the process which have high potential for improvement which water and lignin were identified. Based on the sustainability analysis of the base case design, three main ideas with seven new alternatives design were generated. The first idea was heat integration to reduce energy. The second idea was wastewater recovery by membrane. Lastly, the third idea was the combustion of lignin as fuel.

In term of water consumption, it was shown that alternative 4 and 7 were the most saving water quantity processes compared with all of alternative design. Regarding to profitability, alternatives 4 and alternative 7 have shown to have the highest profit, were considered as the best designs for investment. In term of environmental aspect, alternatives 5 has shown to be the most environment friendly when considering on global warming together with other impacts.

Based on these results, alternative 4, wastewater recovery using membranes and lignin combustion was the best design for bioethanol production process from cassava rhizome because this design had the most water saving and highest profit while environmentally friendly.

According to the results, several recommendations can be offered:

1. Cassava rhizome is a good and abundant lignocellulosic material and for bioethanol production compare to other biomasses. Moreover, Cassava rhizome has not acetate component that mean no need to add acetate treatment as others biomasses. Further research in this area should be done to improve the yield by mixing with others lignocellulosic material called multiple feedstock.

2. The capacity this study is about 150,000 liters/day which just 1.30 % of total demand of ethanol in Thailand, required the quantity of cassava rhizome just 12.13 % of total available unused cassava in Thailand. Further research in this respect should be done to increase the capacity of this plant by increasing quantity of unused cassava rhizome in Thailand that will make more benefit of agricultural residues.

3. Some of waste solid and wastewater from the plant could be sent to aerobic fermentation process to produce organic fertilizer as by product. Moreover, Using organic fertilizer instead of synthetic ones that can help reduce environmental impact within life cycle boundary because overall chemical fertilizer consumption can be reduced.