CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

In this study, the life cycle environmental impact assessment (LCIA) was performed for two types of bioplastics (PLA and PBS) and for selected model products made from these two bioplastics which are T-shirt bag, drinking water bottle, and food container. For LCIA, this study focused on the global warming potential (GWP) which is represented by the GHG emission in term of kg CO_2 eq. per units of interest (kg resin or kg product).

5.1 Life Cycle Impact Assessment (LCIA)

5.1.1 Cradle to Gate

Bioplastic Resins

Comparing to commercial PLA resin "Ingeo" of NatureWorks, our Cassava-based PLA resin has shown to have much higher GWP impact of which the major contribution comes from the resin production part. The overall GWP can be lowered by improvement options proposed in this study which are improved cassava yield and utilization of wastewater from cassava plant to produce biogas for electricity generation. If both improvement options are applied, the overall GWP of Cassava-based PLA has shown to be lower than Ingeo. In addition, the GWP performance of Cassava-based PLA with improvement options has shown to be better than conventional plastics such as HDPE and PET which are used to produce to same products. For PBS, its GWP is found to be much higher than PLA and other plastics which is due to the fact that only half (succinic part) of PBS is produced from renewable resources whereas another half (BDO) is still produced from fossil resource.

Bioplastic Products

The processing of bioplastic resins to finish products has shown to have significant uncertainty involved which can be attributed to the unfamiliarity and difficulty in adjusting the process conditions and processing the bioplastic resins due to the difference in their properties compared to conventional plastics. This causes the input data obtained from actual processing plants to be much higher than the typical data reported by the plastic processing industry. Therefore, two sets of data were used in the analysis in this study which represents best case and worst case. It is expected that more reliable data could be obtained in the future when bioplastic products are produced in a mass production to the market.

Disposal Phase of Bioplastic Products

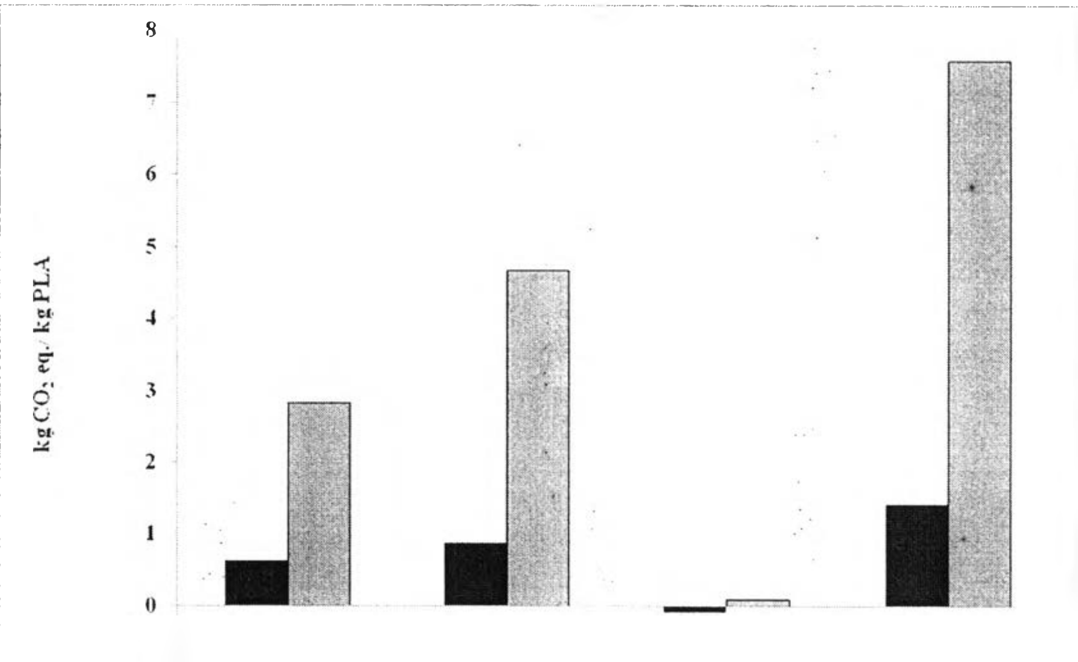
Four disposal technologies including landfill, recycling, composting, and incineration were used in this study to evaluate the environmental impacts of the end of life phase of the bioplastics in combination of four different waste management scenarios. The results show that composting technology has contributed lower GHG emission when compared to other disposal technologies. The analysis also shows that S3 (30% landfill with energy recovery, 30% composting, 30% incineration, and 10% recycle) has shown to be the worst scenario for PLA while base case without energy recovery is the worst case for PBS. The origin of the bioplastic has shown to be a very important factor as well as the use of by-product(s) from each process. This part clearly reveals the appropriated end of life approach to bioplastic waste management and how to improve the life cycle environmental performance of bioplastics.

5.1.2 Cradle to Grave

Whole Life Cycle of Bioplastic Products

When the whole life cycle environmental impact of bioplastic was considered, the results show that the performance of bioplastics in term of GWP is better than that of conventional plastics for both PLA and PBS and for almost all products studied under appropriated waste management scenario.

Figure 5.1 and Figure 5.2 show the distribution of GWP of selected products (T-shirt bag) for PLA and PBS in various stages in the life cycle of the bioplastics. From Figure 5.1, if we consider the best case for PLA T-shirt bag, the total GWP of PLA product has shown to be 1.4168 kg CO_2 eq./kg PLA product. It can be seen that the major GWP distribution comes from processing of bioplastic product which accounts for 62% of total GWP of PLA product. The second contribution comes from the resin itself which accounts for 44% of the total GWP. On the other hand, if we consider the worst case, the total GWP of PLA product can be as high as 7.5923 kg CO_2 eq./kg PLA product which is more than 5 times of the best case value. Similarly, the major GWP distribution comes from processing of bioplastic product which accounts for 62% of total GWP of PLA product while the resin contributes about 37% of the total GWP.



	Resin*	Processing**	Disposal***	Total
■ Best case	0.6299	0.8777	-0.0908	1.4168
□ Worst case	2.8276	4.6718	0.0930	7.5923

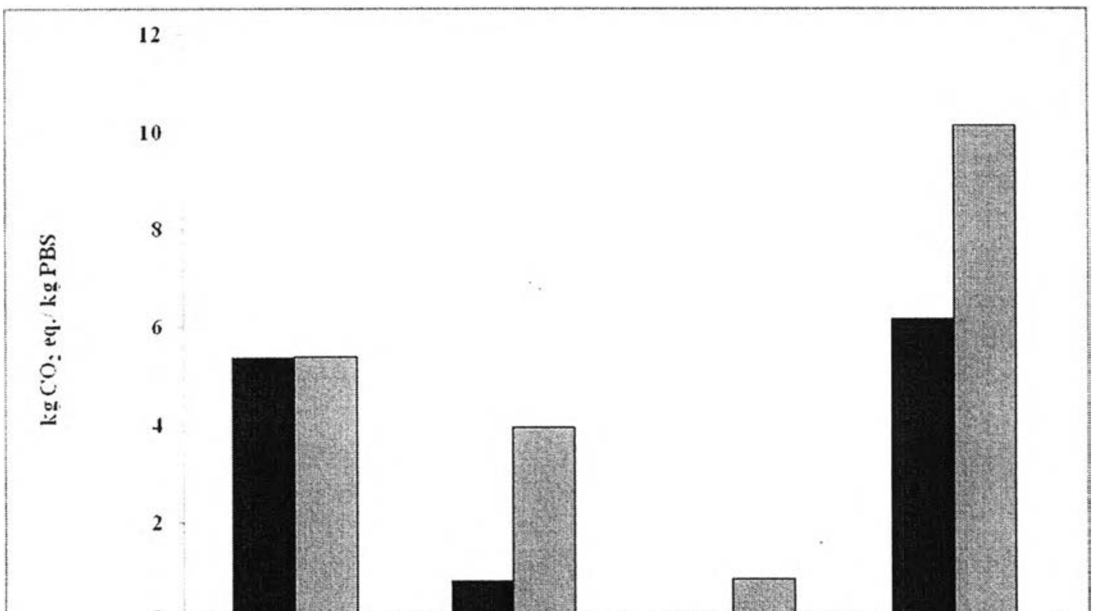
*Note: * Best case for resin includes all improvement options, and without any options for worst case.*

*** This step includes transportation of resin, product processing, and product transportation. The value is an average value between Company A and B.*

**** Best case is Scenario 1 (100% composting), and worst case is Scenario 3 (30% composting, 30% landfill with energy recovery, 30% incineration, and 10% recycle).*

Figure 5.1 Distribution of GWP of PLA T-shirt bag in various life cycle stages for best case and worst case.

In case of PBS, the total GWP of PBS product for the best case is 6.1760 kg CO_2 eq./kg PBS product while GWP for the worst case can be as high as 10.1530 kg CO_2 eq./kg PBS product. It can be seen that the PBS results are different from PLA product as the major GWP distribution comes from PBS resin which is 53% and 87% of total GWP of PBS product for best case, and worst case, respectively. The second contribution comes from processing part which accounts for about 13% to 40% of the total GWP. When compare with PLA product, PBS has obviously shown to have higher GWP than PLA product.



	Resin*	Processing**	Disposal***	Total
■ Best case	5.3835	0.7909	0.0016	6.1760
□ Worst case	5.3835	3.9421	0.8274	10.1530

*Note: * No improvement option for PBS so the values for best case and worst case are the same.*
*** This step includes transportation of resin, product processing, and product transportation.*
**** Best case is Scenario 1 (100% composting), and worst case is the Base Case Scenario (without energy recovery).*

Figure 5.2 Distribution of GWP of PBS T-shirt bag in various life cycle stages for best case and worst case.

5.2 Recommendations

Although the life cycle environmental impact assessment and the life cycle costing were successfully conducted for two types of bioplastics (PLA and PBS), several recommendations could be offered as follows:

5.2.1 Suggestions for Improvement of Inventory Data

As the inventory data for the resin production in this study were extracted mainly from NatureWorks report and substituted with local data from relevant sources (National Database, reports, published papers, etc.), several assumptions and estimations were made in order for the research team to be able to have enough data to assess the environmental impact as planned. This could be improved if more complete and transparent data were achieved. In this regards, the research team leader has already approached Dr.Vink, the author of NatureWorks paper, to seek for collaboration which has seemed to be positive in the future.

It can be seen in Part 4.2.2 that there is a large variation of the data in the plastic processing phase. This is inevitable as the plastic product manufacturers are not familiar with processing bioplastics which have different processing properties when compared to conventional plastics. Therefore, the required processing time and energy consumption were found to be much higher than when processing conventional plastics. This part could be improved if the manufacturers are more familiar with processing bioplastics which may come through 1) the collaborative investigation with researchers in the university or institution or 2) increase in the demand and market of bioplastic products.

The environmental assessment of the end of life (disposal phase) was conducted as scenarios based on disposal technologies currently available and current waste management of Bangkok. In this aspect, further study focusing on end of life phase of plastics/bioplastics could be done in order to achieve more realistic data for the evaluation.

5.2.2 Suggestions for Improvement of Environmental Performance

PLA Resin

From the results, it can be seen that GWP impact mainly comes from the production of cassava-based PLA resin which covers the cassava plantation & harvesting, transportation, starch production, lactic acid and polylactic acid production. We have shown that improving cassava yield and utilization of biogas from wastewater of cassava plant to generate electricity help reduce GWP significantly. However, increasing use of renewable energy in this energy intensive resin production process could help further reduce GWP value of cassava-based PLA resin. In the future, NatureWorks has planned to use more renewable energy in order to improve the GWP of their Ingeo product.

PBS Resin

In case of PBS, it shows high GWP impact which is 5.3835 kg CO_2 eq./kg PBS resin. As PBS composes of 2 parts which are succinic acid and 1,4-butanediol (BDO), succinic acid from bio-based generates net GWP of 1.611 kg CO_2 eq./kg PBS resin while BDO from petroleum-based generates GWP of 2.618 kg CO_2 eq./ kg PBS resin. Since the majority of impacts comes from BDO production, improving this part could lead to a significant improvement. One possible way is to change the process to white technology process which is a process that uses 100% renewable resource to produce PBS resin. At the moment, several companies are interested in utilizing this process to produce PBS in the near future.

End of Life

It is clearly shown in this study that the disposal technology and waste management system are very important to the overall environmental performance of the bioplastics. It is recommended that these two factors should be considered together with the development of bioplastics or even before so that the suitable disposal and waste management system could be set up to handle bioplastic wastes in order to minimize the environmental impacts of the bioplastics.