

COST BENEFIT ANALYSIS OF BIOPLASTIC PRODUCTION IN THAILAND ¹

Siriluk Chiarakorn ²

Chompoonuh K. Permpoonwiwat ³

Paponphanai Nanthachatchavankul ⁴

Abstract

This paper aimed to analyze the net social benefits from switching petroleum-based plastic to bioplastic based on Cost-Benefit Analysis (CBA). The status quo was no PLA production in Thailand and another case is having PLA production based on the assumption that the HDPE production was not replaced by the PLA production. This paper calculated cost of PLA production from two cases: 1) cassava root to PLA resin and 2) cassava starch to PLA resin. The cost structure of PLA production comprises of investment cost, direct production cost and indirect environmental cost. Total costs and benefits of PLA and HDPE production were calculated on the basis of 100,000 tonnes. For case 1, the integrated PLA production provided positive net benefit as 7.34 millions USD due to large benefit from selling cassava meals. Without the revenue from cassava meal, the net benefit is negative (-297.66 millions USD). Plus CDM implementation, the case 1 gains more benefit from selling carbon credit than another case due to less amount of wastewater produced. In comparison to PLA production, the net benefit of HDPE production is -186.66 millions USD. Therefore, only the PLA production under case 1 can be competitive with the HDPE production. The case 2 was selected as Status quo for calculation of net present values (NPV) using real discount rate of 1.89 %. Moreover, NPV of three options: 1) change in benefit due to expected PLA price development, 2) change in cost due to technological development and 3) combination of option 1 and 2 were calculated. All three options provided positive NPV. The sensitivity analysis was conducted based on the variation in real discount rates; 1.89 % (status quo), 4.5% and 7.0%. All results were insensitive to the increase of real discount rates.

¹ Based on a Research Project on “Financial and Economic Viability of Bioplastic Production in Thailand,” funded by Economy and Environment Program for Southeast Asia (EEPSEA)

² School of Energy, Environment, and Materials, King Mongkut's University of Technology Thonburi

³ School of Economics and Public Policy, Srinakharinwirot University

⁴ School of Energy, Environment, and Materials, King Mongkut's University of Technology Thonburi

1. Introduction

Since petroleum-based plastic has been commercialized in the late 18th century, it has been widely utilized to serve our daily life in various purposes such as clothes, containers, packaging, and so on. As a result, it becomes one of the most important and unstoppable consumable product. However, it does not provide only advantages but it also leads us to the unexpected consequences. Firstly, because their feedstocks are derived from petroleum product which is the non-renewable resource, the more it has been manufactured, the less the fossil fuels exist. Next, the production of petroleum-based plastic generates carbon dioxide (CO₂), the most prominent greenhouse gas. According to energy technology perspective 2008 (IEA 2008), chemical and petrochemical industry had globally emitted around 800 Mt CO₂ in 2005. As widely known, the increase in quantity of greenhouse gas in the earth atmosphere results in climate change or global warming problem, which is the most globally intriguing issue at this moment. Last but not least, the degradation time of petroleum-based plastics requires about few hundred years to be perfectly decomposed. From that reason, there are many attempts to utilize their wastes such as recycling, reuse, energy conversion, but most of them have been currently managed by landfill operation which brings about the undesirable environmental pollution problem.

Even though it is difficult to immediately discontinue the petroleum-base plastic consumption, the possible option is to alternatively introduce new material which is produced from renewable feedstock. Bioplastic is; therefore, be the desirable alternative because it is originated from the natural resources such as corn, cassava, etc which is considered as renewable materials. At present time, there are only two major commercial bioplastic in the market, Polylactic acid (PLA) and Polyhydroxyalkanoates (PHA), that can be biodegradable and truly produced from renewable sources such as sugar cane, cassava, and rice (Rudnik 2008).

As Thailand is one of the world leader agricultural countries and regional petrochemical producer in Southeast Asia, bioplastic industry may be a challenging alternative for our petrochemical industry as well as agricultural sector. Among all carbohydrate plants in Thailand, cassava production was ranked 4th in the world and the 1st exporter to global market in 2007 (Central of Agricultural Information, 2007). In addition, its price is the lowest as compared to potato, wheat, and corn. In 2007, the lactic acid plant has just been established in Thailand to produce lactic acid which is the main raw material for producing PLA. Apparently, this should

be good opportunity to utilize and enhance the cassava's value rather being commodity food products.

Accordingly, Thai government established the National Innovative Agency (NIA) as a national focal point for bioplastic industry development and has launched the five years National Roadmap for bioplastic production (2008-2012), which aims to prepare readiness and strengthening bioplastic industry and its product chains in Thailand. The roadmap action plan requires many relevant researches and developments as supporting database. Current researches are mostly deal with financial analysis of bioplastic production. No indirect cost and benefit from environmental aspects has been taken into account. In order to support the National Roadmap, the study of economic analysis of bioplastic production is urgently required

Thus, this paper aimed at applying the economical analysis tool (Cost Benefit Analysis) for determining the potential of bioplastic production in Thailand.

2. Objectives

The main goal of this research was to analyze the net social benefits from switching petroleum-based plastic to bioplastic based on Cost-Benefit Analysis (CBA).

The specific objectives were:

1. To analyze economic estimations involving cost and benefits of PLA production
2. To calculate net social benefits based on the assumption that bioplastic is an alternative to the existing petroleum-based plastic

3. Methodology

A concept of **Cost-Benefit Analysis-CBA** was applied as a tool for evaluating a project in order to help public sector to inform their decisions about pursuing bioplastics as the new wave industry. The CBA has been conducted to evaluate the scenarios of bioplastics production as a replacement of fossil-based plastics.

The conduct of this study follows the 9 step procedures:

Step 1: Specify the set of alternative project.

The portfolio of the project consists of two scenarios:

Scenario 1: Status Quo scenario in which no bioplastics production is introduced. The baseline is only the production of the comparable petroleum plastic as High-density polyethylene (HDPE)

Scenario 2: New scenario in which PLA bioplastics production is taken place with the production capacity of 100,000 tonnes.

This study is based on assumption that the production of conventional plastics is not replaced by the production of bioplastic because currently bioplastics are served for some niche and green markets. No replacement of conventional plastics with the bioplastics are commonly found. Under scenario 2, two cases are studied.

Case 1 : There is PLA production starting from cassava root to PLA resin.

Case 2 : There is PLA production starting from cassava starch to PLA resin.

The latter case is considered as more realistic than the previous one due to the surplus of cassava starch production in the country. The investor can buy cassava starch as a raw material for sugar production and then converting sugar to lactic acid which is a monomer for PLA production. Due to the surplus of cassava starch, the exact same amounts of cassava starch will be produced with and without the Scenario 2.

Step 2: Decide whose benefit and costs count

The referent group refers to the group(s) of individuals whose welfare will be accounted for when assessing the costs and benefits of the project. Within this study, the people of Thailand are the referent groups but there are a number of constituent groups which are (1) the fossil-based plastic and bioplastic industries (2) the cassava farmers and (3) the government. Those referent groups are selected based on the policy from Thai government to which the benefit and welfare will be provided according to the roadmap for development of bioplastics production. Scenario 2 will show who relatively gain or who lose. For example, farmer and social may gain the social benefit from the production of PLA. However, the fossil-based plastic industry might be relative loss.

Step 3: Catalogue the impacts and select measurement indicators

The potential positive and negative impacts used in this study are itemized in Table 1.

Table 1. Items of costs and benefits from PLA production.

Production process	Costs	Benefits	Data sources
1. Starch production	Investment Cost	Animal feed product	research journals, plant owner interview
	Operation cost		
	Cost of waste water treatment		
2. Lactic acid production	Investment Cost	By products such as ethanol, gypsum	NatureWorks, NIA, research journals
	Operation cost		
	Cost of waste water treatment		
3. PLA polymerization	Investment Cost	Carbon offset	NatureWorks, NIA, research journals
		Cost of hazardous waste treatment	
	Operation cost		

Step 4: Predict the impact quantitatively over the life of the project

Bioplastics production will have an impact over extended periods of time. This study assumes a time horizon of 25 years due to timeframe of the current roadmap for development of bioplastic industry. Analysts have to predict the magnitude of all impacts in terms of measurable units over the life of a particular production. If there are any impacts that cannot be quantified or measured in physical units, for example, social and cultural impacts, analysts should provide descriptive information on them. Sometimes, the required information may not be available for prediction. In such a case, analysts will have to make certain assumptions to estimate anticipated impacts.

Step 5: Monetize all impacts

The monetization of outputs and impacts does not imply that money is all that matters, but merely a convenient way of translating the physical measures of the impact comparable in common units (Hanley 2000). Given that many of the environmental goods and services are not traded in the market, there are no prices to use as reference. Shadow prices, therefore, will be used to reflect the true economic values of the costs and benefits. In this study, benefit transfer

is the method used to estimate the costs and benefits of a similar environment in a specific area. Environment values may be estimated from existing studies or secondary data. Fixed value transfer and expert opinion will be adopted in order to derive the monetary values used in the calculation. In addition, shadow exchange rate (SER) for tradables and nontradables will be adopted to proxy economic price of foreign currency.

Step 6: Discount benefit and cost to obtain present values

Net present value (NPV) is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits. The discounting reflects the time value of money. In this research, we assume a 25-year project life time. All future benefits and costs of bioplastic production, including nonmonetized benefits and costs, are discounted. For the investment in bioplastic, with costs concentrated in early periods and benefits following in later periods, raising the discount rate tends to reduce the net present value. In this case, a real discount rate that reflects expected inflation will be used to discount nominal benefits and costs. As of November 2009, the Bank of Thailand has issued the 30-year interest rate of government bond yield of 4.29%, the real discount rate of 1.29%. The NPV for the status quo (PLA production starting from cassava starch to PLA resin) and other three options: 1) change in benefit due to expected PLA price development, 2) change in cost due to technological development and 3) combination of option 1 and 2 were calculated.

The sum of discounted benefits and costs of the different projects are then compared. Discounting benefits and costs transforms gains and losses occurring in different time periods to a common unit of measurement. In principle, all projects with NPVs > 0 are considered to have passed the NPV test since it is deemed as an improvement in the social welfare. Comparison of the values of NPVs constitutes the main criteria to choose among projects. A number of criteria such as the B/C ratio and the Internal Rate of Return (IRR) while useful as supporting information, are not the decisive factor to determine whether or not projects should be adopted. The B/C ratio indicates the cost effectiveness of investment while the IRR can support decision-making by comparing returns of one project against another relative to the opportunity cost of funds (Hanley 2000).

Step 7: Compute the net present value of each alternative

The NPV of a project is equivalent to the present value of the total cost minus the total benefits. With the project time frame of this study being 25 years, the NPV is calculated from the following:

$$\text{NPV} = V_0 + \frac{V_1}{(1+i)} + \frac{V_2}{(1+i)^2} + \dots + \frac{V_t}{(1+i)^t}$$

$$\text{NPV} = \sum_{t=0}^n \frac{V_t}{(1+i)^t}$$

Where	V_t	=	Value at time t
	i	=	Discount rate
	t	=	Year
	n	=	0,1,2,.....,25

Step 8: Performing sensitivity analysis

The purpose for conducting the sensitivity analysis stems from the uncertainty over various assumptions that relate to the predictions of the parameters and their future relative values (Folmer and Gabel 1998). Sensitivity analyses are therefore an essential stage of CBA to determine the sensitivity of the NPV given changes in key parameters.

The parameters that deserve the most attention will depend on the dominant benefit and cost elements and the areas of greatest uncertainty of the program being analyzed. In the year 2005, the rate of Thailand government bond has increased up to 6.72%, higher than the present rate (4.29%). In this study, sensitivity analysis should be considered for estimates of different real discount rates of 1.29%, 3.29% and 5.29% with the inflation rate of 3% during the 25 - years period.

Step 9: Make a recommendation

After having gone through the successive steps described above, the interpretation of the results of the CBA must be made with recognition of the principle of what the tool offers as well as the limitations in application. The limitations can arise from the fact that a number of parameters may be unpredictable while others maybe unknown in the present times (Hanley

2000). Eventhough there are some existing policy relavent bioplastic,the outcome of this study will be beneficial to the policy maker (government sides such as NIA, ONEP) in order to initiate the new environmental law/ legistration as well as to amend the existing laws as mentioned previously.

RESULTS AND DISCUSSION

HDPE production process and input data

In Thailand, HDPE is produced from the naphtha and ethane based feedstock. However, the production cost of HDPE in this research is evaluated from naphtha production route. While the technology for HDPE production is Ziegler Slurry process licensed by Mitsui Chemical (Mitsui CX process) which account for 91% percent of HDPE total production in Thailand. The production of HDPE in this study is 100,000 tonnes (as equal as PLA for their comparison). According to IPPC 2007, the average ethylene consumption of HDPE production is 1.027 ton/ton HDPE. Ethylene yield from naphtha in steam cracking process yields is approximately 28.4 ton/ton naphtha. (IPPC, 2003). It is reported that Naphtha 1 tonne is produced from crude oil refinery by consuming curding 1.1 toe (tonnes of oil equivalent)/ tonne naphtha referred from Eco-profiles of the European Plastic Industry.

Air pollution and energy use are transferred from the Eco-profiles of the European Plastic Industry of crude oil, naphtha, ethylene, and HDPE. The gate to gate of each product can be obtained by the deduction the cradle-to-gate Eco-profile of each product with that of their raw material. The equations below show the gate-to-gate calculation of each product

$$\text{HDPE (gate-to-gate)} = \text{HDPE (Cradle-to-gate)} - \text{Ethylene (cradle-to-gate)}$$

$$\text{Ethylene (gate-to-gate)} = \text{Ethylene (cradle-to-gate)} - \text{Naphtha (cradle-to-gate)}$$

CO₂ emission is the summation of energy use (electricity and fuel oil) and air emission. Since the production technology of HDPE has been developed more than sixty years (since 1951), its energy consumption was efficiently improved to the maturing stage. As a result, the HDPE process should logically require less energy (by tonne product) than the production of PLA which is in the embryonic stage. In this research, the fuel oil will be assumed to be the representative of fuel use as same as the assumption of PLA energy use calculation.

Cost of HDPE production is shown in Table 2. Aside from the direct cost, there is another indirect cost from the opportunity of land that will be lost from the payment of renting the plant area. The renting cost of area in the industrial estate is approximately 0.74 millions USD per year but it will be increased by 5% every 5 years. Plus, plant owner have to pay for other fees, environmental fee and maintenance fee. Consequently, the average 25 years for the opportunity cost from the rental fee of 100,000 tonnes PLA's plant is 0.92 millions USD per year. Thus, the total cost of HDPE is 329.66 millions USD. The benefit from selling HDPE is 143 millions USD.

Table 2. Cost and Benefit of 100,000 tonnes HDPE production from naphtha (1USD = 0.8 Euro, as of 25 August 2010)

	Millions USD	Percentage of Total Cost
Direct Cost		
1. Production cost (a) ^a	77	23.36
2. Investment cost		
- Capital & Technology (b)	108	32.76
- Land cost (c) ^b	0.74	0.22
Total Direct Cost (d) = (a)+(b)+(c)	185.74	
Indirect Cost^c		
1. CO ₂ emission (e) ^d	124	37.61
2. CH ₄ emission (f)	13	3.94
3. CO emission (g)	1	0.31
4. SO ₂ emission (h)	3	0.91
5. NO ₂ emission (i)	2	0.61
6. Opportunity from land cost (j) ^e	0.92	0.28
Total Indirect cost (j) = (e)+(f)+(g)+(h)+(i)+(j)	143.92	
Total Cost (k) = (d)+(j)	329.66	100
Benefit^f	143	

^a Total cost of HDPE (from Naphtha) = Total cash cost + Depreciation = 702 + 68 = 770 USD/tonne

Total cash cost = Variable cost + Direct cost + Allocated cost = 702 USD/t

Variable cost = Monomer (ethylene) and Comonomer + Other raw material + Utilities
= 600 USD/t + 30 USD/t + 30 USD/tonne
= 660 USD/tonne

Direct costs = 21 USD/tonne

Allocated costs = 21 USD/tonne

Depreciation = 68 USD/tonne

^b The renting cost for the area in Map-ta-Phut Industrial Estate of 160,000 (100 rai) 40,000 m² for HDPE's plant with 100,000 tonnes capacity is approximately 0.74 millions USD per year.

^c Environmental cost evaluated from the EPS model developed in Sweden. The external cost of air pollutants are listed as below (Nguyen and Gheewala, 2008).

- CO₂ 40 USD per tonne CO₂
- CO 130 USD per tonne CO
- CH₄ 1070 USD per tonne CH₄
- SO₂ 1300 USD per tonne SO₂
- NO₂ 840 USD per tonne NO₂

^d CO₂ emission factor of electricity is 140 tCO₂/TJ while that of fuel oil is 77.4 tCO₂/TJ.

^e The opportunity cost of land was calculated from the deposited money for the five-year bank warranty which is equal to one-year rental fee or 680,533 USD. This money will be refunded in the 5th year on the investment. The calculation was based on the government bond rate which is 3% for the first and the second year and 4% for the third year and 5% for the fourth and the fifth year (BOT, 2011).

^f The benefit of HDPE is the average domestic price of HDPE (Jan-Aug 2010) sourced from Thai plastic industry association.

PLA production process and input data

In this research, there are two cases constructed for the production of PLA as described in the subsequent section. The first case considers the production of PLA starting from the production of cassava starch using cassava root as a raw material, production of glucose, and production of PLA whereas the second case changes the starting point by commencing with the production of glucose from cassava starch and following with the same flow.

Case 1

Poly(lactic acid) (PLA) is a transparent plastic produced from Glucose. As the only commercial Technology of PLA bioplastic, the NatureWorks production process called "Cargill Dow process" is applied in this study. As shown in Figure 2, cassava roots are used as feedstock to produce PLA resins. Cassava root produced in Thailand has 25 wt% starch content which can convert to lactic acid with the weight ratio of 1.3 to 1 (TTSA, 2010). The expected production capacity of PLA in Thailand was estimated from the availability of cassava production studied by the NIA (Suppasri and Sermcheep, 2010). By transforming cassava starch to glucose, to lactic acid, and to PLA, cassava meals and gypsum are the two main by-products. In the whole production process, certain amounts of wastewater are also produced.

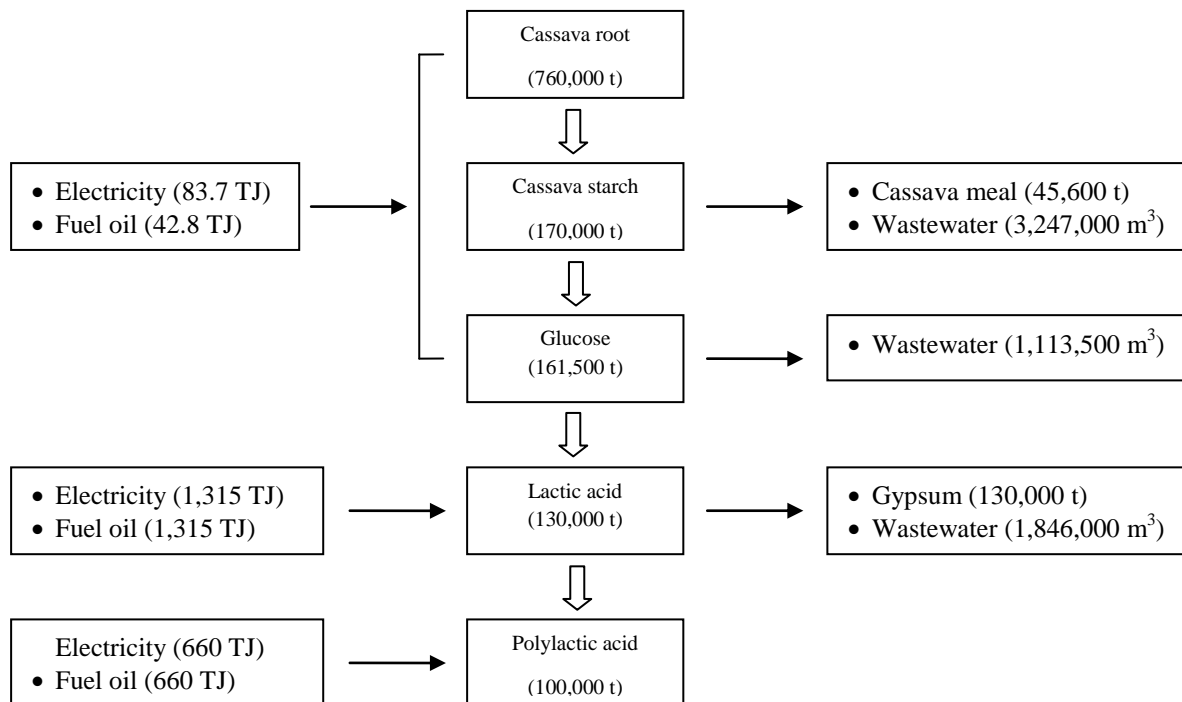


Figure 2. Mass and energy flow for PLA production from cassava root (Case 1)

According to Chavalparit and Ongwandee (2009), wastewater produced from cassava starch production was about 19.1 m^3 per ton. However, there is no publication regarding to the quantity of wastewater produced from glucose production of cassava starch available. The information from owner plant interview was approximately 27 m^3 water used per ton sugar during converting cassava roots to sugar. The quantity of wastewater produced in the fermentation process converting cassava starch to sugar is, therefore, the net of $1,113,000 \text{ m}^3$. Moreover, the process of lactic acid production from dextrose consumed 14.2 m^3 of water per kg lactic acid produced which was assumed as amounts of wastewater discharged (Johansson, 2005).

In terms of energy use, the sum of energy uses from dextrose (D-glucose) to lactic acid production and lactic acid to PLA production was 26.3 and 13.2 MJ per kg PLA, respectively (Vink et al., 2003). However, the ratio of energy sources was not specified in Vink's study. In this study, an assumption that total energy comes from 50% of electricity and 50% of fuel oil is applied. To calculate the overall energy use starting from cassava root to PLA production, the amount of energy used in the process of dextrose production (cassava root to dextrose) was added. However, the information of energy and electricity use regarding to dextrose production from cassava in Thailand has not been published. Thus, the interview process from one of the

owner of the existing plant was carried out. The referent plant produces glucose from cassava root with the production capacity of 300 tonnes sugar per day. The process consumes the electricity of 144 kWh and the fuel oil of 6.67 liters per ton of sugar produced.

Case 2

The indirect benefit (sales of cassava meal) from the previous scenario did not directly go to the PLA producers but to the cassava starch owner. As a consequence, another scenario is simulated to study whether it is worth to invest the PLA production in Thailand by focusing on the advantages of the PLA investor. In figure 3, the new route of mass and energy flow for PLA production is proposed.

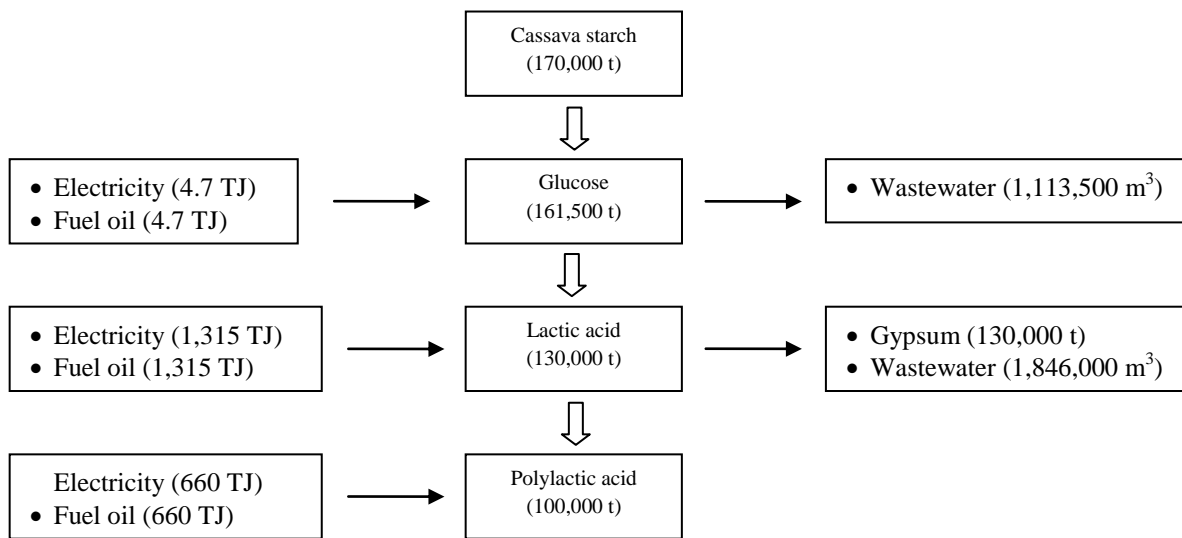


Figure 3. Mass and energy flow for PLA production from cassava starch (Case 2)

Practically, PLA producer is likely to use cassava starch as a raw material so this should be another plausible case concerning in the PLA producer’s perspective. It is; therefore, assumed that cassava starch is purchased as the raw material of PLA production. As shown in figure 3, cassava root and cassava starch production are removed from the energy and mass flow diagram of PLA production. Therefore, their by product (cassava meal) and wastewater are also eliminated from cost and benefit calculation in the subsequent sections. According to Vink (2003), energy and fuel to be used in production of glucose are not specifically identified. Hence, those values are assumed to be equal (0.047 MJ/kg PLA) while other values of lactic acid and PLA production in this diagram are similar to the first case.

Cost of PLA production

Aside from the financial cost or the direct cost, which is typically applied in the feasibility study of the project, in this study, environmental cost or the indirect cost is also accounted for the cost of PLA production. Therefore, cost of PLA production can be divided into 2 parts, namely direct cost and indirect cost of PLA production which are carefully scrutinized in the following two sub-sections.

Direct cost of PLA production

Currently, no information on production cost of PLA from cassava root is publicly available. This study, therefore, applied an estimated cost of PLA produced from US corn which followed Cargill Dow's process of 1.97-2.42 USD per kg PLA with capacity of 140,000 tonnes per year (Shen et al. 2009). The yield of corn to PLA resin is 1.74 (Vink et al. 2003). The difference in the production cost is mainly from the cost of starch production which depends on types of crops. Basically, there are two PLA production routes; ring-opening of lactide and direct polymerization of lactic acid. Nowadays, only ring-opening of lactide has been recognized and commercialized. Thus, the process of sugar conversion to PLA becomes well-known technology. The process is similar; even though its raw materials come from different crops.

For case 1, the total cost is the production cost of PLA which includes an investment cost, and an operating cost. For the investment cost, it composes of two categories, including land cost and capital&technology cost. In order to calculate the total cost of PLA production, the below formula is applied:

Case 1

$$\begin{aligned} \text{Total production cost of PLA from cassava} &= \text{total production cost of PLA from corn} \\ &- \text{production cost of corn starch} + \text{production cost of cassava starch} \end{aligned}$$

In case 2, the price of corn starch is replaced by the price of cassava starch. In order to calculate the cost of PLA production starting from cassava starch, the below formula is applied:

Case 2

$$\begin{aligned} \text{Total production cost of PLA from cassava} &= \text{total cost of PLA from corn} \\ &- \text{price of corn starch} + \text{price of cassava starch} \end{aligned}$$

For the first case, the production cost of PLA production from cassava (conversion of cassava root to PLA resin) was the production cost of PLA production from corn which is 2.2 USD per kg PLA subtracted by production cost of corn and corn starch and added production cost of cassava starch. The cost of US corn production is 0.2436 USD per kg PLA. The cost of corn starch production; ready-to-use corn to starch is 0.0052 USD per kg PLA. And the cost of cassava starch production in Thailand is 0.30 USD per kg PLA. For the second case, the average price of corn starch (EXIM 2009) and cassava starch (TTSA 2010) are 0.68 and 0.94 USD per kg, respectively. Therefore, the production cost (excluded any land cost) of 100,000 tonnes PLA from cassava for both cases are equal to USD 225 million and USD 246 million, respectively.

According to news published on Bangkok Post dated on 27 December 2010, the investment cost of PLA production based on 100,000 tpa (tonnes per annual) for licensing the NatureWorks™ technology is approximately 330 millions USD. According to the interview from the industrial estate in Thailand, the renting cost for the 160,000 (100 rai) 40,000 m² for PLA's plant with 100,000 tonnes capacity is approximately 0.74 millions USD per year and the rental fee will be increased by 5% every five years. As a result, the total direct cost (operating cost and investment cost) of 100,000 tonnes PLA production for the first case is USD 555.74 million and USD 576.74 million.

Indirect cost of PLA production

The environmental costs or the indirect costs comprise two cost items: the cost of CH₄ emission from waste water and the cost of CO₂ emission from electricity and fuel consumptions. The calculation of CH₄ emission from wastewater was adapted from the Project Design Document (PDD) for Clean Development Mechanism (CDM); #2556, #2645 and #2678 based on the assumption that wastewater treatment was aerated lagoon with an capacity of COD removed as 0.019 ton per m³, B₀ of 0.8 and MCF of 0.21, and there is no CH₄ emission from the sludge. Wastewater produced 0.19 and 0.09 tonnes of CH₄ per ton PLA for the first and second case respectively. In the first case, the CO₂ emissions from fuel oil and electricity are 1.56 and 2.89 tonnes of CO₂ per ton PLA, respectively while those of the second case are 1.53 and 2.77 tonnes per ton PLA respectively. The CO₂ emission factors are 77.4 ton CO₂ per TJ for fuel oil and 0.5057 ton CO₂ per MWh or 140 ton CO₂ per TJ (DEDE, 2010), respectively. According to Shen (2009), carbon embedded in PLA is determined from PLA molecular structure with the molecular weight of 566 kg per mol PLA (n=7,858). The CO₂ avoided from using renewable materials for PLA production is 1.83 tonnes CO₂ per ton PLA. The summary of the

environmental impact from the PLA production, namely CO₂ emission, CH₄ emission, and CO₂ avoid are presented in table 3. The net of CO₂ emission for both cases are 2.62 and 2.47 tonnes CO₂ per ton PLA respectively as shown in Table 3.

Table 3. Environmental impacts from PLA production

Environmental impacts	Case 1 Cassava root to PLA (kg per kg PLA)	Case 2 Cassava starch to PLA (kg per kg PLA)
Greenhouse gas emission		
a) CH ₄ from wastewater	0.19	0.09
b) CO ₂ from electricity	2.89	2.77
c) CO ₂ from fuel oil	1.56	1.53
Greenhouse gas avoided		
d) CO ₂ avoid from renewable material	1.83	1.83
Net CH ₄ emission	0.19	0.09
Net CO ₂ emission (b+c-d)	2.62	2.47

In addition, there is another indirect cost from the opportunity of land that will be lost from the payment of renting the plant area. As addressed earlier, the renting cost of area in the industrial estate is approximately 0.74 millions USD per year but it will be increased by 5% every 5 years. Plus, plant owner have to pay for other fees, environmental fee and maintenance fee. Consequently, the average 25 years for the opportunity cost from the rental fee of 100,000 tonnes PLA's plant is 0.92 millions USD per year. Finally, the total indirect cost for the first and second case of 100,000 tonnes PLA production in Thailand is 30.92 and 20.92 millions USD as shown in table 4.

Net Benefits of PLA Production from Cassava

Like the previous section, the benefits of PLA production are also categorized into 2 sub-sections, namely direct benefit and indirect benefit. Both are detailed in the following parts.

Direct benefit of PLA production

According to Wolf et al. (2005), the expected price of PLA in 2005 is 3.00 USD per kg PLA which is nearly equal to the current PLA market price interviewed from PTT in 2010. Therefore, the direct benefit from the PLA production applied in this study for both cases is 3.00 USD per kg PLA.

Indirect benefit of PLA production

The indirect benefit from the PLA production is 2.94 USD per kg PLA in which the price of cassava meal is about 6.45 USD per ton (TTSA 2010). Gypsum as a by-product from PLA production process has relatively low market value and is not accounted in this study. By deducting the total cost from the total benefit, the net benefit accrued from the 100,000 tonnes of PLA production in both cases are USD 7.34 million and USD -297.66 million respectively as shown in table 5.

Table 4. Cost of PLA production from cassava^a (of 100,000 tonnes PLA)

	Case 1 Millions USD ^a	Case 2 Millions USD
Direct cost		
Operating cost of PLA production ^b	225	246
Investment cost of PLA production		
- Capital & Technology	330	330
- Land cost ^c	0.74	0.74
Total direct cost	555.74	576.74
Indirect cost^d		
1. CH ₄ emission	20	10
2. CO ₂ emission	10	10
3. Opportunity cost of land ^e	0.92	0.92
Total indirect cost	30.92	20.92
Total costs	586.66	597.66

NOTE:

^a 1 USD = 0.8 Euro, reported on 25 August 2010

^b cost of US corn production (corn plantation and harvest) = 0.14 USD per kg US corn (USDA, 2010).

cost of US corn starch production (corn receiving, storage and milling) = 0.003 USD per kg corn (Krishman et al., 2000)

cost of cassava starch production in Thailand = 0.174 USD per kg starch including cost of fresh cassava root (0.154 USD per kg starch) and operating cost of 0.020 USD per kg starch (Chavalparit and Ongwandee, 2009).

^c Land cost is referred to the current rental land rate and other fees in Map-ta-Phut Industrial Estate in which HDPE and other petrochemicals plants are located.

^d 40 USD per ton CO₂ and 1070 USD per ton CH₄ which were estimated from the EPS model developed in Sweden. The hypothesis in adaption of the model to Thailand is that the Willingness to Pay (WTP) is proportional to the GDP per capita. The ratio of WTP Thailand and WTP Sweden is derived as 0.288. (Nguyen and Gheewala, 2008)

^e The opportunity cost of land was calculated from the deposited money for the five-year bank warranty which is equal to one-year rental fee or 680,533 USD. This money will be refunded in the 5th year on the investment. The calculation was based on the government bond rate which is 3% for the first and the second year and 4% for the third year and 5% for the fourth and the fifth year (BOT, 2011).

Table 5. Benefits - Cost Analysis of PLA production

	Case 1	Case 2
	Millions USD	Millions USD
Direct cost		
Operating cost of PLA production	225	246
Investment cost of PLA production question		
- Capital & Technology	330	330
- Land cost	0.74	0.74
Total direct cost	555.74	576.74
Indirect cost		
1. CH ₄ emission	20	10
2. CO ₂ emission	10	10
3. Opportunity cost of land	0.92	0.92
Total indirect cost	30.92	20.92
Total costs	586.66	597.66
Benefit		
4. Direct benefits	300	300
5. Indirect Benefits	294	0
Total benefits	594	300
Total Net Benefits	7.34	-297.66

The comparisons between PLA and HDPE production cost and benefit are demonstrated in Table 6 and 7. As shown in table 6, the net benefit from PLA production from case 1 is USD 7.34 million, higher than the benefit from HDPE as 25 times. On the contrary, the comparison of case 2 of PLA production and HDPE production in table 7 shows the opposite result which the net benefit of HDPE production is higher than that of PLA about 111 millions USD. This mainly results from the different starting point of the each case where cassava starch is purchased as a raw material. In the other words, the second case does not account for the sales of by product or cassava meal which turns into the substantial lower net benefit of PLA production. By considering the selling price of both resins, it is interesting that the price of PLA is more expensive than that of HDPE almost two times but the benefit of PLA resin is significantly lower. This can be explained by the three times higher of PLA investment cost comparing to that of HDPE. However, the technology of PLA production is still being in the initial stage so there should be more room of improvement for the production of PLA which can be further minimized.

Table 6. Cost-benefit analysis of PLA (Case 1) compared to HDPE production

Case 1		PLA production (Millions USD)	HDPE production (Millions USD)
Direct Cost			
	Production cost	225	77 ^a
	Investment cost		
	- Capital & Technology	330	108
	- Land cost	0.74	0.74
Indirect Cost			
	GHG emissions	30	143 ^b
	Opportunity cost of land	0.92	0.92
Total Cost		586.66	329.66
Direct benefits			
	Sales of product	300	143 ^c
Indirect benefits			
	Sales of by product	294	-
Total Benefit		594	143
Net benefit		7.34	-186.66

Table 7. Cost-benefit analysis of PLA (Case 2) compared to HDPE production

Case 2		PLA production (Millions USD)	HDPE production (Millions USD)
Direct Cost			
	Production cost	246	77 ^a
	Investment cost		
	- Capital & Technology	330	108
	- Land cost	0.74	0.74
Indirect Cost			
	GHG Emissions	20	143 ^b
	Opportunity cost of land	0.92	0.92
Total Cost		597.66	329.66
Direct benefits			
	Sales of product	300	143 ^c
Total Benefit		300	143
Net benefit		-297.66	-186.66

NOTE:

^a Production Cost = Investment Cost + Operation Cost

^b Environmental cost or emissions evaluated from the EPS model developed in Sweden. This values were corrected by Nguyen and Gheewala (2008) using the ratio of Willingness to Pay (WPP) of Thailand to Sweden as 0.288. The external cost of air pollutants include 40 USD per tonne CO₂, 1070 USD per tonne CH₄, 840 USD per tonne NO₂, 1300 USD per tonne SO₂, and 130 USD per tonne CO

^c The direct benefit of HDPE is the average domestic price of HDPE (Thai plastic industry association, 2010)

As mention earlier, this study interests in the advantages of PLA investor. Accordingly, case 2 is chosen as status quo in the NPV calculation in the next section in order to evaluate if it is worth to invest the PLA production in Thailand by taking both financial and environmental costs and benefits into account.

Moreover, this study assumes a time horizon of 25 years which will commit the industry to the stream of expenditures appearing in column (2) of the table 8 below and which will result in a series of benefits appearing in column (3). The discount factor for a 1.89 percent real discount rate is shown in column (4). Before eliminating an impact of inflation, a nominal discount rate of 4.77% from the Asian Development Bank for Thailand 30-year project loan has been applied in the analysis, considered as a social opportunity cost of capital (SOCC). The present value cost for each of the 25 years is calculated by multiplying column (2) by column (4); the present value benefit is calculated by multiplying column (3) by column (4). The present values of costs and benefits are presented in columns (5) and (6) respectively. It is noted that total cost is the sum of investment cost and operation cost and the operation cost is from the sum of production cost and indirect cost. The production cost of PLA production is estimated from 45 % share for lactic acid production (PROBIP, 2009).

Table 8. Present values of cost and benefits for PLA in Status Quo (Case 2)

Year (1)	Expected yearly cost ^a (2)	Expected yearly benefit (3)	Discount factors (1.89% ^b) (4)	Present value of costs (5)	Present value of benefits (6)
1	280,169,158	300,000,000	1.0000	280,169,158	300,000,000
2	278,960,624	300,000,000	0.9815	273,799,504	294,449,625
3	278,460,550	300,000,000	0.9633	268,252,128	289,001,938
4	277,980,750	300,000,000	0.9455	262,835,470	283,655,041
5	277,513,609	300,000,000	0.9280	257,539,167	278,407,067
6	277,102,101	300,000,000	0.9109	252,399,546	273,256,188
7	276,671,584	300,000,000	0.8940	247,344,956	268,200,607
8	276,258,288	300,000,000	0.8775	242,406,113	263,238,560
9	275,861,523	300,000,000	0.8612	237,579,592	258,368,317
10	275,480,630	300,000,000	0.8453	232,862,105	253,588,180
11	275,193,042	300,000,000	0.8297	228,315,266	248,896,481
12	274,842,010	300,000,000	0.8143	223,805,301	244,291,585
13	274,505,020	300,000,000	0.7992	219,395,287	239,771,885
14	274,181,509	300,000,000	0.7845	215,082,421	235,335,805

Year (1)	Expected yearly cost ^a (2)	Expected yearly benefit (3)	Discount factors (1.89% ^b) (4)	Present value of costs (5)	Present value of benefits (6)
15	273,870,939	300,000,000	0.7699	210,864,006	230,981,798
16	273,658,668	300,000,000	0.7557	206,802,347	226,708,346
17	273,372,447	300,000,000	0.7417	202,763,950	222,513,958
18	273,097,674	300,000,000	0.7280	198,812,531	218,397,171
19	272,833,892	300,000,000	0.7145	194,945,773	214,356,550
20	272,580,662	300,000,000	0.7013	191,161,441	210,390,686
21	272,432,025	300,000,000	0.6883	187,522,404	206,498,195
22	272,198,648	300,000,000	0.6756	183,895,337	202,677,720
23	271,974,606	300,000,000	0.6631	180,344,483	198,927,928
24	271,759,525	300,000,000	0.6508	176,867,904	195,247,513
25	271,553,048	300,000,000	0.6388	173,463,732	191,635,189
Total	6,872,512,532	7,500,000,000	20	5,549,229,921	6,048,796,330
				NPV	499,566,408

NOTE:

^a Investment cost was recalculated by depreciation rate of 4 % each year. (Total cost = Investment Cost + Operation Cost).

^b Real Discount Rate = $(1 - \text{nominal}) / (1 - \text{inflation}) = (1 - 4.77) / (1 - 3) = 1.89\%$

From table 8, the sum of column (5) is the total present value of costs and the sum of column (6) is the total present value of benefits. Net present value is USD (total benefits – total cost), the difference between the sum of discounted benefits and the sum of discounted costs. The net present value for 25-years life time project is positive value as 499,566,408 USD.

In addition, three more scenarios have been applied in this study. Option 1 is a case of expected PLA price developments. Option 2 is a change in cost of PLA due to technological development. Option 3 is a change in both benefit and cost of PLA. The first scenario is under the expected price developments of PLA over the time period.

For Option 1, according to Wolf (2005), PLA price would fall approximately 0.7% each year due to further improvements in price competitiveness. The benefit in column (3) of table 9 shows a decreasing in selling price as a proxy for PLA benefits. The NPV of this option, then, shows a reduction of net present value, despite a remaining of positive sign.

Table 9. Present values of cost and benefit for PLA with expected price developments (Option 1)

Year (1)	Expected yearly cost (2)	Expected yearly benefit (3)	Discount factors for 1.89% (4)	Present value of costs (5)	Present value of benefits (6)
1	280,169,158	300,000,000	1.0000	280,169,158	300,000,000
2	278,960,624	297,916,667	0.9815	273,799,504	292,404,836
3	278,460,550	295,833,333	0.9633	268,252,128	284,988,022
4	277,980,750	293,750,000	0.9455	262,835,470	277,745,561
5	277,513,609	291,666,667	0.9280	257,539,167	270,673,538
6	277,102,101	289,583,333	0.9109	252,399,546	263,768,126
7	276,671,584	287,500,000	0.8940	247,344,956	257,025,581
8	276,258,288	285,416,667	0.8775	242,406,113	250,442,241
9	275,861,523	283,333,333	0.8612	237,579,592	244,014,522
10	275,480,630	281,250,000	0.8453	232,862,105	237,738,919
11	275,193,042	279,166,667	0.8297	228,315,266	231,612,003
12	274,842,010	277,083,333	0.8143	223,805,301	225,630,422
13	274,505,020	275,000,000	0.7992	219,395,287	219,790,894
14	274,181,509	272,916,667	0.7845	215,082,421	214,090,211
15	273,870,939	270,833,333	0.7699	210,864,006	208,525,234
16	273,658,668	268,750,000	0.7557	206,802,347	203,092,893
17	273,372,447	266,666,667	0.7417	202,763,950	197,790,185
18	273,097,674	264,583,333	0.7280	198,812,531	192,614,172
19	272,833,892	262,500,000	0.7145	194,945,773	187,561,981
20	272,580,662	260,416,667	0.7013	191,161,441	182,630,803
21	272,432,025	258,333,333	0.6883	187,522,404	177,817,890
22	272,198,648	256,250,000	0.6756	183,895,337	173,120,552
23	271,974,606	254,166,667	0.6631	180,344,483	168,536,161
24	271,759,525	252,083,333	0.6508	176,867,904	164,062,146
25	271,553,048	250,000,000	0.6388	173,463,732	159,695,991
Total	6,872,512,532	6,875,000,000	20	5,549,229,921	5,585,372,884
				NPV	36,142,963

Option 2 is applied by the fact that several companies have been active in developing their technologies for bioplastic production. With one possible outcomes is Purac company publicly indicates that the company's technology could lower the production cost of lactic acid production by 40 percent of PLA production cost in the year 2016 (Bohlmann, 2007). In this study, we assumed that the reduction of production cost of lactic acid was constant at 4% each

year for 25 years. As mention previously, lactic acid is accounted for 45 percent of total PLA production cost (PROBIP, 2009). Thus, the production cost of lactic acid is 1.10 USD per kg PLA. With this technological change option, a reduction in the cost of PLA production cost is shown in the column (3) of table 10. As a result, the NPV of this option is 1,482,543,147 USD, which is higher than the Status Quo's NPV of 499,566,408 USD.

Table 10. Present values of cost and benefit for PLA production with technological developments (Option 2)

Unit: USD

Year (1)	Expected yearly cost (2)	Expected yearly benefit (3)	Discount factors for 1.89% (4)	Present value of costs (5)	Present value of benefits (6)
1	280,169,158	300,000,000	1.0000	280,169,158	300,000,000
2	274,541,624	300,000,000	0.9815	269,462,261	294,449,625
3	269,622,550	300,000,000	0.9633	259,738,131	289,001,938
4	264,723,750	300,000,000	0.9455	250,300,754	283,655,041
5	259,837,609	300,000,000	0.9280	241,135,423	278,407,067
6	255,007,101	300,000,000	0.9109	232,274,228	273,256,188
7	250,157,584	300,000,000	0.8940	223,641,386	268,200,607
8	245,325,288	300,000,000	0.8775	215,263,585	263,238,560
9	240,509,523	300,000,000	0.8612	207,133,469	258,368,317
10	235,709,630	300,000,000	0.8453	199,243,920	253,588,180
11	231,003,042	300,000,000	0.8297	191,652,814	248,896,481
12	226,233,010	300,000,000	0.8143	184,222,735	244,291,585
13	221,477,020	300,000,000	0.7992	177,013,208	239,771,885
14	216,734,509	300,000,000	0.7845	170,017,967	235,335,805
15	212,004,939	300,000,000	0.7699	163,230,940	230,981,798
16	207,373,668	300,000,000	0.7557	156,711,138	226,708,346
17	202,668,447	300,000,000	0.7417	150,321,861	222,513,958
18	197,974,674	300,000,000	0.7280	144,123,696	218,397,171
19	193,291,892	300,000,000	0.7145	138,111,277	214,356,550
20	188,619,662	300,000,000	0.7013	132,279,400	210,390,686
21	184,052,025	300,000,000	0.6883	126,688,036	206,498,195
22	179,399,648	300,000,000	0.6756	121,201,038	202,677,720
23	174,756,606	300,000,000	0.6631	115,879,898	198,927,928
24	170,122,525	300,000,000	0.6508	110,720,000	195,247,513
25	165,497,048	300,000,000	0.6388	105,716,860	191,635,189
Total	5,546,812,532	7,500,000,000	20	4,566,253,183	6,048,796,330
				NPV	1,482,543,147

Under the last assumption, this scenario combines the two possible outcomes realistically with future changes in both cost and benefit sides. As shown in table 11, an estimate of positive NPV (1,019,119,702 USD) has been influenced by expected market price for PLA and technological improvement within the same time frame of 25 years. Therefore, it would be more worthwhile for policy makers to step up efforts in launching a bioplastic plant in Thailand.

Table 11. Present values of cost and benefit for PLA production (combination of option 1 and 2)

Unit: USD

Year (1)	Expected yearly cost (2)	Expected yearly benefit (3)	Discount factors (1.89%) (4)	Present value of costs (5)	Present value of benefits (6)
1	280,169,158	300,000,000	1.0000	280,169,158	300,000,000
2	274,541,624	297,916,667	0.9815	269,462,261	292,404,836
3	269,622,550	295,833,333	0.9633	259,738,131	284,988,022
4	264,723,750	293,750,000	0.9455	250,300,754	277,745,561
5	259,837,609	291,666,667	0.9280	241,135,423	270,673,538
6	255,007,101	289,583,333	0.9109	232,274,228	263,768,126
7	250,157,584	287,500,000	0.8940	223,641,386	257,025,581
8	245,325,288	285,416,667	0.8775	215,263,585	250,442,241
9	240,509,523	283,333,333	0.8612	207,133,469	244,014,522
10	235,709,630	281,250,000	0.8453	199,243,920	237,738,919
11	231,003,042	279,166,667	0.8297	191,652,814	231,612,003
12	226,233,010	277,083,333	0.8143	184,222,735	225,630,422
13	221,477,020	275,000,000	0.7992	177,013,208	219,790,894
14	216,734,509	272,916,667	0.7845	170,017,967	214,090,211
15	212,004,939	270,833,333	0.7699	163,230,940	208,525,234
16	207,373,668	268,750,000	0.7557	156,711,138	203,092,893
17	202,668,447	266,666,667	0.7417	150,321,861	197,790,185
18	197,974,674	264,583,333	0.7280	144,123,696	192,614,172
19	193,291,892	262,500,000	0.7145	138,111,277	187,561,981
20	188,619,662	260,416,667	0.7013	132,279,400	182,630,803
21	184,052,025	258,333,333	0.6883	126,688,036	177,817,890
22	179,399,648	256,250,000	0.6756	121,201,038	173,120,552
23	174,756,606	254,166,667	0.6631	115,879,898	168,536,161
24	170,122,525	252,083,333	0.6508	110,720,000	164,062,146
25	165,497,048	250,000,000	0.6388	105,716,860	159,695,991
Total	5,546,812,532	6,875,000,000	20	4,566,253,183	5,585,372,884
				NPV	1,019,119,702

Sensitivity Analysis

As a new project for Thailand, different discount rates must be set in order to perceive a risk of the project. In this study, we consider higher discount rates than a status quo for illustrating sensitivity of the possible NPVs. Three nominal discount rates are conducted in the calculation of NPV, namely 4.77% (as status quo), 10.00%, and 15.00% (as a new and high risk project). Therefore, the testing over a range of 1.89 to 7.00 % in real term is proposed. By using an artificially low discount rate for project evaluation can make future generations worse off. The real discount rate of 1.89% as a base rate is considered to be low due to the expected inflation of 3%. In addition, the maximum commercial loan rate of 15% (Bangkok Bank, 2011) draws an assumption in this study of a possibility of an increase in the nominal interest rate.

The NPVs for PLA production with 25-year life time are presented in Table 12. As a result, all assumptions are good for investment; $NPV > 0$. In every option, except a case of reduction in profit over time by changing in PLA prices, the NPVs decrease gradually when the discount rates increase. Even though the NPV becomes smaller and the discount rate is larger as theoretically indicated, the result is insensitive to the changes in the above assumptions. Therefore, the choice of discount rate has no or little influence on the cost and benefit of PLA production in Thailand.

Table 12. Costs and benefits of the various options

Unit: USD

Options	Discount rates	PV – Benefit	PV - Cost	NPV
Status Quo	1.89%*	6,048,796,330	5,549,229,921	499,566,408
	4.50%**	4,648,643,510	4,271,464,256	377,179,254
	7.00%***	3,740,800,200	3,442,160,038	298,640,163
Reduction in Benefit only	1.89%	5,585,372,884	5,549,229,921	36,142,963
	4.50%	4,333,694,828	4,271,464,256	62,230,572
	7.00%	3,516,375,542	3,442,160,038	74,215,505
Reduction in Cost only	1.89%	6,048,796,330	4,566,253,183	1,482,543,147
	4.50%	4,648,643,510	3,603,420,308	1,045,223,202
	7.00%	3,740,800,200	2,996,128,408	774,671,793
Reduction in Cost and Benefit	1.89%	5,585,372,884	4,566,253,183	1,019,119,702
	4.50%	4,333,694,828	3,603,420,308	730,274,520
	7.00%	3,516,375,542	2,966,128,408	550,247,135

Note:

* Real Discount Rate = $(1 - \text{nominal}) / (1 - \text{inflation}) = (1 - 4.77) / (1 - 3) = 1.89\%$

** Real Discount Rate = $(1 - \text{nominal}) / (1 - \text{inflation}) = (1 - 10) / (1 - 3) = 4.5\%$

*** Real Discount Rate = $(1 - \text{nominal}) / (1 - \text{inflation}) = (1 - 15) / (1 - 3) = 7\%$

Conclusions

The cost of PLA production from cassava calculated in this study was transferred from the cost of PLA production from corn in the boundary of *Gate-to-Gate*. The cost structure of PLA production comprises of direct cost (production cost and investment cost) and indirect environmental cost. The cost of PLA production starting from cassava starch production to PLA resin with the production capacity of 100,000 tonnes PLA (case 1) is 586.66 millions USD. When considering the PLA production starting from sugar production using purchased starch to PLA resin production, the cost is little higher, 597.66 millions USD. The production of PLA from cassava root provides by product as cassava meal during starch production. The large benefit from selling of cassava meal is 294 millions USD which turns to the positive net benefit of PLA production equal to 7.34 millions USD. Without the revenue from cassava meal, the net benefit is negative (-297.66 millions USD). Thus, the integrated PLA production industry is potentially more attractive for the investment. Plus CDM implementation (example: biogas recovery project), the case 1 gets more benefit from selling carbon credit but another case (excluding starch production) has more negative net benefit due to less amount of wastewater. In comparison to PLA production, the net benefit of HDPE production is -186.66 millions USD. Therefore, only the PLA production under case 1 can be competitive with the HDPE production. The NPV of the PLA production (cassava starch to PLA resin) calculated for the 25-year life time with the real discount rate of 1.89% is positive. Even subjected to both PLA price development and technological development, the NPV is still positive. The sensitivity analysis indicated that the NPV of the PLA production in this study is insensitive to the increase of real discount rates (1.89, 4.5 and 7%). In environmental aspects, the CO₂ avoided from using cassava as a renewable material for PLA production was 1.83 kg CO₂ per kg PLA, which is less than equivalent CO₂ emission from its electricity, fuel oil used and wastewater. This study indicates that the HDPE production has better environmental performances in terms of energy efficiency and environmental pollution control than the PLA production. This finding might be resulted from the differences in advances of production and pollution control technology of both plastics. Accordingly, it is implied that there are large opportunities of PLA production for its production improvement; for examples, increasing energy efficiency, utilizing biomass waste as fuel and recovery of greenhouse gases from wastewater treatment as energy source. Even though the environmental impact from PLA in this study is higher than those from HDPE, it should be noted the embedded carbon in HDPE will not be released until its final state of their life cycle (waste treatment). Consequently, further study for investigating the entire life cycle of both materials is required in order to evaluate their total environmental impacts.

Suggestions

According to the result from this research, the benefit of PLA production starting from cassava root to PLA resin (case 1) is more attractive for the investor due to its positive net benefit. Inversely, the net benefit of PLA production starting from cassava starch to PLA resin (case 2) presents the negative benefit. Even 25-years project life time with the reduction of price and the development of technology, the case 2 still has positive NPV. In the economic point of view, the PLA production following both scenarios has the potential to be established in Thailand. However, the investment cost of PLA production is considerably expensive compared to the conventional one.

Interestingly, with the positive NPV, the bioplastic production contractly emits more greenhouse gas than the conventional plastic production. This leads to the environmental burden especially global warming. Results from this study indicated that wastewater treatment from cassava starch production was a major source of greenhouse gases, followed by electricity and fuel oil consumption. Thus, these environmental burdens should be intensively reduced. Initially, the government should pay more attention on how to reduce energy used and pollutions emitted from the production process and encourage the relevant stakeholders to implement. For example, the cassava starch and sugar producer should be recommended to enroll the energy and environmental related programs such as energy audit and energy efficiency improvement, cleaner technology (CT) or waste minimization programs coupling with 4Rs (Reduce, Reuse, Recycle and Recover) strategy and implementing the appropriate pollution control technology to ensure that the PLA production is truly green. Moreover, the investment in the research of advance technology and innovation for alternative cleaner PLA production is essential for sustainable development of bioplastic industry in the long run. Therefore, the coherence between environmental and innovation policy are needed.

At present, the law of fiscal measures for the environment has been enacted in Thailand since October 2010. The measures are focused on environmental tax, production tax, pollution treatment fee, and emission permit. These measures will be implimented to the whole PLA production chains to ensure that bioplastic is an environmental friendly product and worth to invest. However, in order to gain net social benefit, government also need to provide favorable conditions for policy supporting both demand and supply for bioplastic industry, not only from the supply side. Further studies on polution impact and lifecycle management of bioplastic will be beneficial for the greening of bioplatic industry.

Acknowledgements

The authors would like to thank to the Economy and Environment Program for Southeast Asia (EEPSEA) for the support of this research. Moreover, we gratefully acknowledge the National Innovation Agency (NIA), Ms. Pornpan Thiensathid, PURAC (Thailand) Company Limited, Dr.Narin Kabbuathong, PTT Public Company Limited, and Ms. Pornnipa Somboonlertsiri, P.S.C Strach Products PCL. for their kind corporations.

References

- Agriculture and Horticulture Development (HGCA), Industrial uses for crops: Bioplastic, Available from: http://www.hgca.com/publications/documents/Bioplastics_web28409.pdf_ (9 September 2010).
- Bank of Thailand, Government Bond Yield Curve, Available from: <http://www.bot.or.th/English/FinancialMarkets/IntroductionToGovernmentDebtSecurities/InterestingContent/Pages/GovernmentBondYieldCurve.aspx> (19 June, 2011).
- Bangkok Bank, Loan Rates, Available from: <http://www.bangkokbank.com/bangkok%20bank/web%20services/rates/pages/loan%20interest%20rates.aspx> (19 June, 2011).
- Bohlmann, G. M. 2007. "Bioplastic & biofuels Pricing & production trends", *Industrial Biotechnology*, Vol. 3. No. 1, pp. 25-28.
- Chiarakorn, S, Permpoonwiwat, C.K., and Nanthachatchavankul, P. 2011. "Financial and Economic Viability of Bioplastic Production in Thailand," *Economy and Environment Program for Southeast Asia (EEPSEA)*, Available from: <http://www.eepsea.org>. (22 November, 2011).
- Chavalparit, O and M. Ongwandee. 2009. "Clean technology for the tapioca starch industry in Thailand", *Journal of Cleaner Production*, Vol. 17, pp. 105-110.
- Department of Alternative Energy Development and Efficiency (DEDE), the Ministry of Energy of Thailand, Annual Reports and Energy Situations, Available from: <http://www.dede.go.th/dede/>. (22 August ,2010).
- Dornburg, V.; A. Faaij, M. Patel and W.C. Turkenburg. 2006. "Economics and GHG emission reduction of a PLA bio-refinery system-Combining bottom-up analysis with price elasticity effects. *Resources, Conservation and Recycling*", Vol 46, pp.377-409.

- Energy Information Administration (EIA), Monthly crude oil price (Nymex), Available from: http://www.eia.gov/dnav/pet/pet_pri_fut_s1_m.htm (10 September 2010)
- European Bioplastics, 2008, Bioplastics, Available from: <http://www.european-bioplastics.org>. (5 September 2010).
- Export-Import Bank of Thailand (EXIM), 2009, Economic direction and Thai entrepreneur opportunities, pp. 27-30
- Feteke, Tibor. 2009, Production of Bimodal Polyethylene. MOL Scientific Magazine. 2009/1 pp. 68-75
- Fiscal Policy Office (FPO), 2010, The law of fiscal measures for the environment, Available from: <http://www.fpo.go.th/FPO/index2.php>. (26 October 2010)
- Garlotta, D. 2001. "A Literature Review of Poly (Lactic Acid)", Journal of Journal of Polymers and the Environment", Vol. 9, pp.. 63-84.
- Gielen. D.J.K., B. Cecilia, T. 2006, IEA Petrochemical Scenarios for 2030-2050: Energy Technology Perspective 2006, International Energy Agency, Paris.
- Groot, W.J. 2010, Life cycle assessment L-Lactide and PLLA, Research and Development, PURAC.
- Integrated Pollution Prevention and Control (IPPC), 2003, Best Available Techniques in the Large Volume Organic Chemical Industry, February 2003.
- Integrated Pollution Prevention and Control (IPPC), 2007, Best Available Techniques in the Production of Polymer, August 2007.
- Integrate Refinery Petrochemical Complex (IRPC), 2009, IRPC Annual Report 2009.
- Intergovernmental Panel on Climate Change (IPCCC), 2006, IPCC Guidelines for National Greenhouse Gas Inventories, Vol.2, Energy Sector.
- Johansson, M. 2005, Life cycle assessment of fossil and bio based materials for 3D shell applications. Material eco-profiles and example with a blow moulded clear rigid packaging, 2-40.
- Krishman, M.S.; F. Taylor; B.H. Davison and N.P. Nghiem, 2000. "Economic analysis of fuel ethanol production from corn starch using fluidized-bed bioreactors. Bioresource Technology", Vol. 75, pp. 99-105.
- Martin P, 2001, Review of Life Cycle Assessments for Bioplastics. Science, technology and society, Utrecht University., Available from: [http://www.ienica.net/bioplastics/patel.ppt#312,2,Steps of an LCA](http://www.ienica.net/bioplastics/patel.ppt#312,2,Steps%20of%20an%20LCA). (9 September 2010).
- Mitsui Chemicals. n.d, Mitsui CX Process High and Medium Density Polyethylene.

- National Innovation Agency (NIA), 2008, "National Roadmap for the Development of Bioplastics Industry", Ministry of Science and Technology, Thailand, pp. 1-106.
- Nguyen, T.L.T. and S.H. Gheewala, 2008. "Fossil energy, environmental and cost performance of ethanol in Thailand", *Journal of Cleaner Production* Vol. 16, 1816.
- Office of Agricultural Economics (OAE), the Ministry of Agriculture and Cooperatives of Thailand. Agricultural Statistic, Available from: <http://www.oae.go.th>. (22 August 2010).
- Office of Industrial Economics (OIE), Prices of Plastics in Thailand, Available from: <http://plastic.oie.go.th>. (12 September 2010).
- Orawan Cheumkum, 2001, Production of Lactic Acid from Cassava Solid Waste. Master thesis of Engineering in Environmental Engineering, Suranaree University of Technology, Thailand.
- PURAC. Purac starts construction Lactide plant in Thailand, Available from: <http://www.purac.com> (5 September, 2010).
- Rafael A. A., L. Lim, S. E. M. Selke and H. Tsuji, 2010, Poly(lactic acid): Synthesis, Structures, Properties, Processing and Applications, John Wiley & Sons, Inc.
- Rundik, E. 2008, "Compostable polymer materials, Amsterdam", The Netherlands: Elsevier
- Shen, L.; J. Haufe and M.K. Patel, 2009, Production Overview and Market Projection of Emerging Bio-based Plastics PRO-BIP 2009., Final report. Copernicus Institute of Sustainable Development and Innovation, Utrecht University.
- Sriroth, K.; B. Lamchaiyaphum and K. Piyachomkwan, Present Situation and Future Potential of Cassava in Thailand, Available from: <http://www.cassava.org/doc/presentsituation2.pdf>. (22 August 2010).
- Suppasri., C. and S. Sermcheep, 2010, Bioplastics Industry: Economic Analysis Part. Presentation in Brainstorming of Policy making for promoting Bioplastic Industry in Thailand, 12 May 2010
- Thailand Greenhouse Gas Management Organization (TGO), 2009, Guidelines for carbon footprint of Thai products (in Thai), Available from: <http://www.tgo.or.th>. (9 September 2010).
- Thailand Greenhouse Gas Management Organization (Public Organization) (TGO), Thailand CDM Projects, Available from: <http://www.tgo.or.th/english/> (31 August 2010).
- Thai Plastic Industries Association (TPIA), Monthly price of HDPE in Thailand, <http://www.tpia.org/stat/graphyear.asp?chk=1>. Available from: (10 September 2010)

- Thai Tapioca Starch Association (TTSA), 2010, The Process of Tapioca Starch Production, (20 August 2010).
- United Nations Framework Convention on Climate Change (UNFCCC), 2009, Bangna Starch Wastewater Treatment and Biogas Utilization Project, Thailand. Project Design Document #2556.
- United Nations Framework Convention on Climate Change (UNFCCC), 2009, Wastewater Treatment with Biogas Technology in a Tapioca Processing Plant at Roi Et Flour Company Limited, Thailand, Project Design Document #2645.
- United Nations Framework Convention on Climate Change (UNFCCC), 2009, Tapioca starch wastewater biogas extraction and utilization project, Sakaeo Province, Thailand, Project Design Document #2678.
- United States Department of Agriculture (USDA), Commodity Costs and Returns Data, Available from: <http://www.ers.usda.gov/>. (22 August 2010).
- Vink, E.T.H. K.R Rabago, D.A. Glassner and P.R. Gruber, 2003, "Application of life cycle assessment to NatureWorks™ polylactide (PLA) production", Vol. 80. 403-149.
- Wolf, O, (ed), Martin, P, Frank, M. W, Joachim, S, Barbel. H, and Gerhard, H, 2005, Techno-economic Feasibility of Large-scale Production of Bio-based Polymers in Europe, Technical Report Series, European Commission Joint Research Center.
- World Business Council for Sustainable Development (WBCSD), "Cargill Dow LLC and Nature works for NatureWorks™ PLA", Available from: http://www.wbcd.org/web/publications/case/natureworks_full_case_web.pdf. (9 September 2010)