UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into the Use of Biodegradable Packing Materials in the New Student Union Building (SUB): A Triple Bottom-Line Assessment

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University of British Columbia

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ABSTRACT

The search for alternative and more environmentally friendly packing materials has recently become a popular topic as the existing conventional packing materials are made from non-renewable and are also non-biodegradable. Nonetheless, the benefit from materials made from bio-based resources are debatable.

The new SUB in UBC is targeting to reduce waste stream as part of the sustainable action plan. As a result, the main objectives of this experiment are to conduct a triple bottom line assessment on PHA (proposed bio-based material) and PE (conventional material) and to present the results to the retailer for alternative and more sustainable packing material options. This study only focuses on the soft plastic bags which will be used for apparel businesses in the new SUB. For economic analysis, the unit selling price and market growth of both materials are compared. It is found that the selling price of PHA bags is 2-3 times greater than that of the PE bags. The market for PHA is 1.4% while PE market is 39%. To assess the environmental impact of both materials, the global warming, eutrophication and photochemical ozone are used as the indicators. Different sources of energy for PHA production process and end-of-life options are examined in comparison to PE ones. The energy source of PHA production is the main factor which dominates the impact on environment. Geothermal is found to be the resource which has the lowest impact but it is highly dependent on the geographic region. Also, coal-fired power for PHA production and landfill disposal option for both types of bags have the largest environmental impact. For social assessment, the risks for human health in production process, consumer- and retailer-based surveys, and banning of PE are studied. It is shown that PHA bags has lower overall risk than PE bags. However, the PHA involves more serious health problems such as fatal accidents and pulmonary health problems. The surveys show that both consumers and retailers are financial-oriented, and this greatly influences their behavior. As a result, PHA bags are not recommended to substitute PE bags. However, it is recommended that further research and analysis on another potential bio-based materials should continue.

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GLOSSARY

Biodegradable	Capable of undergoing biological anaerobic or aerobic decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be measured by standardized tests, in a specified period of time, reflecting available disposal condition.
Conventional Risks	Risks of well-established processes to human health and life, taking into account accidents, illnesses, and external risks imposed on the public by emissions and technological disasters.
Eutrophication	The process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. These typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms.
Global warming	The gradual increase in the temperature of the earth's atmosphere due to the greenhouse effect
Photochem ozone	A form of oxygen, and an atmospheric trace gas, made by natural photochemical reactions associated with solar ultraviolet radiation.
Polymer resin	A clear liquid plastic product that hardens to create a thick, durable, glossy coating.
Years of life lost	To express all of the categories in terms of personyears of life expectancy. This unit was used to quantify the risks of all inputs in this risk assessment.

LIST OF ABBREVIATIONS

ASTM	The American Society of Testing and Materials
PE	Polyethylene
PHA	Polyhydroxyalkanoates
SUB	Student Union Building
UBC	University of British Columbia
UES	Urea-Elemental Sulfur
YOLL	Years of life lost

1.0 INTRODUCTION

Currently, a significant portion of the world's plastic consumption is represented by plastic packaging materials. In general, the raw materials used in production are cost-effective but the majority of these materials are composed of non-renewable petroleum-based products and are non-biodegradable in the environment. Polyethylene (PE) is the most commonly used material for conventional plastic bag production, but since PE is petroleum-based, it is harmful to the environment. Recently, companies have begun innovating and assessing various sustainable materials to replace polyethylene as a plastic packaging material and a potential alternative material is polyhydroxyalkanoates (PHA). PHA is a bio-based and biodegradable polymer which is produced by bacterial fermentation of sugars and lipids. It is considered biodegradable as it has been tested and measured by The American Society of Testing and Materials (ASTM), an institution which develops standardized test for various products.

The UBC new SUB is aiming to be a sustainable and green building with minimal waste stream. In order to recommend PHA as a replacement of conventional plastics, it is essential to assess the economic, environmental, and social impacts through the triple bottom line assessment. Therefore, the main objectives of this study is to conduct a triple bottom line assessment on soft plastic bags which are made from polyethylene (PE) and polyhydroxyalkonoate (PHA) and to present the finding to the retailers which provide viable options for more sustainable packing materials, thus minimizing their impacts in the new SUB. The main goal is to eliminate soft plastics from the waste stream produced by apparel businesses which will operate in the new SUB.

2.0 ECONOMIC ASSESSMENT

2.1 PHA UNIT SELLING PRICE

PHA plastic bags cost approximately $5-16 per kg in 1997 which is equivalent to an average material cost of $0.0441 per bag (Lant, 2007). However, the retail price of the PHA plastic bag is expected to be higher as manufacturing, delivery, and disposal costs have to be considered. The manufacturing cost is $0.0308, delivery cost is $0.000016, and the disposal cost is $0.00011 per bag which results in the retail price of $0.09676 per bag (Lant, 2007). In terms of cost per volume of an average PHA bag, it is calculated to be approximately $6.25 per liter and since a typical shopping bag for apparel has a carrying capacity of 10 L, the cost of full utilization of the PHA bag is $62.5 (Hsien, 2010).

As shown in Table 1, it is apparent that the income generated in an Australian PHA Bioplastic company in 2005 was $5,414,286 while its production cost was only $2,317,443, thus generating revenue of $3,096,843. PHA development does in fact produce revenue in a small scale environment regardless if its selling price is considered expensive compared to PET and polyolefin.

Table 1: Cash flow of an Australian Bioplastic company

Product	PHA_{MC} P(3HB)
Economic [2005 US$/year]	
Income	
Production[a]	4,218,546
Savings[b]	1,195,740
Costs	
Resources[c]	992,217
Energy[d]	1,325,226

Lant, P. (2007). Comparative Life Cycle Assessment and Financial Analysis of Mixed Culture PHA Production. *Elsevier, 98*, 11.

2.2 PHA COMPANY AND MARKET GROWTH

There are currently over 10 major companies worldwide that are actively involved in the PHA industry as shown in Table 2. It is apparent that the retail price of PHA is still considered significantly higher than other biodegradable polymers. Nonetheless, P&G and Telles are striving to be cost-competitive with other plastics such as polyethylene.

Table 2: Current and potential large capacity manufacturers of PHA

Manufacturers	Capacity (tons)	Price (kg^{-1}) (in 2010)
Mitsubishi Gas Chemical Company Inc. (Japan)	10,000	€2.5–3.0
Telles (US)	50,000	€1.50[a]
PHB Industrial Company (Brazil)	50	n/a
Biomer Inc. (Germany)	50	€3.0–5.0
Tianan Biologic, Ningbo (China)	10,000	€3.26
P&G (US)	20,000–50,000	€2.50
Lianyi Biotech (China)	2000	€3.70
Kaneka Corporation (Japan)	1000	n/a[b]
Tianjin Gree Bio-Science Co/DSM	10,000	n/a
Meredian (US)	272,000 (2013)	n/a

Chanprateep, S. (2010). Current trends in biodegradable Polyhydroxyalkanoates. *Journal of Bioscience and Bioengineering*, *2*, 12.

The PHA-based market is still in it developmental stage as there is a lack of major companies innovating commercial applications of PHA. In 2005, the market tonnage of PHA was estimated at 200-300 tonnes worldwide (Platt, 2010). However, there is a potential for PHA to thrive in the market as the market consumption rose to 2,500 tonnes in 2010 and is also projected to increase each year (Platt, 2010). As depict by Table 3, PHA demand in Western European market was essentially non-existent in 2000 but by 2010, the demand for PHA rose to 1,000 tonnes.

Table 3: Western European market for polymers from year 2000-2010. The reported values are in 10^3 tonnes.

	2000	2005	2010
Starch	10.3	29.9	62.1
PLA	3.7	19.0	50.5
Synthetic	1.5	6.7	15.8
PHA	0.0	0.1	1.0

Platt, D. K. (2006). *Biodegradable polymers market report*. Shrewsbury, Shropshire, U.K.: Smithers Rapra.

In North American market, the PHA demand in year 2000 was once again non-existent but in 2010, the demand for PHA rose to 1,500 tonnes (see Table 4). Assessing this trend, it is apparent that in a global scale, the demand and consumption of PHA is increasing.

Table 4: North American market for polymers from year 2000-2010. The reported values are in 10^3 tonnes.

	2000	2005	2010
Starch	2.8	8.0	14.0
PLA	2.7	9.6	22.6
Synthetic	1.2	3.6	8.4
PHA	0.0	0.1	1.5

Platt, D. K. (2006). *Biodegradable polymers market report*. Shrewsbury, Shropshire, U.K.: Smithers Rapra.

Although the PHA market is considered small, PHA provides significant potential in the plastic packaging industry, Telles, a US-based bioplastics company collaborated with chemical company Metabolix to build the largest commercial scale PHA plant in the world. With this innovation in mind, Pira International, a UK-based consultant firm expects that by 2020, the global bioplastic packaging demand is expected to reach 884,000 tonnes which indicates a growth rate of 25% from 2010-2015 (Guzman, 2011). PHA is expected to overall achieve a 41% growth from 2010-2020 (Guzman, 2011).

2.3 PE UNIT SELLING PRICE

Polyethylene is the conventional material used for plastic bags and it is considerably cheaper than PHA. About 50% of the total value of economic activities in PE is attributed to manufacturing. The average cost of PE is $1-3 per kg which equates to approximately $0.0103 per bag (Biron, 2007). Together with the additional costs of production such as the supplies and fuel cost, the direct cost of per PE bag is actually $0.0327 (Biron, 2007). In terms of cost per unit volume of an average PE bag, it is found to be approximately $0.905 per liter (Hsien, 2010). Since a typical shopping bag for apparel usage has a carrying capacity of approximately 10 L, the cost of full utilization of the bag is $9.05.

The main factors affecting the selling price of polyethylene are the price of the raw materials and transportation costs. Figure 1 shows that the average monthly price of various polyethylene resins is increasing over the years which indicates a rising in retail price of Polyethylene. Transportation costs are generally reported to account for 8.8% of the total production cost of polyethylene (Okun, 2010).

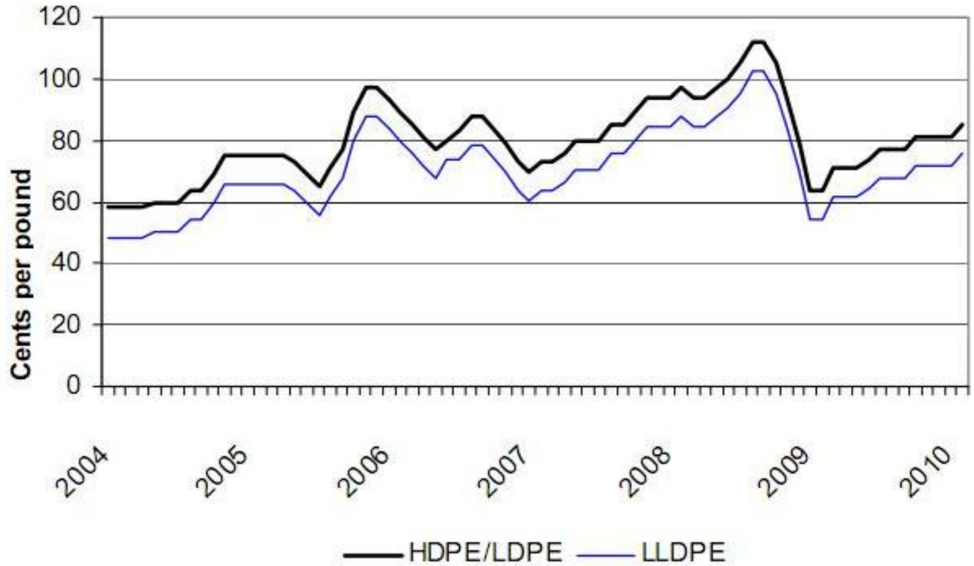


Figure 1: Average polyethylene resin prices from January 2004 to February 2010

Okun, D. (2010). Polyethylene Retail Carrier Bags from China, Malaysia, and Thailand. *US International Trade Commision*, *4160*, 166.

2.4 PE COMPANY AND MARKET GROWTH

Table 5 provides economic information of the U.S polyethylene market from year 2004 to 2009. It is evident that the price of polyethylene decreased from \$0.01253 to \$0.01168. The number of production workers dropped from 3,249 to 2,883 but wages increased from \$14.56 to \$17.27 per hour (Okun, 2010).

In 2002, global consumption of polyethylene was approximately 55 million metric tons (Rappaport, 2003). In U.S alone, 100 billion pounds of polyethylene bags are imported annually which results in 1.4 billion pounds of polyethylene resin produced (Rappaport, 2003). In addition, polyethylene production has an annual growth rate of 3-5% which indicates that biopolymer demand is significantly smaller than polyethylene one (Rappaport, 2010).

Table 5: U.S polyethylene market and production

U.S. producers':						
Average capacity quantity	77,535,428	85,101,376	83,182,701	83,232,332	79,737,217	89,549,284
Production quantity	72,255,007	72,693,116	70,212,269	72,320,872	66,276,349	70,188,622
Capacity utilization (1)	93.2	85.4	84.4	86.9	83.1	78.4
U.S. shipments:						
Quantity	69,608,961	70,942,423	66,786,015	69,767,941	65,119,412	68,985,490
Value	872,370	992,683	961,398	922,941	983,006	805,630
Unit value	$12.53	$13.99	$14.40	$13.23	$15.10	$11.68
Export shipments:						
Quantity	1,544,127	1,628,483	2,207,673	2,351,519	2,209,901	1,714,509
Value	22,030	30,901	37,645	38,575	30,330	21,128
Unit value	$14.27	$18.98	$17.05	$16.40	$13.72	$12.32
Ending inventory quantity	2,461,914	2,582,387	3,800,923	4,002,589	2,976,270	2,464,790
Inventories/total shipments (1)	3.5	3.6	5.5	5.5	4.4	3.5
Production workers	3,249	3,394	3,495	3,160	2,971	2,883
Hours worked (1,000s)	7,005	6,990	7,582	7,233	6,757	6,471
Wages paid ($1,000s)	101,967	102,564	110,212	115,133	111,750	111,743
Hourly wages	$14.56	$14.67	$14.54	$15.92	$16.54	$17.27
Productivity (bags per hour) . .	10,315	10,400	9,260	9,998	9,808	10,847
Unit labor costs	$1.41	$1.41	$1.57	$1.59	$1.69	$1.59
Net sales:						
Quantity	70,388,272	72,697,684	68,722,520	72,907,011	67,293,513	70,775,673
Value	892,052	1,021,877	995,328	968,903	1,012,514	830,559
Unit value	$12.67	$14.06	$14.48	$13.29	$15.05	$11.74

Okun, D. (2010). Polyethylene Retail Carrier Bags from China, Malaysia, and Thailand. *US International Trade Commision*, *4160*, 166.

The main economic factor being assessed is the unit selling price of PHA and PE. Table 6 denotes that polyethylene is significantly cheaper than PHA which is important in a small scale environment like the new SUB. Through surveys conducted with UBC retailers, the consensus is that price is the major driving factor on the decision to use alternative packaging materials. On average, UBC retailers would only tolerate a 10% increase in packaging material cost (refer to the Appendix for detailed survey information). However, PHA presents a 30% increase in price, thus PHA is not a viable choice to replace polyethylene soft plastic bags for the new SUB.

PHA industry is still in its development stage, but bio-based industry has a potential to thrive in the near future as its prices are projected to decrease over the years. However, the new SUB will be fully operational in 2014, and PHA prices will not decrease rapidly by that time period. In addition, polyethylene consumption continues to increase and retail prices continue to decrease annually, thus it is economically viable to continue using polyethylene as a packaging material in the new SUB.

Table 6: Summarized economic aspect of PHA and PE

	PHA[1]	**PE**[2]
Price per unit weight	$4-5 per kg	$1-3 per kg
Price per volume	$6.25 per L	$0.905 per L
Price per bag	$0.097 per bag	$0.03 per bag
World market	1.4 %	39 %

1 Guzman, D. (2011). PHA shows great promise in packaging application. Chemical Industry News & Chemical Market Intelligence | ICIS.com. Retrieved April 2, 2013, from http://www.icis.com/Articles/2011/02/15/9433445/pha-shows-great-promise-in-packaging-applcation.html

2 Hendrickson, C. T., Lave, L. B., & Matthews, H. S. (2006). *Environmental life cycle assessment of goods and services: an input-output approach*. Washington, DC: Resources for the Future.

3.0 ENVIRONMENTAL ASSESSMENT

3.1 LIFE CYCLE PRODUCTION

Despite PHA being introduced as an eco-friendly alternative to conventional or petrochemical-based plastics, the environmental benefits of the PHA are still remained questionable. In this section, the environmental impacts from production process of PE and PHA is investigated. The life cycle assessment is focused on the effect of different sources of energy supply for production of PHA on the environment compared to the impact from petroleum-based production of PE. The following energy sources are studied: electricity, coal-fired power, natural gas and geothermal. Three impact categories are considered: global warming potential, eutrophication and photochemical ozone formation. Table 7 summarized the main cause and unit measurement used to analyze each impact.

Table 7: Summary of causation and measurement unit for each impact category

Impact category	Main cause	Measurement
Photochem ozone	CO, CH_4, NO_x	person ppm h/capita/yr
Terrestrial eutrophication	acidic emissions of SO_x and NO_x	UES m^2/capita/yr
Global warming	CO, CO_2, CH_4, and N_2O	kg CO_2 eq/capita/yr

Khoo, H.H., Tan, R.B.H., & Chng, K.W.L. (2010). Environmental impacts of conventional plastic and bio-based carrier bags part 1: life cycle production. Int J Life Cycle, 15, 284-293.

From life cycle analysis illustrated by Figure 2, it can be observed that for PHA bags, the highest contribution to global warming and terrestrial eutrophication is primarily from coal-fired power. Overall, PHA production with coal-fired power has the largest environmental impact with electricity being the next largest. PHA production with geothermal or clean energy has the least impact on the environment. In comparison, the impact from coal-fired power supply is 5 times greater than the impact from PE bag production. With clean energy from geothermal, the impact of PHA production is lower than that of PE bag by 80% while with electricity, PHA bags have 69% higher impact than PE bags. For natural gas, the environmental impact for both bags is similar. Hence, plastic bags made from bio-based material do not necessarily imply that they are greener. It is dependent on the source of energy supply during the production process.

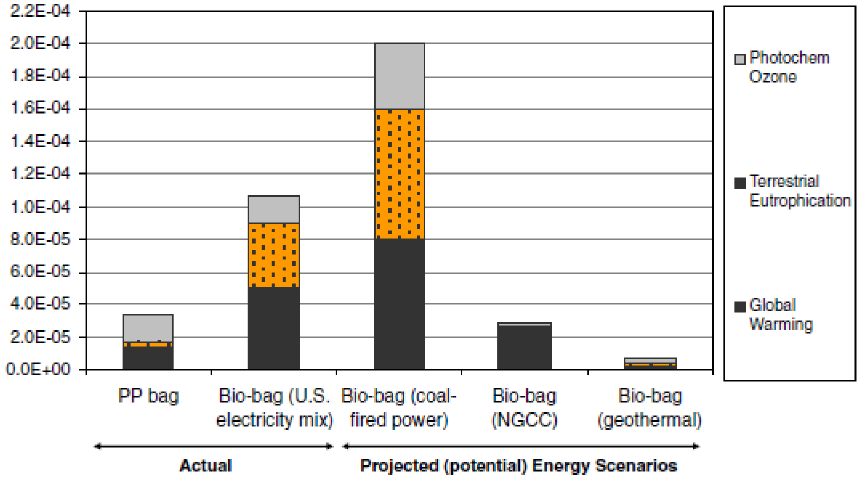


Figure 2: Environmental impact assessment on different energy sources for PE and PHA production

Khoo, H.H., Tan, R.B.H., & Chng, K.W.L. (2010). Environmental impacts of conventional plastic and bio-based carrier bags part 1: life cycle production. Int J Life Cycle, 15, 284-293.

3.2 END-OF-LIFE OPTIONS

In this section, the end-of-life or disposal options of both PHA and PE bags is investigated. The life cycle assessment is focused on the following end-of-life scenarios: landfill, incineration, and composting (only for bio-based plastics). The same impact categories and measurement unit presented in the earlier section is use in this study with addition of estimated land use impact. As shown in Figure 3, the landfill option for PHA bags has the largest distribution to the global warming effect while incineration of PE bags has the second largest impact. Composting of PHA bags and landfill option for PE bags have the similar impact to global warming. Landfill is the major contributor to the eutrophication impact for both PE and PHA bags according to Figure 4. For photochemical ozone, landfill option for PHA bags give the largest impact as seen in Figure 5. As depicted by Figure 6, landfill option has the highest impact on land use capacity. The overall effect of both life cycle production and end-of-life option is illustrated by Figure 7. It is observed that life cycle production dominates the overall impact on the environment for both types of bag. The total environmental impact is greatest for all end-of-life options with coal-fired power source while electricity source for all end-of-life options is the second highest. Geothermal still remains the energy source with the lowest impact for all end-of-life options. Also, landfill has the highest with incineration as the second largest and composting as the smallest impact.

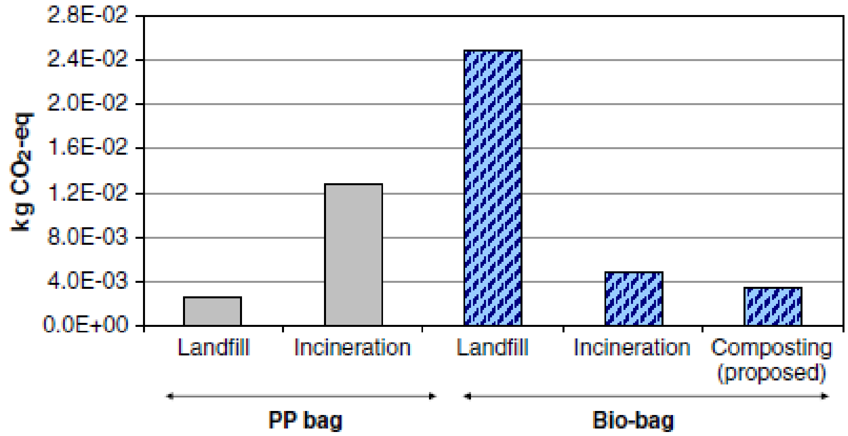


Figure 3: Global warming result for different PE and PHA end-of-life options

Khoo, H.H., & Tan, R.B.H. (2010). Environmental impacts of conventional plastic and bio-based carrier bags part 2: end-of-life options. Int J Life Cycle, 15, 338-345.

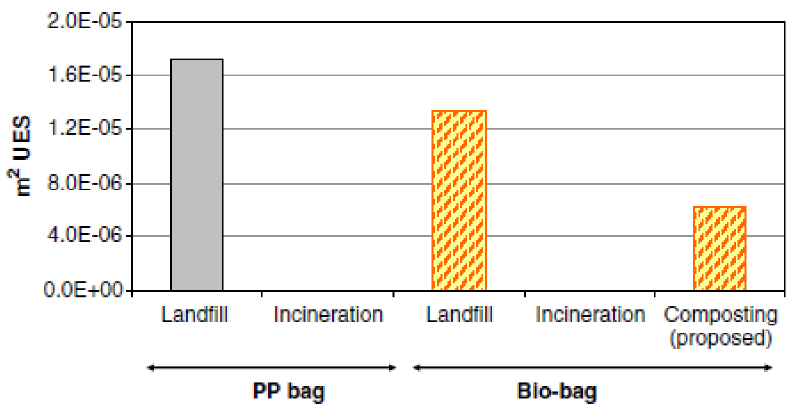


Figure 4: Eutrophication result for different PE and PHA end-of-life options

Khoo, H.H., & Tan, R.B.H. (2010). Environmental impacts of conventional plastic and bio-based carrier bags part 2: end-of-life options. Int J Life Cycle, 15, 338-345.

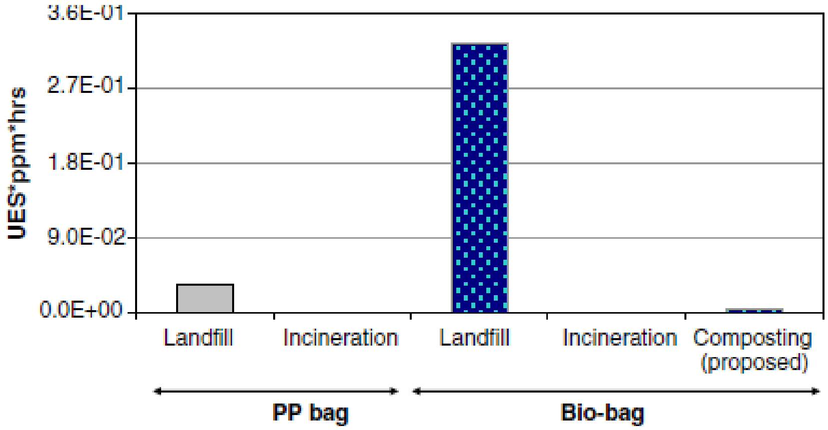


Figure 5: Photochemical ozone result for different PE and PHA end-of-life options

Khoo, H.H., & Tan, R.B.H. (2010). Environmental impacts of conventional plastic and bio-based carrier bags part 2: end-of-life options. Int J Life Cycle, 15, 338-345.

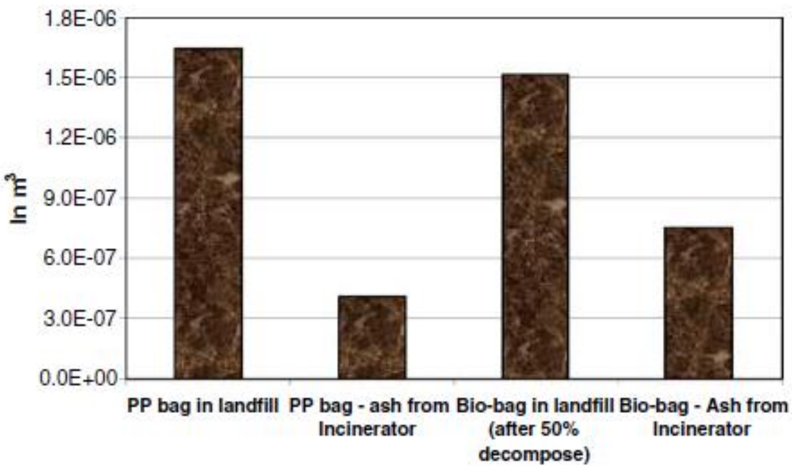
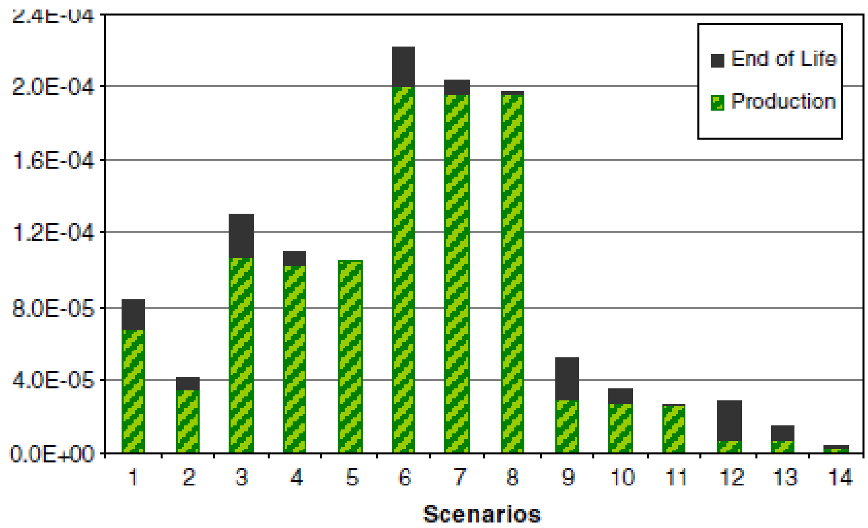


Figure 6: Projected impact on land use capacity of PE and PHA bags

Khoo, H.H., & Tan, R.B.H. (2010). Environmental impacts of conventional plastic and bio-based carrier bags part 2: end-of-life options. Int J Life Cycle, 15, 338-345.



Scenarios	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Product	PP bags		Bio-bag			Bio-bag			Bio-bag			Bio-bag		
Energy supplied in production	Singapore grid electricity		US electricity grid mix			Coal-fired power			NGCC			Geothermal power		
End-of-life options	Landfill	Incineration	Landfill	Incineration	Compost	Landfill	Incineration	Compost	Landfill	Incineration	Compost	Landfill	Incineration	Compost

Figure 7: Total environmental impacts from cradle-to-grave: production and end-of-life scenarios

Khoo, H.H., & Tan, R.B.H. (2010). Environmental impacts of conventional plastic and bio-based carrier bags part 2: end-of-life options. Int J Life Cycle, 15, 338-345.

Therefore, the choice of energy source used for production of the plastic bags are the major parameter which will determine the impact on environment. As discussed, coal-fired power has the largest contribution to the environment while green energy like geothermal has the least. In considering the option for disposal, landfill has the highest environmental impact while composting for PHA has the smallest.

4.0 SOCIAL ASSESSMENT

4.1 LIFE CYCLE RISKS FOR HUMAN HEALTH

For the social impact of PHA and PE, the risks for human health in the production process are investigated. This study combines classical risk assessment methods (largely based on toxicology) with statistics on technological disasters, accidents, and work-related illnesses. Moreover, it covers the total process chain for both petrochemical and bio-based products from cradle to grave which includes the following six sectors: agriculture, extraction and refining of fossil fuels, chemical industry, power generation, transport, and waste management. This approach allows one to make a first estimate of the conventional risks in the total system leading to a given chemical. The total risk to human health throughout a chemical's life cycle is estimated by summing the results of the following four risk categories: external risks due to regular release of emissions and technological disasters, risks of work related accidents (fatal accidents and accidents causing more than 3 days of absence from work) and risks of work related illness (pulmonary and musculoskeletal health problems).

The risks are estimated for the total number of years of life lost (YOLL) per unit of product throughout the process chain. The final results of risk assessment for PHA and PE are shown in Table 8. PE has risk of 0.004949 YOLL per ton of product which is 39-49% greater than the risk from PHA production which is 0.002501-0.002988 YOLL per ton of product. Moreover, the results shown in Figures 8 and 9 distinguish between the types of risks and sectors in which the risks occur. PE clearly shows a large impact from regular emission. Although PE has the highest total risks, it does not involve much of fatal accidents and pulmonary health problems compared to PHA. Figure 7 illustrates that risk from chemical industry is more important for PE than for PHA products. In contrast, risks from waste management is similar for all production routes since it is based on calorific value of the product such that the production method has no influence on the risk. It must be noted that PHA 1 is produced from glucose while PHA 2 is produced from glycerol which is considered to be a waste product from biodiesel production. As a result, none of the impacts related to agriculture are allocated to glycerol. The risk from agricultural for PHA 1 yields negative risk due to uptake of CO_2 by the crops from the air. Transportation effect is equal for both PHA and PE since same transportation is assumed for all routes.

Table 8: Results of the risk analysis for PE and PHA

Product	Risk (YOLL/ Ton Product)
PTT[a]	
-From ethylene oxide	0.003821
-From acrolein	0.004031
-Via anaerobic fermentation on dextrose	0.003001
-Via anaerobic fermentation on glycerol	0.003227
-Via aerobic fermentation 1	0.003039
-Via aerobic fermentation 2	0.003381
PHA[b]	
-Via fermentation 1	0.002501
-Via fermentation 2	0.002988
PET[c]	0.003211
PE	0.004949
Ethanol[d]	
-From ethene	0.003535
-Via maize dry milling 1 (low estimate)	0.000934
-Via maize dry milling 2 (high estimate)	0.001114

Alexander, L. R., & Martin, K. P. (2007). Life cycle risks for human health: a comparison of petroleum versus bio-based production of five bulk organic chemicals. Society for Risk Analysis, 27, 5.

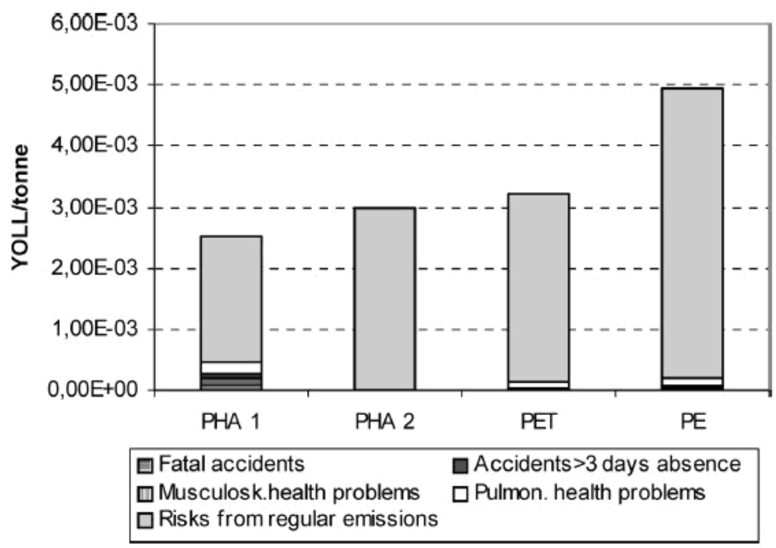


Figure 8: Risk for 1 ton of PHA and PE per risk category

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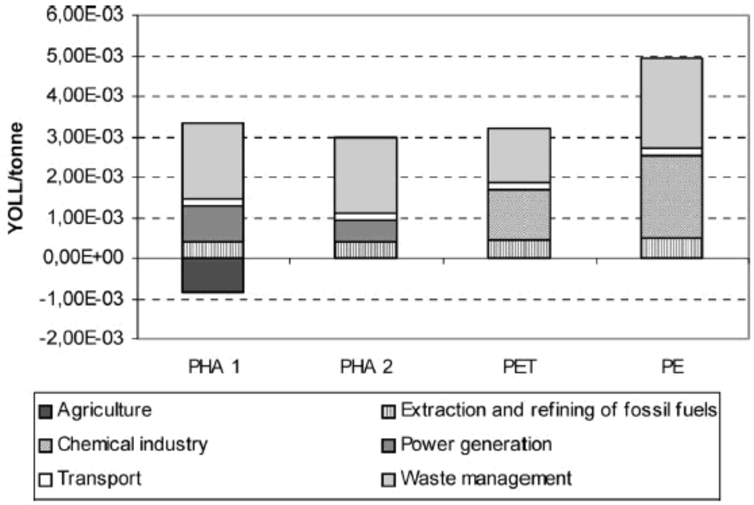

Figure 9: Risk for 1 ton of PHA and PE per sector

Alexander, L. R., & Martin, K. P. (2007). Life cycle risks for human health: a comparison of petroleum versus bio-based production of five bulk organic chemicals. Society for Risk Analysis, 27, 5.

4.2 BANNING OF PE

Some countries have started to ban the use of PE plastic bags. For example, Italy passed a ban on single-use polyethylene-based retail carryout bags on December 22, 2010, making its country the first to prohibit plastic bags in the European Union (Chemical Business Newsbase, 2011). The new measure, which became effective on January 1, 2011, mandates that all stores in Italy offer biodegradable clothes or paper bags to their customers with a fee, attempting to change consumers' behavior and encouraging more usage of reusable clothes and plastic bags made from biodegradable plastic or paper. Retail stores and supermarkets in Italy, however, are still permitted to use up their plastic bag inventories. The ban has been imposed following a petition from citizens' appeal. The plastic bags will be provide to the customers with no charge, instead of retailers' traditional practice of charging for them. According to Italian environment group, Legabiente, annual plastic bag use in Italy has been around 20 billion plastic bags which is about one plastic bag per person, per day, each year. The PE bag ban is already in effect in 200 of Italy’s 8,000 municipalities as its country roughly twice the size of Florida is consuming 25% of the total amount of plastic bags in all of Europe each year. This pushes the nation to outlaw them across the board. According to Reuters, “Italian critics say polyethylene bags use too much oil to produce, take too long to break down, clog drains, and easily spread to become eye sores and environmental hazards" (Chemical Business Newsbase, 2011). Italy takes its place on the spectrum of plastic bag bans and restrictions to spring up across the globe in recent years. China cut its plastic bag consumption in half when stores were forced to charge consumers for plastic bags in 2010. Washington, D.C. imposed a five-cent tax on plastic bags in April this year. The capital city succeeds in reducing plastic waste and also generates $150,000 in revenue which will go to cleaning up the local Anacostia River. In 2007, San Francisco skipped the tax and went straight to banning plastic bags. Los Angeles followed San Fran's lead, first imposing a 25 cent tax per bag for consumers, and then approving a ban that went into effect in July of this year. Ireland passed a $0.33 tax on plastic bags in 2002. Within weeks, plastic bag use dropped 94%. Within a year, nearly everyone had bought reusable cloth bags, keeping them in offices and in the backs of cars (Chemical Business Newsbase, 2011). Plastic bags are not outlawed, but carrying them becomes socially unacceptable; on a par with wearing a fur coat or not cleaning up after one's dog. However, where the convenience factor, taxes, environmental ethics, and fines do not make a difference, peer perception and social implications are worth their weight in gold.

4.3 CONSUMER- AND RETAILER-BASED SURVEYS

Two surveys were conducted; one is based on UBC students' or consumers' opinion and another survey is retailer-based from UBC bookstore. Both surveys show similar results as UBC bookstore and student responded that the main barrier of switching to a more sustainable packaging material is the purchasing price of the materials. Nonetheless, they are willing to accept small change in price, roughly about 5-10% increase from the current price. However, if the price of the carrier bag is high, UBC students prefer to bring their own reusable bag. The students also claim that they will act more sustainable if they are surrounded by a sustainable environment. UBC bookstore would slightly increase the price of their products to offset the increase in the price of packing materials and believe that consumers would barely notice the change in the product price. Currently, UBC bookstore is helping the environment by reuse and recycle packing materials when possible. Thus, the economic aspect of switching to more sustainable packing materials is the main driving force for the behavior of the consumers and retailers. More detailed information about the surveys is available in the Appendix.

5.0 CONCLUSION AND RECOMMENDATION

In conclusion, the economic analysis shows that the unit selling price of PHA is approximately 2-3 times greater than that of PE. Currently, the market for PHA is relatively small and the selling price is less likely to decrease to PE price range in the near future. The environmental assessment results in the conclusion that the impact on the environment is greatly dependent on the source of energy supplied during the production process. With geothermal as the only energy source with lower impact for production of PHA when compared to PE, PHA bags are unlikely to be greener than PE bags as geothermal is geography dependent. In considering social impact, the life cycle risks for human health is investigated and the results show that PHA bags have smaller total health risk than PE bags. However, PHA risks involve more fatal accidents and pulmonary health problems than the PE one. Also, the survey results imply that consumers' and retailers' behavior is greatly influenced by the economics impact. Therefore, PHA bags are not recommended to be implement in the new SUB in place of conventional plastic bags. It is recommended that more research and triple bottom line analysis should be done on other bio-based materials such as bio-BOPP, Eco-cradle (mushroom-based packing) and PHB.

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APPENDIX

Retailer-based Survey Response (UBC bookstore)

1. Would you switch to a more sustainable packaging material if this change will increase the purchasing price of the packaging material?

   Yes, we will consider switching to a more sustainable packaging material only if the increase of purchasing price of the packaging material ranges from 5-10% compared to the previous packaging material. It will depend solely on the price.

2. Would you increase the selling price of your product to cover the extra cost of the new packaging material? If yes, how do you think the consumers will respond? How will it affect your revenue? Briefly explain.

   Yes, we will increase the selling price of our product to accommodate for our loss. We believe the consumers will still purchase our products because the change in price will barely be noticeable and that our products will always be sold because the availability of our products can only be found in our store.

3. What do you do with the delivery packaging materials once the products are unpacked?

   We reuse our plastic bags and recycle cardboard boxes. Styrofoam boxes are also reused if needed but they are usually recycled.

4. What is the degree of consideration regarding the sustainability when purchasing the packing materials?

   The sustainability policy that UBC invokes in our stores will encourage us to purchase alternative materials but the main reason that ultimately decides what we use for our packing material is up to UBC.

5. What are the challenges do you think that may prevent you from being more sustainable?

   The price of the packaging material is the main challenge.

6. What are some of the actions that you have been taking to achieve sustainability?

   We encourage students to purchase our water bottles and to bring their own carrier bags. We also strive to recycle and reuse all packaging material if possible.

Consumer-based Survey Response (UBC student)

1. Are you aware of the new SUB's goals to achieve sustainability, particularly for the packing materials used in the new stores?

Consumer based Survey Questions 1

Edit this item»

Response	Chart	Frequency	Count
Yes		33%	10
No		67%	20
		Total responses:	30

2. Do you think we can minimize the waste generated by packing materials in the new SUB?

Consumer based Survey Questions 2

Edit this item»

Response	Chart	Frequency	Count
Yes		93%	28
No		7%	2
		Total responses:	30

3. Would you act more sustainable if you were surrounded by a sustainable environment, such as the new SUB?

Consumer based Survey Questions 3

Edit this item»

Response	Chart	Frequency	Count
Yes		93%	27
No		7%	2
		Total responses:	29

4. If we tag a price on the carrier bag, would you feel encouraged to bring your own bags? Briefly explain.

- yes of course, it saves money, and helps reduce waste
- Yes
- Not necessarily, depends on how expensive the carrier bag is.
- 100 USD
- I bring a backpack to avoid paying for bags at grocery stores because bags cost money
- Yes, I could save on the money to pay for the carrier bag just simply by bringing my own bag, and be sustainable at the same time.
- Yes, FRUGAL
- Yes
- I would bring a cloth carrier bag or old plastic bags, but if I forgot (which I do do sometimes) then I would just pay for the carrier bags.
- Yes, but it depends on the price of the bags. If it's too cheap then I would not bother.

- yes, economic reinforcement helps.
- No, because I would already have a back pack to put it in and I would not want extra bags in that back pack.
- yes because not only are we saving money we are also going green.
- Yes, during my previous work at IKEA, they had the same idea. Customers started using either old boxes we also provided or they got reusable bags to hold their goods in.
- no because i always forget to bring a bag
- Yeah, don't want to pay for the extra bag.
- Yes, it reduces waste and minimizes cost.
- yes. cause it costs money
- Yes.
- Yes I will, saving money is always an incentive. however I feel that the concept needs to be well advertised as well so that everyone knows about it.

yes I'm cheap
yes
what carrier bag?
More encouraged since I would rather save money and act more sustainable.
Yes, I wouldn't want to pay.
Yes because I would want to save myself some money if it is convenient to do so.
yes because I wanna save money too
Yes. For me, a price tag helps create the awareness that I should not only save money, but help save the environment by minimalizing waste.
yes because i want to save money
Yes Because I get to save money and every penny counts.

Generally, the students prefer to bring their own bag if the price of the carrier is high.

5. What do you do with the leftover packaging materials after making a purchase?

reuse if big enough. if not, throw it away
recycle them
Recycle it if there is a recycling bin close by, otherwise discard it.
eat it.
Plastics, cardboard, paper and metals are recycled. The non-recyclables go in the garbage
I use the plastic bags garbage bags, and recycle the paper bags.
garbage can, unless the appropriate recycling container is closer
If the means to recycle it are accessible I use them. Otherwise, I put it in the garbage.
I reuse grocery bags, but packaging such as boxes/plastic wrap I throw in the recycle/throw in the trash, respectively.
Use them as garbage bags at home

- recycle or throw.
- Usually throw in the garbage. However, if they are high quality, then I may re-use to store my own things.
- keep it
- when possible, try to reuse/recycle them. In the case of good boxes/containers, reuse, as well as with bags when possible
- throw away
- Throw it away.
- Recycle packaging if possible (or compost)
- throw it away
- Throw them into corresponding recycling bins.
- throw it away or try to compost it. Not enough compost bins

- store it at home
- throw it in the garbage or recycle if possible
- throw or recycle
- Throw it away in the garbage or reuse if possible.
- Try to recycle if I can...if not, throw away in garbage
- Dispose of it.
- throw it in the trash
- If it's shopping bags, I reuse them for storing other material or pass them on when I give a gift. If it's plastic bags from the grocery, I store them to use as garbage bags!
- leave it around the house
- Trash

Some students reuse the plastic bag as garbage bags, recycle them, or throw them into the trash.

6. If switching to a more sustainable packaging material causes the selling price of a product to increase, what is your opinion on this consequence?

marginal increase wouldnt be bad, but a noticeable difference will be unwanted
As long as the increasing price is reasonable, then it's okay.
Not a good marketing tactic for the already expensive fast food chains in the sub.
nothing.
It would depend on the magnitude of the increase and the increase in relation to the price of the item. A 50 cent increase on a $2 item is a lot but 50 cents on something $10 is ok
If the increase in price is not too high, I will have no objection. However, if the price is too high, then I would rather not buy or use my own bag for the product.
FRUGAL
Depends on the increase in price.
If the new packaging material is able to be reused for something else then I wouldn't mind spending a little more, but if I were to just throw the packaging in the trash then I would not be inclined to buy the product.
People will not be as willing to buy the product. I would rather have the price to not increase but maybe have a smaller amount. At least the impact is not as noticeable.

it should not be significant, or else it will affect sales. probably less than 5 cents.
If the sub is the only place in a 2-3km radius to sell the product, I will have to concede to buy from there even though it is slightly more expensive.
thats no go
As long as the price to switch over isn't too drastic, I'm in favour of the switch. Just keep it reasonable.
unless its much more i probably wont notice
If it doesn't decrease too much then its okay.
As long as it's not a drastic increase and the packaging if truly more sustainable, I would still buy it.
worth it. we are being sustainable
I will try to bring my own lunch more often.
I feel that the amount of students buying food will be about the same. However the students will be annoyed. I also feel that it does create an incentive for people to bring their own containers if it means a lower price.

won't buy from there
depends how much the cost increase by. I would be fine if packaging doesn't change the price too much
students are very price sensitive. it's probably less of an incentive to buy something if it's costly
It depends on the product and how much the selling price has increased.
I personally wouldn't prefer that...but wouldn't oppose it either
I would might buy less of the product.
not gonna support that because it defeats the purpose of saving money
Depends on how much the price of the product increases by. If the price increases significantly, it would make me less inclined to buy the product; if the price is not too noticeable I would be happy to purchase and help the environment at the same time.
I don't like it
I think It's fair, we only get one earth.

Many students make their decisions based on the increase in price. They generally accept a small increase in the price of the product.