UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

Biodegradable Plastic Based Food Containers

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BIODEGRADABLE PLASTIC BASED FOOD CONTAINERS

Life Cycle Analysis Study

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UBC SEEDS Project

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1. INTRODUCTION

Due to the recent shift towards environmentally friendly and sustainable choices, caused by the growing concern for scarcity of resources and greenhouse gas emissions, new options for established items and processes are being sought. One of these items is plastic. The most common industrially used plastics are petroleum based. Currently 8% of the World's oil is consumed by the plastic production industry (Environmental Impact, 2009). Not only is the source of these plastics non-renewable, but the extraction and production processes are heavily energy consumptive and therefore generate large amounts of greenhouse gas emissions. In order to lessen the impact of the plastic industry on the environment, new production methods and materials must be developed and implemented.

This report focuses on the production and use of biodegradable plastic for use in food packaging at the University of British Columbia (UBC). More specifically, it will focus on the results of a product life cycle analysis completed for several food container manufacturers utilizing two different types of biodegradable plastic resins.

Currently the two main base resins used in the production of biodegradable plastic containers are polylactic acid (PLA) and plastarch marterial (PSM). The main difference between these two resins is the original raw material source. PLA is produced mainly from a corn feedstock while PSM uses a potato wash feedstock. Both resins are produced using a biofermentative process and can subsequently be formed into containers and/or utensils using the same methods.

The three companies chosen for this lifecycle analysis were Biodegradable Food Services (BDFS), Inno Ware (IW), and Eco-Packaging (EP). The life cycle analysis (LCA) completed for BDFS focuses solely on their PSM product line (Tater Ware). The LCA for both IW and EP focuses on their PLA product lines. It is important to note that both IW and EP use the Ingeo© PLA resin produced by NatureWorks, the only commercial supplier of PLA resin in North America (NatureWorks, 2010).

Initially this report was meant to utilize the software GaBi to produce the life cycle assessment; however, after inputting the data into GaBi, the obtained results were unreasonable. Multiple attempts were taken in order to try and correct the results but were unsuccessful. This report will now focus on data from literature to produce a life cycle assessment of all the products.

2. Biodegradable Plastic Resins

Two different biodegradable plastic resins are compared in this report. The first is made from Polylactic Acid (PLA) and the second is from Plastarch Material (PSM). Both are described in detail below.

2.1 Polylactic Acid

Polylactic Acid (PLA) based resin is produced mainly from corn starch, though other starch-rich substances like sugar or wheat can also be used (Polylactic Acid, 2009). Biofermentation converts dextrose (which is derived from corn starch) into lactic acid, which is then further converted into lactide through a dehydration process. The lactide then undergoes polymerization to become PLA. PLA based plastics have the ability to biodegrade in commercial composters and can also be incinerated.

2.2 Plastarch Material

Plastarch Material (PSM) based resin is a thermoplastic made from a starch polymer that can be produced using either corn starch or potato starch. Starch is a natural glucose polymer, and as a raw material it contains between 10%-15% water content (Macromolecular Symposia). To process starch into PSM, it must be modified which is done by mixing in cellulose and enzymes. The properties of the starch change; it becomes hydrophobic, high temperature resistant and gains plasticity (PSM HK). This is done in a closed vessel at temperatures above 100°C (Macromolecular Symposia). PSM products biodegrade in municipal and commercial composters, and can safely be incinerated.

3. Company Overview

3.1 Biodegradable Food Services LLC

Biodegradable Food Services (BDFS) produces a variety of biodegradable food containers and utensils including those made from sugarcane, cellulose and limestone, PLA and PSM. BDFS's PSM products are produced from potato starch. This project focuses on the PSM (Tater Ware™) line.

BDFS is currently in the process of opening a new production plant in Prineville, Oregon to replace the production plant in China. This report assumes the Oregon production facility will be used to manufacture PSM containers.

3.2 Eco-Packaging

Eco-Packaging (EP) produces cutlery made from PSM, hot cups made from paper products, plates and containers made from sugarcane and a range of cold cups and containers produced from PLA. EP utilizes NatureWorks' Ingeo™ resin to produce all of their PLA products. This report focuses only on the PLA product line.

Upon purchase of the Ingeo™ resin, EP ships it to China, where it is manufactured into food containers before being sent back to North America, to the warehouse located in Richmond BC prior to distribution.

3.3 Inno Ware

Inno Ware (IW) produces both PLA and paper-based food packaging containers. This project focuses only on the PLA product line.

IW uses NatureWorks' Ingeo™ resin to produce their PLA line. The production plant is located in Thomaston, Georgia and the warehouse is located in LaVergne, Tennessee.

3.4 NatureWorks LLC

NatureWorks LLC (NatureWorks) is based out of Blair, Nebraska and is one of the leading producers of PLA resin from 100% biodegradable materials. Their PLA is produced from dextrose which is derived from corn grown throughout the Central United States. NatureWorks claims that their products use less fossil fuel resources than other forms of plastic and are able to fully biodegrade, under proper conditions, in 47 days (NatureWorks, 2010).

4. Life Cycle Analysis

4.1 Resin Production

The following section describes the portion of the LCA dealing with resin production for both PLA and PSM.

4.1.1 PLA Resin (NatureWorks Ingeo™ Resin)

As both EP and IW use Ingeo™ resin, the initial portion of their life cycle analyses is the same and is therefore incorporated into one section. This following section provides a cradle to gate life cycle analysis for NatureWorks LLC's PLA Ingeo™ resin. An outline of the assumptions used in order to produce a life-cycle analysis for the PLA resin will be described in detail along with the results of the life cycle analysis

NatureWorks PLA resin manufacturing facility is in Blair, Nebraska, located in the Central United States. The specific corn which is used for the production of PLA is Number 2 Yellow Dent with 15% moisture content (NatureWorks, 2010). This species of corn is the most common type within the United States, accounting for approximately 80% of the total corn grown. According to NatureWorks, it requires 2.5kg of raw Number 2 Yellow Dent corn in order to produce 1kg of PLA resin. The Blair, Nebraska facility has a current capacity of 140 000tonnes of PLA per year which should be taken into account when interpreting the data from this report (NatureWorks 2010).

According to a past study done by NatureWorks on their process in 2005, it takes a gross energy input of approximately 82.5MJ/kg of PLA polymer produced. This energy input takes into account the amount of energy in the corn feedstock which NatureWorks estimated to be 28.4MJ/kg of PLA. This value is derived from the heat of combustion of corn which is 16.3MJ/kg of corn. This energy input can be considered renewable so in order to determine the non-renewable energy input into the system this value must be subtracted from the gross energy input. This yields a non-renewable energy input of 54.1MJ/kg of PLA. NatureWorks states that it takes 3.8MJ/kg of PLA to operate farm supplies, 1.1MJ/kg of PLA accounting for electricity use at the farm, and 0.4MJ/kg of PLA for transportation of corn to the mill. This process can be assumed to be mature so an energy input of 5.3MJ/kg of PLA can be assumed to be the energy inputs of growing the corn and transporting it to the mill (Vink, 2003).

NatureWorks produces their PLA from dextrose, a by-product of the corn milling process; therefore, the energy inputs required to mill the corn as well as to separate the dextrose in the milling process must also be taken into account. This energy use accounts for 9.4MJ/kg of PLA with 8.8MJ/kg of PLA going towards the actual milling process and 0.6MJ/kg of PLA going towards treatment for waste water from the plant. As in the growing and transportation of corn, this process can be assumed to be a mature technology so these energy inputs will be fixed over time (Vink, 2003).

Lactic acid production accounts for the majority of the energy input in the production of PLA resin. This manufacturing step requires 26.3MJ/kg of PLA produced. 14.9MJ/kg of PLA is used in the actual manufacturing of lactic acid while the remaining 11.4MJ/kg of PLA is used in treating the waste water effluent from the plant. This technology is new and will allow this energy input to be reduced as it matures (Vink, 2003).

The final step is producing PLA from lactide derived from the lactic acid produced above. This production step accounts for 13.2MJ/kg of PLA; with 12.8MJ/kg of PLA going towards the polylactide production facility and 0.4MJ/kg of PLA going towards the waste water treatment of the plant. As in the lactic acid production, this step was assumed to having not yet reached maturity so a decrease in the energy input here was assumed to be possible as advances in technology occur (Vink, 2003).

Overall, 14.7MJ/kg of PLA was assumed to be a fixed amount of energy input relating to the amount of energy required to grow and transport the corn as well as to mill it and produce dextrose. The remaining 39.4MJ/kg of PLA is used in the production of lactic acid and finally PLA. This energy input is also expected to decrease as advances in technology occur.

According to NatureWorks LLC, the amount of non-renewable energy input required to produce PLA resin from corn has decreased from 54.1MJ/kg of PLA to 42.2MJ/kg of PLA (NatureWorks 2010). Assuming 14.7MJ/kg of PLA is fixed, it can be assumed that the manufacturing of lactic acid and lastly PLA now only requires an energy input of

27.5MJ/kg of PLA. In order to determine the makeup of the energy input for the new total input of non-renewable energy, energy inputs of lactic acid production and PLA production need to be scaled to represent their current values.

In the old process, lactic acid production accounted for 66.8% of the variable energy inputs and PLA production accounted for the remaining 33.2%. Scaling this value to the new total variable energy input of 27.5MJ/kg of PLA, 18.3MJ/kg of PLA will be the amount of energy required for lactic acid production and 9.2MJ/kg will account for the amount of energy required to produce PLA from the lactic acid. A plot showing the relative contributions of each portion of the process to the total energy input is shown below in figure 1.

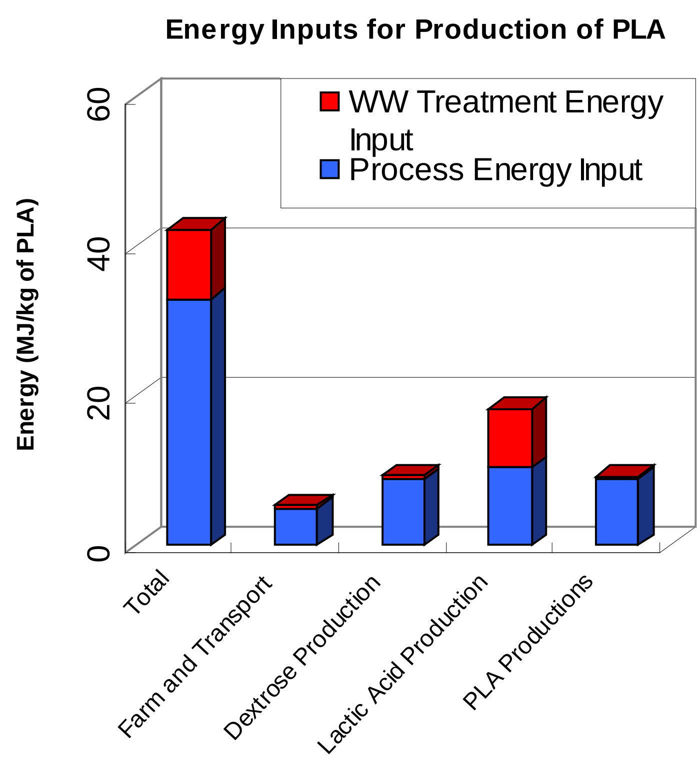

Figure 1: Energy Inputs for the Production of NatureWorks PLA

NatureWorks claims it requires 2.5kg of raw Number 2 Yellow Dent corn in order to produce 1kg of PLA resin. According to values from literature, 2.5kg of raw Number 2 Yellow Dent corn yields 1.51kg of dextrose. This means that 1.51kg of dextrose is required per kg of PLA (Gray, 1991). This value will be used in the dextrose production process.

According to literature, 0.117g of enzyme (proteass) is used per kg of corn in the dextrose production process. This scales to a value of 0.194g of enzyme per kg of dextrose produced. The dextrose production process also requires the use of sulphuric acid to pre-treat the corn before it is milled. This process requires the use of 49kg/h of sulphuric acid for a corn flow of 106,000kg/h. This is equal to 0.462g sulphuric acid/kg corn which leads to 0.765g sulphuric acid/kg of dextrose. Water use for this portion of the process also needs to be taken into account. For the same case study as above, 134,624kg/h of water were used for 106,000kg/h of corn. This leads to 1.92kg of water/kg of dextrose produced (Ramirez, 2009).

Sources of energy going to the PLA manufacturing plant as well as the other facilities were derived from a general energy composition for the Central United States. This composition was 62.1% hard coal, 20.9% nuclear, 2.6% natural gas, 3.6% hyrdo, and the remaining 10.8% came from a variety of sources. For the purpose of this LCA, the remaining 10.8% was distributed among the other sources of energy (NPPD, 2004).

Greenhouse gas emissions which were calculated by NatureWorks LLC for the PLA production process in 2005 were 2.0kg CO_2 eq/kg of PLA. NatureWorks also claims that in 2009 this value has been reduced to 1.3kg CO_2 eq/kg of PLA. Furthermore, through more research and development NatureWorks hopes to achieve green house gas emissions of 0.75kg CO_2 eq/kg of PLA. Energy needed for the process is also expected to drop to 35.2MJ/kg of PLA. To put these values into perspective, to produce 1kg of PET, a non-biodegradable plastic, it requires 80.3MJ of energy and emits 3.2kg CO_2 eq (NatureWorks 2010).

A variety of end of life possibilities are possible for PLA polymer. This LCA will not include the destruction of the PLA products; however, it is important that the different methods of destruction be noted. Composting of PLA polymer is the simplest form of destruction.

4.1.2 Plastarch Resin Production (Tater Ware Resin)

BDFS's PSM products are made from potato starch and are called Tater Ware. The starch used is from genetically modified organism (GMO) free potatoes which are regenerated annually (BFDS). Potato starch is a waste product from the food industry generated from washing potatoes. The properties of this starch polymer are similar to a polypropylene in terms of manufacturing; therefore, PSM products can be produced in existing plastics facilities with little to no adjustments to the process (PSM HK).

BDFS has a production plant in China and is opening a plant in Prineville, Oregon that will be operational by the end of June 2010 (Duffy, 2010). This report assumes that the products UBC will potentially be purchasing come from the Oregon facility. If the products are coming from Asia, there will be significantly higher energy requirements and greenhouse gas emissions due to the additional transportation required. It is of note that previously starch was also shipped from Oregon to China, to the Chinese production facility but this practice has been eliminated and now potato starch for this facility is sourced within China (Duffy, 2010).

Because the potato starch is a waste product from another industry it can be assumed that no energy is required to acquire the starch other than the transportation to the production facility. From email correspondence with BDFS it is known that the potato starch to be used in the Oregon facility is sourced from the Pacific Northwest, including within Oregon, Washington, and Idaho (BDFS Customer Service, 2010).

The energy requirements for processing PSM from potato starch are assumed to be the same as for processing from corn starch. To process 1kg of corn starch based resin pellets, 0.46kWh is required (Drachman, 2009). The total energy required is approximately 4.72MJ and the greenhouse gas produced is about 0.325kg CO_2 equivalent (Drachman, 2009). A cradle to gate analysis found that approximately 48.8MJ is used for 1kg of pellets, and 1.54kg CO_2 equivalent are emitted.

To process the polymer into the desired products, BDFS uses traditional injection molding and thermal forming equipment (Duffy, 2010). This process is the same as used in PLA production and is explained in further detail in section 4.2.

The new Oregon production facility both processes the starch into PSM polymer and forms the polymer into the many available food ware products. The specific electricity generation source in Prineville is unknown. Oregon uses power from many sources, including hydropower, coal, natural gas, and renewable (US Department of Energy, 2008). The percentage breakdown of these sources for all of Oregon was found and the plant in Prineville was assumed to use the same sources. The figure below presents the electricity sources.

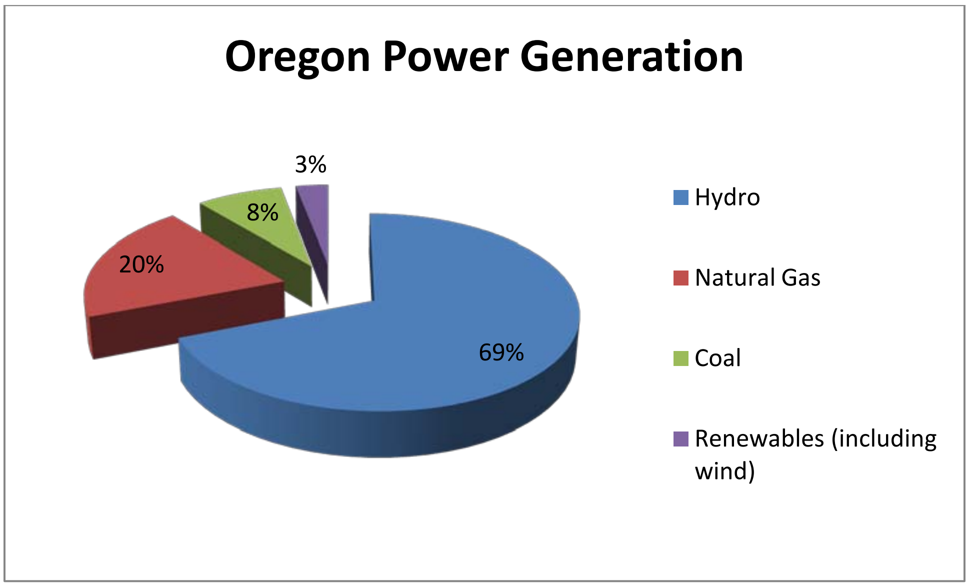

Figure 2: Sources of electricity generation for Oregon

Although this report is a cradle to gate life cycle analysis, it is important to note that PSM products claim to be fully biodegradable and are also safe for incineration (PSM HK). Incineration of PSM only emits 0.5 tons of CO_2 per ton of PSM burnt compared to 3.13 tons of CO_2 emitted per ton of plastic burnt (PSM HK). BDFS advises that the products from the Oregon facility will meet ASTM International 6400 D composting standards (Duffy, 2010). This standard is for plastics designed for composting in municipal and commercial aerobic facilities at a rate similar to recognized compostables (ASTM). There is not an equivalent ISO standard for composting plastics (ASTM).

4.2 Food Container Production

Biodegradable plastic resins such as PLA and PSM can be manipulated into final products in the same way traditional plastics are. The main methods for producing food packaging containers and utensils are thermoforming and injection molding.

Injection molding is used to produce utensils for the food industry and is the main method used for processing plastic (Methods, 2010). Dry resin is heated until it is in a fluid state. At this point it is pushed out of the heating chamber, into a series of closed molds where it cools in the desired shape. Once cool, the plastic is ejected from the mold in its finished shape.

Thermoforming is used to produce plastic food containers and beverage cups. It is the process by which a flat sheet is softened and fitted over a mold where it is allowed to cool into its final shape. Modern day industrial plants have complicated thermoforming processes which include automatic sheet placement, plug or pneumatic stretching and pressure forming and multi-axis router trimming (Throne, 1996).

As previously mentioned, few differences exist between the processes used to form general plastic containers and PLA or PSM based containers. The main difference is the melting temperature of the plastic. PLA has the lowest melting point, followed by PSM and finally by general petroleum based plastic. This lower melting/softening point lowers the heat requirements for this process, however, due to the lack of information available on the exact energy required for PLA and PSM thermoforming, this difference will be deemed negligible.

The energy required in the thermoforming process used to produce one container was calculated using the GaBi software. The thermoforming of polystyrene was chosen and used to model the thermoforming of PLA and PSM based resins. The overall energy consumption per container as computed by GaBi is 92.7kJ. Of this, 55.5% of the energy is recovered. Therefore the overall energy consumption per container is 41.2kJ.

4.3 Transportation

The transportation of raw materials and products is an integral part of the life cycle analysis due to the high consumption of fossil fuels and subsequent greenhouse gas emissions. Due to the scattered nature of the various preparatory and production plants, large distances must be traveled and the resulting emissions make up a large percentage of the overall emissions for the life cycle. Where specific details for methods of transportation could not be specified, assumptions based on country and regions were made. Maximum distances between processing facilities were estimated based on general locations and known major routes.

The production process for both BDFS and IW is fully contained within the USA before transport to Canada. Therefore for these two companies, all transportation was assumed to be by truck. EP manufactures their final product in China. Therefore additional transportation by sea (cargo ship) and by rail had to be included. As only a general location was provided by the representative from EP, it was assumed that the cargo ship would travel to Shanghai, from which a train would be used to transport the resin for a maximum distance of 1000km to the processing plant.

Greenhouse gas (CO_2-eqivalent) emissions were calculated using emission rates provided by CN, a rail transport company. These were provided as grams of CO_2-equivalent emissions per tonne of cargo transported per km. As the estimated weight of a container is 15g, these emissions were broken down further to grams of CO_2-equivalent per container per km as can be seen in the table below.

Table 1: Transportation Emissions Calculator

CN Cargo Transportation Emissions Calculator		
	$g_{CO2eq.}$/t-km	$g_{CO2eq.}$/container-km
Truck	114	0.0017100
Ship	11	0.0001650
Rail	17.85	0.0002678

A full breakdown of distances travelled between specific production facilities for each company is located on the following page.

Table 2: Detailed Transportation Distances and Methods

	Inno Ware	Eco-Packaging	Biodegradable Food Solutions
Raw Material Crop			
Location	Iowa USA	Iowa USA	Western USA
Raw Material processing plant			
Location	Iowa USA	Iowa USA	Western USA
Distance Travelled (km)	200	200	-
Mode of Transporation	Truck	Truck	-
CO_2-eq. Emissions	0.34	0.34	
Resin Production Plant			
Location	Blaire, Nebraska USA	Blaire, Nebraska USA	Prineville, Oregon USA
Distance Travelled (km)	600	600	550
Mode of Transporation	Truck	Truck	Truck
CO_2-eq. Emissions	1.03	1.03	0.94
Final Product Production Plant			
Location	Thomaston, Georgia, USA	China	Prineville, Oregon USA
Distance Travelled (km)	1800	2700km truck, 13000km sea, 1000km train	0
Mode of Transporation	Truck	Truck/Ship/Train	-
CO_2-eq. Emissions	3.08	7.03	0
Distribution Center			
Location	LaVergne, Tennessee USA	Richmond, BC	Prineville, Oregon USA
Distance Travelled (km)	500	100km truck, 13000km sea, 1000km train	0
Mode of Transporation	Truck	Truck/Ship/Train	-
CO_2-eq. Emissions	0.86	2.58	0
Final Destination (UBC)			
Location	Vancouver BC Canada	Vancouver BC Canada	Vancouver BC Canada
Distance Travelled (km)	4200	30	750
Mode of Transporation	Truck	Truck	Truck
CO_2-eq. Emissions	7.18	0.05	1.28

The total CO_2-equivalent transportation emissions can be seen in Figure 3, below. As can be seen, IW produces the most transportation related greenhouse gas emissions, which is surprising due to the lower total distance travelled over EP's product. This is due mainly to the efficiency of cargo ships, and to their large capacity. As all of these emissions were broken down based on the weight of one 15g food container, the emissions for a cargo ship was divided by the total weight carrying capacity, which is several orders of magnitude greater than that of a commercial truck.

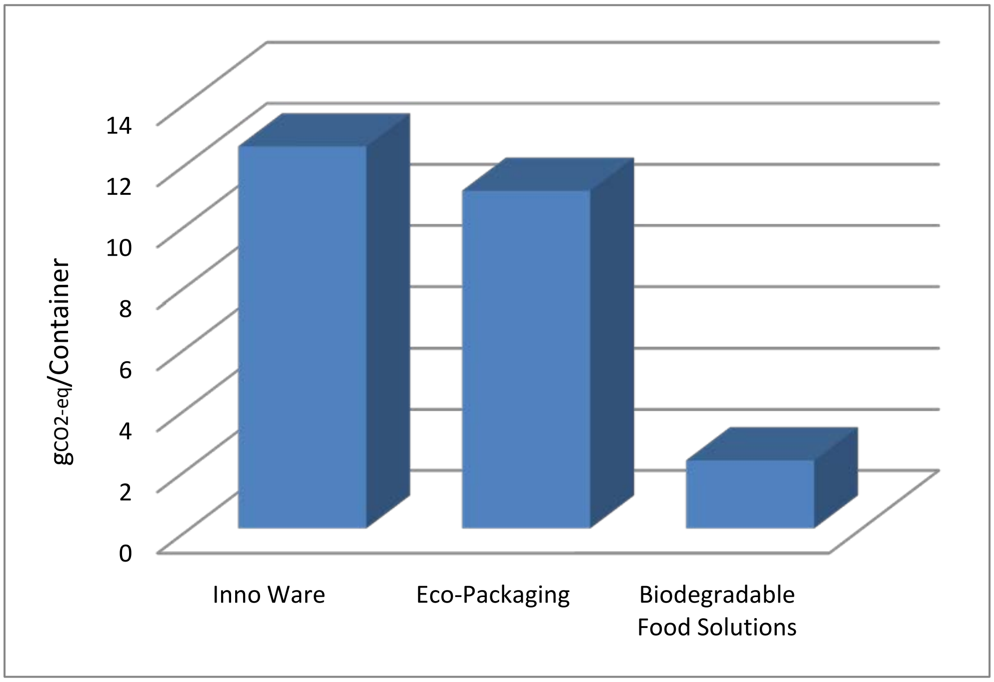

Figure 3: Overall Transportation-based CO_2-eq. Emissions per Container.

The overall fuel consumption was calculated based on an emission rate of 2.772kg of CO_2 per litre of diesel fuel (Calculated, 2010). Subsequently, the energy required was calculated using a value of 36.4MJ/L of diesel fuel (Elert, 2008). These values were included in the conclusion.

5. SUSTAINABILITY

5.1 Labor Practices

While both BDFS and IW products are fully manufactured in the USA, EP ships its PLA resin to China where it is converted into containers and subsequently shipped to Canada. This section reviews the labor practices and laws followed in both the USA and China. While the product is shipped within Canada, no production actually takes place here and therefore this country is not included in the comparison.

5.1.1 USA

The United States Department of Labor sets and enforces the minimum wage and workweek standards throughout the USA under the Fair Labor Standards Act. These standards apply to all states and regions in the USA and protect everyone covered by the Fair Labor Standards Act. This includes citizens, green card holders, legal immigrants and Visa holders (Wages, 2010).

The minimum wage in the USA is $7.25 per hour ($7.26 CAD at the current exchange rate). This translates to approximately $1,161 CAD per month (Wages, 2010). The standard work week is 40 hours and overtime pay must be issued for work completed beyond 40 hours. Overtime pay is set to 1.5 times the regular pay.

5.1.2 China

Labor practices in China vary between companies and do not follow a set of clearly defined laws unlike those in the USA or Canada. Labor laws are created by local authorities and change from region to region (Simons, 2007). Therefore it is difficult to make assumptions as to the exact nature of the working conditions in a production plant without being given the specific information.

The minimum wage in China is regulated by local and regional authorities and therefore cannot be reported. However, guidelines and standards for setting a minimum wage have been issued by the Ministry of Labor and Social Security (Wages, 2008). The minimum wage should be no less than 40% of the average wage earned by a region. However, in large cities such as Beijing and Shanghai the minimum wage is approximately 20% of the average monthly wage (Wages, 2008), and in many regions the minimum wage regulations remain less than ideal.

The average wage in 2006, as reported by the China Labour Board, was 1,750 Yuan (Approximately $257 CAD) per month. However, the average wage of workers in primary industries was 786 Yuan ($115 CAD) per month, which is 44% of the average wage. Though this appears to be an optimistic number, judging from other reports, it will be used in the comparison of labor practices between the three countries.

The standard work week in China is 40 hours long with overtime not exceeding 3 hours per day. Overtime pay follows a similar structure to the USA and Canada in that it is 1.5 times that of the employee's wage. Unfortunately numerous reports exist detailing the prevalence of 60 hour work weeks with little additional payment (Simons, 2007).

5.1.3 Conclusion

Based on a comparison of minimum wages it can be concluded that payment in the USA is higher than in China. The minimum wage in the USA is nation-wide and is closely monitored by the United States Department of Labor. In China, the minimum wage is set by regional authorities, and therefore is not closely monitored by a general governing body. Though neither country is immune to unfair and illegal practices, it can be assumed that these are more prevalent in China's less regulated workplace.

5.2 Environmental Impacts

5.2.1 Land Usage

Land use to produce NatureWorks PLA resin $3m^2$/kg of PLA resin. This is the amount of area required to grow the corn for the process. It should be noted that though dextrose is the main resource used in the production of PLA, the other products coming from the corn feed should also be considered.

Tater Ware produces all of their PSM from potato starch. Potato starch is a waste product from the food service industry so the amount of land used to produce the resource can be considered to be zero.

6. CONCLUSION

BFDS and IW both manufacture products within the United States, making them a more attractive option than EP products in terms of labour practices and societal impacts. Also, the distances travelled by the materials through all stages of production are significantly decreased.

The overall energy consumption for each Company is shown in Figure 4, below.

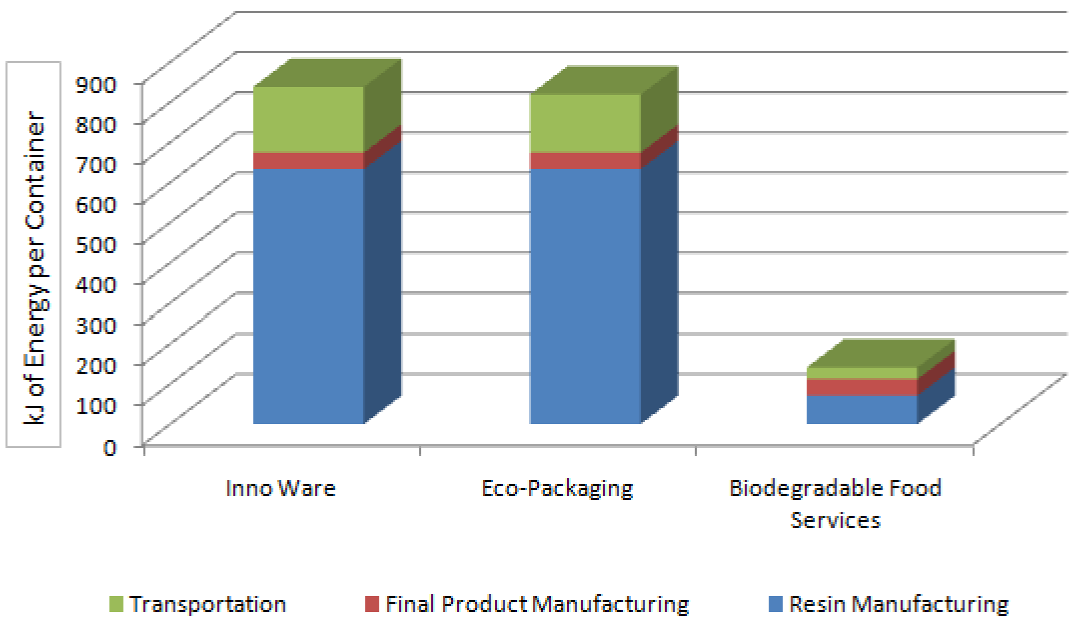

Figure 4: Overall Energy Consumption

This figure clearly shows that BDFS is the best option for UBC in terms of sustainability. The use of PSM to produce bioplastic significantly reduces the amount of energy required to produce the resin. The energy required to grow the corn and mill it in order to produce PLA resin is a very large input that does not need to be taken into account since BDFS uses a waste product from the food industry. Final product manufacturing for all the products is very similar as they are all produced using a similar method.

Figure 5 below details the overall greenhouse gas emissions for each company. As can be seen from the figure, BDFS is once again the clear choice as it produces less than half of the emissions produced by IW and EP. The emissions for final product manufacturing are not included. These emissions are assumed to be the same for each of the three products as the same manufacturing method is employed.

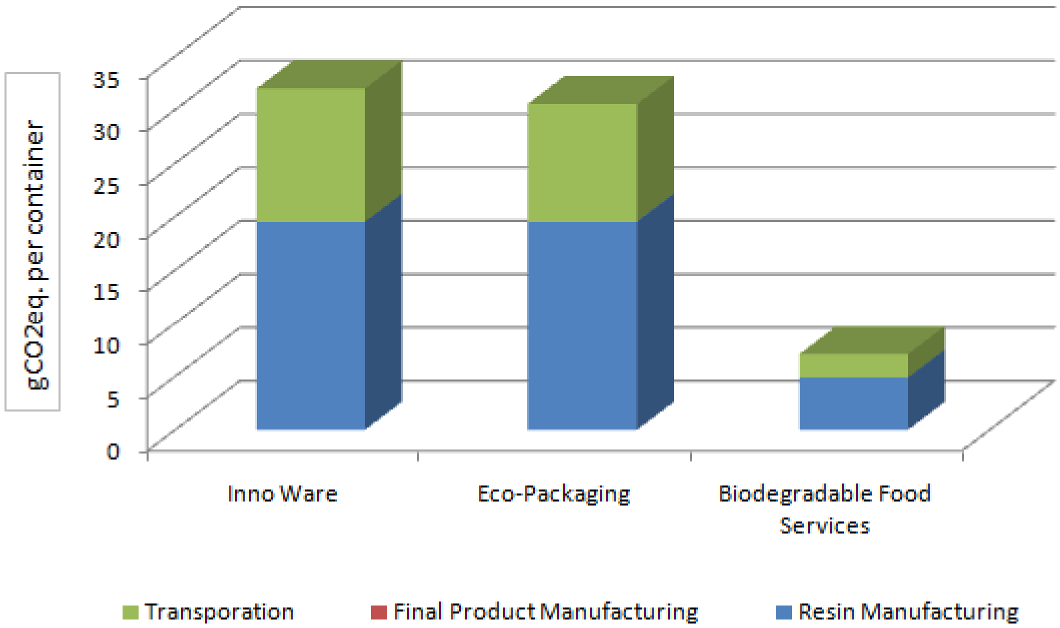

Figure 5: Total Greenhouse Gas Emissions per Container

Upon completion of this LCA it can be seen that BDFS is the most sustainable and environmentally friendly option for provision of biodegradable food containers to UBC.

NOMENCLATURE

Symbol/Abbreviation	Definition	Units
ρ	Density	kg/m^3
ΔT	Change in Temperature	°C
°C	Degrees Celsius	
BDFS	Biodegradable Food Services LLC	
CO_2	Carbon Dioxide	
EP	Eco-Packaging	
g	Grams	
g/L	Grams per Liter	
g/(L-h)	Grams per Liter per Hour	
h^{-1}	Per hour	
IW	Inno Ware	
J	Joule	
K	Kelvin	
kg	Kilogram	
kJ	Kilo Joule	
M	Mass flow	kg/s
m	Meters	
m^3	Cubic meters	
P	Power	Watts
s	second	
Q	Heat	J
UBC	University of British Columbia	
watts	Joule per second	W

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