LIFE CYCLE ANALYSIS:
COMPARING PLA PLASTIC FOOD USE PRODUCTS ON THE BASIS OF ENERGY CONSUMPTION

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Executive Summary

A life cycle analysis (LCA) was conducted to compare the polylactic acid (PLA) plastic products from two companies: Biodegradable Solutions International (BSI) and Biodegradable Food Service (BFS). The Alma Mater Society at the University of British Columbia (UBC) currently purchases from the former. An interest was expressed to determine if a more environmentally friendly alternative could be found.

The lifecycles of the products were divided into three sections—agriculture, manufacture and transport. Energy inputs for each of these sections were determined, and a total energy consumption for the entire lifecycle calculated.

BSI products use the highest amount of energy—about five times more than the BFS Taterware products. This is primarily because BSI purchases PLA resin that is produced from corn; thus, the energy required to grow the corn is included in the analysis. BFS, however, avoids this energy input by purchasing a starch that is a waste stream from another industry to produce PLA resin.

BFS manufactures its Taterware in both China and Oregon, USA. Due to lower transport demands, the products that stay within the continent require about half the energy of those that are manufactured in China. Indeed, Oregon manufactured products only travel approximately 3% of the distance their China bound counterparts travel.

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1 Introduction

The AMS currently purchases biodegradable polylactic acid (PLA) plastic food use products from Biodegradable Solutions International (BSI), a company that manufactures its wares overseas using corn based resin. To determine if there was a more environmentally friendly option available, a SEEDS project was launched to compare the current products against similar biodegradable products from another company.

The challenger company chosen was Biodegradable Food Service (BFS), which provides both corn and potato-based products. This report shall discuss only their Taterware line, which uses potato starch to form PLA.[i]

A life cycle analysis was conducted to quantify and compare the amount of energy required to make and deliver each company's products to UBC. The product lifecycles were considered in three stages: agriculture, manufacture and transport.

2 Background

PLA plastic has grown in popularity within recent years. Made from plant starches, it is renewable and biodegradable, and could potentially help to cut down on plastic wastes.[ii]

However, PLA still has a number of issues. For example, outside of the controlled environment of an industrial composter, it is unlikely to decompose. In a landfill, PLA could take from a hundred to a thousand years to break down. There are also logistical concerns: PLA plastic cannot be recycled with petroleum plastics, and thus must be separated out.[iii]

Nevertheless, despite these and other issues, PLA plastic still has a great deal of potential to become an environmentally friendlier alternative to petroleum plastic.[iv]

To make PLA, a crop (typically corn) is grown, harvested, and milled to separate out its starch. This starch is hydrolyzed into dextrose, which in turn is converted to lactic acid using microorganisms. After some more chemical treatment, the lactic acid forms into long polymer chains, becoming PLA resin. This resin can then be used for a variety of applications: it can be extruded into sheets and thermally formed into clamshell containers, plates, or drinking cup lids; it can also be injection molded to form cutlery.[v] [vi]

3 Life Cycle Overview

A life cycle analysis (LCA) is a tool for investigating the environmental impact of a product or process over its entire "lifespan." For the food use products under consideration in this analysis, their lifespans were defined as beginning with any initial farming to produce starch, and ending with the finished product's arrival at UBC. This LCA uses the quantity of energy required to make and deliver the final product as its means of assessing environmental impact.

The lifespan of a PLA plastic product by BSI was diagramed in Figure 1 below. Corn is grown in China, and then trucked to a manufacturing site elsewhere in the country. When the product leaves China, it will be in its final form, be it container, lid or utensil. Once it reaches Canada, it will be stored in a warehouse, then shipped to a distributor, and finally to UBC.[vii]

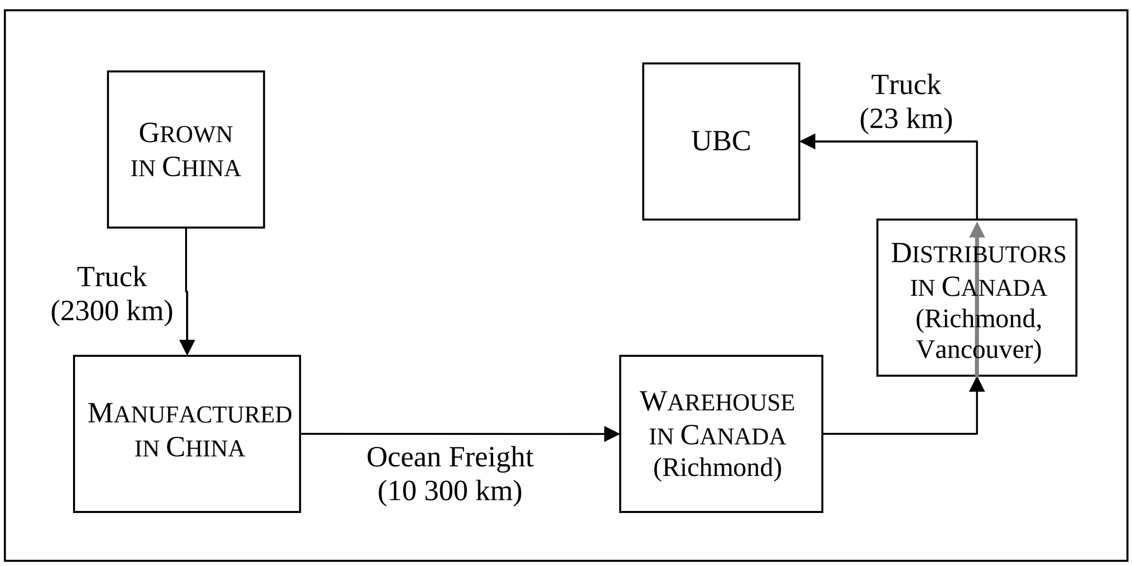

Figure 1 BSI Process Location and Transport Diagram

Similarly, the lifespan of a Taterware product by BFS has been illustrated in Figure 2 below. Potato wash is first purchased in Oregon. Twenty-five percent of this wash is sent to Gresham, Oregon for manufacturing; the remaining 75% is sent to China. The finished products are returned to the US and stored in a warehouse. From there, they will be transported to a distributor, then finally to UBC.[viii]

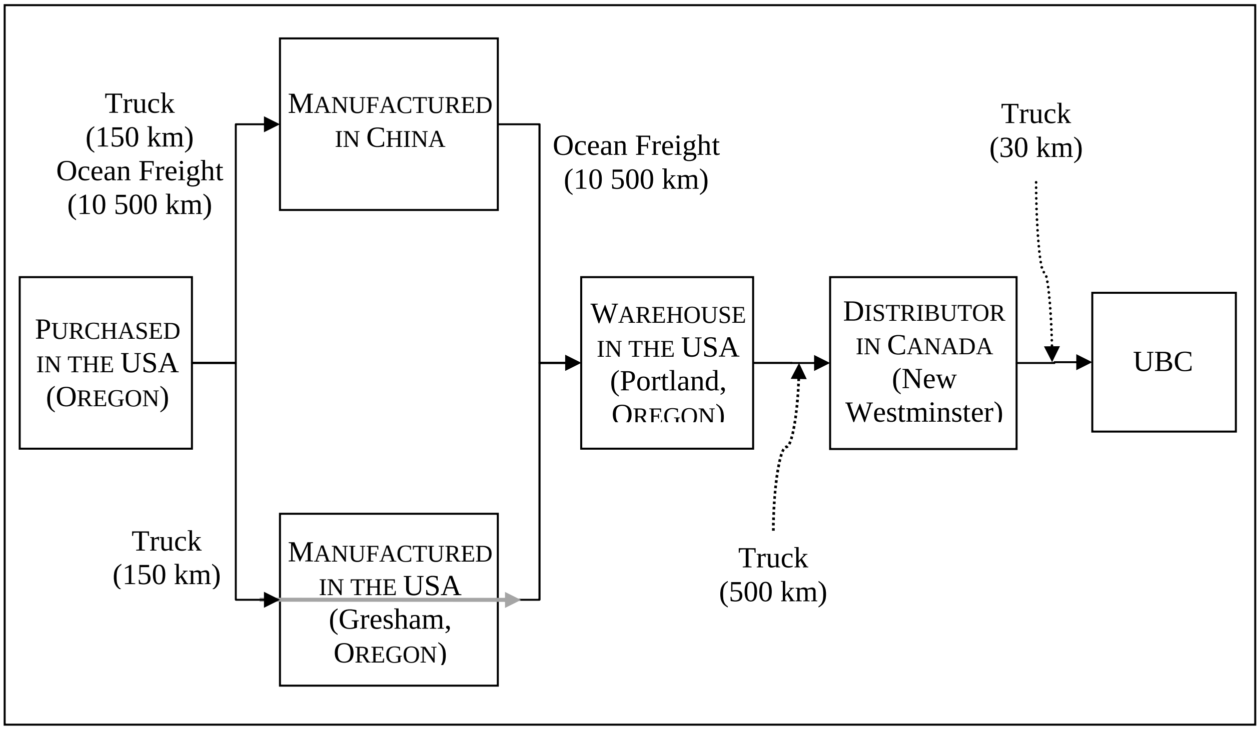

Figure 2 BFS (Taterware) Process Location and Transport Diagram

4 Agriculture

BSI and BFS have chosen different approaches for obtaining the PLA that forms their containers and utensils. BSI purchases PLA resin that is made from corn, whereas BFS purchases potato starch that must be further processed into resin.

For the purposes of this LCA, both corn and potato based starches are considered equivalent. Agricultural energy inputs are defined as those up to and including the production of starch.

4.1 BSI: Production of Corn Starch

Table 1 below summarizes the energy inputs required for the production of corn starch.

Table 1 Energy Inputs for the Production of Corn Starch

Farming		
Energy Input[ix]	73033211	kJ/ha
Crop Yield[x]	5014	kg/ha
Input per kg Corn	14567	kJ/kg
Input per kg PLA	25874	kJ/kg
Milling		
Input per kg Corn[xi]	2315	kJ/kg
Input per kg PLA	4112	kJ/kg
Total		
Input per kg Corn	16882	kJ/kg
Input per kg PLA	29986	kJ/kg

The farming energy input and crop yield values found in Table 1 above are based on agricultural practices in the Liaoning province in China in the 1980's. The Liaoning province is part of the North China Plain, a major agricultural and corn producing region.[xii] As no specific region in China could be identified as the source of the corn used in BSI's products, this assumption may be allowed to stand.

It should also be noted that this data may be somewhat outdated, as farming practices have likely become more mechanized (and thus more energy intensive) within the last thirty years. Nevertheless, these values have been accepted, as a parallel calculation based on corn farming practices in the USA resulted in a value of approximately 23 000 kJ/kg of corn, which is on par with the value given in Table 1.[xiii]

Once the corn is harvested, it undergoes a wet milling operation. This involves slow cooking the corn in water for thirty or forty hours at approximately 50^{o}C to cause it to soften and release its starch. The corn is then ground, allowing for the starch to be separated out.[xiv] [xv] The milling process was calculated to require about 2300 kJ/kg of corn.

The total energy input per kilogram of corn was calculated to be 16 882 kJ/kg; this was then converted to 29 986 kJ/kg of *PLA*. Accounting for a water content of 15%, corn is approximately 63% starch.[xvi] In addition, perhaps 10% of the starch is not converted into PLA (this assumes that the starch can be completely broken down into dextrose).[xvii] Thus, only about 56% of the corn harvested and milled is converted into the desired end product. For consistency, this LCA normalizes all energy flows against a unit mass of PLA.

4.2 BFS: Purchase of Potato Wash

BFS purchases potato wash and converts this into PLA resin. Potato wash is essentially starch and water. When potatoes are cleaned before processing, they are subjected to high pressure water which not only removes their skin, but a portion of starch as well.

Because potato wash is considered a waste product, the energy required for growing and processing potatoes will not be considered in this analysis.

However, as was with the corn, it is assumed that only about 90% of the potato starch is converted into PLA resin.[xviii] Thus, one kilogram of potato based PLA requires 1.1 kg of potato starch to produce.

5 Manufacture

The manufacturing portion of this LCA is bounded by the conversion of starch into resin and the production of the final utensil or food container product.

5.1 Process and Energy

While BFS produces its own resin, and BSI purchases it, both companies either directly or indirectly follow a very similar sequence of steps: converting starch to resin, plastic compounding, and some method of shape formation, such as injection molding in the case of utensils.[xix] [xx] While energy usage will certainly vary due to equipment or process differences, given the scope of this analysis and a lack of specific machine details, it is assumed that both companies use the same amount of energy for manufacture. A rough estimate of 4000 kJ/kg of PLA was obtained to encompass the manufacturing process.[xxi]

5.2 Sources of Power Generation

Both companies report using electric power from their local power grids for at least some of their manufacturing processes. While this report shall not delve into upstream energy costs, it is worth noting that while both companies may use similar quantities of energy, the energy itself is generated using differently weighted methods.

BSI manufactures its products in China. In 2004, China produced 82% of its electricity from conventional thermal sources (predominately coal), 16% from hydroelectricity, and 2% from nuclear sources.[xxii] This breakdown is illustrated in Figure 3 below.

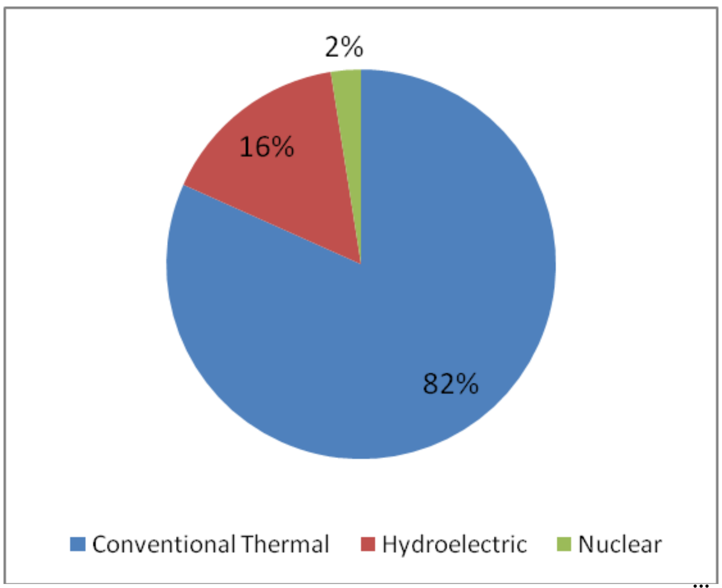

Figure 3 Electric Power Generation, China 2004[xxiii]

BFS also manufactures most of its products in China. However, 25% of its manufacturing is done in Oregon, USA. As seen in Figure 4 below, 72% of its electricity is generated using renewable sources (mainly hydroelectric).[xxiv]

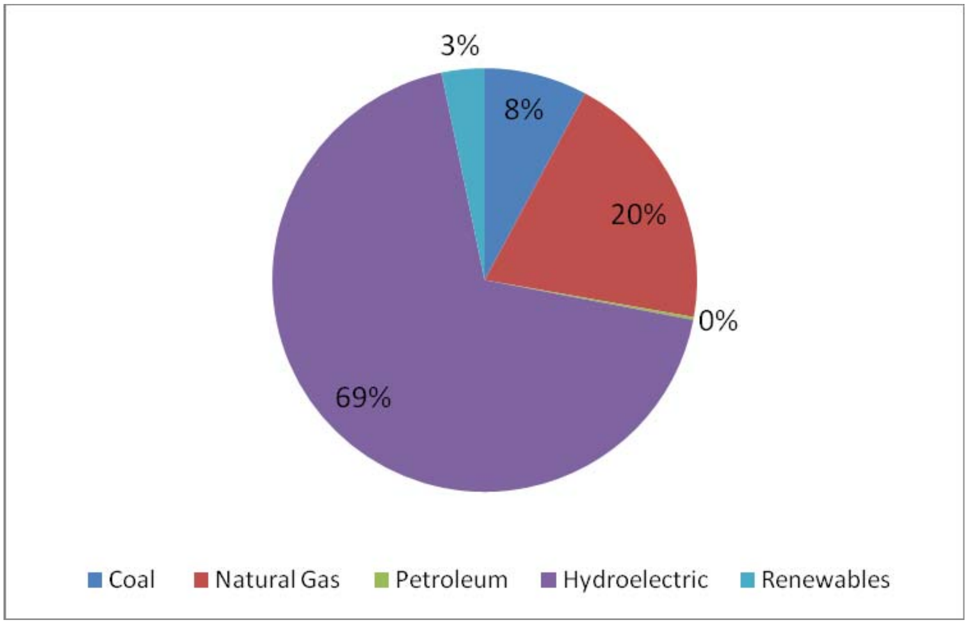

Figure 4 Electric Power Generation, Oregon 2005[xxv]

Assuming that each company uses electric power that reflects the general trend of its region, then BSI and BFS's China stream use the most non-renewable energy. BFS's Oregon option uses the least amount of conventional thermal sources, only 28%. When weighted (25% Oregon, 75% China), BFS uses 13.4% less non-renewable energy than BSI for its manufacturing process. The manufacture of BFS products will also likely produce fewer air pollutant emissions, as it uses less coal, which is notoriously dirty. These values are summarized below in Table 2.

Table 2 Electric Power Generation by Source

Supplier	Conventional Thermal	Hydroelectric and Renewable	Nuclear
	Percentages		
BSI	81.7	15.8	2.5
BFS (Taterware)			
Oregon Option	28.0	72.0	0.0
China Option	81.7	15.8	2.5
Weighted Average	68.3	29.9	1.9

6 Transport

As seen in Figure 1 and Figure 2, both BSI and BFS travel between China and North America using a combination of trucks and ocean freights. This analysis considers one complete trip, starting from the corn farm or the site of potato wash purchase, and ending at UBC. It excludes any return trips the trucks or freighters may have to take. It also excludes the upstream energy costs of manufacturing these vessels, and rather focuses on the energy immediately expended for locomotion.

6.1 BSI: Shipping Path

BSI uses corn grown in China; as was stated in Section 4, it is assumed that this occurs in the Liaoning Province. As a departure point from China could not be determined (other than to note that it was in southern China), a port near the city of Hong Kong was assumed. The site of manufacture was noted to be very near the port (about 10 km away).[xxvi] Thus, the corn grown in Liaoning must be trucked to Hong Kong; using the Direction Function in Google Maps[xxvii], this was determined to be about 2 300 km. (All other distances, unless specified by representatives from either company, were estimated using Google Maps as well.) The distance from Hong Kong to BSI’s warehouse in Richmond, Canada is approximately 10 300 km by ocean freight. Finally, the distance from the warehouse to UBC is about 23 km.[xxviii]

6.2 BFS: Shipping Path

BFS purchases its potato wash in Oregon. From there, 25% of it travels to Gresham, Oregon for manufacturing, while the remaining 75% is freighted over to China.[xxix]

Assuming a central point in Oregon as the point of purchase, the distance to Gresham is approximately 125 km. From there, the manufactured product is transported to a warehouse. BFS has three warehouses located in Renton, Portland, and Hayward.[xxx] Portland, which is central to these three locations, was assumed to be the warehouse that supplies UBC. From Gresham to Portland, it is approximately 25 km. From Portland, the products travel to a Unisource distributor. While Unisource has many locations, its site in New Westminster, Canada is the closest to UBC, and thus the one that was used in this analysis. The distance from Portland to New Westminster is about 500 km, Finally, the distance from the distributor to UBC is approximately 30 km.

For the potato wash that is transported to China, it is estimated that a distance of 150 km must be covered by truck to reach a port (assuming Portland). From Portland to Hong Kong, a distance of approximately 10 500 km is traveled. It is assumed, as was the case with BSI, that the manufacturing takes place very close to where the freight docks. The return trip back to Portland is another 10 500 km by ocean freight, followed by another 530 km by truck to reach the distributor and then UBC.

6.3 Calculating Energy Usage

To calculate the energy consumed traveling by ocean freight, a rate of 0.2 kJ/kg km was determined via literature review.[xxxi]

To determine the energy consumption of trucks, values were used from the GHGenius LCA model. For a heavy duty diesel truck driving on a highway, 0.35 L/km of fuel are consumed. The high heating value of diesel is 38 653 kJ/L. Finally, at full capacity, the weight of the product and the fuel in the vehicle was assumed to be 20.384 tonnes.[xxxii] From these values, 0.6634 kJ/kg km was calculated as the rate of energy consumption of a truck.

Using the distances estimated and the energy consumption rates, a table of distances and energy usage was produced (Table 3). Note that this table shows energy usage per kilogram of PLA. For example, since it takes about 1.1 tonnes of potato wash to produce one tonne of PLA, the shipping requirements will be greater for the unprocessed wash than the PLA. Thus, more energy is used. (Please see Section 4 for more details regarding the basis of these conversions.)

Table 3 Shipping Distances and Energy Usage

Supplier	Truck	Ocean Freight	Total	Percentage of BSI
	Distances (km)			
BSI	2323	10300	12623	100%
BFS (Taterware)				
Oregon Option	680	0	680	5%
China Option	680	21000	21680	172%
Weighted Average	680	15750	16430	130%
	Energy Usage (kJ/kg of PLA)			
BSI	2706	2060	4766	100%
BFS (Taterware)				
Oregon Option	460	0	460	10%
China Option	479	4433	4912	103%
Weighted Average	474	3325	3799	80%

The distances traveled by BFS's products range from 5% to 172% of the distance traveled by BSI's products. However, in terms of energy use, BFS uses approximately equal or lesser amounts of energy than BSI, depending on the option.

The travel energy expenditures of BSI and BFS's China option are almost equivalent, despite the latter traveling 72% farther. This is because of two reasons. The first is because significantly more corn is required to make PLA than potato wash (1.8 kg of corn and 1.1 kg of wash both make 1 kg of PLA). The second is because BFS's products that are manufactured in China travel mostly by ocean freighter, which consumes less than a third of the energy that trucks do.

7 Overall Energy Usage

Table 4 below summarizes the total energy usage for each company and sub option.

Table 4 Total Energy Usage

Supplier	Agriculture	Manufacture	Transport	Total	Percentage of BSI
	Energy Usage (kJ/kg of PLA)				
BSI	29986	4000	4766	38752	100%
BFS (Taterware)					
Oregon Option	0	4000	460	4460	12%
China Option	0	4000	4912	8912	23%
Weighted Average	0	4000	3799	7799	20%

In the case of BSI's products, the agricultural portion of their lifecycle is by far the most significant, requiring about 77% of their total energy input.

In the cases of BFS's China and weighted options, both manufacture and transport consume about the same amounts of energy. However, with BFS's Oregon option, its transport energy expenditure is quite small, making the manufacturing process the most energy intensive step in its production.

Compared against each other, BSI uses by far the most amount of energy, while BFS's Oregon option uses the least.

8 Conclusion

Of the two companies considered, BSI and BFS, the PLA products of the latter were found to consume less energy throughout their lifecycles. An analysis of BSI's products must include the energy invested into growing and processing corn. However, the analysis of BFS's products did not include any agricultural energy inputs, since they use a waste stream from another industry as their base material.

Of BFS's Oregon and China sub-categories, the products manufactured in Oregon use significantly less energy. This is because the energy inputs required for transport are much lower. Products manufactured in Oregon only travel about 3% of the distance of those that are manufactured in China.

While this analysis has indicated a clear “winner” in terms energy consumption, there is still a great deal of room for future improvements, such as increased accuracy of estimates and assumptions, expansion to include upstream fuel costs, and the consideration of greenhouse gases.

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