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An Investigation Into Compostable Plastic Bags

Sicong Liu

Ian Moult

Boguslav Long

University of British Columbia

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An Investigation Into Compostable Plastic Bags

Instructor: Mr. Dipanjan Sengupta

Group members:

Sicong Liu

Ian Moult

Boguslav Long

ABSTRACT

Plastic packaging, and in particular plastic bags are one of the most commonly found items in landfills. In an attempt to improve the sustainability of the new Student Union Building at U.B.C. biodegradable plastic bags are being considered. This report will focus on the use of biodegradable plastic bags in the new SUB building at U.B.C. and on which products currently available on the market would be best suited for this application.

Three different types of biodegradable plastics are reviewed. These are starch based plastics, poly- lactic acid (PLA) plastics and poly-3-hydroxybutyrate plastics, all of which were chosen as they are the most readily available. A thorough analysis of each plastic was performed with a focus on the durability, sustainability, biodegradability and cost.

This report finds that PLA based plastic bags are the most promising for use in the new SUB building. PLA bags are readily available, are both durable and water resistant, and decompose readily in a landfill environment. They therefore meet all the desired requirements, which was not true of the two other plastics reviewed.

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1.0 INTRODUCTION

Plastic bags are one of the staples of any commercial vendor. Nearly all products that we buy come in plastic bags, and nearly all of them end up in the landfill. Plastic bags are one of the largest sources of waste in both developed and un-developed countries. This is a significant problem as conventional plastics do not biodegrade in a reasonable time span, with typical plastics taking hundreds of years to decompose. As such, plastic bags made of conventional plastics accumulate in landfills, our oceans and wilderness. Because of this, when developing a new commercial center such as the new SUB, it is essential to incorporate ways to reduce the plastic waste from these facilities if the building is to be sustainable. This is, however, a difficult problem to address as plastic bags are used in everything from the commercial vendors who sell them to hold food, to the janitorial staff that uses them for garbage removal. Plastic bags have traditionally been used to fill all these roles as they are inexpensive, impermeable to water, lightweight yet mechanically strong, and do not decompose or dissolve in the presence of the substances they hold. In an attempt to eliminate the use of plastic bags, many approaches have been attempted in the past. One method is to use reusable bags. This however has the disadvantage that it is much more expensive, and does not work for garbage disposal. With the advent of biodegradable plastics it is now possible to create plastic bags, as well as other plastic items such as utensils, which will biodegrade much more rapidly. This gives the opportunity to greatly reduce the waste generated by commercial facilities, in particular the new SUB, by using decomposing plastic bags.

This report will discuss the possible choices for biodegradable plastic bags to be used in the new SUB at UBC. A review of the most common biodegradable plastics on the market has been performed to determine which plastics would be the most beneficial for garbage bags in the new SUB. When performing this analysis many factors other than simply the rate at which the plastic bags will decompose were taken into account. Most importantly, it is necessary that the plastic bags be financially sustainable, and furthermore they must be able to meet the mechanical requirements that are satisfied by traditional plastic bags. We believe that it is essential that these requirements are met, or else it will be difficult to enforce the use of biodegradable plastic bags by vendors and staff if there are advantages to the traditional plastic bags.

This report will focus on three types of biodegradable plastics. The most commonly used biodegradable plastics are starch based plastics which constitute 50% of the biodegradable plastic market. Poly-lactic acid and poly-3-hydroxybutyrate plastics will also be investigated. This report will conclude with a recommendation on which plastic we believe to be best suited for the applications in the new SUB building.

2.0 INTODUCTION TO SUSTAINABLE PLASTICS

Traditionally, plastics have been made from petroleum products. This approach to plastics is unsustainable as the plastics are both made from a non-renewable source, and are also generally difficult to recycle and do not biodegrade. Due to the widespread use of plastic in our society, and in particular plastic bags, other materials have been proposed to replace plastics in a more sustainable manner. The two major approaches to this are bio-plastics and biodegradable plastics. Although similar, these two terms are often misused and confused. Bio-plastics refer to plastics that are made from biological materials. This however does not guarantee that they are biodegradable. On the other hand, biodegradable plastics are plastics that will biodegrade with a certain rate in traditional landfill conditions. The certification of bio-plastics and biodegradable plastics will be discussed in more detail later in this section.

The commercial marketability of bio-plastics and biodegradable plastics began in the 1950s with the advent of amylomaize, a high starch content corn. Starch based plastics are now one of the most abundant types of biodegradable plastics available. They are particularly attractive as they are resistant to fairly high temperatures, and can be injection molded using the same techniques as for petroleum based plastics.

In 2004, another important category of biodegradable plastics, poly-lactic acid (PLA) plastics, were developed by the NEC corporation of Japan. PLA plastics have the advantage that they are transparent, and thus can be used in many packaging applications that have been traditionally reserved for petroleum based plastics. The market for PLA plastics has grown substantially, and there is now an American company called Natureworks LLC that exclusively manufactures and markets PLA based plastics. The development of this variety of high quality biodegradable plastics has made it feasible to replace traditional plastic products with biodegradable plastics. An example of this is Fujitsu computers which now manufactures computer cases from biodegradable plastics. This gives hope to the idea that biodegradable plastics could be implemented in the new SUB.

Before beginning the investigation into the applicability of biodegradable plastics for the new SUB, the regulations defining bio-plastics and biodegradable plastics will be reviewed. In the United States a plastic is deemed biodegradable under the ASTM D6400 specifications if it will decompose by 60% in 180 days in aerobic industrial or commercial compositing facilities. In Europe, these regulations are stronger, as to be deemed biodegradable a plastic must decompose by 90% in 90 days. These regulations are in place to ensure that the time span for the degradation of biodegradable plastics is comparable with that for traditional compostable materials. On the other hand, regulations on bio-plastics enforce only the percentage of biological material used in the fabrication of the material, but make no claim towards the biodegrability of the product.

3.0 STARCH BASED PLASTICS

3.1 INTRODUCTION TO STARCH BASED PLASTICS

Starch based plastics are the most commonly used bio-plastic and occupy almost fifty percent of the bio-plastic market, moreover, the demand for the starch based plastics increased thirty five million pounds in the last five years. The most basic component of starch is a semi-crystalline component isolated from corn, rice, wheat and even the tubers of potato and cassava. The process to convert the semi-crystalline component of the starch to the terminal material for the starch based plastics is complex. The original starches are non-plastic and the manufacturers have to mix them with gelling agents and plasticizers in order to reshape the structure of the starch to form a plastic which is homogeneous and amorphous. For some products such as loose-fill packaging, the manufacturers have to remove the nutrition components of the starch in order to avoid attracting pests and children.

3.2 THE PROCESS OF DECOMPOSITION

Compared with conventional plastic products, the other advantage for starch based plastics is that they are decomposable. The easiest way to decompose the starch is to heat it up to three hundred degrees centigrade. The following figure illustrates the procedure for the degradation of the starch. There are two main phases where weight is lost while heating the starch. The first occurs when the temperature reaches one hundred degrees which indicates the evaporation of moisture which is another important element in the starch based plastics. When the temperature increases to three hundred degrees, the second phase occurs and starch based plastics will be decomposed completely.

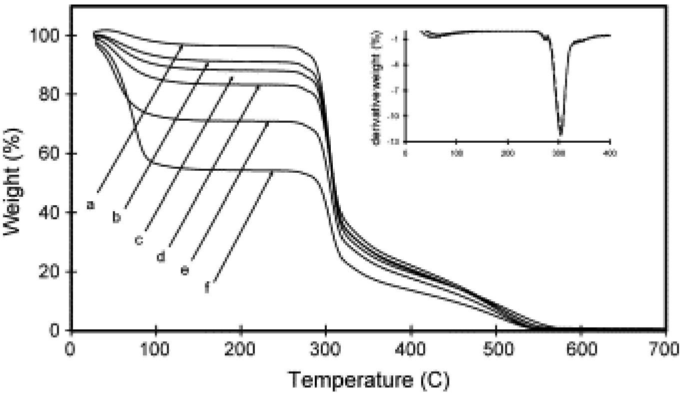

Figure 1: Decomposition Diagram of Starch Based Plastics

3.3 PRODUCTS OF STARCH BASED PLASTICS

As technologies advance, an increasing number of starch based plastic products have been developed including agricultural mulches, hygiene products, paper coating, loose-fill packaging and starch–polyester films. The most commonly used product is loose-fill packaging which is used to prevent damage to items during shipping. Compared with regular peanuts, the loose-fill packaging made by starch based plastics is far better for our living environment, since it does not contain any toxic elements and the price for the resource is cheaper. However, it has higher weight, less durable and has higher production costs than conventional plastic peanuts.

Figure 2: Loose-fill Packaging

3.4 WEAKNESSES AND IMPORVEMENTS

According to a recent study made by Sathya Kalambur and Syed Rizvi at the Department of Food Science, Cornell University, starch can be used to replace plastic packaging in the future, because it does not have any negative influence on the environment. However, compared to the other two biodegradable plastics, poly-lactic acid plastics and poly-3-hydroxybutyrate, the growth rate of producing starch packaging is much lower. This is mainly because starch has many disadvantages including poor water resistance, deterioration of mechanical properties and brittleness in the absence of suitable plasticizers. Scientists are trying to blend the starch with other polymers so that it can be used in different applications to replace plastics. But, they still can not find an efficient way to reach their achievement because of the miscibility between starch and other polymers, the deteriorative mechanical property after blending with other polymers and the high costs incurred. As a result, even though the starch based plastics still occupy the largest bioplastic market, it could be replaced by poly-lactic acid plastics, poly-3-hydroxybutyrate or other types of bio-plastics in the future.

4.0 POLY-LACTIC ACID PLASTICS

Poly-lactic Acid (PLA) plastics are compostable as they are made from vegetable sourced polyester polymers spun by the process of melt-spinning into a fiber with varying properties dependent upon the ratio of enantiomers used when made.[1] These properties make it an ideal choice for the plastic base for any and all disposable plastics being used in a project with a focus on sustainability such as the construction of the new SUB.

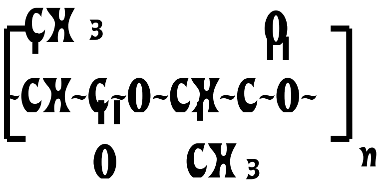

Figure 3: Poly-lactic Acid Chain Formula for Chain Length 'n'

4.1 HOW ARE PLA PLASTICS MADE

The manufacture of PLA is a two phase procedure. First the PLA must be extracted and formed into pellets. Regardless of whether corn starch or cane sugar is used, the process for PLA manufacture begins by fermenting it with a bacterial culture that excretes lactic acid.[1] Once the bacteria culture has converted as much as it can of the starch/sugar base stock to lactic acid, the acid must be separated and "oligomerized and then catalytically dimerized to make the cyclic lactide monomer."[1] Natureworks, the leading North American company in this field, tells us that "[on] average, approximately 2.5 kg of corn (15% moisture) are required per kg Ingeo™ biopolymer."[5] Although it seems like a lot of waste, "A part of this difference is simply water, a part of it ends up in other corn wet mill products such as germ oil, corn gluten meal and corn gluten feed, and a part compensates for the yield losses in the different processes"[5] which makes the process more efficient and therefore more environmentally sound. Second the polymer, usually in the form of pellets, must be melted and spun into fibers useful for the specific application being considered. PLA fibers are spun using melt-spinning, a process which is much less energy intensive than solvent-spinning and which produces a more flexible range of properties for the plastic.[1]

4.2 COSTS

Unfortunately, PLA is still more expensive than most petroleum plastics, but its price has been dropping as its production rate increases.[1] The demand for the vegetable sources that PLA is made from is growing as they are not only used for food, but for bioethanol and other starch-based plastics.

4.3 DURABILITY

Since PLA will not compost until it is hydrolyzed under the right conditions, the durability of PLA products is not affected by the capacity for the polymer to be degraded.[12]

4.4 BIODEGRADABILITY

PLA is arguably a one-hundred percent biodegradable polymer, although there is no current regulation to specify exactly what that means. What can be said is that PLA is a plastic that will compost when left in the right conditions for a period of one hundred and eighty days.[1] What this means is that if the products made of PLA are left exposed to heat and moisture at sixty degrees centigrade, they will degrade into components that can be consumed by bacteria and eventually converted into simple molecules such as CO_2 and H_2O. It is important when considering purchasing a PLA product to be conscious as to whether or not it is blended with a conventional petroleum plastic as the mixture can greatly affect the biodegradability and result in a product which is only degradable. Degradable products decompose into their fundamental fibers but are not capable of being consumed by bacteria to CO_2 and H_2O. If the measured conversion of a biodegradable plastic to CO_2 in the prescribed compost conditions exceeds sixty percent, but does not exceed ninety percent over 180 days, the plastic product is certified “ASTM D6400-04”, and if it exceeds ninety percent, “EN 13432” certification is issued.[1] PLA garbage bags that do not blend conventional petroleum plastic boast EN 13432 certification as their structure is completely compostable.

4.5 SUSTAINABILITY

PLA plastics seem like they are a very sustainable source of plastic. PLA is not perfectly sustainable, however, as energy is lost to the endothermic polymerization reaction and the conversion of PLA into fibers by melt-spinning. Also, because PLA plastics are made from corn or other vegetation, food is being used to make biodegradable plastics. PLA does, however boast a smaller environmental impact than any of the other synthetic fibers. Although this is a more sustainable process than making non-biodegradable plastics from finite reserves of oil, it isn’t a completely sustainable solution to the world’s growing plastic demands. The number of plastic bags produced each year is immense, and in 2002 alone, “Factories around the world churned out a whopping 4-5 trillion of [them]… ranging from large trash bags to thick shopping totes to flimsy grocery sacks.”[6] And “Each year, Americans throw away some 100 billion polyethylene plastic bags. (Only 0.6 percent of plastic bags are recycled.)”[6] If PLA replaced the conventional petroleum plastics which traditionally end up thrown away, it could be the future solution to seemingly endless accumulation of plastic garbage in the biosphere.

5.0 Poly-3-Hydroxybutyrate Plastics

Poly-3-Hydroxybutyrate plastics are a plant-based plastic polymer which boasts biodegradability. It is similar to PLA plastics in its synthesis in that plant matter is fermented in a bacterial culture to produce the virgin polymer. The plastic produced is resistant to water and doesn't degrade, but it is a little brittle, and for instance, dropping a brick into a PHB garbage bag would certainly break it. Unfortunately, the longer PHB is stored, the more brittle it becomes

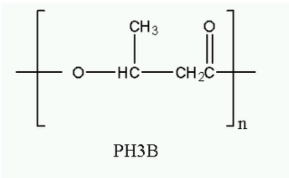

Figure 4: Molecular Structure of Poly-3-Hydroxybutyrate

5.1 HOW ARE PHB PLASTICS MADE

Poly-3-Hydroxybutyrate plastics (PHB plastics) are formed from polyhydroxybutyrate, a molecule formed by certain microorganisms, such as *Alcaligenes eutrophus* or *Bacillus megaterium,* when they are under "physiological stress".[8] The molecule is formed to store energy for later use, similar to how animals store fat.[12] The first time PHB was identified was in 1926 when Maurice Lemoigne, a French researcher working with the bacterium *Bacillus megaterium*.[13] This discovery was not appreciated until recently as inexpensive petroleum becomes scarcer.

5.2 COSTS

The cost of manufacturing garbage bags from PHB is quite high when compared to conventional petroleum plastic bags, but quite reasonable compared to other biodegradable plastics. PHB has a low molecular weight which makes it unstable near its melting point. It is said to be "difficult to process since it decomposes at temperatures roughly 10^{o}C above its 177 ^{o}C melting point"[12]

5.3 DURABILITY

PHB is not a very durable plastic when used as a thin film. Its brittle nature means that many types of garbage will rip the bag rendering it useless for its function.[11, 8] As a consequence, this report does not recommend PHB garbage bags be used in the new SUB.

5.4 BIODEGRADABILITY

PHB is a completely biodegradable polymer as it is created from sugar by bacteria trying to store energy. There are numerous bacteria which will consume PHB and reduce it to CO_2 and H_2O in the right conditions of a temperature of 30^{o}C to 60^{o}C and slightly alkaline with a pH of 7.1-7.3.[13] This process happens both anaerobically and aerobically which makes compost heaps a perfect solution to PHB waste. PHB tends to degrade completely in about a month at these conditions.[13]

5.5 SUSTAINABILITY

When one considers the sustainability of a replacement technology it is important to keep in mind its relative environmental impact to the technology it replaces. For instance, "In PE production, the impact of abiotic depletion, fresh water toxicity, terrestrial toxicity, human toxicity, photochemical oxidation (HDPE) and ozone layer depletion are 1.7, 1.6–1.9, 3–4, 3, 22 and 4–10 fold those for PHB production"[12] according to one life cycle analysis study. PHB is clearly a much more environmentally friendly polymer when compared to conventional petroleum polymers. The reason PHB is so much better for the environment is because it degrades naturally in the ecosystem provided the right bacteria are present at the right temperature, which isn't unrealistic in many circumstances considering the large number of bacteria that can break down PHB. PHB does use sugar as a feedstock which forces a competition in market prices between sugar as a food commodity and sugar as a plastic commodity. This makes PHB an interesting biopolymer with the potential to offset the negative impacts of plastic refuse in a sustainable manner.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This report finds that PLA based plastic bags would be the best suited, of the three plastics reviewed, for use in the new SUB building. PLA plastic bags have the advantage that they are more durable than the alternatives, especially PHB based plastics, which we highly recommend against, as they are quite brittle. Furthermore, PLA based plastics are water resistant which is extremely important if they are to be used for garbage disposal in the SUB building. Starch based plastics on the other hand generally have poor water resistance and in fact absorb humidity, which could present problems for storage and use. Another advantage of PLA based plastic bags is that although they are more expensive than petroleum based plastic bags, their prices are declining due to the popularity of PLA plastic bags which are now readily available. PLA plastics also meet the requirement for complete decomposability and will decompose in a typical landfill environment in a period of 180 days. This is an improvement over starch based products which typically require heating. Based on these findings, we would recommend the use of PLA based plastic bags in the new SUB building, as we believe them to be an excellent, more sustainable replacement for traditional petroleum based plastic bags.

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