Comparative Life cycle Assessment of Polylactic acid (PLA) and Polyethylene terephthalate (PET)

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ABSTRACT

Most municipal solid wastes and compostable plastics are disposed of in an anaerobic system in landfills, where compostable materials do not decompose. This high volume of municipal waste produced from cradle-to-grave processes can partially change into cradle-to-cradle processes through compositing. The objective of this research project is to determine the difference in environmental impacts of PET and PLA plastics by performing simple life cycle assessments for plastics and categorizing industry representatives' opinions on the differences between PET and PLA plastics. The life cycle assessment (LCA) shows that PLA is considered a greener alternative to PET because its supply chain requires less transportation and thus contributes less CO_2 to the atmosphere. However, results from interviews suggest a disconnection among the various actors along the supply chain with implications for PLA as an environmentally viable alternative to PET. PLA producer and retailers favor PLA use because it is profitable and emits less CO_2. Transfer stations and composter do not accept PLA in their waste streams because they consider PLA as contaminants to the recycling and composting market. The LCA shows that PLA is a sustainable alternative to PET when PLA is fully diverted from landfills. However interviews support that PLA is not fully diverted and most of the material ends up in landfills instead of compost facilities as originally assumed.

KEYWORDS

composting, transfer stations, life cycle assessment, bioplastics, carbon emissions

INTRODUCTION

Most wastes and compostable goods continuously go end up in landfills. These municipal solid wastes (MSW) are kept in anaerobic systems in landfills, where waste materials do not decomposed and produce methane, a greenhouse gas (GHG) 10x greater global warming potential than CO_2 (Lashof & Ahuja, 1990). The land used for landfills is lost due to chemical and environmental hazards from the wastes (Huhtula, 1996). As landfill space slowly decreases, and recycling and composting sites stabilize costs (Lave et al. 1999), landfill alternatives such as recycling and composting become more favorable. Disposable plastics are major contributors to MSW, and most of the materials are can be diverted (Subramanian, 2000). Many possible solutions are proposed, such as burning MSW and recovering the energy produced as electricity. Others have successfully created compostable, plant based plastics that work as well or better than traditional plastics ($Natureworks_1$, 2011).

Traditional disposal plastic goods are commonly made from polymer 1 or Polyethylene terephthalate (PET). PET is a thermoploymer resin refined from petroleum and natural gas. It is a popular polymer because it is lightweight, easily moldable, and strong (Vargas, 2009). PET resin is produce outside the US because most petroleum is produced outside of the country, causing new polymer production costly in terms of transportation and GHG emissions. PET bottles and film are recycled and repurposed into other plastic goods. However, there are some PET goods, such as disposal utensils and food containers, are not recycled (Subramanian, 2000).

For these purposes, Polylactic acid (PLA) may be a better choice due to its compostable properties. PLA is produced from renewable materials such as cornstarch or other plant-based starches. The current PLA market is based around corn due to its abundance and accessibility. PLA is created to be compostable at the end of use ($Natureworks_1$, 2011). The material is usually composted while mixed with other compostable material. Composters learned that PLA compost slower than other materials (Ghorpade, Gennadios & Hanna, 2001) and it does not turn into compost within the time frame they want.

Past LCA comparing PET and PLA suggest that PLA is a better alterative to PET when the product is produced regionally and composted after use (Kuo, Hsiao, Lan, 2005; Vink, Rabago, Glassner, & Gruber, 2002). We do not know if PLA is 100% composted as paste studies have assumed. If the product is not composted and is instead sent to the landfills, then the past

LCA may show a realistic representation of the current PLA market. There are current very few studies has gathered PLA industry representatives' opinions on PLA produce, use and disposal and mapped out the current life cycle of PLA compared to PET.

The objective of this research project is to determine the difference in environmental impacts of PET and PLA plastics by performing simple life cycle assessments for each plastic and understanding industry opinions by answering the two questions. What are the environmental impacts of PLA and PET in terms of distance and energy use? A life cycle assessment will answer the first question because it assesses the distance traveled, energy consumption, and carbon emissions and of PET, from cradle to grave, and PLA, from cradle to cradle. What are the opinions of PLA industry representative on current and future PLA use? To answer the question I conduct interviews with various representatives of the PLA industry to gather their opinions on processing PLA and it's end-of-life options. I then integrate the data gathered from the LCA and interviews to analyze the decision-making process for each representative.

METHODS

System boundaries

System boundaries, especially starting and ending boundaries, are defined before I started to gather data to minimize variation. I set the boundaries for the LCA of two plastics to start at the moment the corn stalks or the crude oil barrels begin their respective journey to the refineries. I assumed that PET is produced from crude oil from the OPEC countries, which produces 41% of the world's oil (BP, 2007). Specifically I am looking at petroleum that comes from the Middle Eastern OPEC countries. And the PLA is produced from corn in Midwest United States, because the US produced 39% of the world's corn and Midwestern states produces more than 50% of corn in the US (USGC, 2010). I could not find the exact location of corn production so the estimated that it was grown somewhere in Nebraska. I used the landfill in Livermore, CA (acgov.org, 2010) as graves for PET. Recology Hay Road of Vacaville and Dixon (Recology Hay Road, n.d) was the grave for PLA for this study. I assumed that all PLA would go into composting facilities while all PET would go to landfills. I did not consider any activities outside of the refinery or manufacturer since these variables are too broad and beyond the scope of this study.

Travel

I gathered the locations of sites the plastics had been transported from one production process to the next, and measure the miles the products had to travel for each step, beginning at the raw material extraction and ending at the disposal site. I did not count the travels made within each life cycle point because the travel made within a life cycle point is minimal compared to the rest of travels.

Carbon emissions

I gathered data for carbon emissions from energy consumption of transportation. I assumed trucks, trains, and container ships are the only modes of transportation used. I also assumed diesel is the only form of fuel used to power the various modes of transportation. I divided distance it traveled by the fuel economy to calculate the total fuel consumption. Lastly, I multiplied total fuel consumption the carbon emission factor for each fuel to calculate the total carbon emission in tons.

Interviews

I conducted semi-structured interviews with PLA industry representatives. I contacted representatives from the environmental board of Alameda County. I then used snowball sampling to contact various potential participants. The interviews were either conducted over the telephone or in person. I started the interviews with the interview questions and continued the interview depending on the interviewee and the topic he/she is familiar with. I did not use the interview contents for statistical analysis since the sample since is too small to be statistically significant. However the information will provide supportive evidence for current use of PET and PLA plastics.

RESULTS

Travel

I found that PET travels a greater distance of 16,480 km compared to PLA, 3940 km. PET traveled 5440 km more than PLA for raw material to refineries/producers. PET traveled 7100 km more than PLA for refineries/producer to retailers/consumers. The two materials traveled the same amount of distance for consumers to disposals sites.

Table 1. Distance traveled by each plastic. I calculated the partial distances and the total distance each plastic travel in its lifecycle

	PLA (km)	PET (km)
Raw material to refineries/producers	1060	6500
Producers to retailers/consumers	2800	9900
Consumers to disposal sites	80	80
Total	3940	16,480

Carbon emissions

I found that PET emits more carbon, 3000.02 tons, than PLA, 0.97 tons. PET and PLA emitted majority of their carbon from transportation from raw materials to consumers, 3000 tons and 0.95 tons, respectively. PET and PLA have similar carbon emission when traveling from consumers to disposal sites. Fuel consumption mirrors thus carbon emission results, such that PET consumes 4.11×10^6 liters of diesel and PLA consumes 1.31×10^3 liters of diesel.

Table 2. Possible modes of transportation, their emission factor and fuel economy. I found the emission factor for each type of fuel and the fuel economy of each type of transportation.

Mode of Transportation	Fuel type	Carbon Emission Factor	km or kWh per unit of fuel
Cargo Ships	Diesel	734 g (C)/liter	0.004 km/liter
Trucks	Diesel	734 g (C)/liter	3 km/liter
Trains	Diesel	734 g (C)/liter	0.85 km/liter
Electricity	Coal	2.93 kg CO_2/kg	2 kWh/kg

*Carbon Emissions Factor values taken from EPA

Table 3. Possible modes of transportation. I found the mode of transportation used from point to point and the type of fuel that is used.

	PLA	PET
Raw materials to refineries/producers	Trucks	Container ships
Producers to retailers/consumers	Trucks	Container ships
Consumers to disposal sites	Trucks	Trucks

Table 4. Carbon emission for PLA and PET. I calculated the values by multiplying the distance traveled from Table 1 with emissions per unit and km/kW per unit of fuel from Table 2.

	PLA		PET	
	Fuel consumption	Carbon production	Fuel consumption	Carbon production
Raw materials to refineries/producers	9.53×10^2 liters	0.26 tons	1.63×10^6 liters	1200 tons
Producers to retailers/consumers	9.33×10^2 liters	0.69 tons	2.48×10^6 liters	1800 tons
Consumers to disposal sites	27 liters	0.02 tons	27 liters	0.02 tons
Total	1.31×10^3 liters	0.97 tons	4.11×10^6 liters	3000.02 tons

Interviews

Results from interviews are summarized in Table 5, and suggest a disconnection among the various actors. Producers, retailers and consumer are in favor of PLA use while transfer stations and composters do not favor PLA use in the current industry. The disconnection is apparent once the material reaches transfer stations because the material starts to cause problems for that industry. Producers and retailers are profiting from selling PLA and consumers believe they are buying a sustainable good.

Table 5. PLA lifecycle industry representative responses. Each interview is categorized into it Producers, Retailers, Consumers, Transfer Stations, and Composter. Then their response is categorized to various points on the life cycle.

		Interviews				
		Producers	Retailers	Consumers	Transfer Stations	Composters
PLA Lifecycle Points	Production	-Regionally produced -Made of renewable material -Uses wind energy	-Made of renewable material -There is a lot of corn -Takes less energy to produce	-Made from plant material, more sustainable	-Need to make PLA distinguishable from PET with low cost technology	-The plastic is compostable, but not in the time range we compost in
	Retail	-Profitable -Decrease foreign dependence -Need to work with local composters	-Profitable -Only clear compostable bioplastic in the market	-The plastic is labeled "Green", it must be good for environment	- PLA venders should collect their materials to reduce confusion	N/A
	Consumption	-People are willing to buy greener material	-Durable and environmental packaging -Customers can't tell the difference between PLA and PET	-Could use the corn to feed people instead of making plastics	-Naked eye cannot distinguish between PLA and PET -PLA ends up in mixed plastics or trash	-People are throwing them in composting bins
	Waste/ Compost	-Work done to help distinguish PLA from PET under black light -Can be composted, does not go to landfill	-Works with commercial composting at high temperatures -Can't be recycled and cannot be sorted by MRF's	-It's a compostable plastic it will disappear -Don't really know how to dispose of it since there's no composting bins available	-Do not purposely accept PLA -No one knows what to do with PLA since policy is not clear	-Some do not accept PLA due to OMRI, certification, see PLA as contaminants -Some compost PLA as MSW -PLA does not completely compost and come out the other end as trash

DISCUSSION

The LCA shows that PLA is a more sustainable alternative to PET on a vehicle-miles traveled basis. Natureworks, LLC laboratories have developed PLA to compost at industrial grade compost facilities (Vink et al, 2002). LCA performed on PLA (INGEO) produced by Natureworks, LLC use less energy to produce from cradle to cradle. Current literature contains many published papers covering various LCA comparing PLA, PET, and polystyrene (PS) (Madival, Auras, Singh, & Narayan, 2009). Most LCAs are concerned about the energy use and GHG emissions of the plastics assuming that each plastic does end up at the assigned end-of-life option. However, I found complaints against PLA for not composting in the short period of time needed to compost food scrapes, as well as complaints of high rates of contamination of PLA in PET recycle streams. There is little literature looking into the rate of contamination at source separation and landfill diversion. This research paper gathers the opinions of various industry representatives to determine the trends of the PLA industry and how it differs from previous assumptions.

Producers

The LCA shows the production process emitting 1200 tons of carbon, and PLA emitting only 0.26 tons of carbon. Transportation mode and fuel type for transporting PET is the main reason for such high consumption (Facanha & Horvath). PLA, produced locally, does not travel the long distance the PET travels from point of extraction to the point of production. PET also uses more energy in its production processes because the polymer has higher density (Madival et al, 2009). Assuming that it is produced with the most common form of energy, coal, the carbon emissions is higher than PLA, which uses 60% wind power in its production process (Vink et al, 2002). Past LCA data also shows PLA producing less carbon as a result of less distance traveled, cleaner energy used for production, and biodegradable properties (Franklin Associates, 2009; Kuo et all, 2005; Vink et al, 2002). Energy usage and GHG emissions can be greatly reduced for both materials if the material is extracted and produced locally and uses renewable energy.

Producers take the position that their product is sustainable and a better alternative to PET because it is regionally produced and from renewable resources. The PLA producer in the

US takes the extra step to reduce its carbon emissions by using wind energy. Molds used for shaping PET resin can also be used to shape PLA resin, reducing the need for new equipment to produce various PLA goods. PLA passes federal composting tests and have laboratory tested to be compostable (Vink et all, 2002), diverting it away from landfills and closing the life cycle. Producers continue to produce large quantities of PLA because it is profitable and consumers are welling to buy the material, believing that is sustainable and renewable. They explain that PLA is made from renewable resources, mainly corn. Corn is a widely produced agricultural commodity in the US, and producers believe that there is enough corn for food and plastic production. The large corn production in the US is another reason why PLA can be produced regionally. Large PLA production plants are located in the Midwest where corn is mainly produced in the US.

Retailers

The main energy usage and GHG emissions at this stage is from transporting the material from producers to retailers. PET Retailers are assumed to be local, while PET producers are international. The large distance (9900 km) PET travels from producer to retailers requires a longer and more fuel intensive transit (2.48×10^6 liters of diesel). PLA travels a relatively shorter route (2800 km), and uses less fuel (9.93×10^2 liters of diesel). With the large difference in travel translates to a large difference in carbon emission, calculated from the amount of fuel used for the transporting the plastics (Facanha & Horvath, 2007). These results differed from Madival et al's (2009) result, which assumed that the retailers purchase PET from a continental US producer. Without the trans-Pacific travel assumed in this study, PET travels a shorter distance, and reduces the carbon emission by one-third. Retailers, however, do not have production or storage concerns because plastics are relatively durable goods that do not need extensive energy and care before it is shipped to consumers.

Retailers profit from PLA sells, and continue to promote it by marketing PLA as a sustainable alternative and their customers are willing to pay the higher price for PLA's sustainable profile. Retailers base their advertising information on producer's technical information of the material's composting properties. Some retailers have wide range of knowledge on the plastics and other sustainable goods they retail and believe that they are selling a reliable PET alternative. Retailers also like PLA because it is durable and clear, which they believe is what the current consumer want from a PET alternative. However, they voice concerns on the current system and the high rate of contamination due to the similar visual properties of PET and PLA confusing consumers.

Consumers

Transporting PET and PLA to consumers play a negligible role in the LCA, and is not counted in the study. However, consumers do play a role in sorting and disposing wastes and have an influential role on the end-of-life option for both plastics. Consumers can sort their waste carefully at allow low levels of contamination between solid waste, PET, and PLA; or consumers can not sort their waste and allow high levels of contamination between solid waste, PET and PLA. Consumer actions have a great influence on all sectors of the PLA industry, especially the transfer stations and composting facilities.

The bioplastics market currently loosely defines biodegradable as materials that will degrade over a certain period of time (source needed). However, this period of time is not will defined and leads to misconception of what and how biodegradable materials actually are composted. Some consumers believe that anything with the “biodegradable” labeling is compostable while materials similar to PET are recyclable or solid waste (Madival et al. 2009). Most cannot tell the difference between PLA and PET with the naked eye, especially when the products that are not labeled. Consumers could easily dispose of PLA cups and bottles in recycle bin marked for PET because the material looks similar to PET because they cannot distinguish is two (Stopwaste.org, 2011). This disparity often leads to challenges to transfer stations and composters, as they are at the end of the life cycle determining where the wastes will ultimately go.

Transfer stations and Composters

The main carbon emission in this stage is transporting PET to landfills and PLA to composting facilities. In This study the landfill and the compost facility are assumed to be the same distance away from the consumer. At the beginning of the study I assumed that all PLA went to composting facilities (Franklin Associates, 2009); however, after conducting interviews, I found that most PLA in Alameda County goes to landfills instead of composting facilities. This discussion questions the effectiveness of PLA life cycle and how it is affecting the landfill problem because PLA is considered a solution to diverting waste away from landfills by transforming from a cradle-to-grave cycle to a cradle-to-cradle cycle. Now that I have most PLA being sent to and becoming another burden on the landfills, the bioplastics may not be an effective alterative to PET.

Transfer stations help remove contamination and transport various waste materials, but have a hard time sorting PLA from PET. Transfer stations, as of right now, do not have the technology to sort PLA, so any PLA that comes to the stations are sorted as trash when it is not recognized by the Materials Recovery Facility (MRF) or sorted as PET by human sorters. There are some PLA distinguishable under black light (Natureworks_2, 2011) in the market, but it is not abundant, and PLA not required have the property by law. Transfer stations consider PLA a nuance; if the material contaminations their recyclable plastics, buyers will stop purchasing their plastics and cause transfer stations to lose a large part of their income. When PLA is sorted a trash instead of recyclables, they have to pay for the extra weight when dumping MSW in landfills.

Composters must adhere to state and local health and safety codes to their facilities as well as organic materials regulations. Composters ensure that their composting process follows OMRI guidelines when they produce OMRI certified compost material. Compost feedstock consisting of PLA or other bio-plastics is not in compliance with OMRI (OMRI, 2010). Some have accepted PLA and composted the material alone for testing purposes, however even under these conditions; dense PLA plastics come out of the thermophilic process partially composted and require longer periods of time to become completely composted. To solve to problem of PLA contamination composters would sort out plastic materials and sent it to landfills (Stopwaste.org, 2011). Producers mention that PLA can be composted when buyers work with composter to find a solution. Composters on the other hand do not want to change their processes to fit a new plastic coming into the market. They do not want to change their processes each time a new compostable material appears on the market. They believe producers can change the material to fit their processes since these processes have been used since the beginning of the composting industry

Limitations

This study only covered the county of Alameda and the sample pool is small. The interviews do not represent the opinion of all members of each category and needs a larger sample pool to have more generalizable results. The interviews were conducted by snowball sampling and may have only included member who are interested in the topic instead of the general industry. Interviews with producers were limited to PR managers of firms instead of actual producers of PLA. Interviews of consumers were limited to Berkeley area residents and do not represent all residents of Alameda County. With a larger sample pool, the disconnections will become more visible and more categories of representatives will be identified. Another limitation is the boundaries of the LCA. Since boundaries cannot be set clearly because of large number of manufactures of the same product in various locations. The location for corn production was not clear and transportation values maybe different from actual values. Clearer boundaries can help provide more accurate travel distances and energy use.

Future Directions/Recommendations

This research project only shows the disconnections between actors of the PLA industry for Alameda County. Future projects can expand the interviews to PLA industry representatives in all of California or even the entire country. I only found one disconnection between producers and composter, as the study population expands, more disconnection can be found. Government agencies can then, create policies that will address these issues. As previously mentioned, there are many other types of bioplastics that are not part of this research. I can expand the project to cover other bioplastics and various actors in their respective industries. I will compare various bioplastics and their presumed life cycle and a more sustainable alternative to PET overall.

For this case study I recommend a few changes in the PLA industry to close the gap between the various actors. The best end-of-life option as of current industry standards is to recycling PLA. PLA is easy to recycle through hydrolysis, and a large percentage of the material is recovered (Natuerworks$_2$, 2011). Currently, there is no market for recycling PLA because there is not enough material in the market to recycle it; however once the market matures recycling PLA should be its main end-of-life option. Another way to close the cap is to encourage PLA producers to continue to refine the material and improve the plastic by shortening the time the material takes to compost. Lastly, government agencies, such as OMRI and Stopwaste.org, can work together with composters and producers to redesign policies to allow PLA and other bioplastics that are produced form organic raw material to be accepted as organic compost. Composter can also adopt a new organic certification such as USCC's Seal of Testing Assurance Program (USCC, 2010) instead of OMRI so assure compost buyer of their organic compost.

Broader Implications/Conclusion

PLA is considered a good alternative compared to PET because it is regionally produced. PLA production requires less electricity and uses energy from renewable and local sources. PLA is produced more sustainably than PET, but current disposal methods question the effectiveness of the PLA in terms of waste generation and environmental impact. The current composting industry in Alameda does not compost PLA. It is screen out as municipal solid waste (MSW) and sent to the landfills. Even when the material is composted, it does not compost completely and is later selected out and sent to landfills. The best end-of-life option is for a recycling industry to develop a recycling program PLA as a separate plastic. Composting will not be good options until the material is compostable under current conditions or composting facility have acquired better technology.

The LCA results show PLA as a sustainable alternative to PET when PLA is fully diverted from landfills. However, interviews with industry representatives indicate that majority of PLA in the current life stream do not divert away from landfills. Although this is a case study with a limited number of representatives from Alameda County, the results show a disconnection between producers, composters and other actors in the PLA industry. PLA will continue to go to landfills instead of compost facilities until this disconnection is acknowledged and resolved in the county. In other areas, such as San Jose, PLA is composted with other MSW as low-grade compost. What ever not composted after the process is hauled to landfills. While other areas burn MSW to create electricity, including bioplastics that are not accepted in compost facilities. All of these end-of-life solutions are not optimal because the material is mostly lost a GHG.

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