The Life Cycle of Compostable/Biodegradable Plastics

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GLOSSARY

INTRODUCTION

The Plastics Problem

Since the commercialization of petroleum-based plastics in the 1930s, the material has caused a variety of issues in our natural environment (Colwill, Wright , Rahimifard & Clegg, 2012). From innovations in food packaging and medical devices to the invention of brand new consumer products, plastic has enabled the culture in which humanity exists. The implementation of plastics has been successful and thorough; between 1950 and 2007, the production of plastic globally increased from 0.5 million to 260 million tonnes (O'Brine & Thompson, 2010). The success of plastics and the plastics industry, however, comes at a cost. Approximately 50% of plastics are discarded after just one use (Napper & Thompson, 2019). In Canada, only 9% of plastics are recycled (CBC, 2020). As a result, we are left with endless amounts of plastic waste, which clogs our landfills and litters our natural environment. Our oceans take the biggest hit; 60-80% of marine litter is plastic (Derraik, 2002, in O'Brine & Thompson, 2010). By 2050, it is estimated that there could be more plastic than fish in our oceans (CBC, 2018c). In a world with a growing population, single-use plastics are becoming an unsustainable solution.

Adoption of Bioplastics

As the issues with single-use plastics became known, industries, communities, governments, organizations and individuals have been thinking of new innovations to replace conventional plastics (Napper & Thompson, 2010). Bioplastics have been introduced as a key solution: "being one of the most promising renewable source materials, bio-plastics (e.g. PLA) are considered as one of the highest potential candidates to replace commodity plastics." (Karana, 2012, p. 316). Bioplastics are currently being used around the world in consumer products such as plastic carrier bags, cutlery, containers, straws, bottles and product packaging (Cho, 2017 & Peelman et al., 2013). In these applications, bioplastics are typically single-use. Bioplastics, however, are also being used in reusable contexts such as 3D printing, car insulation, medical implants, bicycles, wind turbine blades and even plane parts (Cho, 2017 & The Conversation, 2018). The adoption of bioplastics has a high rate of growth; the use of biodegradable plastics, specifically, is "increasing at a rate of 30% per year in some markets worldwide" (Greene, 2007, p. 270). In North America, large companies and corporations such as Starbucks are beginning to provide customers with bioplastics in place of conventional plastics (Huffington Post, 2018). By 2022, the global bioplastic market is projected to grow to $44 billion (BusinessWire, 2017). Bioplastics have been introduced in the context of new plastics bans, which are being developed in many Northern American cities, such as Victoria, Vancouver, Seattle, San Francisco and Malibu, among many others (Huffington Post, 2018). Bioplastics are not regulated in most of these bans and therefore, businesses are turning to compostable plastics as a greener alternative. Some cities are even "[requiring] businesses to only offer compostable plastics" (Huffington Post, 2018).

Greenwashing Claims

Despite initial promise and praise, there have been claims that bioplastics do not provide many environmental benefits as advertised. Napper & Thompson (2019) note a "lack of clear evidence that biodegradable, oxo-biodegradable, and compostable materials offer an environmental advantage over conventional plastics" (p. 4776). Greene & Tonjes (2014) agrees, suggesting that "compostable plastics do not achieve any substantial advantages at this time and are not fully sustainable" (p. 100). As a result of the challenges with conventional petroleum-based plastics, small and large businesses are attempting to cater to an environmentally-conscious audience and promote new products as environmentally sustainable (Furlow, 2010). This naturally leads to claims that are simplistic, misleading, or simply false (Furlow, 2010). Activists have created a term for this concept - greenwashing, which can be defined as "the dissemination of false or incomplete information by an organization to present an environmentally responsible public image" (Furlow, 2010, p. 1). As a new innovation, some types of bioplastics have been accused of greenwashing. Greenwashing is a significant threat and can have implications on the trajectory of more sustainable innovations. When false claims are made, companies promoting truly sustainable products "lose their competitiveness" (Furlow, 2010, p. 2). Consumers, in turn, begin to lose trust in sustainability claims and truly "green" technologies are delegitimized (Furlow, 2010).

Paper Summary

This paper will examine literature on bioplastics to summarize the debates on whether this innovation is an effective solution to conventional plastics. The paper will be separated into three sections: the production of bioplastics, the degradation of bioplastics and analysis/discussion. Bioplastics are a very broad category of material; this paper's main focus is on single-use bioplastics made of PLA, specifically compostable and biodegradable plastics. Typically, these products are used as plastic bags or in the food service industry. Much of the information presented, however, is applicable to other forms of bioplastic.

PRODUCTION

Variability in Definitions

The many different types of bioplastics can be confusing to consumers. It is important to note that none of these terms have meaning without certifications and/or regulations. If products are not associated with a certification, no formal definition can apply. There are various certifications available across regions and countries. This makes it difficult to judge bioplastics in general, since each certification may interpret plastics differently and have different standards for how the material breaks down. We can make some general assumptions about each product, but it's important to keep this variability in mind.

Degradable Plastics

Most plastics are degradable, including conventional petroleum-based plastics (Parliamentary Commissioner for the Environment, 2018). Being "degradable" just means that weathering effects such as sunlight, heat and friction will break down the plastic to some extent over time (Parliamentary Commissioner for the Environment, 2018). The end result is typically large fragments of plastic (Parliamentary Commissioner for the Environment, 2018). There are generally no guidelines for how long degradable plastics take to break down.

Biodegradable Plastics

In contrast to degradable plastics, biodegradable plastics can be broken up by *living things*. Biodegradable plastics "can be broken down by the action of enzymes and/or chemical deterioration associated with living organisms, bacteria, fungi and algae" (Napper & Thompson, 2019, p. 4776). Like degradable plastics, biodegradable plastic certifications often do not give any clear timeline for the length of time it takes to break down (Napper & Thompson, 2019). There also isn't a clear picture of the end product, although it typically consists of small chemical elements such as methane, water and carbon dioxide (Parliamentary Commissioner for the Environment, 2018).

Compostable Plastics

Compostable plastics have stricter requirements for breaking down. The end result is compost, which contains nutrients and leaves no toxic residue (Cho, 2017 & Napper & Thompson, 2019). Essentially, they provide the same kind of soil that food waste would after breaking down. Compostable plastics are often associated with the ASTM D6400 certification. The ASTM D6400 certification requires specific industrial composting conditions, including the presence of certain organisms, temperatures above 50 degrees centigrade, and up to 180 days of processing time (Situ Biosciences, n.d.). If an environment does not host these conditions, the plastic is not certified to break down. In Canada, the Bureau de normalisation du Québec (BNQ) established a certification for compostable plastics, CAN/BNQ 0017-988 (Compostable.info, n.d.).

Oxo-degradable Plastics

Oxo-degradable plastics are another form of bioplastic which contain an additive, called a pro-oxidant, that is designed to break up the plastic polymer, leading to biodegradation (Napper & Thompson, 2019). Like biodegradable plastics, there is no clear timeline for biodegradation of oxo-degradable plastics (Napper & Thompson, 2019). Oxo-degradable plastics are known to leave a heavy metal residue after degradation (Compost Education Centre, n.d.).

Bio-based/Bioplastics

Bio-based plastics, often just referred to as bioplastics, are made from natural sources such as corn (Parliamentary Commissioner for the Environment, 2018). It is important to note that when a plastic is labeled bio-based, it is only referring to the material the plastic is made of. Bio-based plastics, therefore, are not necessarily compostable/biodegradable, or vise versa (Parliamentary Commissioner for the Environment, 2018). Compostable plastics can technically be made from fossil fuel-based sources, and fossil-fuel based plastics can be created as compostable plastic. Bio-based or plant based plastics can be misleading because they do not disclose the proportion of the plastics which is bio-based (Parliamentary Commissioner for the Environment, 2018). In the United States, a product listed as “biobased” only needs to contain 25% natural materials (CBC, 2020). In Canada, we have no equivalent regulation (CBC, 2020). Some of the different types of bioplastics include PLA, PHA, cellulose, starch, wheat, and soy protein (Peelman et al., 2013). PLA, or polylactide, is a family of biodegradable polyester (Peelman et al., 2013). PLA is the most common, advanced and cheapest form of bioplastic (Colwill et al., 2012 and National Geographic, 2018). PLA is commonly made from corn or other carbohydrate sources, and is first produced as dextrose and then fermented into lactic acid (Peelman et al., 2013). NatureWorks is a large producer of PLA-based bioplastics. Their product line of PLA is called Ingeo. Ingeo PLA plastics are created using "dextrose and sucrose from canvassa, corn starch, sugar cane, or beets" (NatureWorks, n.d.). In the future, NatureWorks (n.d.) aims to develop PLA from bagasse, wood chips, switchgrass, or straw. NatureWorks is also assessing the possibility of converting carbon dioxide or methane directly into lactic acid, which can be used to make PLA. PHA (polyhydroxyalkanoates) are another common form of biodegradable polymers used to make plastics, and are "produced by a wide range of microorganisms" (Peelman et al, 2013, p.). PLAs are the material typically used in food packaging, whereas PHA is often used for medical purposes (National Geographic, 2018).

Additives

The use of additives in bioplastics is another factor that can impact the end result when they break down in composting facilities or in the environment (Parliamentary Commissioner for the Environment, 2018). These additives can have harmful effects on the natural environment during the degradation process (The Guardian, 2016) and can make the products hard, if not impossible, to recycle (The Guardian, 2016). New Zealand's Parliamentary Commissioner for the Environment (2018) notes that "questions remain as to whether currently available standards adequately address these additives".

Land Use

One of the key debates surrounding bioplastics is the sustainability of using food stock as material for plastics development. Given a growing global population and that many regions still experience food insecurity, using food crops for bioplastics can seem poorly informed. However, the literature on this topic provides conflicting information, especially given the uncertainty of future projections. Colwill et al. (2012) acknowledges that "the production of [bioplastics] requires the use of agricultural land, which is limited in its availability" (p.3). Land, of course, is also an "essential requirement for food production" (Colwill et al., 2012, p. 3). Colwill et al. (2012) notes that food and bioplastics are not the only two things competing for agricultural land; an increasing global demand for biofuel is also a factor. It is unclear whether the production of bioplastics requires an entire food crop, or whether bioplastics are more often produced using the byproducts of existing food production. NatureWorks, the producer of Ingeo PLA, states that crops used to make Ingeo are "purposefully grown to supply both feed and industrial end-uses simultaneously" (NatureWorks, n.d.). NatureWorks claims to make Ingeo PLA using the starch from corn, whereas the proteins from the same corn are used to make animal feed (NatureWorks, n.d.). Quoting research completed by the Nova-institute, NatureWorks (n.d.) advocates for the existence of the bioplastics industry. The Nova-institute describes the use of food crops for bioplastic as a "quintuple win situation" (Carus & Dammer, 2013, p. 6). It is important to note that the Nova-institute has been granted funding from NatureWorks, the European Starch Industry Association, European Bioplastics and other actors either producing bioplastics or advocating for them. The fact that NatureWorks cites a publication from an organization it helped to fund shows the biased nature of many bioplastics studies, and how they are often closely connected to the bioplastics industry. To ensure objective and accurate academic research on bioplastics production, producers must work closely with independent researchers to identify and solve core problems, such as land use.

Amount of Land Used

It is unclear how much land bioplastics currently use, or how much they are projected to use in the future. In evaluating the current amount of land being used for bioplastic production globally, European Bioplastics (n.d.) uses the analogy of a cherry tomato placed next to the Eiffel Tower, with the cherry tomato representing all the land currently being used for bioplastics, and the Eiffel Tower being all the agricultural land in the world. By the year 2024, European Bioplastics (n.d.), the association representing the bioplastics industry in Europe, estimates that land use for bioplastic production could reach about 1 million hectares, or about 0.02% of the available agricultural land in the world. Land-use projections for the future, however, are dependent on many factors such as population growth, agricultural productivity, and consumption patterns (Colwill et al., 2012). Colwill et al. (2012) uses these three factors, among others, to analyze a future in which global oil and gas production is terminated by 2050, and all conventional plastics are replaced by bioplastics. In the most likely scenario, all of the available cropland in the world would be needed to support the future production of food, plastics, and biofuels. Colwill et al. (2012) suggests that this solution is not sustainable and is worse than it seems, taking into consideration the simplistic nature of their study and inefficiencies in the production and distribution process. Colwill et al. (2012) concludes that bioplastics "do not provide a straightforward global solution that will allow human consumption patterns to remain unchecked" (p. 14). In the worst case scenario projected, Colwill et al. (2012) calculated that the demand for agricultural land "far exceeded" (p. 14) production, even taking into consideration the expansion of farmland into forest environments. As for a situation which would adequately meet our future needs, Colwill et al. (2012) states that it is theoretically possible, but unlikely.

Emissions and Climate Impact

Bioplastics have been advertised as a solution to reduce our dependence on petroleum, therefore reducing global emissions and curbing climate change. Plastic production takes up about 4% of the world's petroleum production (Greene & Tonjes, 2014 & Colwill et al., 2012). Displacing this petroleum production would naturally reduce some emissions. Yu & Chen (2008) finds that bioplastic PHA can generate up to 80% fewer emissions compared to conventional plastics. Many LCA (life-cycle analysis) studies have pointed to the emissions benefits of using renewable food sources instead of petroleum to make bioplastics (Piemonte & Gironi, 2011). However, it's important to keep in mind that it is not just the production that's the problem - the "transportation, manufacturing, processing and distribution" (CBC, 2020) of bioplastics can also create emissions. A study by the European Commission's Joint Research Center discovered that "there would be no real difference in lifetime emissions between traditional..[plastic]...bottles and those made from bioplastics" (CBC, 2020) because bioplastics are created in the United States, and would result in significant emissions through their transportation to Europe. Petroleum-based plastics, on the other hand, are produced locally in Europe (CBC, 2020).

Land Use Change Emissions

Studies have also pointed to the large amount of emissions caused by the land-use change needed to produce bioplastics. Piemonte & Gironi (2011) estimate that land use change emissions from bioplastics would release 9 - 170 times more carbon dioxide than the potential carbon reductions from production. Piemonte & Gironi (2011) state that "most life-cycle studies have found that a reduction of greenhouse gases (GHGs) emissions can be achievable by replacing petroleum-based plastics with bioplastics made from renewable feedstocks, but these... failed to count the carbon emissions that occur as farmers worldwide convert forest and grassland to new cropland to replace the corn diverted to bioplastics" (p. 689). Piemonte & Gironi (2011) suggests that to reduce emissions, policy-makers would likely be better focusing on "restor[ing] natural forest and grassland habitats on cropland that is not needed for food" (p. 689).

Storage of Carbon

Another aspect to this debate is the storage of carbon. Since bioplastics are derived from plant material, the conversion of carbon dioxide to sugars results in carbon being held from our atmosphere, as long as they are not biodegraded or incinerated (The Conversation, 2018). The Conversation (2018) states that if "the current world supply of around 300 million tons of polymers were all…bio-based, this would equate to…a billion tons..of sequestered CO2". This is equivalent to about "2.8 percent of current global emissions" (The Conversation, 2018). National Geographic (2018) adds that even if a bioplastic does release carbon when it degrades, it will still "add less carbon to the atmosphere [than conventional plastics] because [it's] simply returning the carbon the plants sucked up while growing". Conventional petroleum-based plastics, on the other hand, releases "carbon that had previously been trapped underground in the form of oil" (National Geographic, 2018). In landfill environments, however, biodegrading bioplastics can create methane, a powerful greenhouse gas which contributes to climate change (Coast Environmental, n.d.).

Discussion: Emissions

There are a lot of things to consider regarding emissions and bioplastics use. Each piece of research brings a unique perspective that contributes to an understanding of the actual amount of emissions involved. Bringing these perspectives together into one study would provide additional clarity. We also should not ignore the other environmental concerns associated with bioplastic production. Tabone, Cregg, Beckman & Landis (2010) find that the production of biopolymers results in "relatively high environmental impacts" (p. 5) including eutrophication, eco-toxicity, and human health concerns. This is a result of the "fertilizer use, pesticide use, and land use change required for agriculture production" (Tabone et al., 2010, p. 5), as well as fermentation and chemical processing. We should keep in mind that PLA bioplastics, by nature, remain single-use products. Therefore, regardless of best practices, there will "still [be] considerable energy outputs and unsustainable resources used in the manufacturing" (Compost Education Centre, n.d.) of these products.

DEGRADATION

Waste Management

Of all the concerns associated with bioplastics, waste management is the issue most often debated and discussed. Single-use plastics have been a significant waste management issue long before bioplastics were invented; approximately 50% of all plastics are discarded after just one use (Napper & Thompson, 2019, p. 4775). In the United Kingdom, plastics account for 8-10% of all the waste generated (Napper & Thompson, 2019, p. 4775). Some forms of single use plastics, such as plastic water bottles and plastic cups, can take up to 450 years to break down (WWF, 2018). As a result, there is a lot of plastic waste in the world needing a home for a long time. Bioplastics are designed to mitigate this issue, and create products that will not last nearly as long in our waste management facilities. Unfortunately, the realities in composting facilities do not live up to the promise of bioplastics. CBC (2018c) states that "most composting facilities are built around food waste and have a turnaround time of between 45 and 90 days". Most compostable plastics, on the other hand, need around 180 days to compost (CBC, 2018c).

Both compostable and biodegradable plastics, as described in their associated certifications such as ASTM D6400, will only degrade in very specific composting conditions (The Telegraph, 2019 & Metro Vancouver, n.d.). For example, they need to reach a temperature of about 60 degrees celsius, and also need to "allow enough moisture to support the micro-organisms which break down biodegradable products" (The Telegraph, 2019). There are more than 90 types of microorganisms that support the biodegradation of compostable or biodegradable plastics including aerobes, anaerobes, and photosynthetic bacteria (Emadian, Onay, & Demirel, 2017). In an industrial facility, compostable plastics need to be in the composting cycle for a longer period of time than regular food scraps (CBC, 2018). In many cases, composting facilities also don't host the conditions necessary to process compostable plastics (The Telegraph, 2019 & Greene & Tonjes, 2014). Karen Storry, a senior engineer with Metro Vancouver, states that "there seems to be confusion about compostable plastics...even if they are compostable, they may not be accepted at your local facilities" (CBC, 2018). Most municipal compost facilities in Canada do not accept compostable plastics (CBC, 2020). If compostable or biodegradable plastics do end up in a composting environment which does not accept them, it can cause harm: “they can cause operational problems, may not break down properly during processing, and may contaminate the finished compost” (Metro Vancouver, n.d.).

Metro Vancouver (n.d.) states that “not all commercial composting and digestion facilities operate under [the] conditions” required for compostable plastics, and as a result, “most municipal food scraps recycling programs in Metro Vancouver currently do not accept plastic items labelled "biodegradable" or "compostable" (Metro Vancouver, n.d.). All compostable or biodegradable plastics in the green bins in the city of Vancouver will be sorted and sent to the landfill (City of Vancouver, n.d.). The City of Vancouver (n.d.) states that “the composting facility in Richmond cannot process any kind of plastic, even bags marketed biodegradable or compostable as it degrades the quality of the finished compost”. Metro Vancouver (n.d.) recommends we dispose of compostable and biodegradable plastic products in the garbage rather than the compost, a practice that results in these plastics going directly to the landfill. Surfrider Foundation Vancouver Island, a non-profit organization, was invited to tour a local composting facility on Vancouver Island, Coast Environmental. At the facility, a manager summarized the issue with compostable plastics: “they just don’t compost!” (Rocketships Inc., 2014). Compostable plastics at the facility often go through a composting cycle several times; anything that remains intact after three-four cycles does directly to the landfill (Rocketships Inc., 2014). There is also a cost implication for facilities; running compostable plastics through the cooker several times can come at an additional expense (Rocketships Inc., 2014). The only compostable items that often break down at Coast Environmental are compostable plastic bags (Surfrider Foundation Vancouver Island, 2020).

On Prince Edward Island, the CEO for Island Waste Management Corporation highlights a key challenge for facilities processing compostable plastics: “compostable [plastics] are very hard to distinguish from regular plastic” (CBC, 2018b). If an Island Waste Management Corporation driver sees a load of compost with compostable plastic items, the CEO states that they “may reject the load not knowing that the items in there were compostable” (CBC, 2018b). Many bioplastics are not associated with a certification, and therefore, even in composting facilities that can process bioplastics, uncertified bioplastics can result in loads of compost being contaminated (Greene & Tonjes, 2014). Susan Antler, the executive director of the Compost Council of Canada, which represents composting facilities across Canada, states that facilities have strict conditions for the types of materials that can be included in their end compost product before it can be sold (CBC, 2018). Antler describes that composting facilities therefore need to be careful about which products are allowed into their compost, especially since it is impossible to tell a compostable plastic product from a conventional plastic product (CBC, 2018). This is complicated by the fact that even when compostable plastics are labeled "compostable", they aren't always actually a certified compostable product.

Home Compost/Terrestrial Environment

The rigorous composting conditions required for the full degradation of compostable plastics can not be met in a backyard compost pile or in a natural environment (The Telegraph, 2019). If compostable/biodegradable plastics end up in a home compost pile, they will degrade "barely any quicker than normal plastic waste" (The Guardian, 2019). Compostable/biodegradable plastics, to be fair, were never certified to break down in home compost environments: "they don't reach high enough temperatures and moisture levels or have the right microorganisms" (Huffington Post, 2018). Napper & Thompson (2019) studied the degradability of compostable, biodegradable, and oxo-biodegradable bags in soil environments, and found that biodegradable and oxo-biodegradable bags remained completely intact 27 months (3 years) after being buried and were still capable of carrying a full 2.25kg load of groceries (Napper & Thompson, 2019). Compostable bags, after 3 years buried in soil, were also not completely degraded (Napper & Thompson, 2019).

Landfill

Most literature suggests that compostable and biodegradable plastics will not degrade in a landfill environment either, and may emit harmful methane emissions. Karen Storry, a senior engineer with Metro Vancouver, states that research is currently inconclusive as to whether or not compostable plastics are better than conventional plastics in a landfill environment (CBC, 2017). Professor Mark Miodownik, who is a materials specialist at the University College London, states that "most compostable and biodegradable products end up in the landfill, where they will not biodegrade" (The Telegraph, 2019). Green & Tonjes (2014) finds that in a landfill environment, bioplastics will likely not behave differently than conventional plastics. If compostable plastics do begin to degrade in landfills, they will likely produce methane (Greene & Tonjes, 2014 & Tabone et al., 2010). Unless facilities collect this methane, it has the potential to negatively impact the environment; methane is "28 times more powerful than carbon dioxide at warming the earth" (National Geographic, 2019).

Recycling

Compostable and biodegradable plastics can also cause issues if they end up in the recycling process. Recycle B.C. (2014) describes bioplastics as “incompatible with the recycling process”. If they end up in the recycling remanufacturing process, they can “compromise the quality and lifespan of the re-manufactured products” (Recycle B.C., 2014). As a result, “material re-manufacturers refuse bales that contain biodegradable material” (Recycle B.C., 2014). If compostable or biodegradable plastics contaminate a load of regular plastic, the entire load could end up in the landfill (Cho, 2017). Recycling facilities have similar problems; the presence of too many compostable plastics in a recycling load could see the whole load being rejected and ultimately sent to the landfill (CBC, 2018b). The Association of Plastic Recyclers (n.d.) states that “PLA collection systems are limited in North America so this does not currently meet the collection accessibility criteria”. In other words, PLA material is not currently accepted at recycling facilities.

Marine Environments

Plastics end up in our marine environments for a variety of reasons. The most obvious is by littering. However, lightweight bags, even when disposed properly, can be transferred away from disposal sites by wind or other weather conditions (Napper & Thompson, 2019). Therefore, we can make the assumption that any kind of plastic will naturally end up in marine environments one way or another. Creating plastics that are fully degradable in natural environments is a challenge, especially since so much variability exists in those environments (Napper & Thompson, 2019). Jacqueline McGlade, the chief scientist of the UN Environment Programme in 2016, criticized the idea of disposing biodegradable plastics in the ocean: “it’s well-intentioned but wrong” (The Guardian, 2016). McGlade states that “a lot of plastics labeled biodegradable, like shopping bags, will only break down in temperatures of 50C and that is not the ocean” (The Guardian, 2016). National Geographic (2018) finds that biodegradable and compostable plastics “function similarly to petroleum-based plastic, breaking down into micro-sized pieces [in the marine environment], lasting for decades, and presenting a danger to marine life”. When bioplastics degrade partially, they can still be “consumed by filter-feeding organisms in the ocean or earthworks on land” (Greene & Tonjes, 2014, p. 99). The University of Houston’s Chief Energy Officer states that even if high-performance bioplastics exist, "they won't automatically solve the problem of plastic pollution in the marine environment" (Forbes, 2019).

There are some conditions, however, that can result in the degradation of some types of bioplastics in the marine environment. Emadian, Onay, & Demirel (2017) state that the biodegradation of bioplastics in the ocean has many factors, including weather temperature, the specific ocean habitat, as well as the different sea waters based on the microorganisms present. In a controlled environment, Napper & Thompson (2019) conducted an experiment in which a compostable plastic bag deteriorated within a 3-month period in the marine environment. O'Brine & Thompson (2010) conducted a similar study, which found the complete degradation of a compostable plastic carrier bag in a marine environment after 24 weeks. Neither O'Brine & Thompson (2010) or Napper & Thompson (2019) tested any other compostable plastics, such as cutlery or plastic cups. Napper & Thompson (2019) also tested biodegradable and oxo-biodegradable bags, which ultimately did not break down in marine environments over the course of 3 years (Napper & Thompson, 2019). After 3 years in the marine environment, an oxo-biodegradable bag was still capable of carrying a full 2.25kg load of groceries (Napper & Thompson, 2019). Napper & Thompson (2019) suggests further research to identify any other potential consequences for the marine environment when compostable bags are degraded, such as the presence of microplastics or nanoplastics. Emadian, Onay & Demirel (2017) also recommend further studies to examine the degradability of compostable plastics in marine environments.

<u>Consumer Behaviour & Awareness</u>

Napper & Thompson (2019) notes that it is impossible for composability to occur unless "products have a high probability of actually reaching the appropriate waste stream" (p. 4781). The Executive Director of Lonely Whale, an environmental non-profit in Seattle, describes that regardless of the debate that exists around composting facilities, "there's still that human element of you and me" (National Geographic, 2018). The Lonely Whale conducted an investigation of waste processed at local businesses in Seattle, Washington. The non-profit discovered that bioplastics rarely make it into compost bins (National Geographic, 2018). A materials specialist at the University College London finds that most people put compostable/biodegradable plastics in the garbage, where they are not sorted out because "they do not look any different to regular plastic" (The Telegraph, 2019). These plastics then end up in the landfill. The Guardian (2019) finds that consumers also often put compostable and biodegradable plastics in their home compost pile, where they are not certified to degrade. A plastic's status as compostable or biodegradable can also have implications for how we use the product: "a plastic carrier bag that is labelled as being 'degradable' or biodegradable is likely to be used for a single application, and could make consumers more relaxed about discarding it, rather than reusing and recycling" (O'Brine & Thompson, 2010, p. 2282).

Several studies have surveyed the public, and found low consumer awareness around bioplastics. In Victoria, B.C., University of Victoria students Carmen Pavlov and Emily Wharin conducted a waste audit of compostable plastics. By auditing trash, recycling and compost bins on the university campus, Carmen and Emily found that more compostable plastics were found in the garbage and recycling bins than compost bins (Surfrider Foundation Vancouver Island, 2020). They also found that 10.7% of respondents hadn't heard of compostable plastics, despite the fact that they were used on campus. 39.3% of respondents weren't aware that compostable plastics were used on campus. 25% of respondents believed that the garbage or recycling bins were the appropriate place for compostable plastics. 50.9% of respondents believed that compostable plastics were "maybe" a good alternative to conventional plastics, whereas 32.1% believed that they were not a good alternative. Carmen and Emily described "lots of confusion [and] lack of awareness" (Surfrider Foundation Vancouver Island, 2020) surrounding compostable plastic products. While Carmen and Emily's audit was limited in scope, the public's unfamiliarity with bio-based, compostable, and biodegradable products is clear in a variety of studies internationally. In a study conducted by Dilkes-Hoffmann et al. (2019) in Australia, consumer awareness of bioplastics was low; 30% of candidates surveyed expressed no familiarity with the term "bioplastic". 70% of those surveyed also did not know if all plastics made from plants are biodegradable (Dilkes-Hoffman et al., 2019). Sijtsema et al. (2016) conducted a similar study in 5 European countries. Previous studies in the Netherlands suggest that "contemporary consumers do not have a clear notion of 'bio-based' as a concept and do not have much ready knowledge of bio-based plastics either" (Sijtsema et al., 2016, p. 62).

As a result of low consumer awareness surrounding bioplastics, many consumers are not processing bioplastics properly. Without consumer understanding of the product and process, bioplastics do not stand a chance at degrading in an industrial facility; lack of consumer awareness delegitimizes the process as a whole. Napper & Thompson (2019) suggest that "it is only by providing accurate, unambiguous, and complete guidance to the user regarding disposal that the potential benefits of these novel materials can be realized without the negative consequences that could result in inappropriate disposal as well as unintended environmental consequences" (p. 4781). This is especially challenging since the science and process behind bioplastics is incredibly complicated for the average consumer to understand: "scientific knowledge required to understand many environmental issues is often complex and subject to change, thereby making it difficult for the general public to comprehend" (Furlow, 2010, p.2).

Discussion: Degradation

Overall, the literature suggests that compostable and biodegradable plastics do not degrade as advertised in composting facilities, in recycling facilities, or in the landfill. Compostable/biodegradable plastic certifications also do not suggest that these materials are able to degrade in marine or terrestrial environments. There is, therefore, a "mismatch between producer claims and consumer experiences" (Greene & Tonjes, 2014, p. 96); compostable and biodegradable plastics are not often able to degrade as they are advertised.

ANALYSIS

Conclusion

This paper highlights some key discussions surrounding bioplastics, and investigates whether bioplastics are adequate solutions to conventional plastics. Environmental Engineer and National Geographic explorer Jenna Jambeck answers the question best: "[its] a big question based on many ifs" (National Geographic, 2018). Throughout academic literature, there was a lot of variation in the context in which bioplastics were studied. Bioplastics, by nature, are a difficult topic to study due to the variance in certifications and materials across geographies. This is especially true as research took place in various different countries, and were informed by various studies around the world. However, certifications for bioplastics are not the same across countries, and the production process is not the same for every producer. Many studies were based out of Europe or the U.K., for example, and it was unclear how relevant these studies were for compostable plastics certified in Canada or the United States. There was also a lack of localized research applicable to Canada. This was of particular concern when it came to waste management; the facilities available vary on a regional basis. Therefore, concerns about compostability in one jurisdiction may or may not transfer to another. Since waste management is a local issue, local research and knowledge is needed to draw conclusions about bioplastics for any one community. Localized research would also better inform policy and regulation around bioplastics.

There is no clear consensus across academic literature about what is considered a compostable or biodegradable plastic; different studies sometimes had slightly different definitions or interpretations. Many studies mentioned "biodegradable plastics", but were referring to plastics that were certified as "compostable". It was difficult to analyze compostable or biodegradable plastics as a whole, since each producer has a different process for the production of bioplastics. For example, NatureWorks Ingeo PLA is created using byproducts from corn used for animal feed, but it is unclear if other types of compostable PLA use the byproducts from existing crops, or if dedicated crops are grown for these products. This knowledge would be valuable in evaluating both the land use and emission patterns associated with bioplastic production.

There were some areas in which the research on bioplastics was mostly conclusive. Most bioplastics will not degrade in a marine or terrestrial environment, nor will they degrade in home compost bins. People generally aren't aware how to properly process bioplastics. The way we currently process bioplastics isn't working, and if we decide to continue using bioplastics, we will need to address the discrepancies that exist between bioplastics certifications and the realities in composting facilities. In order for bioplastics to be effectively implemented, it is clear that there needs to be "availability of a dedicated waste stream, the appropriate infrastructure such as an industrial composting facility and sufficient understanding among consumers to correctly separate their waste accordingly" (Napper & Thompson, 2019, p. 4781). However, other questions have been left unanswered. The sustainability of using agricultural land for bioplastics was inconclusive, as was the amount of emissions created in the production and degradation process. Further research is needed in these areas to clarify the overall impact of bioplastics on our society and community.

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