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Biopolymer production and end of life comparisons using life cycle assessment

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ABSTRACT

This paper presents an attributional life cycle assessment of biopolymers and traditional plastics using real world disposal methods based on collected data and existing inventories. The focus of this LCA is to investigate actual disposal methods for the end of life phase of biopolymers and traditional fossil-based plastics relative to their corresponding production impacts. This paper connects commonly available methods of disposal for traditional fossil-based plastics and the compostability of polylactic acid and thermoplastic starch to compare these materials not just based on production impacts but also on various scenarios for recycling, composting, and landfilling. Additionally, three traditional resins were evaluated (PET, HDPE, and LDPE) using fossil and bio-based production pathways to assess the performance of bio-based products in the recycling stream. The results demonstrate real environmental tradeoffs associated with agricultural production of plastics and the consequential changes resulting from shifting from recyclable to compostable products. The potential for methane production in landfills is a significant factor for global warming impacts associated with biopolymers while recycling provides major benefits in the global warming and fossil fuel depletion categories. A sensitivity analysis was conducted to investigate the relative importance of locale-specific factors such as travel distances and sorting technologies to the end of life treatment methods of recycling, composting, and landfilling. The results show that composting has some advantages, especially when compared to impacts associated with landfilling, but that recycling provides the greatest benefits at end of life.

1. Introduction

Biopolymers are a growing segment of the plastics market primarily in packaging and disposable products (Shen et al., 2010). Biopolymers are plastics that can be produced, at least in part, from renewable materials such as corn and sugar cane. Some biopolymers, like Bio-PET, are blends of conventional and renewable feedstocks (Shen et al., 2010; Hartmann, 1998; Shen et al., 2009). These bio-based plastics have gained interest as an alternative to fossil based plastics because of the potential to shift to more environmentally friendly production and waste handling (Meeks et al., 2015). Some commercially available biopolymers are compostable, though many require conditions for degradation only attainable in commercial-scale composting facilities (Meeks et al., 2015; Hottle et al., 2013; Yates and Barlow, 2013).

Traditional plastic production is a mature industry with materials produced using fossil resources such as petroleum and natural gas. The US Environmental Protection Agency (EPA) reported that in 2013, plastics contributed to 13%, by weight, of the municipal solid waste (MSW) in the US totaling about 32.5 million tons of plastic waste generated annually (USEPA, 2015). Nine percent of plastics entering the waste stream were recovered for recycling, though recovery rate is not necessarily indicative of a final recycling rate. Of total plastics, about 91% are discarded to a landfill or are incinerated. While overall recovery of plastics for recycling was only 9%, recovery of certain plastic containers is more significant. In 2013 polyethylene terephthalate (PET) soft drink bottles were recovered at a rate of 31% while high-density polyethylene (HDPE) milk and water bottles were estimated at about 28% (USEPA, 2015). Despite the ability to increase recovery rates of fossil based plastic mate-

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rials, concerns over increased fossil resource use, greenhouse gas emissions, pollution, and human health impacts associated with plastics have driven an increasing interest in the use of biopolymers (Gironi and Piemonte, 2011; Ren, 2003; Gómez and Michel, 2013; Kijchavengkul and Auras, 2008; Álvarez-Chávez et al., 2012).

Bio-PET is the same polymer as PET aside from the fact that the ethylene glycol component is bio-based rather than fossil-based and they can be recycled together since they are chemically identical (Tabone et al., 2010; Morschbacker, 2009). A fully bio-based PET has been developed which includes both ethylene glycol and terephthalic acid components derived from renewable feedstocks but is not expected to be implemented into the market until 2020 (Plastics Technology Coca-Cola Debuts, 2017). Bio-PET is used in Coca-Cola's Plantbottle™ and is the most prevalent biopolymer in the market (European Bioplastics, 2014; Coca-Cola Coca-Cola GRI Report, 2012). Other biopolymers such as polylactic acid (PLA) and thermoplastic starch (TPS) are compostable (Song et al., 2009). PLA is the most prevalent compostable biopolymer on the market and although it is also technically recyclable, given the current infrastructure and material flow, recycling is not a widely available option for PLA (European Bioplastics, 2014; Song et al., 2009; Soroudi and Jakubowicz, 2013). Compostable biopolymers must conform to American Society of Testing and Materials (ASTM) standards; ASTM D6400-04 Standard Specification for Compostable Plastics and ASTM D6868-03 Standard Specification for Biodegradable Plastics Used as Coatings on Paper and Other Compostable Substrates (Song et al., 2009; ASTM, 2004; ASTM, 2003). Compostable biopolymers often have specific time and temperature requirements needed to achieve efficient degradation and these often necessitate processing at a commercial composting operation (Kijchavengkul and Auras, 2008; Álvarez-Chávez et al., 2012). However, some compostable biopolymer products are coming under increasing scrutiny because they are not fully degrading in commercial composting facilities, complicating the waste management for users and waste handlers of these products (Gómez and Michel, 2013; Cedar Grove Compostabilty Testing, 2014; Ghorpade et al., 2001; Mohee and Unmar, 2007).

Life cycle assessment (LCA) is a well-established method used to quantify the environmental impacts of products and processes. Previous LCAs and environmental assessments of biopolymers are largely limited to global warming potential and fossil fuel depletion impact categories which may favor biopolymers because of the inherent properties of plastics made from biogenic carbon, which is carbon that was recently captured from the atmosphere through the biological process of photosynthesis by plants, compared to fossil based plastics and may miss the potential environmental tradeoffs that can occur when shifting to agriculturally produced feedstocks. Additionally, few past LCAs of biopolymers address end of life (EOL) (Hottle et al., 2013; Miller et al., 2007; Landis et al., 2007).

EOL, the processes involved in handling and treating a material after it enters the waste stream, has been shown to be significant for traditional plastics (USEPA, 2015; Björklund and Finnveden, 2005; Hopewell et al., 2009). When waste scenarios are included in biopolymer LCAs, findings vary widely based on the chosen EOL scenarios (e.g. landfilling, recycling, incinerating, composting) which are not always based on realistically available disposal methods (Hottle et al., 2013; Yates and Barlow, 2013; Koller et al., 2013; Shen and Patel, 2008; Weiss et al., 2012). Of the twenty-one LCAs reviewed in Hottle et al. (2013) only seven included EOL within the system boundaries. Of the seven studies which evaluated EOL, only one study included composting as an EOL scenario for compostable biopolymers. Only four studies evaluated landfilling scenarios while five included scenarios for incineration which is a less common disposal method for plastics garbage compared to landfilling (USEPA, 2015). Increasingly there have been calls to further investigate the EOL for biopolymers (Hottle et al., 2013; Yates and Barlow, 2013; Weiss et al., 2012; Rossi et al., 2014; Hermann et al., 2011). At the same time, there have been inventory improvements for the production of biopolymers and waste streams in the United States that can be used for refining LCAs (Kolstad et al., 2012; Hermann et al., 2011; Vink et al., 2010a; Pressley et al., 2015; Vink and Davies, 2015).

This life cycle assessment (LCA) seeks to explore the impacts associated with the production and disposal of biopolymers compared to fossil-based plastics; most literature on biopolymers has neglected EOL, which studies say could significantly impact the overall life-cycle impacts of biopolymers (Hottle et al., 2013; Hottle et al., 2015). The model presented herein explores the production of biopolymers and traditional fossil based plastics as well as EOL model scenarios including landfill, compost, and recycle. For each recyclable polymer (PET, Bio-PET, HDPE, Bio-HDPE, LDPE, and Bio-LDPE) landfill and recycling scenarios are used, while the remaining compostable polymers (PLA and TPS) are modeled using compost and landfill scenarios.

2. Methods

LCA is a well-established method used to quantify impacts that can be attributed to the life cycle of products to help identify tradeoffs between impacts and to avoid shifting burdens to other products or processes. The International Organization for Standardization (ISO) defines LCA and its applications in ISO-14040 (ISO Environmental management, 2006, ISO 14040) and ISO-14044 (ISO Environmental management, 2006, ISO 14044). The LCA framework as defined by ISO includes an iterative process of: 1) Goal and Scope Definition, 2) Inventory Analysis, 3) Impact Analysis, and 4) Interpretation (ISO Environmental management, 2006, ISO 14040). LCAs require large amounts of data to provide accurate inventories for all of the processes associated with the production, use, and EOL for a product. The data used in this study come from existing inventories, literature sources, and new inventory data collected specifically for this research. The methodological details are described below.

2.1. Scope and system boundary

Fig. 1 depicts the system boundaries for the LCA. This study conducted an attributional, cradle-to-grave LCA with a functional unit of 1 kg of polymer with allocations calculated on a mass basis. The LCA evaluated the materials, processes, and technologies available at the time the assessment was conducted in 2015. Eight polymers were evaluated in the study: PLA, TPS, PET, Bio-PET, HDPE, Bio-HDPE, LDPE, and Bio-LDPE. These polymers were selected because PLA, TPS, Bio-PE and Bio-PET represent the most common biopolymers globally with 11.4%, 11.3%, 12.3%, and 37% market shares of biopolymers, respectively (European Bioplastics, 2014). PLA is made from corn grown in the US and produced at the NatureWorks facility in Blair, Nebraska. The Bio-PET is synthesized in part from ethylene glycol which, in this model, comes from sugar cane grown and distilled in Brazil while the terephthalic acid component remains a fossil input (Tabone et al., 2010; Brehmer and Sanders, 2009). Bio-HDPE and Bio-LDPE modeled the use of Brazilian sugar cane based ethylene. Both the ethylene glycol and ethylene processes included freighter shipment to the U.S. Transportation for the production of the other polymers were based on published inventories. TPS was modeled based on the global corn market and US-based production. The traditional fossil-based polymers, HDPE, LDPE, and PET, were modeled based on standard production technologies using inventories published by Franklin Associates (Franklin Associates Revised Final Report, 2011). Product formation (e.g. blown film extrusion, sheet extrusion, thermoforming,