biobased

MATERIAL ATTRIBUTE:

BIOBASED CONTENT

How well does it predict the life cycle environmental impacts of packaging and food service ware?

A summary report from a meta-analysis by:

State of Oregon Department of Environmental Quality

Franklin Associates, a Division of Eastern Research Group

State of Oregon
DEQ Department of Environmental Quality

November 2018

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This Summary Report

Mistry M, Allaway D, Canepa P, and Rivin J. Material Attribute: BIOBASED CONTENT – How well does it predict the life cycle environmental impacts of packaging and food service ware? State of Oregon Department of Environmental Quality. Portland, Oregon. 2018.

FULL REPORTED CAN BE DOWNLOADED AT:

https://www.oregon.gov/deq/mm/production/Pages/Materials-Attributes.aspx

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ACKNOWLEDGMENTS:

The State of Oregon thanks the following organizations for participating in a project advisory group that advised on and informed this research effort: County of Alameda (CA), StopWaste.org, Washington Department of Ecology, Metro (Portland, OR), City of Seattle, Minnesota Pollution Control Agency, CalRecycle, Sustainable Packaging Coalition, Sustainable Purchasing Leadership Council, City of Eugene (OR), U.S. Green Building Council, City of Portland (OR), and the Northeast Waste Management Officials Association.

Summary Highlights – *Biobased Content*

Many businesses, governments and others are designing or purchasing packaging and food service ware that is made from *biobased* or *renewable* content as a means to reduce environmental impacts, conserve resources and reduce reliance on fossil fuels. This is often based on some assumptions about the environmental benefits of *biobased* materials when compared against alternatives.

To evaluate those assumptions, DEQ reviewed literature from the last 18 years of environmental life cycle assessments that included *biobased* packaging and food service ware. Nearly 460 comparisons involving *biobased* packaging and nearly 330 comparisons for *biobased* food service ware were found.

Biobased packaging is often promoted as an alternative to packaging derived from fossil fuels. Without a doubt, widespread use of fossil fuels – whether to produce packaging or to produce energy – poses serious threats to the environment. But all *biobased* materials – at least as currently produced – result in the combustion of fossil fuels during production. In comparisons between *biobased* plastic packaging and fossil fuel-based packaging of the same resin (for example, bio-PET vs. fossil-based PET), *biobased* packaging almost always was found to reduce fossil energy use. However, the results were reversed when comparing *biobased* packaging against functionally equivalent packaging of a different (and non-biobased) material, for example, a polyethylene shipping bag compared against a corrugated cardboard box. And in the case of *biobased* vs. non-biobased food service ware, the literature was evenly divided. This suggests that if one's goal is to reduce the use of fossil fuels, the attribute of *biobased* should be used very carefully and selectively.

Mixed results were also found for various types of environmental impacts, suggesting that significant tradeoffs exist for *biobased* feedstocks. The literature generally found greenhouse gas benefits from using *biobased* packaging and food service ware – although this was not universally true. But for several other types of environmental impacts, such as acidification (acid rain) and eutrophication (nutrient loading into waterways), *biobased* packaging more often increased negative impacts when compared to alternatives. This is typically because of emissions and pollution releases associated with growing feedstocks.

Biobased materials are also not necessarily *compostable* or degradable. Many *biobased* resins are not marine degradable and thus may not be a solution to the problems of marine plastics.

This suggests that *biobased* as an attribute is of limited utility for predicting reduced environmental impacts. Instead of relying on this attribute, designers and purchasers instead should ask a different set of questions: not just "is it *biobased*?" but rather "how much and what type of energy is required to produce this material?" and "what are the environmental impacts – evaluated over the entire life cycle – of this material?" Asking these questions – while more difficult than relying on simple attributes such as *biobased* – is more likely to result in environmental improvements in the long term, and can prevent society from falsely believing that they have "solved" the problem of environmental impacts.

Background

Every day we encounter – and make decisions about – a wide variety of manmade materials. Packaging is a category of materials that is ubiquitous in our culture. We come in contact with packaging throughout our day. Most of the products we purchase are protected in packaging (such as thin films or containers) and often, the food we consume is also packaged.

Biobased materials are made from renewable feedstocks that can be replenished as they are used or within short- or medium-term timeframes.

At times, we make individual purchasing choices based on characteristics of the packaging. It is common to use popular material attributes to make buying decisions, especially when we assume the attribute will lead to lower detrimental environmental impacts. Many governments similarly promote the use of these attributes. Businesses use them as well, often in response to public opinion or government mandates.

It is widely believed that common packaging attributes such as being made from recycled or biobased content means the package has lower adverse environmental impacts relative to options without the same attribute. Similarly, packaging claiming to be recyclable or compostable is widely assumed to be environmentally preferable relative to non-recyclable or non-compostable alternatives. This research evaluates the validity of these assumptions and the ability of these four packaging attributes to predict better overall environmental outcomes.

One such popular packaging attribute is *biobased* material[1]. It is commonly assumed that a package made from *biobased* materials will have a smaller environmental footprint than if it was made from other materials, such as fossil fuels. This makes intuitive sense, on several fronts: fossil-based resources are not renewable, while *biobased* materials are; the extraction of fossil fuels is understood to result in significant, adverse environmental impacts; and most fossil fuel-based plastics are slow to degrade in the environment.

Yet a closer look at the topic uncovers some counter-intuitive findings. *Biobased* materials should – in principle – reduce our use of fossil fuels. Yet fossil fuels are typically used in the course of producing the feedstocks for most *biobased* materials (for example, to operate agricultural equipment), and then again to convert those feedstocks to usable materials (for example, to operate a bio-refinery). How do the amounts of fossil fuels compare? And while most fossil fuel-derived packaging is not marine degradable, not all *biobased* packaging is either. Marine debris, of course, is just one way in which materials impact the oceans. Ocean acidification (a result of carbon dioxide emissions) and eutrophication (nutrient loading from land-based sources) are also significant threats to marine life. How do *biobased* and competing

[1] Materials made from renewable feedstocks that can be replenished as they are used or within short- or midterm timeframes.

materials compare on those fronts? Given the significant environmental impacts resulting from agriculture, are *biobased* materials consistently a good choice? Is it sufficient to simply produce and use *biobased* materials, or is there additional nuance that needs to be considered, so that *biobased* materials truly deliver on their promise to reduce negative environmental impacts?

The Oregon Department of Environmental Quality worked with Franklin Associates to evaluate how well popular environmental attributes for packaging and food service ware (FSW) predict environmental outcomes, and under what conditions. The four attributes examined are *recycled content, biobased* (or *renewable*) *content, recyclable* and *compostable*. This summary focuses on the *biobased* attribute, and describes the findings from the meta-analysis of available research from the past two decades to determine how well the attribute *biobased* correlates with reduced environmental impacts for packaging and food service ware.

Introduction

Packaging is often targeted in sustainable materials management strategies because it is generally disposed of after a single use and because of the large quantities of packaging entering the municipal solid waste (MSW) stream each year. According to the U.S. EPA's Advancing Sustainable Materials Management: 2015 Fact Sheet, Americans generated 78 million tons of packaging waste, comprising 30 percent of total MSW generation by weight. Even with a packaging recycling rate of 53 percent, packaging still represents 21 percent of the MSW sent to landfills or incinerated.

Public concern and policy often focuses on the impacts of packaging at the time of its disposal when it becomes waste. However, packaging affects the environment in many other ways. The production and transport of packaging consumes raw materials and energy which in turn generates pollution. In addition, the disposal of packaging in landfills or by incineration represents a loss of the resources they contain as well as further pollution. Packaging that is not correctly managed at end of life may end up in rivers or oceans, with negative impacts in freshwater and marine environments that are not yet fully understood. While packaging plays an important role in minimizing waste by preventing damage to products, improvements in packaging design and informed choices of packaging material have the potential to considerably lower environmental impacts of packaging.

The life cycle of packaging

The life cycle of packaging, as shown in Figure 1, includes raw material extraction, primary material production, packaging production, distribution, use, and end-of-life treatment consisting of recycling, reuse, composting or disposal. Litter refers to material that is released into the environment in an uncontrolled manner, whether on land or water. The environmental impacts of many of these activities can be estimated using a quantitative method called Life Cycle Assessment or LCA[2]. Often comparative LCAs omit parts of the life cycle that are identical

[2] Life cycle assessment or LCA is a systematic approach to estimating environmental burdens associated with drawing resources from the Earth, transforming them into usable technical materials, making items from them, distributing the items, using them and ultimately dealing with the remaining solid waste via different waste treatment and recycling activities. LCA is governed by several international standards that provide guidance about various aspects of accounting for the different processing and materials needed

across comparisons. For example, when studying the impacts associated with different packaging options to package soft drinks, it isn't necessary to include the soft drink production steps (unless the soft drinks themselves are also being studied). For this reason, the environmental burdens related to the product contained in the package may or may not be included in LCAs examining packaging. This will affect the percent changes in impact metrics associated with packaging and food service ware scenarios. In general, the product itself contributes more to the overall life cycle impacts than the packaging.

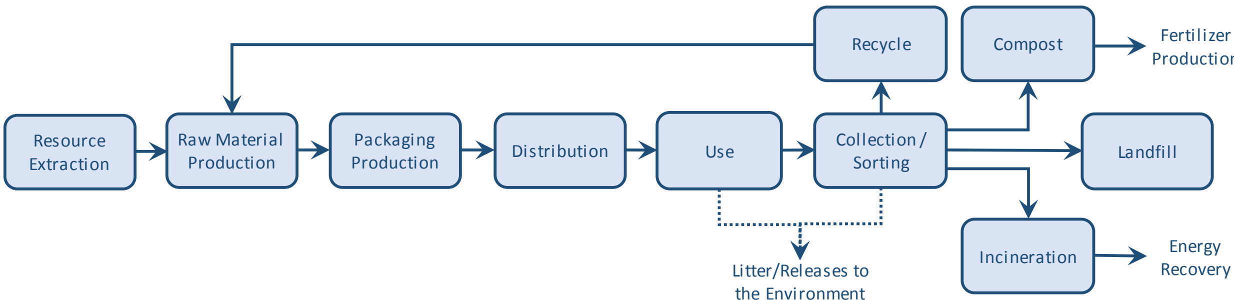

FIGURE 1 LIFE CYCLE OF SINGLE USE PACKAGING AND FOOD SERVICE WARE

How are attributes and life cycle impacts connected?

Material attributes are used as a simple way to communicate the characteristic of a material or product, and often also to convey some sort of environmental benefit. Material attributes are commonly used as design criteria and for product marketing and differentiation. While material attributes are related to the specific product or material, often marketing and purchasing decisions assume that these material attributes correlate with environmental goodness. Of course, the environment is affected by *all* activities related to the manufacturing, using and discarding of products. Some of these life cycle impacts can have local implications such as

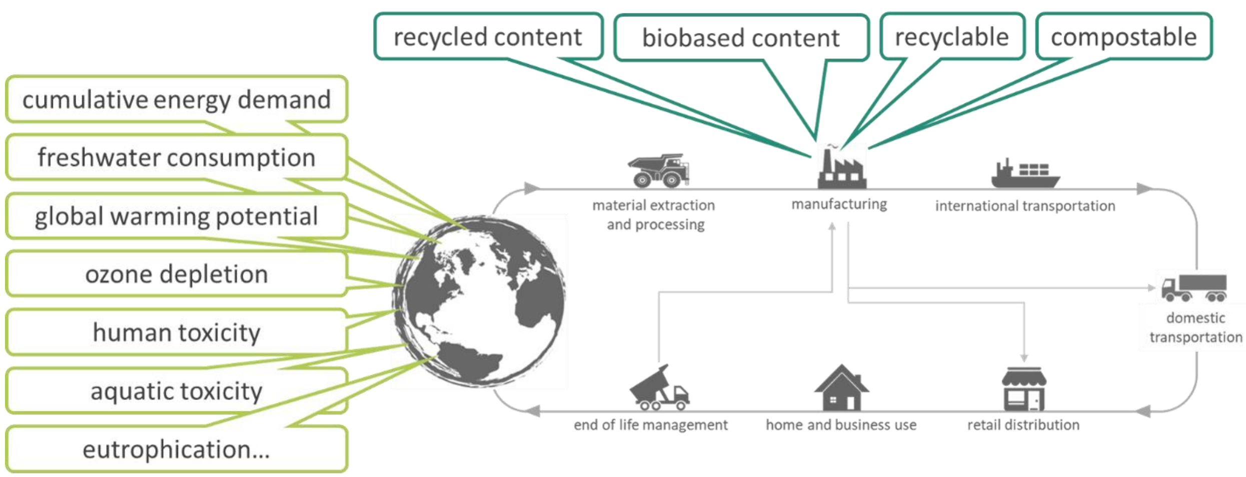

FIGURE 2 MATERIAL ATTRIBUTES AND LIFE CYCLE IMPACTS

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to make, use, and treat products at end of life. LCA is a foundational analytical approach to estimate environmental burdens of industrial systems and allows fair comparisons between different functionally equivalent systems. To learn more see: http://www.lcatextbook.com/.

pollution in waterways or to soil, while others can affect wider areas or the whole planet such as greenhouse gas emissions. Figure 2 illustrates some common attributes and life cycle impacts.

The product categories and attributes included in the study were selected based on their role in many sustainable materials management strategies and the availability of sufficient LCA studies. Two product categories – packaging and food service ware – were evaluated against four attributes: *recycled content, biobased, recyclable* and *compostable.*

Research approach

Packaging has been studied extensively by life cycle assessment. In fact, some of the first LCA studies performed focused on packaging, when almost 50 years ago companies like The Coca-Cola Company were evaluating the then novel material called plastic to deliver their products. Since then, many new formats and materials have been used for making packaging and food service ware, and many different scenarios have been independently studied by different researchers around the world. In this study we employed an approach called meta-analysis whereby we collected existing peer-reviewed and published studies from 2000-2017, and gleaned comparisons relevant to the four attributes of interest here.

While it is common practice to represent environmental outcomes in terms of climate change and greenhouse gas emissions, LCA is capable of simultaneously tabulating estimates of many other impact areas. These include indicators of human health and ecotoxicity, and effects on water systems such as eutrophication and acidification. Resource consumption measures such as water, energy and mineral consumption can also be included. This makes LCA a very effective tool to evaluate tradeoffs and hotspots – areas or steps in the life cycle of a system where disproportionately high environmental impacts occur. This broader perspective allows us to make informed choices for materials and design criteria to help optimize packaging and product systems. Some categories of impacts – such as marine debris[3] and human toxicological impacts associated with product use – are not currently evaluated well in LCA studies. Efforts are underway to better understand which marine debris related impacts could be evaluated well via LCA, including the data and methodological needs. Nevertheless, the inclusion of multiple other types of impact categories and consideration of all (or multiple) life cycle stages makes LCA a more holistic evaluation framework than other methods. In this research we documented all the impact or results categories represented in the literature to understand the overall picture in the past two decades of packaging analyses.

[3] It is critical to acknowledge that while marine debris is spoken of as an "impact" in the common vernacular, it is not an impact category *per se.* This is because impacts of litter and pollution on the marine (or freshwater) environment can occur in a variety of ways including implications to the water chemistry, trophic variations in the water column, effects on filter feeders, herbivores and predators, bioaccumulation, changes to the benthic region, interaction of microorganism with micro plastics and more. Each of these impacts need specific methodological approaches to capture appropriate parameters, data requirements, validation and assessment. The marine debris issue will take time to untangle.

To maintain consistency, we evaluated the results within each study independently, generating intra-study comparisons based on the same background assumptions including the system boundary being assessed, energy mix and fuels used, end-of-life treatment, etc. This is critical to making apples to apples comparisons based on functional equivalency.[4] For example, our assessment compared a package with a given attribute (in this case *biobased*) with a functionally-equivalent package that was not *biobased*. This basic approach gave us comparison ratios for all the attributes. It also allowed us to chart a range of five levels between "meaningfully lower life cycle impacts" and "meaningfully higher life cycle impacts" shown in Table 1.

Ratio = Impact result with attribute A ÷ Impact result without attribute A		
Category	**Ratio**	**Interpretation**
Meaningfully Lower Life Cycle Impact	<0.75	Suggests the attribute is potentially a good Indicator of environmental performance
Marginally Lower Life Cycle Impact	≥0.75 and <1.0	Inconclusive
No difference	1.0	No difference
Marginally Higher Life Cycle Impact	>1.0 and ≤1.25	Inconclusive
Meaningfully Higher Life Cycle Impact	>1.25	Attribute is potentially not a good indicator of environmental performance
The lower the ratio value, the lower the environmental impact of the material(s) being evaluated (*with* the attribute) compared to the equivalent material *without* the attribute.		

TABLE 1 MATERIAL ATTRIBUTE EVALUATION FRAMEWORK

The conclusions presented in this summary for *biobased* packaging and food service ware are drawn solely on the best case (meaningfully lower life cycle impacts) and the worst case (meaningfully higher life cycle impacts) – the dark green and dark red data points only (Table 1). This simple framework allowed us to objectively answer the research questions below.

Research Questions

Since the packaging material attributes *recycled content*, *biobased*, *recyclable* and *compostable* are commonly used to infer environmental preference, the main questions are:

1. How well do these material attributes predict positive environmental outcomes for packaging and food service ware?
2. Under what conditions are environmental impacts reduced?

[4] Functional equivalence refers to the idea of comparing two or more things that serve as substitutes for each other to fulfill the function of interest. In LCA the functional unit establishes the basis for comparisons such that the assessment is apples to apples, or for like function.

Research outcomes

Packaging

The research uncovered 17 studies offering nearly 460 comparisons for packaging (excluding food service ware) containing *biobased* content. Figure 3 shows the collective body of knowledge identified for the attribute *biobased* for packaging (excluding food service ware). The chart shows three pieces of information (for detailed explanations see the technical report).

1. The materials represented in the literature.
2. The system boundaries, or the life cycle stages the researchers included.
3. The result categories or impacts.[5]

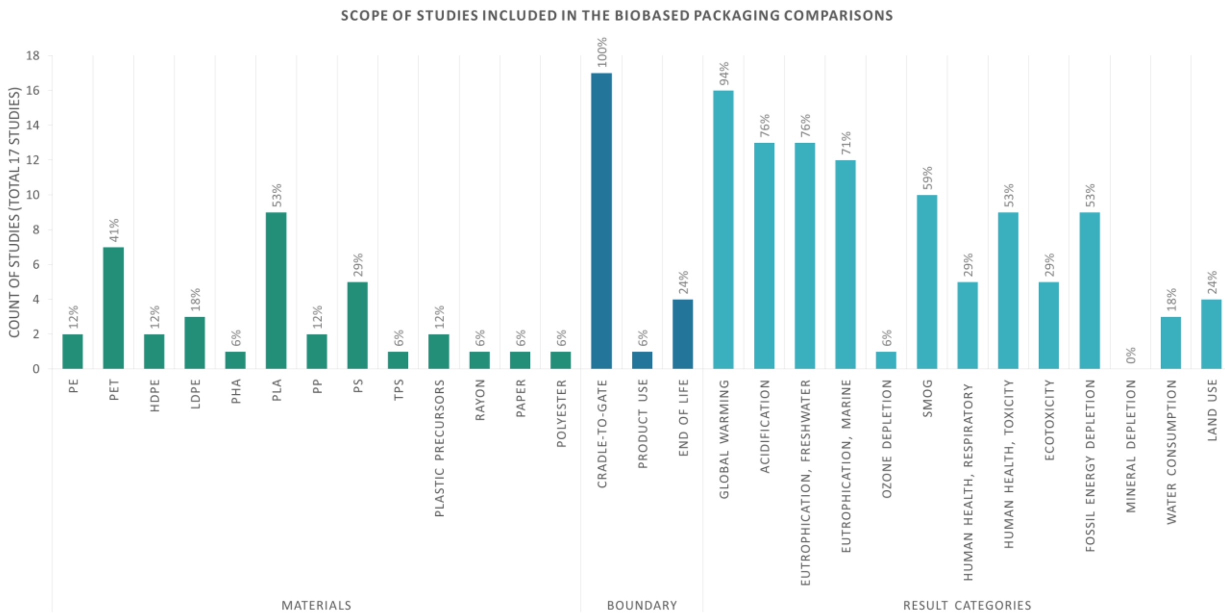

FIGURE 3 SCOPE OF RESEARCH FOR *BIOBASED* CONTENT IN PACKAGING (PERCENT VALUES REPRESENT FREQUENCY OF THE CATEGORY WITHIN STUDIES INCLUDED IN THE RESEARCH)

The *biobased* packaging materials assessed by these studies include cellulosic materials, such as wood and plant fibers, and seven plastics: polylactic acid (PLA), polyhydroxyalkanoates (PHA), high-density polyethylene (HDPE), low-density polyethylene (LDPE), laminated films (variety of feedstocks), polyethylene terephthalate (PET) and thermoplastic starch (TPS). As shown in Figure 3, end-of-life treatment was not represented in all the studies.

[5] Note: Not all categories found in the studies represent impacts. Some such as mineral depletion are indicators and not impacts *per se*.

Packaging findings (excluding food service ware)

The use of *biobased* feedstock to replace part, or all, of the fossil fuel-based input to make a material is a popular strategy to reduce environmental impacts. The *biobased* attribute is used as a shorthand predictor of reduced environmental impacts for packaging in general. The assumption is straightforward: that replacing fossil fuel-based inputs with renewable inputs will improve the environmental profile of a product or package. Significant efforts have been expended on shifting to *biobased* and renewable materials. Although the goal of these shifts is to move away from fossil fuel-based products and processes, many current *biobased* materials rely heavily on fossil fuel-based inputs upstream (for growing, processing, and transportation). Figure 4 summarizes research over the past two decades comparing *biobased* packages with non-*biobased* alternatives and suggests that using *biobased* as a shorthand approach to predict environmental outcomes is not a good approach. Over 50 percent of the time, the *biobased* package exhibited higher net environmental impacts.

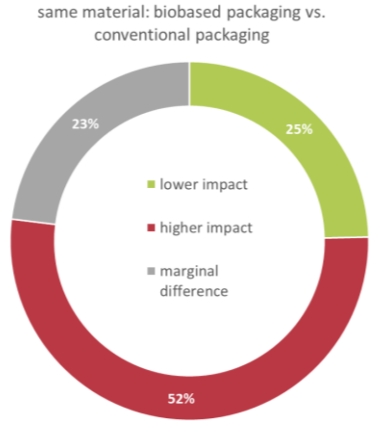

FIGURE 4 SUMMARY OF COMPARISONS FOR *BIOBASED* AS THE SOLE PREDICTOR OF REDUCED ENVIRONMENTAL OUTCOMES OF PACKAGING

TRADEOFFS OF *BIOBASED* PACKAGING

Biobased packaging is often believed to be associated with benefits for global warming potential and fossil fuel depletion but, as seen in Figure 5, this is not consistently the case. Figure 5a represents comparisons for the same material (e.g., *biobased* PET vs. traditional PET). Figure 5b represents comparisons of different materials (e.g., *biobased* PLA vs. traditional HDPE). The results of comparisons are mixed and often vary across different impact categories. For example, when comparing *biobased* and fossil-based versions of the same plastic resin used in packaging (such as *biobased* PET vs. fossil-based PET), the *biobased* option almost always uses less fossil energy, and often, but not always, results in fewer greenhouse gases (see Figure 5a). But when comparing a *biobased* packaging against a different nonrenewable alternative, global warming impacts are mixed and fossil energy use is typically higher for the *biobased* option (see Figure 5b). This range of results can be associated with factors like the crop type, climate and geography, as well as processing technologies used to convert agricultural feedstocks into packaging materials. In particular, producing biopolymer feedstocks requires a significant amount of fossil fuel for agricultural operations and inputs such as fertilizers and pesticides as well as milling, fermentation, and other conversion processes. While the results for energy and greenhouse gases are mixed, other environmental impacts, especially eutrophication and acidification, tend to be worse for *biobased* packaging.

Biobased materials do not consistently reduce life cycle impacts across impact categories.

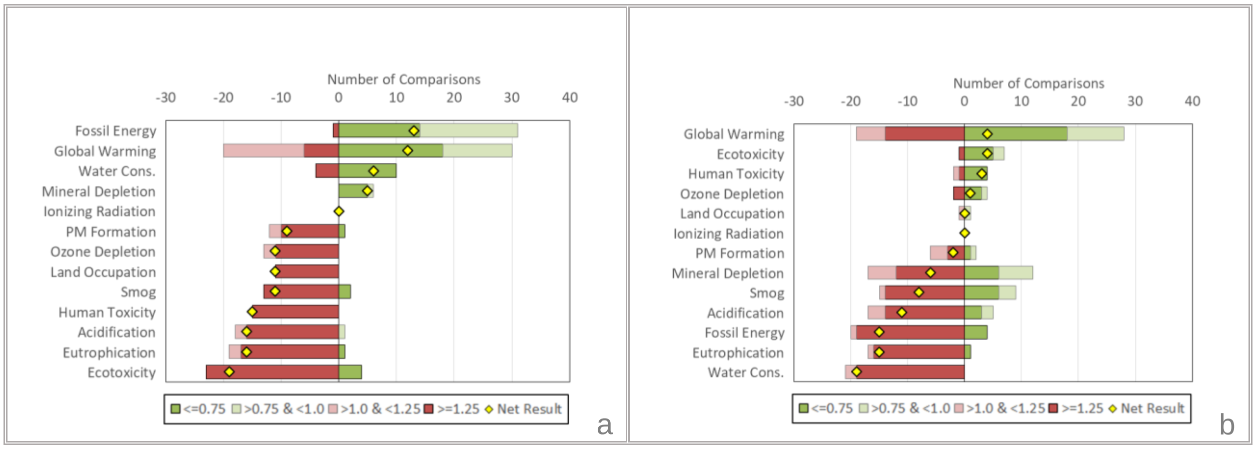

FIGURE 5 SUMMARY OF COMPARISONS OF *BIOBASED* PACKAGING TO CONVENTIONAL PACKAGING: (A) SAME MATERIAL, (B) DIFFERENT MATERIALS[6]

Shifting to a *biobased* production pathway can also result in different potential waste management pathways during end of life. Figure 5b, for example, comparing *biobased* packaging (some of which may be composted) against conventional packaging (some of which may be recycled). The graph highlights the divergent results associated with specific materials and across comparisons. Only four of the 17 studies however included waste management options in their impact assessments, which indicates a potential limitation in some of these results.

Of the studies that model the end of life for *biobased* packaging materials, four waste pathways were analyzed: recycling, composting, incineration and landfilling. Recycling results in life cycle impact reductions for fossil fuel-based resins. These benefits could extend to biopolymers if they are identical to polymers that can be recycled in existing collection systems or, in the case of biopolymers like PLA, recycling technologies can be scaled to warrant the collection and processing efforts, including effective sorting of “look alike” materials.

Biobased materials are also commonly part of the compostability discourse. However, it was found that mechanical recycling leads to the greatest reductions of environmental impacts, whereas composting was less favorable in some categories when comparing end-of-life options for TPS and PLA. When composting *biobased* packaging, the finished compost was found to have low levels of available nutrients (nitrogen, phosphorous and potassium), and therefore was considered an inadequate replacement for fertilizer.[7] Conversely, recycling was more favorable in the literature as it offsets the impacts associated with production of virgin materials.

[6] Ratios reflect the result for the *biobased* packaging divided by the result for the non-biobased packaging. Thus ratios <1 indicate *biobased* packaging performs better and are shown in the figure in green as the positive number of comparisons while ratios >1 indicates *biobased* packaging performs worse and are shown in the figure in red as the negative number of comparisons. Dark green and dark red represent counts of comparisons with ratios <0.75 and >1.25 respectively and are considered meaningful.

[7] More broadly, compost (such as from yard debris and food waste) can confer other benefits to soil health and sustainability. These assets can be both highly variable and difficult to quantify, and were usually not included in the LCA studies reviewed here.

Food service ware findings

Seven studies were identified that provided nearly 330 comparisons between *biobased* and non-biobased FSW. Figure 6 shows the collective body of knowledge identified for the attribute *biobased* for food service ware. The chart shows three pieces of information (for detailed explanations see the technical report).

1. The materials represented in the literature.
2. The system boundaries, or the life cycle stages the researchers included.
3. The result categories or impacts.[8]

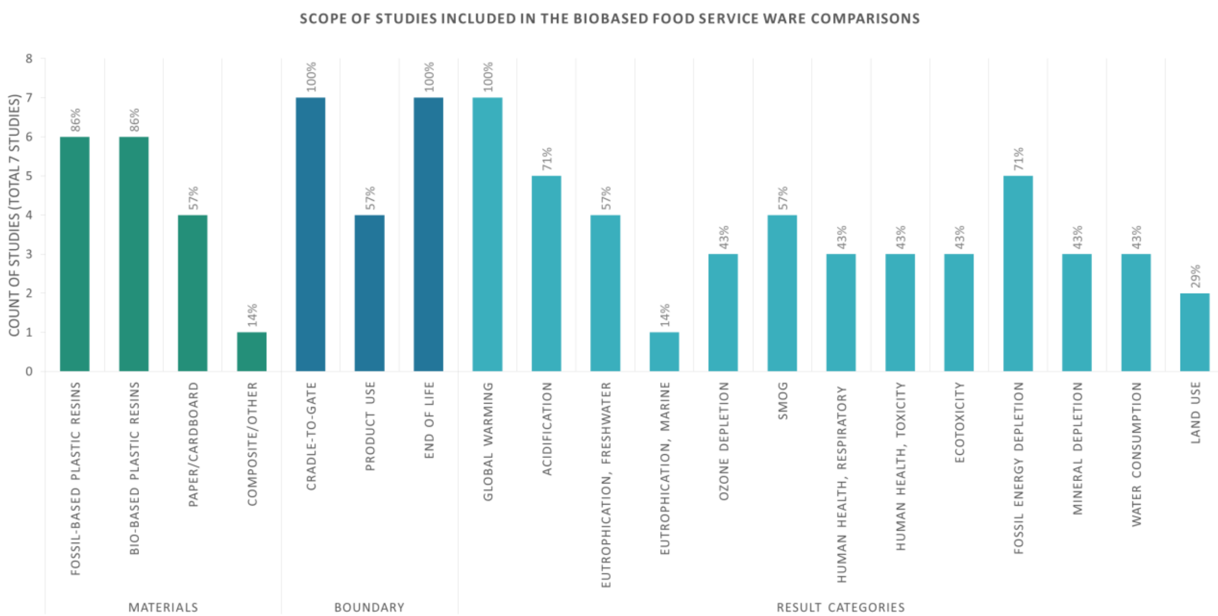

FIGURE 6 SCOPE OF RESEARCH FOR *BIOBASED* CONTENT IN FOOD SERVICE WARE (PERCENT VALUES REPRESENT FREQUENCY OF THE CATEGORY WITHIN STUDIES INCLUDED IN THE RESEARCH)

Biobased materials include PLA, cellulose and molded fiber, paper and board. None of the studies considered *biobased* versions of conventional polymers, such as bioPET. Figure 6 shows the variety of materials and the different impact areas represented in literature. Global warming potential was the most commonly analyzed impact category, included in all studies, followed by acidification and fossil energy depletion, included in five each. Even though land use requirements can be significant for *biobased* products, due to feedstock growth, it was only included in two studies.

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[8] Note: Not all categories found in the studies represent impacts. Some such as mineral depletion are indicators and not impacts *per se*.

The comparisons of *biobased* FSW presented in this section were limited to comparisons between *biobased* and non-*biobased* FSW that undergo the same treatment at end of life. Thus, the comparisons in this section focus on the impacts of the *biobased* attribute, without differences in waste management methods affecting the results.

ENVIRONMENTAL PROFILE OF *BIOBASED* FOOD SERVICE WARE

The results of comparing *biobased* and non-biobased FSW are mixed, just as they were for comparisons of *biobased* and non-biobased packaging, previously presented in Figure 5. As with packaging, results are driven by the higher production impacts for *biobased* products for most impact categories, though impacts vary by specific material and end-of-life modeling assumptions. Figure 7a shows that when comparing *biobased* and non-biobased analogs treated via same end-of-life fate, the *biobased* materials are more likely to result in higher negative impacts.

As with biobased packaging, Figure 7b shows that *biobased* FSW generates mixed results tending toward improved performance for global warming potential and tending toward worse performance for eutrophication, water use, acidification, ozone depletion, respirable particulate formation, land use and toxicity potential impact categories. These impacts primarily occur during the growing and processing of the feedstocks for *biobased* materials. Significant numbers of comparisons pointing in opposite directions means that the attribute *biobased* is a poor predictor of environmental outcomes.

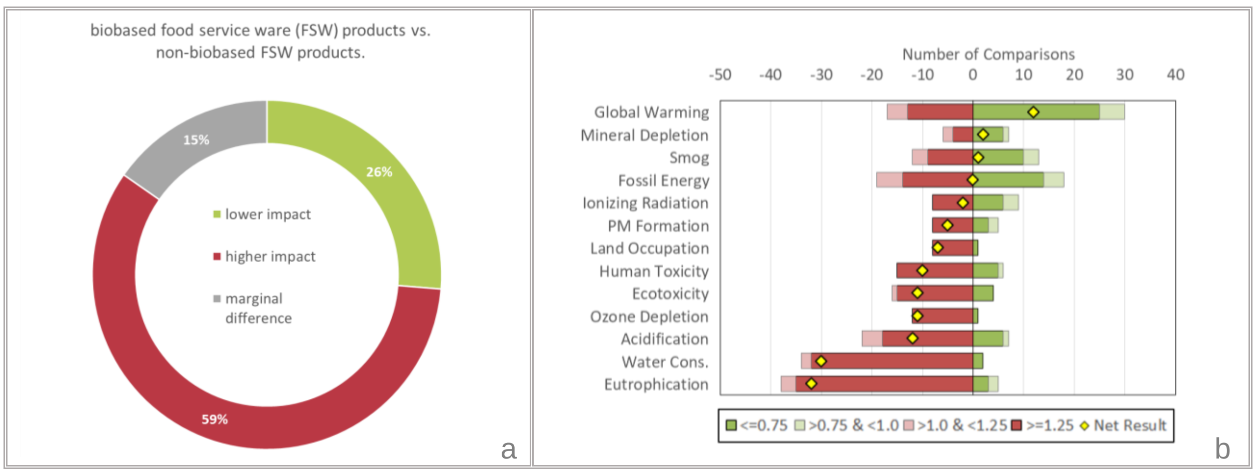

FIGURE 7 SUMMARY OF COMPARISONS FOR *BIOBASED* VS NON-BIOBASED FOOD SERVICE WARE: (A) SUMMARY OF COMPARISONS ACROSS ALL IMPACT CATEGORIES, (B) SUMMARY OF COMPARISONS FOR EACH REPORTED IMPACT CATEGORY (SEE FOOTNOTE 6)

> *Biobased food service ware tends to perform worse for eutrophication, water use, acidification, ozone depletion, respirable particulate formation, land use and toxicity potentials and better for global warming potential.*

Polylactic acid (PLA) is the most studied *biobased* polymer used in FSW, and most comparisons in the literature between FSW made of *biobased* PLA and non-biobased FSW show significantly higher impacts for the FSW made of PLA. These higher impacts are caused by the emissions during feedstock production and resin manufacturing for PLA. It is important to note, however, that a limitation of this type of backward-looking literature review is that it summarizes historic conditions, which may deviate from current or future ones. For example, recent technology changes in PLA production in North America have lowered the energy required (and resulting emissions) to produce this resin. Those lower impacts are not reflected in most of the historic literature.

A total of 211 comparisons were performed for FSW products made from PLA. Across all impact categories, 61 percent show significantly higher impacts for PLA while 22 percent show significantly lower impacts for PLA. Despite the overall higher impacts for PLA based FSW, the results vary depending upon which materials PLA is being compared against. Comparisons between *biobased* PLA and non-biobased polystyrene (PS) or polypropylene (PP) products consistently resulted in impact ratios greater than 1.25 (impacts at least 125 percent those of PS or PP) for PLA in most impact categories. Comparisons between PLA and polyethylene terephthalate (PET) yielded mixed results: PLA generally resulted in lower impacts (impacts of PLA no more than 75 percent those of PET) for global warming potential and fossil energy depletion categories, while resulting in significantly higher impacts for the acidification, eutrophication, and water depletion categories.

Other considerations related to *biobased* packaging and food service ware

A common misperception is that *biobased* is the same as "biodegradable." It is important to understand that while some *biobased* packages are biodegradable, not all are – and that not all biodegradable packages are *biobased*. For example, PLA is a *biobased* plastic resin (commonly produced using corn as the primary material feedstock), but it does not biodegrade in most environments. On the flip side, oxodegradable plastics are degradable when exposed to oxygen, but most are made from conventional plastic resins derived from natural gas, mixed with an additive to trigger fragmentation. To confirm, the discussions and findings of this document focus on the packaging material attribute *biobased* (referring to the feedstock), not biodegradable.

Regardless, readers should not assume that biodegradable packages are inherently better from an environmental perspective, particularly in areas where relatively little littering or other releases to the open environment occur. The promotion of degradability should never be used to justify, enable or normalize littering. Even degradable items can cause environmental harm when littered, and some materials only partially degrade, leaving harmful residue behind. Degradable polymers may interfere significantly with plastics recycling processes, and when placed into landfills, degradable packaging produces methane as it degrades. Methane is a potent greenhouse gas, and while many landfills capture and destroy some of that gas and use it to produce energy, no landfill entirely eliminates fugitive emissions. Methane's potency results in landfill degradation being an unattractive attribute from a climate protection perspective.

One final consideration is that some users express preference for *biobased* materials because they are believed to also be *compostable*. However, not all *biobased* materials are compostable, and the two attributes should not be conflated. Some *biobased* materials, such as paper, are both *compostable* and *recyclable*. These two attributes were evaluated separately and are summarized in companion documents. Some advocates for high landfill diversion goals treat *recyclable* and *compostable* materials equally, as they both enable landfill diversion. However, it is important to understand that recycling and composting have some fundamental differences. Composting a technically engineered packaging material (such as paper) typically dissipates much of its embedded energy and adds very little fertilizer value to the finished compost. In contrast, recycling often times does a better job at maintaining value, conserving resources and reducing pollution.

Summary

Several high-level conclusions can be drawn from the global literature review about *biobased* feedstock as a predictor of environmental outcomes of packaging and food service ware.

1. A majority of comparisons show that *biobased* packaging materials have significant environmental tradeoffs when compared to non-biobased counterparts, reducing some types of impacts while increasing others.
2. *Biobased* materials had their best performances in the global warming and fossil fuel depletion/energy categories yet these improvements are not consistent across all materials and formats studied.
3. Agricultural production drove consistently meaningful differences in the acidification, eutrophication, ecotoxicity and land use categories when comparing packaging that is *biobased* vs. conventional fossil fuel-based packaging.
4. The difference between *biobased* and conventional packaging materials is not simply a function of differing carbon pathways. The shift from fossil-based to *biobased* alters both the upstream dynamics of feedstock acquisition and the downstream recovery and processing requirements.
5. Fossil-based inputs play a central role in current practices to produce *biobased* feedstocks, making *biobased* FSW generally less preferable to fossil-based FSW in many impact categories. This is because production impacts for *biobased* materials tend to be higher than for conventional materials.

The studies examined suggest that it is not possible to infer environmental preference for packaging of one material type over another solely based on the attribute of biobased feedstock. Environmental performance of biobased materials depends on the manufacturing and feedstock requirements for specific materials.

Discussion and Recommendations

There is a strong commitment to using *biobased* feedstock as a tactic for reducing environmental impacts. Programs such as USDA's BioPreferred give explicit preference to *biobased* products. Yet research suggests that the environmental performance of *biobased* materials depends on the manufacturing and feedstock requirements for a given material. At present, many *biobased* materials intended to substitute for fossil-based equivalent materials are dependent on fossil inputs for their production. *Biobased* packaging and food service ware tend to be produced from agricultural materials, which shifts the burdens in selected environmental impacts, limiting the potential for environmental improvements.

Designing package and food service ware

As a general rule, relying on any one attribute as a design parameter to achieve environmentally preferable outcomes is not scientifically supported. Accounting for environmental impacts across the life cycle of packaging, along with functional and performance criteria is the most sensible means for achieving optimal packaging and environmental outcomes. The *biobased* attribute is no exception to that rule. It is not a certainty that materials derived from *biobased* sources will yield lower environmental outcomes because the environmental impacts are highly dependent upon the growing and processing steps, which can vary significantly between feedstocks. Furthermore, growing and processing are often based on fossil fuel inputs, which add to the environmental burden. Even though *biobased* packaging is widely perceived to be (and even described as) "fossil fuel free," this is highly misleading as it fails to account for the significant (and sometimes greater) quantities of fossil fuels used in production. It is therefore essential to select materials based on a life cycle perspective, with the following recommendations:

1. Establish company-wide or portfolio-level sustainability measurement criteria for packaging.[9] The measurement criteria should be based on an assessment of impacts across the full life cycle of the packaging.
2. Use streamlined life cycle assessment tools for packaging design evaluation[10]. Such a tool is best used consistently for all design alternatives to select those that meet the established criteria.
3. Optimize packaging design by prioritizing the use of materials with the lowest life cycle impact profile.

[9] For guidance see: Global Protocol on Packaging Sustainability 2.0 https://www.theconsumergoodsforum.com/wp-content/uploads/2017/11/CGF-Global-Protocol-on-Packaging.pdf

[10] Various off-the-shelf Design for Environment (DfE) tools exist specifically for packaging design:

1. EcoImpact (formerly Comparative Packaging Assessment or COMPASS) https://ecoimpact.trayak.com/WebLca/dist/#/landing
2. PIQET http://piqet.com/
3. PackageSmart: https://www.earthshiftglobal.com/software/packagesmart
4. GaBi Envision Packaging calculator: http://www.gabi-software.com/international/software/gabi-envision/gabi-packaging-calculator/

Institutional and Corporate Purchasing

Material attributes are commonly used as a shorthand in procurement decisions to denote environmental preferability. State and Federal statutes often promote product selection based on a preference for *biobased* content. However, in the case of packaging generally and food service ware specifically, *biobased* is a criteria that should be avoided, or at least used very carefully. Given that some *biobased* materials were found to reduce impacts (see Figures 5 and 7) but others were not, the question purchasers should ask is not "is it *biobased*?" but rather "what are the impacts across the full life cycle?" Purchasers should:

1. Avoid using *biobased* as a primary sustainability criterion for procurement of packaging and food service ware.
2. Instead, include specific environmental impacts, such as carbon footprint, as purchasing criteria and prioritize procurement to reduce those impacts. Rather than asking for *biobased* materials, ask vendors to provide information on the life cycle environmental impacts of their products, using an environmental product declaration (consistent with a common product category rule), and use those results to inform material selection.
3. If you do ask for *biobased* materials, also ask for vendors to provide information on the life cycle environmental impacts of the materials (consistent with recommendation above).

Although the product environmental assessments referred to in these recommendations are not commonly available (at present), they are becoming more common, and the inquiry process may nudge more manufacturers into re-evaluating their product design and ultimately affect the market.

Marketing

Although a principle function of packaging is to protect the product so it is delivered from the manufacturing facility to the customer, the reality is that packaging is also used as a marketing tool. Brand image is often tied to packaging formats, as is shelf appeal, or the ability of the package to grab the attention of the buyer on the retail shelf. Often design choices are driven by the desire of branding and marketing to satisfy the perceived customer demand. The opportunity to optimize a package for environmental outcomes is often secondary or completely overlooked. However, the two desires need not be in conflict. Packaging design can be optimized for environmental outcomes and meet marketing desire to satisfy demand. In the packaging design realm, there already exists a robust body of work that includes protocols[11], design guidelines[12], and tools[13] to implement informed design choices that can satisfy the

[11] See the Global Protocol on Packaging Sustainability. https://www.theconsumergoodsforum.com/wp-content/uploads/2017/11/CGF-Global-Protocol-on-Packaging.pdf

[12] See Design Guidelines for Sustainable Packaging. https://sustainablepackaging.org/resources/design-guidelines-for-sustainable-packaging/

[13] Various off-the-shelf Design for Environment (DfE) tools exist specifically for packaging design:

1. EcoImpact (formerly Comparative Packaging Assessment or COMPASS) https://ecoimpact.trayak.com/WebLca/dist/#/landing
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3. PackageSmart: https://www.earthshiftglobal.com/software/packagesmart
4. GaBi Envision Packaging calculator: http://www.gabi-software.com/international/software/gabi-envision/gabi-packaging-calculator/

demand for packaging with reduced environmental impacts. The following actions are recommended:

1. Do not make spurious or vague claims based on the attribute *biobased* that are likely to cause a consumer to infer or misinterpret environmental superiority of a product.
2. Follow § 260.16 of the FTC Green Guides regarding marketing claims about renewable (e.g., *biobased*) materials.[14]

Policy for end-of-life management

A primary responsibility of policy measures for municipal solid waste management is to support the creation of usable secondary materials via recycling. Properly functioning recycling systems should collect, sort and process material with the highest potential to reduce environmental impacts and to generate clean and usable recycled material that are in demand for product and package designs. Policy should:

1. Ensure any policies that either promote (e.g., *biobased*) or restrict (e.g., fossil fuel-based) the use of a given material, employ a full life cycle accounting of environmental impacts. Do not just focus on end of life management, *biobased* or otherwise, as the scientific evidence shows this limits the potential for environmental impact reduction.
2. That said, monitor on-going trends in the generation and disposal of *biobased* materials, so that adequate end-of-life management infrastructure can be planned for.
3. Distinguish between recycling and composting as options at end of life. Both appear equally aligned with landfill avoidance and disposal-based "zero waste" goals. Both are often promoted for their ability to maintain materials in circular (closed) loops. But in reality, composting and recycling are not the same and can result in very different environmental outcomes. For *biobased* materials (such as paper) that can be either recycled or composted, recycling is often the more environmentally beneficial option.
4. Account for *biobased* materials in extended producer responsibility (EPR) programs, which can engage the producers of these materials in the burden of developing recovery, recycling and processing infrastructure for their materials.

[14] See https://www.ftc.gov/sites/default/files/attachments/press-releases/ftc-issues-revised-green-guides/greenguides.pdf