compostable

MATERIAL ATTRIBUTE:

COMPOSTABLE

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

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CITE AS

This Summary Report

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FULL REPORT CAN BE DOWNLOADED AT:

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

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Summary Highlights – *Compostable*

Many businesses, governments and individuals are designing or purchasing packaging and food service ware to be *compostable* as a means to reduce environmental impacts and conserve resources. But research suggests that *compostability* is a poor indicator for determining the environmental benefits – and burdens – of packaging and food service ware items.

Composting – the act of recovering nutrients from materials such as food and yard debris – is oftentimes beneficial when compared against its alternatives (such as landfilling). However, *compostable* packaging and food service ware introduces a broader set of trade-offs, including the raw materials used to make *compostable* feedstocks and the environmental impacts of those upstream processes.

DEQ reviewed literature from the last 18 years of environmental life cycle assessments that included *compostable* packaging and food service ware. Over 1,200 comparisons involving *compostable* packaging and over 360 comparisons for food service ware were found. In the majority of these comparisons, making and using *compostable* materials (and composting them) was found to result in *higher* environmental impacts than either using non-compostable materials, or using *compostable* materials and treating them via recycling, landfilling or incineration. One primary reason for this is the potential for higher burdens associated with producing the feedstocks used to make different types of *compostable* packaging. Another is that composting, unlike other end-of-life waste management alternatives such as recycling, is a relatively poor method of recovering nutrients or value embedded in human-made materials such as packaging.

There are a number of additional concerns with *compostable* packaging and food service ware, including:

- Not all certified *compostable* packaging fully composts in all compost facilities due to operational variations. Some *compostable* packaging may burden compost facility operators with higher costs and generate finished compost product that is contaminated with pieces of uncomposted waste.
- The acceptance of *compostable* packaging may increase contamination from "look-alike" materials that further pollute compost, soils and waterways.
- Some paper based *compostable* food service ware is treated with toxic materials such as perfluorinated compounds that are known to accumulate in body tissues and the larger environment.
- Further, most *compostable* plastic packaging does not degrade in marine environments.

As such, DEQ recommends against using *compostability* as a blanket design or procurement criteria. Rather than using this attribute, producers and purchasers should instead use life cycle assessment as part of a more holistic evaluation of environmental impacts. Packaging design should be optimized by prioritizing the use of materials with the lowest life cycle impact profile, then considering the viable end-of-life fates to optimize recovery of those materials. Research suggests recycling to be a better outlet for packaging once it is optimized for life cycle impacts.

For businesses that want to advance the use of *compostable* packaging, the focus needs to shift to using materials that have lower environmental impacts, and that don't inadvertently contaminate finished compost product and undermine the economic sustainability – and environmental benefits – of the compost industry.

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.

Compostable materials are those that degrade by biological processes to yield CO_2, water, inorganic compounds, and biomass at a rate consistent with biodegradation of natural waste while leaving no visually distinguishable remnants or unacceptable levels of toxic residue.

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 negative 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 *compostable*[1]. It is commonly assumed that if a package is made to be *compostable* its environmental footprint will be smaller than if it was made from a material that is not *compostable*. Composting organic materials (such as food) is typically of environmental benefit (compared to landfilling), so it may seem reasonable to assume that *compostable* packaging and food service ware (FSW) are similarly beneficial. But is this assumption valid?

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[1] *Compostable* materials are those that degrade by biological processes to yield CO_2, water, inorganic compounds, and biomass at a rate consistent with biodegradation of natural waste while leaving no visually distinguishable remnants or unacceptable levels of toxic residues (ASTM International, 2012).

Compostable packaging and FSW may be made from a wide variety of feedstocks, and using industrial processes that differ from non-compostable alternatives. As with all materials, the environmental impacts associated with upstream feedstocks and production practices may be less visible to the public, but are no less relevant – and indeed, may be greater in overall magnitude – than the environmental impact reduction associated with end-of-life management methods such as composting.

This study evaluates *compostable* packaging, and *compostable* FSW as a specific subset, which should not be confused with *biodegradable* packaging. *Compostable* packaging is designed to degrade in very specific environmental conditions and the actual conditions needed for different materials can vary. In order to be *compostable*, it must also completely compost within the time that other materials (typically food and yard waste) are undergoing active composting. In contrast, *biodegradable* materials may degrade in a wider variety of environments, and may degrade at a slower rate.

The Oregon Department of Environmental Quality worked with Franklin Associates to evaluate how well popular environmental attributes for packaging and FSW predict environmental outcomes, and under what conditions. The four attributes examined are *recycled content, biobased* or *renewable material, recyclable* and *compostable*. This summary focuses on the *compostable* attribute, and describes the findings from the meta-analysis of available research from the past two decades to determine how well the attribute *compostable* correlates with reduced environmental impacts for packaging including 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. (It is important to note here that *compostable* is not synonymous with "marine degradable" and hence does not necessarily offer a benefit to reducing marine litter.) 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.

Compostability is the potential for a material to be composted, typically via an industrial[2] composting facility. Composting utilizes microbial action to physically disintegrate materials, ideally resulting in no residual toxicity. Nutrient recovery and cycling is a co-benefit that is often hoped for. The finished compost product should also be free of contaminants.

However, a package being *compostable* is not the same as it being composted. Composting is an end-of-life treatment route that produces useable clean compost. That compost may be used for growing vegetables at home or in farms, gardening, and for landscaping and erosion control applications as a soil amendment, mulch, peat substitute and/or replacement for fossil-based fertilizers. Making *compostable* packaging materials, paper-based or plastic, does not necessarily create a product that is compatible with all industrial compost facilities (or home compost piles). This is because industrial composting facilities vary greatly in their ability to treat technical materials such as packaging due to actual operating conditions, temperature, moisture and other factors.

Compostable packaging and FSW is deemed *compostable* in industrial facilities either by virtue of being certified[3] or by self-declaration (which can lack credibility). There is significant discrepancy between the actual efficacy of *compostable* technical materials (coated papers, plastics, etc.) and the operational realities of different composting facilities. Also, the word *compostable* is often interpreted by residents and laypersons to mean *compostable* in backyard compost heaps, which can be an incorrect interpretation. Without the inclusion of clear descriptive and qualifying language, the *compostable* claim may be counterproductive and be deemed as greenwashing.

"*Compostable*" and "composting" should also not be confused or used interchangeably given that the scope of their environmental impacts may be vastly different. When considering the environmental benefits of composting a discarded material, the impacts of composting activities (such as the energy used to operate compost facilities, emissions from compost piles, and benefits of using finished compost) must be compared against an alternative method for managing that material, such as the impacts from landfilling. Similarly, when considering the environmental benefits of using *compostable* packaging, the impacts of that *compostable* packaging – which include not only the end-of-life activities associated with composting, but also sourcing raw materials and converting them into packaging formats – must be compared against the comparable impacts for other (non-compostable) packaging. The environmental impacts of *compostable* packaging extend across the full life cycle of materials. The two concepts – "*compostable*" and "composting" are related but very different, and the scope of their environmental impacts are also very different.

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[2] At home composting standards for packaging do exist but are not widely used at present in North America. See http://www.tuv-at.be/home/

[3] *Compostability* standards include ASTM D64004, D68685, and EN-13432.

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 treatments consisting of recycling, reuse, composting or disposal. Litter refers to uncollected material releases to the environment produced from packaging, 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[4]. Often comparative LCAs omit parts of the life cycle that are identical 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 most cases, the product itself contributes more to the overall life cycle impacts than the packaging.

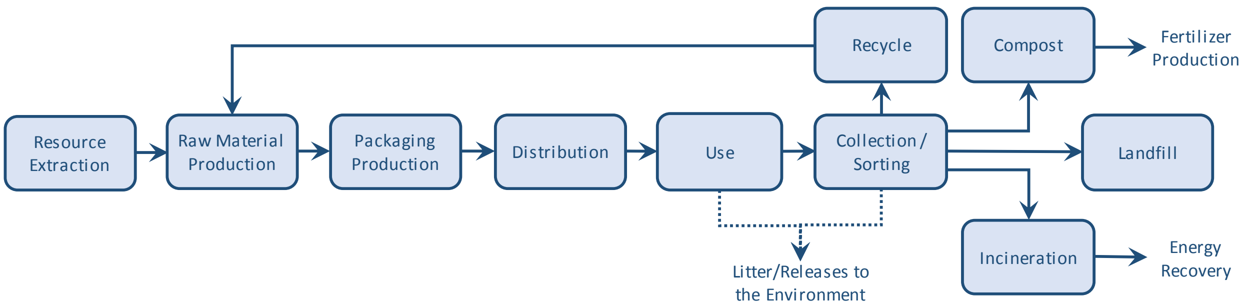

FIGURE 1 LIFE CYCLE OF SINGLE USE PACKAGING AND FOOD SERVICE WARE

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 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.

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[4] 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 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/.

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.*

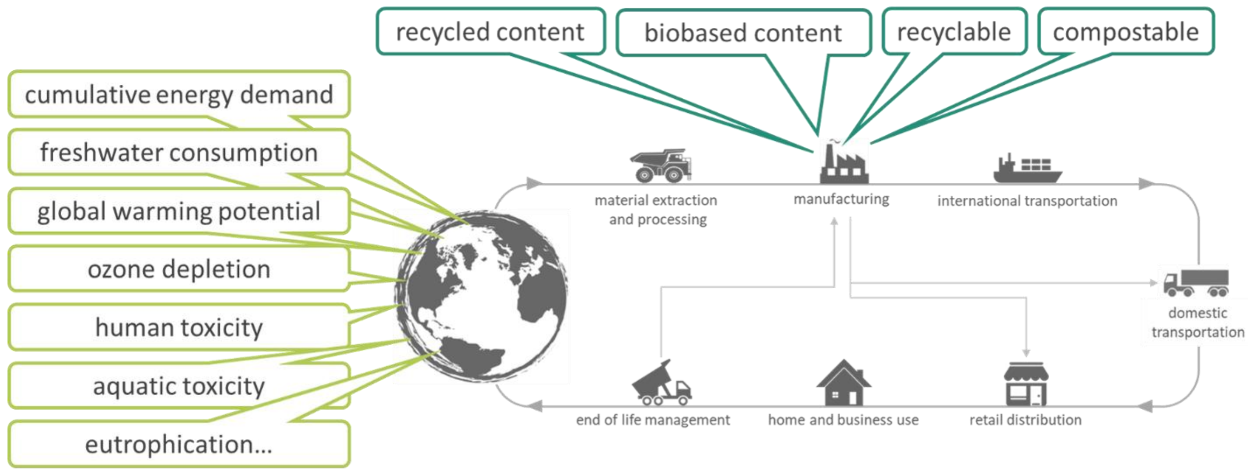

FIGURE 2 MATERIAL ATTRIBUTES AND LIFE CYCLE IMPACTS

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[5] and human toxicological impacts associated

[5] 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

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.

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[6]. For example, our assessment compared a package with a given attribute (in this case *compostable*) with a functionally-equivalent package that was not *compostable*. 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 *compostable* 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 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?

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specific methodological approaches to capture appropriate parameters, data requirements, validation and assessment. The marine debris issue will take time to untangle.

[6] 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 10 studies offering up over 1200 comparisons for *compostability*. Figure 3 shows the collective body of knowledge identified for the attribute *compostable* for packaging (excluding food service ware). The chart shows four pieces of information (for detailed explanations see the technical report).

1. The materials represented in the literature.
2. The scope variations represented in the studies that were included in the final review.
3. The system boundaries, or the life cycle stages the researchers included.
4. The result categories[7] or impacts.

These studies allowed for comparisons between *compostable* and non-compostable materials, as well as between *compostable* materials that are composted versus landfilled, incinerated, or recycled at end of life. The packaging types included in the studies were cushioning (expanded packaging), sheets, wrapping films, thermoformed boxes, water bottles and clamshell packaging.

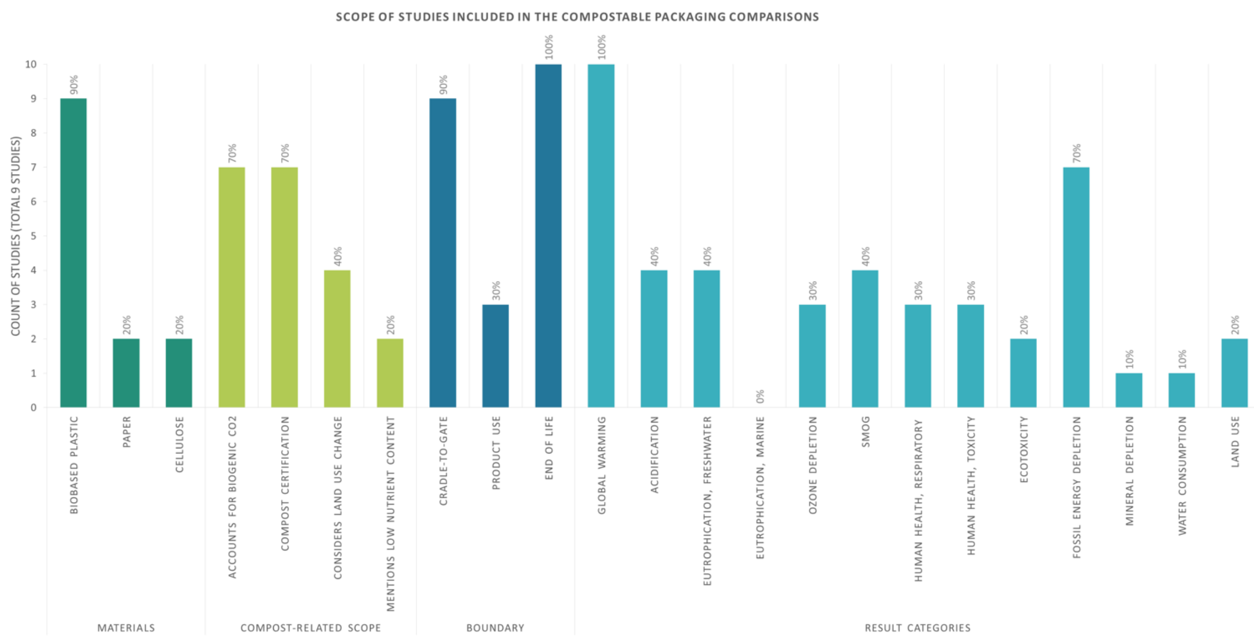

FIGURE 3 SCOPE OF RESEARCH FOR *COMPOSTABLE* PACKAGING (PERCENT VALUES REPRESENT FREQUENCY OF THE CATEGORY WITHIN STUDIES INCLUDED IN THE RESEARCH)

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

The studies also included various polymers used to make *compostable* packaging including polylactic acid (PLA), a starch-based expanded polystyrene (EPS), thermoplastic starch (TPS), and trademarked materials such as Mater-Bi™, starch-based biopolymers, and Ingeo™ (PLA-based). The literature included an assortment of results from different impact categories.

Packaging findings (excluding food service ware)

Promoting packaging as *compostable* is a relatively recent phenomenon. *Compostability* is most commonly used to convey environmental benefits for packaging used in fast food and other food contact applications, some of which are summarized in the next section. However, there is growing interest in making and marketing other types of packaging as *compostable* as well.

The discussion of findings for comparisons between *compostable* and non-compostable packaging in this section is restricted to materials designed for composting in industrial composting facilities, not home compost heaps. As an attribute, *compostability* suggests that a package can be potentially composted. In reality, for a *compostable* package to be composted properly, appropriate collection, sorting and composting facilities must exist. It is important to note that there exists significant discrepancy between *compostability* standards and the actual composting outcomes, primarily due to variability in compost processes across different facilities and geographies.

COMPOSTABLE PACKAGING COMPOSTED VS. NON-COMPOSTABLE PACKAGING WITH OTHER END-OF-LIFE TREATMENTS (EXCLUDING FOOD SERVICE WARE)

The literature review allowed for comparisons between *compostable* materials that are composted at end of life and non-compostable materials that are landfilled, incinerated, or recycled.

Figure 4a shows mixed results (for all impact categories combined) when considering over 620 comparisons found in the literature using *compostability* of a package to predict environmental preference.

Figure 4b shows the spectrum of the environmental impacts tracked across the literature, illustrating potential tradeoffs between *compostable* and non-compostable packaging. Results for *compostable* materials were mixed when looking across all the materials represented in Figure 3.

Compostability of a packaging does not appear to be a clear predictor of environmental preference. Compostable packaging that is composted does not consistently fare better than non-compostable packaging that is either landfilled, incinerated or recycled.

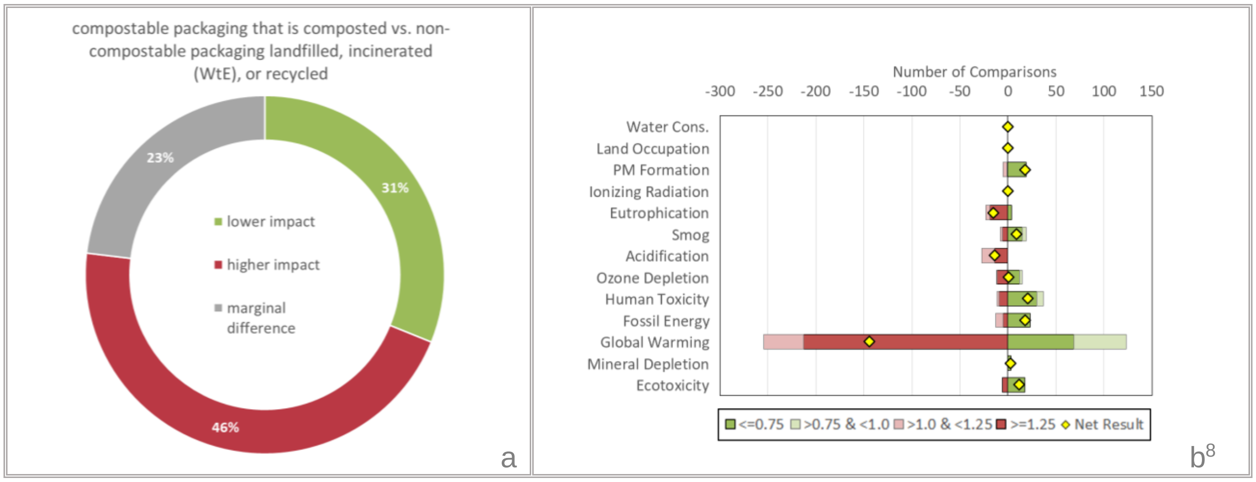

FIGURE 4 RESULTS OF COMPARISONS FOR *COMPOSTABLE* VERSUS NON-COMPOSTABLE PACKAGING, (A) SUMMARY OF COMPARISONS ACROSS ALL IMPACT CATEGORIES, (B) SUMMARY OF COMPARISONS FOR EACH REPORTED IMPACT CATEGORY [9]

COMPOSTABLE PACKAGING COMPOSTED VS. *COMPOSTABLE* PACKAGING NOT COMPOSTED (EXCLUDING FOOD SERVICE WARE)

The literature review also provided comparisons between various end-of-life treatments for *compostable* packaging materials including via landfill and incineration. This allowed a view into the potential outcomes of alternate end-of-life pathways for materials that have been designed for *compostability*. A key driver of whether composting of *compostable* packaging materials results in lower greenhouse gas emissions than landfilling the same materials depends in part on the assumed rate of degradation of the materials in a landfill. In particular, if bio-based *compostable* packaging degrades in a landfill, then it produces methane, a potent greenhouse gas. If it does not degrade, then landfilling it sequesters biogenic carbon from the atmosphere. Primary research is inconsistent regarding the landfill degradability of certain *compostable* packaging materials, such as PLA. As such, assumptions regarding degradation in landfills vary across studies.

[8] Most of the studies included in this review for *compostable* packaging focused on global warming potential (GWP). The large number of entries for GWP is due to one study, by Hermann and colleagues (2010), which produced 89 percent of these comparisons. Hermann (2010) only evaluated end-of-life emissions. Excluding the large number of data points from that one study does not change the directional outcome of Figure 4; 16 comparisons have impact ratios >1.25 and 8 comparisons have impact ratios <0.75. Higher impacts for *compostable* options are due to several factors, including higher production-related emissions and low nutrient value of some *compostable* formats. See technical report for details.

[9] Ratios reflect the result for the *compostable* packaging divided by the result for the non-compostable packaging. Thus ratios <1 indicate *compostable* packaging performs better and are shown in the figure in green as the positive number of comparisons while ratios >1 indicates *compostable* 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 differences. Light green and light red represent counts of comparisons with ratios 0.75-0.99 and 1.01-1.25 respectively.

Composting was not found to consistently result in significantly lower impacts for a given compostable packaging material when considering the various impact metrics.

Figure 5a represents over 240 comparisons of *compostable* packaging where composting was compared to other treatments. It shows that *compostable* packaging typically yielded higher environmental impacts when it was composted than when it was not composted. This can be due to various reasons such as higher benefits resulting from recycling. For materials that can be either composted or recycled, recycling often results in higher energy savings and other benefits.

Figure 5b reflects the overall trends for all impacts in the literature for *compostable* packaging materials that are composted versus managed using other waste management options. It shows a relevant trend towards increased environmental burdens associated with *compostable* packaging being composted.

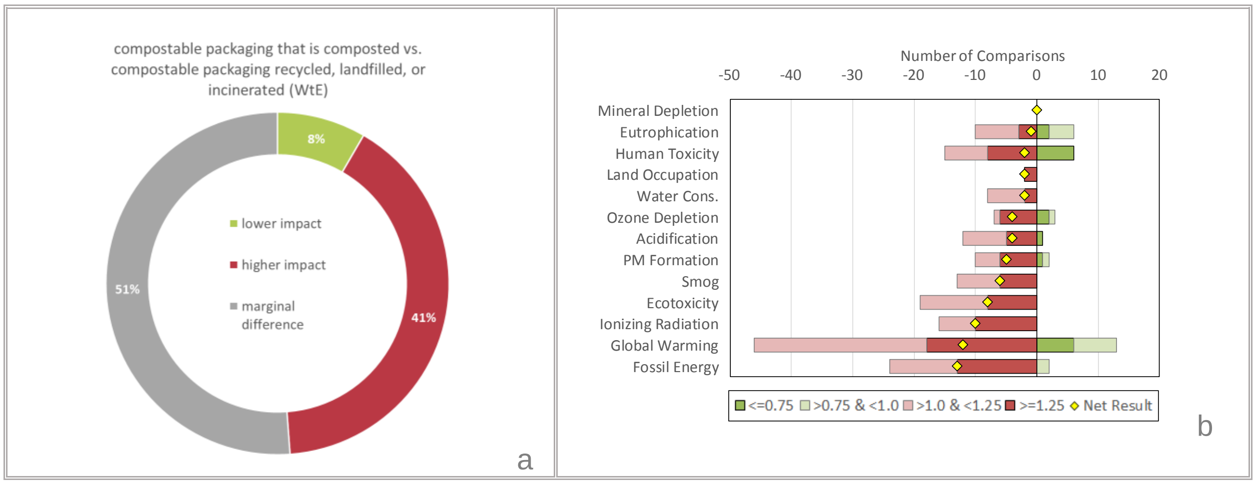

FIGURE 5 RESULTS OF COMPARISONS FOR *COMPOSTABLE* PACKAGING TREATED VIA COMPOSTING VS. OTHER END-OF-LIFE ROUTES (I.E. NOT COMPOSTED), (A) SUMMARY OF COMPARISONS ACROSS ALL IMPACT CATEGORIES, (B) SUMMARY OF COMPARISONS FOR EACH REPORTED IMPACT CATEGORY (SEE FOOTNOTE 9)

Food service ware (FSW)

The seven relevant studies providing over 360 comparisons between *compostable* and non-compostable food service ware is shown in Figure 6. 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[10] or impacts.

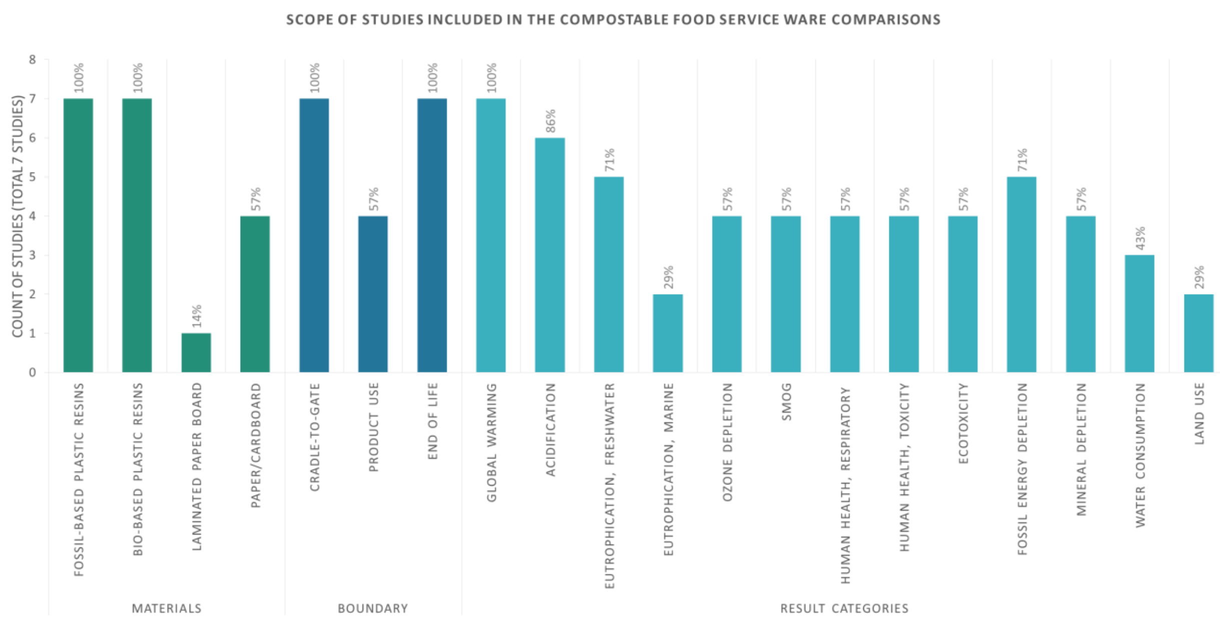

FIGURE 6 SCOPE OF RESEARCH FOR *COMPOSTABLE* FOOD SERVICE WARE (PERCENT VALUES REPRESENT FREQUENCY OF THE CATEGORY WITHIN STUDIES INCLUDED IN THE RESEARCH)

Compostable FSW products studied include cups, plates, clamshells and cutlery. The items were made from various materials including PLA, cellulose pulp, and paper and board. Global warming potential was included in all seven studies. The least represented impact category was land use, present in only two studies. *Compostable* materials are also biobased, and carry with them the burdens associated with biobased feedstock acquisition (see the *Biobased* summary).This can include burdens associated with land use changes.

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

COMPOSTABLE VS. NON-COMPOSTABLE FOOD SERVICE WARE

Figure 7 shows the comparisons of *compostable* FSW that is composted to non-compostable FSW that is landfilled, incinerated, or recycled. Considering nearly 320 comparisons, the *compostable* products exhibited significantly higher impacts in a large majority of comparisons. The primary reason for these results are the higher production impacts of *compostable* materials, which are mostly biobased PLA and fiber-based products.

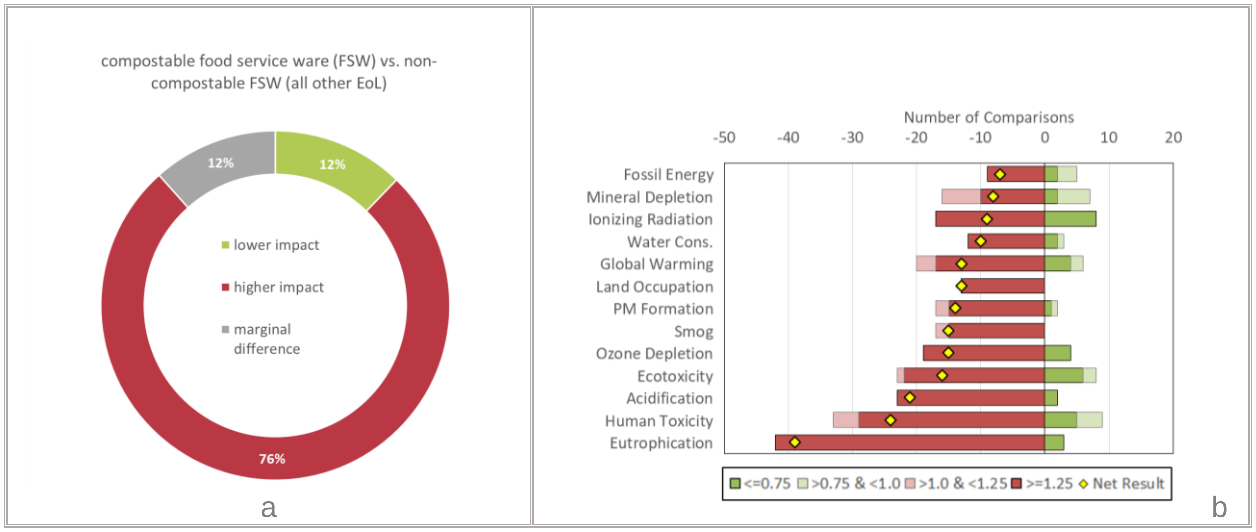

FIGURE 7 SUMMARY OF COMPARISONS FOR *COMPOSTABLE* FSW COMPOSTED VS. NON-COMPOSTABLE FSW, (A) SUMMARY OF COMPARISONS ACROSS ALL IMPACT CATEGORIES, (B) SUMMARY OF COMPARISONS FOR EACH REPORTED IMPACT CATEGORY (SEE FOOTNOTE 9)

> *Data from the past two decades suggest that compostable food service ware (even if composted) is generally not preferable to non-compostable food service ware.*

COMPOSTABLE FOOD SERVICE WARE COMPOSTED VS. *COMPOSTABLE* FOOD SERVICE WARE NOT COMPOSTED

Figure 8 shows the collective finding for *compostable* FSW that is composted with *compostable* FSW treated via other end-of-life routes (not composted). The charts represent 44 relevant comparisons showing no evidence where composting *compostable* packaging reduces environmental impacts. The higher impacts for composted FSW are driven by the relatively low benefits of compost vs. the higher benefits in terms of energy credited to waste to energy incineration, and resource conservation credited to recycling of the *compostable* materials. Of course, waste to energy is not available in all communities, and materials that are both *compostable* and recyclable (for example, paper coffee cups, at least in theory) may not be accepted in recycling collection programs as a practical matter, due to low volumes and/or value. As such, the comparisons shown in Figure 8 are not entirely practical in all communities.

Nevertheless, they suggest that if other end-of-life pathways are available, they may be preferable to composting *compostable* FSW.

In some cases, recycling, incinerating or landfilling compostable food service ware may be preferable to composting compostable food service ware.

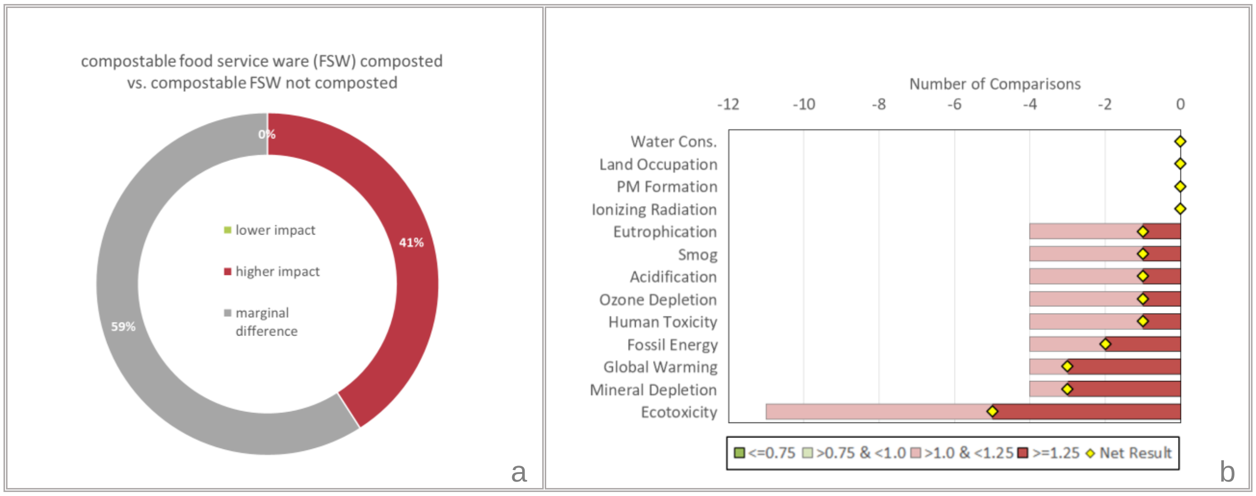

FIGURE 8 SUMMARY OF COMPARISONS FOR *COMPOSTABLE* FSW COMPOSTED VS. *COMPOSTABLE* FSW NOT COMPOSTED (A) SUMMARY OF COMPARISONS ACROSS ALL IMPACT CATEGORIES, (B) SUMMARY OF COMPARISONS FOR EACH REPORTED IMPACT CATEGORY (SEE FOOTNOTE 9)

Food service ware summary

Given the suite of materials and formats evaluated in the literature, *compostable* food service ware (if composted) typically results in higher environmental impacts when compared to other food service ware that is non-compostable, even if that other food service ware is landfilled (see Figure 7). Some of this is related to the assumed rate of displacement of fertilizer by compost. Further, if one chooses to use *compostable* food service ware (often incurring higher upstream impacts), Figure 8 suggests that it may be better to not compost it (especially if the material can be recycled or used for energy production instead).

New formats and materials may change these results, but only if producers invest in lower-impact feedstocks that decouple feedstock acquisition from fossil inputs, or change the intermediary processing steps leading to the final technical material that is converted into packaging and FSW. So long as buyers continue to purchase *compostable* food service ware without also asking for "low impact" options, it is unclear when – if ever – producers of *compostable* FSW will produce *compostable* options that actually deliver reductions in environmental impacts. This suggests that merely designing or selecting FSW for *compostability* is not a viable strategy to reduce environmental impacts. At minimum, the current aspiration of making some types of packaging 100 percent *compostable* should use critical evaluation and consideration through an environmental impacts measurement framework.

Data from the past two decades suggest that *compostable* FSW is generally not preferable to non-*compostable* FSW. This is driven predominantly by the fact that *compostable* FSW is generally biobased, which in the literature review frequently resulted in higher production impacts than fossil-based materials. There is also generally less value in composting technical materials (such as food service ware) than in some other end-of-life pathways, such as recycling. For example, recycling paper back into paper conserves significant resources, including energy, while putting paper in a compost facility degrades most of that value and adds very little in nutrient value to the finished compost.

A possible exception is a case where *compostable* FSW is collected and composted along with food waste, in order to facilitate increased collection of food waste. A common assumption is that the use of *compostable* FSW results in an increase in food waste recovery. That increase in food waste recovery increases the nutrient content of the compost resulting from the additional organic material. Diversion of food waste away from landfills also reduces landfill emissions. However, the only studies found that explored this option focused on *compostable* tableware and cutlery; they showed improvements for global warming potential when compared to non-compostable tableware. The results from those studies were driven by the collection of the *compostable* tableware and the food waste in a single waste stream, and the added benefits resulting from food waste composting (and avoided impacts of food waste disposal). However, no evidence was provided that illustrates the *increase* in food capture and recovery that results from using *compostable* FSW. Food waste recovery is possible without *compostable* FSW (for example, *compostable* FSW is rarely used throughout Oregon). This suggests that more research is needed to fully ascertain the benefits of co-collection of *compostable* FSW and other organic waste.

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

While the results discussed above provide valuable insight into the potential environmental tradeoffs of *compostable* packaging and food service ware, there are several points worth noting that are not well-addressed in the literature.

1. Limited access to industrial-scale composting facilities that process technical materials used in packaging:
    a. While composting may be the intended waste management strategy for *compostable* packaging materials, it is likely that a significant fraction of such materials will be landfilled. This is because landfilling is currently the end case scenario for about half of Municipal Solid Waste (MSW) in the U.S., while composting accounts for just under 9 percent (U.S. EPA Office of Resource Conservation and Recovery 2016).
    b. Most of the studies reviewed assumed adequate facilities for composting (and the other waste management options they considered), but in reality the majority of dedicated composting facilities in the U.S. currently accept only yard trimmings and similar organic refuse (Platt et al. 2014).

2. Misalignment of certification standards and on-the-ground conditions: Certification standards for *compostable* packaging and food service ware are based on the ability of the product to degrade in a laboratory setting. However, real-life conditions in compost facilities vary widely, for example, due to differences in residence time, temperatures achieved, etc. Not all certified *compostable* packaging and FSW fully composts in all compost facilities. The result is either the contamination of finished compost with non-composted packaging and FSW, or that compost facility operators are required to change their operations, sometimes at considerable expense.
3. Confusion and contamination:
    a. Another difficulty for appropriate handling of *compostable* packaging is that often consumers do not have a clear understanding of the differences between biodegradable and *compostable* packaging, and between home and industrial composting.
    b. Acceptance of certified *compostable* packaging in an organics collection system can inadvertently lead to contamination of compost operations and finished compost as similar-looking materials often end up in the bin because people mistake (or wish) them to be *compostable*. Contamination of finished compost with non-degraded plastics (both *compostable* and others) creates added financial costs to the compost industry, lowers the quality and value of finished compost, and distributes plastics into the broader environment. All of these undermine the economic viability and broader sustainability of the composting industry, potentially putting food waste composting at risk.
4. Biodegradation of *compostable* plastic in the environment:
    a. Biodegradation of *compostable* packaging under ambient exposure conditions, such as litter, was not documented in the literature. The pH, moisture, oxygen content, and temperature of the environment, as well as the structural composition of the material, play a significant role in the degree of biodegradation.
    b. *Compostable* bioplastics generally showed high degradability in soil environments, but many do not degrade in fresh water and marine environments. This means that *compostability* is not a viable attribute to consider if fresh water and marine plastic pollution is the goal. Since these materials do not degrade in aquatic systems, they are comparable to conventional plastics in terms of their potential to harm freshwater and marine ecosystems and animals.
5. Potential for other impacts not studied:
    a. Life cycle assessment, while offering a more comprehensive assessment of impacts than other evaluation frameworks, does not address toxicological impacts of materials during use. One particular issue of concern is poly/per-fluorinated alkyl substances (PFAS) used as moisture or oil barriers in some packaging and especially food service ware. These compounds are both persistent in the environment and have negative health impacts. Using them in *compostable* packaging and food service ware can introduce them into finished compost, resulting in negative health and environmental impacts that were not evaluated in the LCA literature we reviewed.

   b. The life cycle assessment studies reviewed also did not evaluate impacts of marine debris. However, since many *compostable* plastic packaging and FSW items are not marine degradable, it is not obvious that their use will in any way reduce the presence of non-degraded plastics in marine environments. Further, the problems of incomplete degradation of some *compostable* plastics, as well as co-contamination with look-alike non-compostable items, results in finished compost that is contaminated with small plastic fragments. Application of this finished compost can create a pathway for polluting waterways including marine pollution.

6. Diversion goals to keep materials out of landfill typically treat the beneficial end-of-life treatment routes – recycling and composting – as being equal to each other. In other words, how the material is diverted from landfill is not relevant to calculating the diversion rate. Yet this research and studies reviewed show that the benefit of recycling is often greater than composting. This is fundamentally because recycling creates usable secondary materials that can displace more impactful materials in production. While decomposing the materials via composting generates some residual nutritive or carbon reduction, it essentially destroys the material – be it fiber or polymer.

In addition it should be noted 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 polylactic acid (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.

Summary

Two high-level conclusions can be drawn from the global literature review about *compostability* of packaging and food service ware.

1. *Compostability* of a packaging and FSW does not appear to be a clear predictor of environmental preference.
2. *Compostable* packaging and FSW that is composted does not consistently result in lower impacts when compared against other end-of-life management options such as landfilling, incineration or recycling (where possible).

In addition, the following concerns pose additional challenges to the use of *compostable* packaging and food service ware:

3. There exists significant functional discrepancies between *compostability* standards and the operational realities of commercial composting facilities. Current composting practices may lead to inconsistent degradation of packaging and FSW designed for *compostability* resulting in contamination of finished products, water and soil in the form of microplastic particles.
4. Front-end contamination of feedstock to composting facilities by *compostable* packaging/FSW and copycat items, as well as toxic additives in packaging and FSW, is a significant operational concern and potential source of contamination of micro plastics and toxicants.

Discussion and Recommendations

Using the compostable attribute as a strategy to reduce life cycle environmental impacts of packaging and food service ware materials is not supported by research from the past two decades. The research suggest that the use of compostable packaging has significant environmental tradeoffs when compared with non-compostable materials and other end-of-life packaging management practices.

Package Design

There are significant movements across the U.S., and indeed worldwide, to make all packaging *recyclable* or *compostable,* and at times both of these attributes are viewed as being equally sound in terms of their environmental benefit. Designing for *compostability* fits into a common practice called Design for Recovery, sometimes referred to as DfR.

Compostable packaging and food service ware is marketed as an environmentally sound attribute and many individual and institutional buying decisions are made based on this attribute. Many businesses, advocacy groups, and governments use the *compostable* attribute with laudable intention to reduce environmental impacts. Such goals are sometimes based on assumptions that include: 1) that if packaging and FSW is made to be *compostable*, and then composted, then its environmental burdens can be offset; 2) that composting and recycling – as two waste recovery methods that both divert waste from landfills – are equally effective strategies for broader goals of conserving resources and reducing pollution; 3) that closing the end-of-life loop via composting of packaging and FSW keeps nutrients in circulation, thereby offsetting other chemical nutrient inputs such as fertilizers; 4) achieving “zero waste” from landfill (which requires that packaging be fully *recyclable* or *compostable*) will offset the pollution associated with the production and use of the packaging; and 5) that if *compostable* packages are consistently composted then marine pollution can be curtailed.

Yet, prevailing material science and packaging systems research presented herein indicates that none of these assumptions are wholly true. There are several reasons for this.

First, materials are inherently different in terms of their life cycle environmental burdens. The life cycle impacts of how these materials are made, as well as their chemical additives and coatings all contribute to the overall burdens associated with the materials.

Second, composting can be viewed as a method for nutrient recovery, similar to recycling as a mechanism for secondary material recovery. While composting is an important activity for organics management such as food waste, it does not mean that all or most of the nutrients are recovered in the compost. Further, composting is not necessarily the optimal route for managing technical materials such as plastics and coated or printed papers. Technical materials used for packaging are different from yard and food waste, and they do not necessarily contribute significant nutrient value to the compost. Little if any of the embodied energy in packaging or FSW is recovered via composting. In contrast, recycling does more to capture and recover embodied energy and materials that have the potential of displacing virgin feedstocks in production. The nutrients recovered via composting packaging are a tiny fraction of the inputs that go into growing food stuff or making the package.

Third, technical materials in the composting feedstock add potential contamination at the front end, and increase the operational complexity of the facility. Sometimes, these materials do not fully break down in the composting process, but rather fragment into smaller particles, creating micro contamination. This creates a potential route for bits of plastics and coated paper materials to enter the environment when the final compost is used as for erosion control or in farming or landscaping applications. The micro contaminants can flow into waterways through normal rain and irrigation processes, potentially adding pollution to rivers and marine ecosystems in coastal regions.

Several actions can be taken via the packaging design process to address these issues:

1. Examine the motivation for designing packaging to be *compostable*. Industrial composting facilities are not universally available and those that are do not always accept packaging. Furthermore, many types of *compostable* packaging cannot be handled via backyard composting.
2. Establish company-wide or portfolio-level sustainability measurement criteria for packaging.[11] The measurement criteria should be based on an assessment of impacts across the full life cycle of the packaging.
3. Optimize packaging design by prioritizing the use of materials with the lowest life cycle impact profile[12], then consider the viable end-of-life treatments to optimize recovery.[13] Research suggests recycling to be a better outlet for packaging once it is optimized for life cycle impacts.
4. Avoid setting, demanding, or promoting unrealistic commitments or targets for *compostability* (i.e., all packaging must be *compostable* by a certain date). Rather consider life cycle burdens of different packaging format options. Designing for *compostability* does not consistently or reliably lead to the lowest environmental impacts.
5. A similar approach should be taken for food service ware given that *compostable* food service ware is not necessary for successful food waste recovery.[14] The magnitude of the

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[11] 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

[12] 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: https://www.thinkstep.com/

[13] Such an approach can be loosely referred to as Design for Environment (DfE). In contrast to the aforementioned Design for Recovery (DfR), DfE attempts to optimize the entire life cycle of the product and package not just select stages such as end-of-life treatment. Various software tools and design guidance exist for packaging to implement DfE.

[14] For example, very few food waste collection programs in Oregon allow for packaging or FSW (including *compostable*) to be included, and yet Oregon successfully diverts thousands of tons of food to compost and anaerobic digestion annually. There are many examples of communities and programs that allow packaging and FSW to be co-collected with food, but this is not proof that co-collection is actually necessary. Proponents of *compostable* FSW sometimes offer anecdotal or qualitative examples of how *compostable*

potential increase in food waste recovery associated with the use of *compostable* FSW has not been well documented, and trade-offs between the impacts of *compostable* food service ware production and benefits of potential increased food waste recovery have not been well evaluated.

6. Use the *compostable* claim judiciously for packaging[15]. Avoid confusing *compostability* – the design criteria for the potential of being composted – with composting, an end-of-life action for organic wastes. They are not one and the same. Composting can be a beneficial end-of-life treatment method for certain types of wastes, such as food. This does not mean however that all *compostable* materials are inherently beneficial or low-impact.

Institutional and Corporate Purchasing

Material attributes are commonly used as a shorthand for procurement decisions to denote environmentally preferable purchasing. *Compostable* packaging may be given preference based on corporate or institutional goals for material management from food vending, catering, and related services. A common assumption is that if all food service packaging is *compostable*, then disposal reduction targets can be met via proper end-of-life management. As described earlier, environmental outcomes and *compostability* do not correlate sufficiently to consider *compostability* a viable attribute to rely on for making packaging or food service ware choices. Therefore, purchasing solely based on *compostability* can increase pollution and resource impacts. The following actions are recommended:

1. Do not use *compostability* of FSW or a product's packaging as the primary sustainability criterion for procurement.
2. Be aware of local infrastructure capacity and reality for collecting and composting *compostable* products prior to committing to using such products. Check with local compost facility operators; they may or may not accept all (or any) materials that are certified *compostable*.
3. Rather than asking for *compostable* materials, ask vendors to provide information on the life cycle environmental impacts of their materials, ideally through an environmental product declaration consistent with a common product category rule, and use those results to inform material selection.
4. If you do ask for *compostable* materials, also ask for vendors to provide information on the life cycle environmental impacts of the materials (consistent with recommendation above). Although the information requested in #3 and #4 are not commonly available (at present), they are becoming more common, and the inquiry process may nudge more manufacturers into re-evaluating their product designs and ultimately affect the market.
5. Where appropriate, consider reusable food service ware. Although not the primary focus of this literature review, it is often found to have lower environmental impacts than single-use items, even when the impacts of washing are included.

FSW enables higher food waste recovery rates, while skeptics point to collection from restaurants that comprise of large quantities of FSW and very little food.

[15] For example, some corrugated board is labeled as "Recyclable and Compostable".

Marketing

Although a principle function of packaging is to protect the product so that it is delivered from the manufacturing facility to the customer, 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. 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 outcome is often 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[16], design guidelines[17], and tools[18] to implement informed design choices that can satisfy the demand for packaging with reduced environmental impacts. The following actions are recommended for both packaging and food service ware:

1. Shift marketing claims of sustainability towards package optimization for life cycle impacts. For example: "This package optimized for lowest carbon footprint."
2. Since *compostability* is not a good indicator of environmental outcomes, avoid greenwashing by claiming *compostability* or implying environmental goodness as a result of *compostability*.

Policy for end-of-life management

Compostability is not a good predictor of reduced environmental impacts for packaging and food service ware. *Compostable* materials are often biobased and tend to have significant life cycle burdens associated with growing, harvesting and processing feedstocks prior to converting them into packaging or food service ware. In many instances biobased materials introduce trade-offs (environmental advantages and disadvantages) when compared to competing materials (see *Biobased* summary). Biobased materials often exhibit improved environmental profiles when treated via end of life methods other than composting, such as recycling or incineration with energy recovery.

A primary responsibility of policy measures for municipal solid waste management is to support the creation of usable secondary materials via recycling or nutrient recovery via composting. Properly functioning composting systems should collect organic materials with the highest potential to reduce environmental impacts and to generate a high quality compost product that is free of plastic particulate and chemical contamination. In other words, an end product that can be safely used to grow vegetables at farms or in home gardens, or for erosion control and soil restoration. While the *compostable* design criterion may set up packaging or FSW for end-of-life treatment via industrial

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

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

[18] Various off-the-shelf Design for Environment (DfE) tools exist specifically for packaging design including but not limited to:

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: https://www.thinkstep.com/

composting, research shows that it does not consistently yield reduced environmental impacts. In fact, evidence over the past two decades shows that the opposite is true – that using and composting *compostable* packaging and food service ware has the potential to increase environmental impacts. In addition, making all things *compostable* makes little practical sense since industrial composting is not consistently available nationwide or worldwide – and not all industrial compost facilities are willing to accept *compostable* packaging or food service ware.

One of the limitations of the existing research is that it fails to account for the hypothesized "carrier benefit" of *compostable* food service ware. Additional research is needed to demonstrate how much (if any) additional food waste is actually recovered using *compostable* food service ware (in a variety of settings), compared to a baseline where food waste is collected without the use of *compostable* food service ware. The additional environmental benefits of that added food waste recovery should be evaluated for environmental impacts that can be compared alongside the impacts of different types of food service ware.

Policy should:

1. Explore and consider durable options where appropriate for food service.
2. Protect the economic viability of the compost industry, and by extension, its ability to provide long-term sustainability benefits including soil restoration, by keeping non-compostable materials out of feedstocks sent to compost facilities.
3. Unless there is a clear benefit that exceeds the added burden of using *compostable* packaging/FSW (see figures), and unless contaminants can be kept out, eliminate *compostable* packaging and food service ware from collection streams destined to composting facilities.
4. Educate stakeholders (e.g., institutional buyers, consumers, etc.) that for packaging and FSW, *compostability* is a poor indicator of lower negative environmental impacts.
5. Encourage material evaluation frameworks and decisions that are based on actual environmental and human health impacts, as opposed to attributes that do not reliably correlate with reductions in those impacts – such as *compostability*.
6. Do the same for waste management decisions related to diversion – material life cycle impact based rather than weight-based landfill avoidance assessment.
7. Explore shifting actions towards recycling of appropriate materials based on potential for reducing environmental impacts and market viability. Recycling, however, requires enhanced scrutiny of recycling end markets, to avoid irresponsible shipments of mixed materials (including contaminants) to regions that lack adequate processing and management infrastructure.