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Review of the Life Cycle Analysis Report on Compostable Food Serviceware Published by Oregon DEQ

BIODEGRADABLE PRODUCTS INSTITUTE

PURPOSE OF THIS DOCUMENT

This document is an industry response to the Oregon DEQ report on "The Significance of Environmental Attributes as Indicators of the Life Cycle Environmental Impacts of Packaging and Food Service Ware" [1] (hereafter referred to as the "report") and focus on the technical merits of the Life Cycle Analysis (LCA) approach used.

The Oregon DEQ report focused on four attributes: Recycled Content, Recyclable, Biobased and Compostable. This document provides a review of the Compostable section of the report and the reference materials cited in the report.

[1] *https://www.oregon.gov/deq/FilterDocs/MaterialAttributes.pdf, accessed Feb. 21, 2020*

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In the compostable section, compostable packaging materials (PM) and the compostable food service ware materials (FSW), were handled separately. There were 11 PM and 7 FSW references cited.

From the following assessment, it can be concluded that the number of relevant studies is too small in both evaluations (PM and FSW) to draw solid and sound conclusions, once the validity of the references and the method of comparison is considered. In addition, some of the studies do not relate to a specific product (cup or clamshell) but to an amount of material (1 kg of material or 1 kg of pellets).

This document reviews the above-mentioned report on the basis of the fundamentals of LCA and illustrates how these aspects were often not evaluated correctly. The fundamentals reviewed and the main conclusions drawn are given below and discussed in more detail further down this document. The referenced LCA studies are listed in Table 1 and 2 at the end of the document.

RELEVANCY: 60% of the referenced studies are obsolete. 100% of LCAs are comparing immature bioplastic production systems with mature fossil-based systems.

PRESENTATION OF DATA: Presenting results of this type in histograms is very debatable and does not show if the differences are significant. No distinction between the relevance of indicators (weighing) has been applied and irrelevant scores are not removed.

ATTRIBUTIONAL VERSUS CONSEQUENTIAL: By mainly using attributional LCA references, the overall benefits of compostable products are not fully demonstrated or calculated.

COMPARISON OF ALTERNATIVES: Some referenced LCAs contained biased or meaningless comparisons. The proper modelling of the value of composting in LCA is an underdeveloped area. Most LCAs are done on product item level, while they should be done on waste stream level to capture and calculate the real value of compostable products in LCA.

ENVIRONMENTAL INDICATORS:; The majority of the PM LCA studies (7 out of 11) focus on one or a very limited number of indicators.

INCONSISTENT REPORTING OF POSITIVE IMPACT: A majority of the references showed that compostable materials performed better, but that is not reflected in the overall conclusions of the report.

MATERIAL COMPARISON: A consistent use of Functional Units: Many references showed an oversimplified and an inconsistent use of the Functional Unit, the basis for a good comparison. Other studies are comparing products which have different functions.

DATA COLLECTION FOR END OF LIFE: The assumptions made in the references about the behavior of PLA in landfill are false. Most of the EOL datasets were incomplete in the references; many LCAs compare alternatives on a packaging level, while comparisons should be made on a waste stream level (e.g. packaging including the food waste).

CONCLUSION OF EXECUTIVE SUMMARY

LCA is inherently biased against new developments (processes, materials and products) when compared to conventional homologues since limited datasets, sometimes only from research and development, are compared to literature data from optimized processes, materials and products with a long history of improvement. LCA's must therefore be carefully considered and nuanced to avoid negatively evaluating a new development before it can demonstrate its merits. Whereas it is not fully neglected in this study, it is given relatively little attention as precaution.

It is acknowledged by experts in the industry that the benefit of compostable packaging material (PM) and compostable food service ware (FSW) does not lie in the composting of the compostable product itself. Instead, it is the "co-benefit" effect whereby compostable PM and FSW enables the diversion of far greater amounts of biowaste from landfills and incineration. While this is briefly mentioned in the study, no attempt was made to include this impact qualitatively or quantitatively in the evaluation. Compostable PM or FSW should be used as a facilitator or catalyst for organic waste diversion and should not be presented as a stand-alone solution.

Many studies referenced in the OR DEQ report were not based on equal LCA comparisons. Several of the studies just dealt with multiple disposal methods for compostable materials, where they should have studied only compostable disposal. Several of the studies did not give equal comparison in credits or equal benefits to material reused or used for another purpose. For example, there is no study that was evaluated to reflect the case where compostable bags are used to preserve food and these same bags being used to collect non-consumable food waste to be processed in compost facilities. This practice is widely practiced in mature composting markets. The relevant question is then: what is the best End of Life (EOL) option for PM or FSW materials for packaging, preserving, and handling food: is it recycling, landfill, incineration or composting? In such comparisons the value of composting will have greater benefits.

Many of the referenced LCA studies in the report showed positive results for compostable materials, however the histogram results in the study do not properly represent this point. From an LCA perspective, there are several topics of concern in the evaluation of the referenced studies and the resulting conclusions. In other cases, compilations of the results are not good science or a proper representation of the composting industry or industrially compostable products. When drawing conclusions from results of the references, one should point out that this evaluation has many technical LCA flaws, and therefore, it is the sole opinion of the Oregon DEQ and not a true representation of the compostable industry or its practices.

INTRODUCTION

The remainder of this document expands on the above-mentioned Executive Summary based on fundamentals of LCA and further illustrates how these aspects were not evaluated correctly. The details and examples of the flawed fundamentals of LCA are expressed in each individual section. The main conclusions drawn for this document are based on these flawed LCA evaluations.

For the development of this document, each study that was referenced in the OR DEQ report for compostable materials, was reviewed and assessed according to the individual LCA fundamental sections listed in the Executive Summary. To support this, two tables were developed to summarize the critical information contained within each study: one for compostable packaging materials (PM) and the other for compostable food service ware materials (FSW). These tables can be found at the end of this document and the relevant columns in these tables are referenced in each section.

RELEVANCY OF THE LCA REFERENCES USED

In LCA comparisons, the relevancy of a study is usually acceptable if the study is less than 5 years old because processes are constantly being optimized and/or the environmental input data for upstream inputs may have changed as well (such as the source of energy). This is especially true for new materials entering the market.

From the NSF Protocol[2], **Validation and Verification of Eco-Efficiency Analyses NSF P352 – 2015**, under Section: **1.2 Limitation**, there is a statement that, "Eco-Efficiency Analysis models and results shall be considered relevant for three years after validation or verification." Therefore, any studies and LCA information should be considered valid for up to 3 years.

The relevance of the age of the study is also illustrated by Figure 1, where the net cradle to polymer factory gate GHG emissions are given in green for NatureWorks Ingeo PLA production from corn starch between 2003 and 2015 (year of publications)[3] and in light green for Total Corbion PLA production from cane sugar in Thailand in 2019 [4]. All production systems have the same system boundaries (cradle to polymer factory exit gate) and are therefore comparable. It can be concluded from these data that studies older than 5 years are rapidly becoming less relevant.

Figure 2 provides similar data, but now considering the nonrenewable or fossil energy use to produce the PLA Biopolymers.

Figure 1. Cradle to Polymer factory gate greenhouse gas emissions for Polylactic acid (PLA) production over time

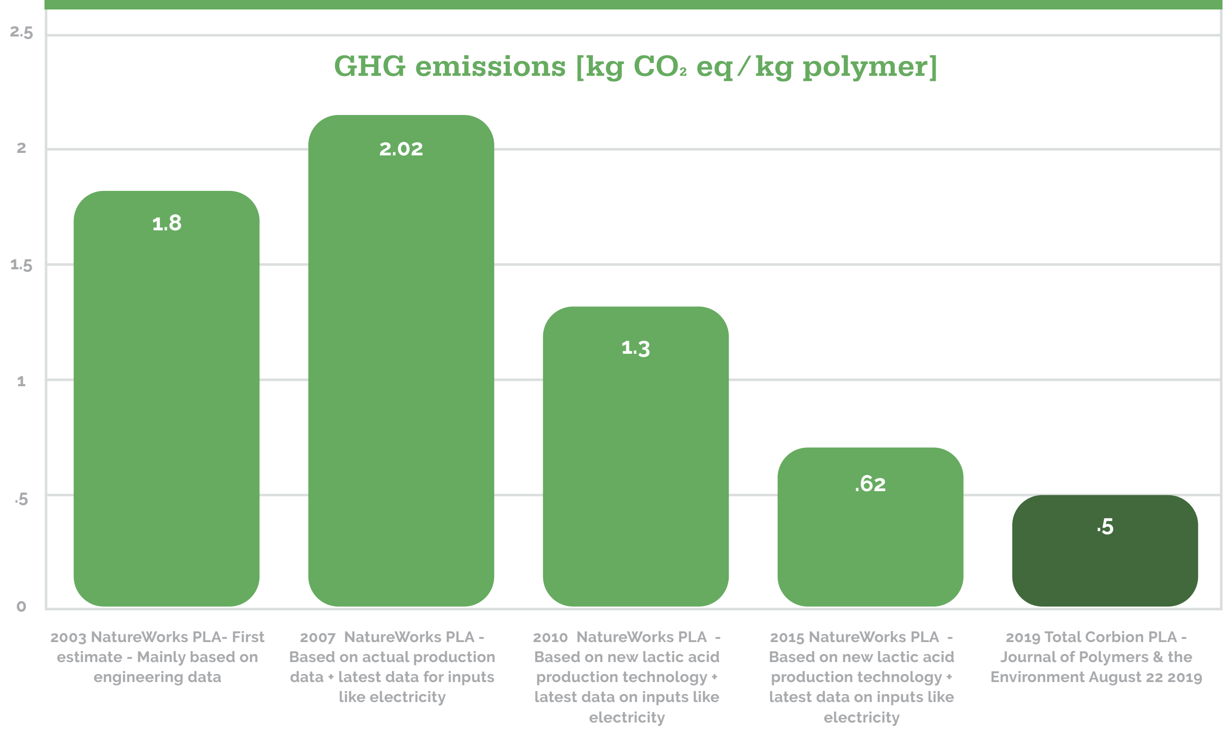
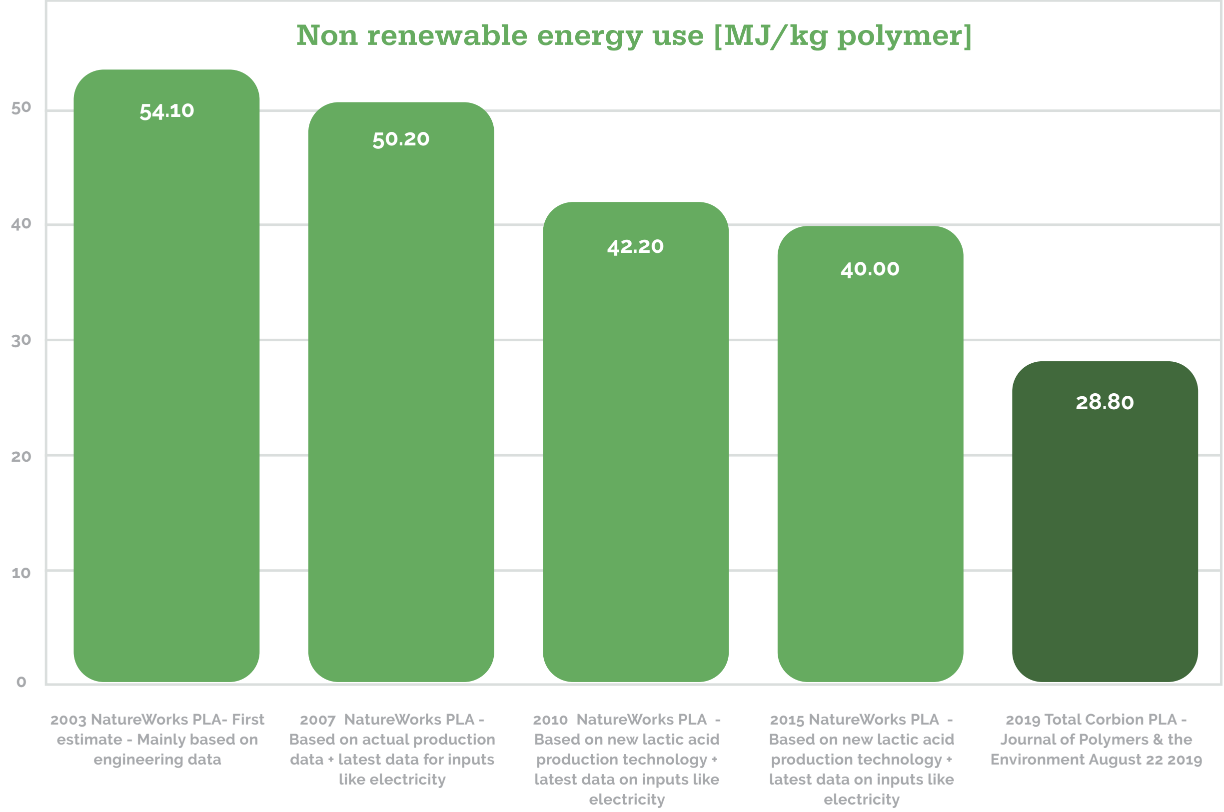


Figure 2. Cradle to Polymer factory gate non renewable energy use for Polylactic acid (PLA) production over time



Of the reference documents in the study, only 4 of the 11 studies for packaging materials are within the acceptable time frame, and 3 of the 7 for FSW. This means that roughly only 40% of the studies were relevant in 2018, the date of publication of the report. In fact, the reference that has the highest number of comparisons (Hermann 2010 has several statements relating to PLA laminates (compostable material), acknowledges that future optimization will occur and therefore will change the calculus: *"For the production of bio-based materials, there is a significant potential to reduce the environmental impacts in the future with increasing technology maturity both at the material production (granulate) and at the processing (film production) stage." (Hermann 2010)*

It is therefore important a) that all decisions fully account for the consequence of choosing the technology perspective or the company perspective and b) that more R&D is carried out towards optimising PLA granulate and film production. Films and laminates containing cellulose produced using today's technology do not show any environmental advantages." (Hermann 2010)

The Hermann (2010) study is based on 2007 data, comparing this with the data as given in Figure 1, the outcome of the Hermann study should be treated with utmost care and just excluded from this study.

This tacit acknowledgement was also mentioned in the Vercalsteren (2006) study:

"The PLA production system is a 'young' system with a limited production capacity while the other systems are 'mature' systems with much higher production volumes. In a 'mature' PLA system with high production volumes the environmental performance shall improve due to efficiency increase and scale aspects".

In principle, there are published standards for life cycle assessments that provide guidance on how to compare different polymers fairly regarding their environmental impacts. However, these standards still leave quite some room to maneuver specifying the methods by which such comparisons are to be carried out. The German Nova Institute [6] assessed the aspects to be included to obtain fair comparisons between the rather immature bioplastics family of products and the mature conventional fossil-based plastics. All the referenced LCAs in the report were based on data representing the current situation at the time; no scenarios were included to model the future. So, in fact all LCAs are measuring the performance of immature production systems with the performance of production systems optimized for the last 60 years. A couple of observations made by the Nova Institute:

- The bio-based processes will be considerably optimized by 2050, while room for improvement in petrochemistry is largely exhausted.
- The environmental impact of biomass production, on the other hand, will be significantly reduced by 2050: Digital and precision farming as well as bio stimulation will reduce fertilizer use and minimize the use of pesticides as well as increase yields.
- The environmental impact of oil production will increase by 2050 because larger proportions of shale gas and oil sands are in the oil mix.
- EOL credits for incinerated fossil-based polymers will decrease since electricity production will shift to renewable energy and therefore will be much cleaner.
- Scientifically uncertain criteria such as indirect land-use changes should not be integrated into the LCA methodology if correspondingly uncertain aspects are also not included for crude oil production.
- Fossil- and bio-based polymer datasets must be brought to the same level of quality in terms of completeness, system boundaries, regional scope, transparency, modelling rules
- The use of renewable carbon instead of fossil carbon is a value that should be regarded.
- New dynamic models should be developed to integrate the storage effect of renewable carbon into LCA.

See the age of the referenced LCAs "Date" column in Tables 1 & 2 in the reference section.

PRESENTATION OF DATA

Within LCA evaluations, there are several factors, like how results are being presented, that can influence the final results and conclusions made; if some of these factors are disregarded or missing, the impact can be misinterpreted. When comparing the referenced documents from this study, there are several examples of compostable materials being better than the alternative materials.

In the OR DEQ report, the use of a histogram chart shows that the use of compostable materials versus alternative materials is equal or better in most environmental comparisons. However, in the Global Warming Potential (GWP) histogram results, the compostable materials are shown to be worse than alternative materials. In the histogram for GWP, there were over 375 comparisons based on the 11 referenced studies. As stated in the OR DEQ Report, *"168 (89 percent) of these comparisons are obtained from the study by Hermann and colleagues (2010). Most comparisons where compostable materials perform poorly compared to non-compostable landfilled materials come from this study, due to its comparatively large sample size."*

This referenced study, Hermann (2010), had over 29 alternatives (defined cases), while most of the other referenced studies had 2 to 4 alternatives. As in any study or analysis, statistically you should base results on at least 20 data points but DEQ's report states most of the poor results for compostables come from this study. Since that was the case, a histogram without this study should have been done for GWP to show how the GWP was influenced by Hermann (2010) study. In the histogram of compostable materials being composted versus alternative waste options, there are over 58 comparisons for GWP. Again, from the Hermann (2010) study, one could mathematically determine that 14 data points out of these 58 could come from this single study, which is about 25%. This is due to 7 of the 29 alternatives being totally compostable. This Hermann (2010) is also the second oldest study out of the 11 references.

Another LCA perspective is that one cannot draw conclusions from data being compiled in a histogram. This type of delivery of data shows a perspective that one of the results was either positive or negative and does not necessarily compare the alternatives equally. Case in point, again from the Hermann (2010) study, compostable materials should not be compared against incineration, since these materials are designed for composting and not for combustion and energy recovery. Also, in the Hermann (2010) study, landfill and incineration have credits given where the compost and digestion disposal have no credits. One cannot see these discrepancies in a histogram.

The thirteen Environmental Indicators used are normalized and equally weighted when making comparisons and final evaluations. However, when evaluating final results it is crucial to take into account the importance or the weight of each considered Environmental Indicator to the subject of the study. Giving all indicators an equal weight gives a false sense of the overall environmental impact, because in reality all Indicators do have different impacts.

Furthermore, when impacts are compared, the margin of error depends on the reliability of the input information. However, the OR DEQ report arbitrarily defines a threshold of 25% to be a meaningful threshold to distinguish which attribute is better without any statistical validation. This threshold of 25% could be acceptable for GWP and energy use but is very debatable for the other impact categories, which are typically smaller in magnitude. Secondly, it is important to note that not all environmental impacts are equal in magnitude, and these environmental impacts often vary by several orders of magnitude. The use of a histogram incorrectly normalizes this data, so that an environmental impact which might be very small or irrelevant when compared to another alternative then equates to one which is very large in the histogram presentation. For example, a study may have a very small number for ozone depletion (ODP) for a compostable and non-compostable material. However, when you compare in this fashion, the irrelevant value now has a meaning value of >1.25, 1 or <1.25. A relevancy check on the data would indicate which environmental impacts are important, which is not done on any of the cited studies with multiple environmental impacts.

See the "Number of Alternatives" and "Environmental Issues" columns in Tables 1 & 2 in the reference section.

ATTRIBUTIONAL VERSUS CONSEQUENTIAL LCA EVALUATIONS

In LCA evaluations, a study can be either attributional or consequential; these are different methods using different input data. Attributional LCA methods would give results for emissions directly associated with the life cycle of a product. Consequential LCA methods are applicable for assessing different scenarios related to the use of the product, informing consumers and policymakers on the change in total emissions from a purchase or policy decision. In the study analysis, 7 of the 11 referenced documents were attributional LCAs for the PM and 6 of the 7 reference documents were attributional LCAs for FSW.

An attributional study uses the stated values or normative allocation in the production, use and disposal. Attributional looks at the actual evaluation data and does not take into consideration changes in any of the product/process.

A consequential study provides information about the consequences of changes in production, use and disposal of a product, including effects both within and outside the life cycle of the product. Consequential modeling evaluates the decision to changes in the output of the product/process.

In evaluations comparing compostable materials, consequential analyses would be the better choice since this would look at the total picture of the life cycle. For example, in multiple studies in this evaluation, the disposal of the composable material have CO_2 being emitted when placed in a landfill, whereas the non-compostable material has no degradability emissions. If a consequential analysis is done, there would be benefits of compostable materials going to a compost site like carbon sequestration in the compost process. There would also be benefits in the use of the compost that are not captured in an attributional analysis. In a consequential analysis of the non-compostable material going to a landfill, there would be negative impacts. These would be land use, resource consumption (when material is placed in landfill there are infrastructure and dirt used) and potential contamination of water sources. In most of these studies, there are no negative impacts to material going to landfill, due to the attributional evaluation method of the analysis.

See the "Conseq/Attrib." column in Tables 1 & 2 in the reference section.

COMPARISON OF ALTERNATIVES IN LCAS

Most of the reference documents had 2 to 5 alternatives compared in the studies, which is considered acceptable in LCA. However, one of the studies, Hermann (2010), had 29 different alternatives for multilayer packaging. Different disposal methods were evaluated in this study and the results were all compared to each other. This reference should have been broken down the appropriate disposal methods by product to get a better comparison of the alternatives. For example, the compostable materials were compared against non-compostable materials in incineration and landfill, where some type of environmental credit is given. Yet in the composting and digestion of compostable materials there is no credit given for carbon sequestration or recovery. Further what is the value of investigating the fate of compostable products in incineration or landfill, while they are not designed to go there? In an equal comparison, all disposal methods should have credits given or all disposal methods should have no credits.

The value of incineration is the recovery of heat. The value of recycling is the recovery of materials. These credits are usually well captured in LCA. The objective of composting is to process organic waste streams from gardening and kitchens to produce compost. The study confuses the role of compost – compost is a soil conditioner, not a fertilizer. The real value of compost is not captured in the referenced LCAs. This is an underdeveloped area in LCA and as long as this exists, we need to conclude that LCA is unsuitable to capture the value of composting. The value of compost can be summarized as:

- Organic matter (compost) improves the soil structure and moisture management.
- Organic matter improves the soil workability.
- Organic matter provides nutrients for growing plants.
- Organic matter reduces runoff of nutrients and plant protection products.
- Organic matter provides food for species living in the soil like worms and insects.
- Organic matter improves the resistance to diseases and pests.
- Organic matter increases the biodiversity of soil life; which consequently increases the biodiversity of species, like birds, living from soil life.
- Organic matter increases carbon capture in soil.

Most LCAs, except Razza, are performed on FSW or PM item level by e.g. asking the question: what is the environmental burden of processing this item in incineration, recycling, composting or landfill? This is the wrong level to understand and capture the value of composting. In reality, FSW waste streams hardly exist of isolated cutlery or plates; they rather exist of a mix of cups, plates, cutlery, napkins, and food waste. If one starts now with the question about the best EOL option, the outcome will probably be different. Bringing the waste stream to recycling will come with additional sorting and washing steps and there is still the food part that needs to go to composting. Recyclers do not like food waste in their operation, since it attracts flies and pests. Incinerating the waste stream is probably not attractive since normally food waste has a high moisture content. In many countries landfills are phased out or will be in the near future. Also, food in landfill leads to methane emissions. The only proper EOL options for such a waste stream is composting. Such a waste stream can be processed at low costs, in a safe way and delivers some valuable compost that can return to the soil. Many of these things are not captured in the referenced LCAs. Compostable packaging can also be valuable in other applications like the coffee capsules ; the only meaningful EOL for the content (80% wet coffee) is composting, so it makes a lot of sense to also make the packaging compostable. This is because the alternative materials used (PP, Aluminum) are not or hardly recycled. This is also valid for compostable tea bags. The latter has the additional benefit that the usually used PP fibers stay behind as microplastics in the final compost. Another benefit which is not captured in LCA.

It is strange that on page 92 of the study the co-collection and co-composting of FSW with food waste is spoken of as a "possible exception" while instead this is the standard practice and the true alternative to other options. There are no current municipal collection programs for an isolated stream of FSW or compostable PM.

The use of the terms biodegradability and compostability is inconsistent and at times incorrect throughout the study. Biodegradability and compostability are not alternative characteristics. Biodegradability must be measured in and specified according to the environment in which it takes place. Compostability includes biodegradability, but additionally includes timely disintegration and environmental safety.

See the "Number of Alternatives" column in Tables 1 & 2 in the reference section.

THE USE OF ENVIRONMENTAL INDICATORS

Seven out of 11 PM LCA studies had no or a very limited (e.g. only GW and Energy) number of Environmental Indicators. In comparative LCAs placed into the public domain this number is just too low to justify any environmental performance related conclusion. All FSW related studies were based on multiple Indicators.

The study is looking only at the classic Environmental Indicators, and only for tangible materials and products. For composting it is important to include other impacts, such as other environmental benefits, other avoided burdens, co-benefit effects, socio-economic impact are hardly mentioned or in several cases not at all. The broader context is missing.

As in most LCA studies done with multiple environmental assessments, a relevance check should be done to determine if the environmental indicator has any importance in the study. For example, if a study is comparing the Ozone Depletion Potential (ODP) and there is a small amount in both alternatives, yet one alternative is 10 times the other. One can not make a claim that one alternative is better than the other if both of the amounts for ODP are irrelevant. In this example, the histogram would show this number would be >1.25, yet both could be in the parts per million (ppm) range for the amount. In a relevance check, this should show the importance of the environmental indicator based on the quantity measured and the importance in the analysis.

See the "Environmental Issues" column in Tables 1 & 2 in the reference section.

INCONSISTENT REPORTING OF POSITIVE IMPACTS

In the PM-referenced LCAs, 7 of the 11 (Emadian 2016, Girgenti 2013, Hermann 2010, Hermann 2011, Hottle 2015, Krueger 2009, Rossi 2014) studies showed positive results for the compostable materials over the other materials, while 2 (Leejarkpai 2016, Quantis 2011) of the 11 showed positive results for alternative materials over compostable materials. The other 2 studies (Hottle 2013, Papong 2013) showed undetermined results of what materials were better. In the 2 studies that showed alternative materials were better than compostable materials, one was Leejarkpai (2016) that had greater GWP for compostable materials due to the decomposition in landfill. The other study, Quantis (2011) had a recycling option that was the best alternative for disposable coffee packs. This study also states that: *"These conclusions are about product systems with specific design and not about the various materials used to produce the capsules".*

For the FSW-referenced LCAs, one study showed positive impact for compostable materials, one showed positive impact for other materials and the other 5 studies had varying results to which material was better.

From this perspective of the evaluation, one could conclude that a majority of the studies showed that compostable materials were better, yet this is not reflected in the overall conclusions of the report.

See the "Determination Best EOL" column in Tables 1 & 2 in the reference section.

MATERIAL COMPARISON: A CONSISTENT USE OF FUNCTIONAL UNITS

In LCA comparisons, a functional unit needs to be determined and compared against all the alternatives. In most of the referenced studies, a functional unit was defined, however in a few of the studies (Harnoto, 2013; Pladerer, 2008; Pro.mo 2015) the functional unit changes or is dependent on reusability. For example, in the Harnoto study, the functional units start out as 360 compostable clamshells to 1 reusable clam shell. Then the study changes to 43 compostable to 1 reusable clamshell. Then the study specifically focuses on GWP and says that the reusable clamshell would need to be used at least 5.5 times to equal 1 compostable clamshell for GWP impact.

Having defined this 5.5X based on GWP, the rest of the comparisons for energy, materials waste and water usage go back to the 360/1 and 43/1 ratios and compostable is worse than the reusable in all these environmental impacts. In the Pladerer study, the reusable option ranges from 2.9 to 41 times, with the lesser number of reusability closer to the compostable cup for GWP.

While the Pro.mo study defines the functional unit as 1,000 uses for reusable and 1 use for disposable plates and cups. A defined requirement of a LCA comparing different products is that the Function of the products is the same. It is clear that a plate that can be used 1,000 times has a different function (e.g. used at home or restaurant) than a single use plate that is normally used at events, so probably such a comparison is meaningless.

Also, for the disposal phase of the studies, the compostable materials being composted should be compared against non-compostable materials disposed of in alternative methods. Although compostable materials may end up in landfill or incineration, they are designed to go in compost operations. An example of this is that three of the referenced studies (Emadian, 2016; Hermann, 2011; Rossi, 2014) compare compostable materials in different disposal methods. In these examples, there would be some difference in the disposal phase, yet all should be compared for composting, since this is the disposal phase the material is designed for. Yet some of the results show a better impact of compostable materials in landfill or incineration even though composting has shown better environmental benefits in many other studies, which were not referenced in the report. These odd results are probably the result of making comparisons on product item level and not on waste stream level. Many studies were performed on product level e.g. comparing cutlery with cutlery or cups with cups. But in reality, the waste disposal systems are not dealing with isolated piles of cutlery to process; they receive a mixed waste stream consisting of cutlery, cups, plates, and food waste. One must consider the best EOL option for this particular waste stream which is food-soiled or carrying food: recycling, landfill, incineration or composting. (See also the Comparison of Alternatives section.)

BPI wholly supports the prioritization of the three "Rs", starting with a reduction in unnecessary usage, followed by reuse, followed by recyclable or compostable. The issue here is the use of different variables, which needs to both be consistent (for comparison) and set at a level of uses that is realistic.

See the "Functional Unit" column in Tables 1 & 2 in the reference section.

DATA COLLECTION FOR END OF LIFE

In the PM referenced documents, there were several studies (Leejarkpai, 2016; Hermann, 2010; Papong, 2013; Quantis, 2011) that compared compostable materials in landfill disposal. In these studies, the Global Warming Potential (GWP) was higher for compostable materials due to the supposed degradation in the landfill. Many LCAs were based on assumptions and estimations of the behavior of PLA in landfill. This is unacceptable from a scientific point of view, especially because these assumptions and estimations were not substantiated and have a significant impact on the final greenhouse balance.

In 2011 NatureWorks commissioned a new study to OWS (Organic Waste Systems) in Ghent, Belgium to research the behavior of PLA in landfills. The overall outcome of this study showed that PLA is stable in landfills.[5]

Most of the studies had one or more end of life disposal options included. In the references, where compostable materials are either composted, landfilled or incinerated, the impacts are captured. However, one could argue why to include for compostable products landfill or incineration as an end of life option, while they are not designed for it. In the studies (Leejarkpai 2016, Quantis 2011.) for the alternative materials investigated, the environmental impacts of landfill or incineration were not captured as well.

Further, the life cycle inventory data for these end of life options is often incomplete. This could be due to the fact that a lot of the references are outdated. Using current data would change a lot of the results to more correctly reflect the environmental impacts. As for landfill and plastic waste, there has been more societal awareness of plastic waste and landfill impacts, and life cycle methods are being updated to more fully account for this.

Finally, in several cases the data showed complete biodegradation, without taking into account that a part of the carbon will be temporarily sequestered in the soil. Yet it is well-known in the compost industry that compost provides many benefits, including the sequestration of carbon. It is not clear if and how this sequestration has been treated.

See the "LC Sys Boundaries" column in Tables 1 & 2 in the reference section.

CONCLUSION

We have shown that many of the studies used to support the position of the OR DEQ report are simply too old to be valid and/or incomplete. The entire data set was ultimately misrepresented through the method of reporting relative environmental impacts via a histogram, with arbitrarily set thresholds for the environmental bins. The data points in the comparisons appear to draw conclusions from one study. Several studies did not include a complete assessment in the disposal phase as the benefits of compost were incomplete. Several did not consider the correct end of life for the product, sending compostable products to landfill and incineration which are not intended. Most of the studies ultimately showed positive results with compostable materials. In some of the studies the Functional Units changed and the data collection for EOL was not up to date and is misleading compared to the other alternatives.

From an LCA perspective, there are several topics of concern in the evaluation of the referenced studies and the resulting conclusions. In other cases, compilations of the results are not good science or a proper representation of the composting industry or industrially compostable products. When drawing conclusions from results of the references, one should point out that this evaluation has many technical LCA flaws, and therefore, it is the sole opinion of the Oregon DEQ and not a true representation of the compostable industry or its practices.

REFERENCES

[1] Vendries J, Hawkins TR, Mosley J, Hottle T, Allaway D, Canepa P, Rivin J, Mistry M. 'The Significance of Environmental Attributes as Indicators of the Life Cycle Environmental Impacts of Packaging and Food Service Ware.' State of Oregon Department of Environmental Quality. Portland, Oregon. 2018.
[2] NSF International, Protocol P352-2015, "Validation and Verification of Eco-Efficiency Analyses," September 2015.
[3] Vink ETH, Davies, S., Life cycle inventory and Impact assessment data for 2014 Ingeo®
Polylactide production, Industrial Biotechnology. June 2015, 11(3): 167-180.
[4] Morao A, Bie de F, Life cycle impact assessment of polylactic acid (PLA) produced from sugarcane in Thailand, Journal of Polymers and the Environment, January 1, 2019.
[5] Kolstad JJ, Vink ETH, De Wilde B, Debeer L, Assessment of anaerobic degradation of IngeoTM polylactides under accelerated landfill conditions, Polymer Degradation and Stability 97 (2012) 1131-1141.
[6] Carus M., vom Berg C., Scharf A., Puente A., How can the environmental effects of bio-based polymers be compared with those of petrochemical polymers on equal footing, Nova-Institute, Hurth, Germany, September 2, 2019

TABLE 1: PACKAGING MATERIAL REFERENCES FROM OREGON DEQ REPORT

Study	Date	LC Sys Boundaries	Conseq/ Attrib	Functional Unit*	Number of Alternatives	Conventional	Biopolymer	Comparisons	Environmental Issue	Determination Best EOL
Emadian	2016	Gate to grave	Attributional	None	3		PCL, PBS, PES	All are bio-polymers, just different disposal methods.	None, biodegradability only	Yes, Compostable
Girgenti	2013	Cradle to grave	Consequential	250 g flow pack	2	PE	Mater-Bi	mulch film, tray wrapping	GWP	Yes, Compostable
Hermann	2010	Cradle to gate, Cradle to grave	Consequential	1 m^2 packaging film	29	multiple	PLA	multi-layer packaging	GWP, land use	Yes, Compostable with wind credits
Hermann	2011	Gate to grave	Attributional	1 kg material	7	All bio-degradable		Disposal of material by home composting, industrial composting, digestion and incineration	GWP	Yes, Compostable
Hottle	2013	Cradle to gate, Cradle to grave	Attributional (Review)	1 kg pellets	3 (6)	PE, PP, PS	PHA, PLA, TPS	Multiple studies with different comparisons	Multiple	Undecided (Bio-based are equal to petroleum based)
Hottle	2015	Gate to grave	Consequential	metric ton?	7	Several materials	PLA	Disposal outlets for waste from ASU baseball games	GWP, Energy	Yes, Composting over Landfill
Krueger	2009	Cradle to grave	Consequential	1000 clam shells	3	PET	Ingeo	Comparison of clamshells made from Indego versus PET, weight advantage not captured.	Multiple	Yes, vary result and comparison. For GWP IngeoNGT is best
Leejarkpai	2016	Cradle to grave	Attributional	1000 boxes	3	PS, PET	PLA	If comparison of PS, PET in landfill versus PLA in compost, PLA is equal. Problem with this study is that GWP for PLA comes from degradation in landfill and PS, PET to not degrade in landfill, so the penalty of landfill is not captured.	GWP	No
Papong	2013	Cradle to grave	Attributional	1000 (250mL) bottles	2	PET	PLA	water bottle with different disposal options	Multiple	Undecided, depends on the environmental issue
Quantis	2011	Cradle to grave	Attributional	40 mL expresso coffee	4	Al, PP/Al/PE, PP/PET	PLA, Starch	Al recycle was best option, however not sure coffee to landfill is captured completely	GWP	No
Rossi	2014	Cradle to grave	Attributional	1 kg dry packaging material	2		PLA, TPS	Both are bio-polymers, just different disposal methods.	GWP, Resource, multiple	Yes, Compostable

**Functional Unit is a quantitative performance of a product system for use as a reference unit in life cycle assessments (ISO 14040)*

Names in red indicate the study fails to meet one of the qualifying criteria (older than 5 years, attributional rather than consequential, inconsistent functional units, etc.)

TABLE 2: FOOD SERVICE WATE REFERENCES FROM OREGON DEQ REPORT

Study	Date	LC Sys Boundaries	Conseq/ Attrib	Functional Unit*	Number of Alternatives	Conventional	Biopolymer	Comparisons	Environmental Issue	Determination Best EOL
Fieschi	2017	Cradle to grave	Attributional	1000 single use FSW	2	GPPS, HIPS, PP, Paper?	Mater-Bi, PLA, Paper	Comparison of multiple FSW and materials	Multiple	Varies
Harnoto	2013	Cradle to grave	Attributional	360 compostable clamshell per/1 reusable clamshell (theoretical) 43 compostable clamshells/1 reusable clamshell (actual)	2	PP	Compostable (sugarcane)		Multiple	Varies
Pladerer	2008	Grade to grave	Consequential	0.5L cup	2	PS, PET, PP	PLA	Depends on reusability	Multiple	Varies
Potting	2015	Cradle to grave	Attributional	1 hot beverage	3	PS	PLA, Paper	Results are general, with large range and higher and lower than.	Multiple	Varies
Promo	2015	Gate to gate	Attributional	1000 uses	5	PP, PS, Ceramic	PLA, Cellulose pulp	Only evaluates the uses, no production or disposal	Multiple	No
Razza	2008	Cradle to grave	Attributional	1000 meals	2	GPPS	Mater-Bi	Shows that composting versus current scenario is better	Multiple	Yes, Compostable
Vercalsteren	2006	Cradle to grave	Attributional	100 L cups	4	PC, PP	Cardboard, PLA		Multiple	Varies

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