Northwest Green Chemistry

April 12, 2019

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Abbreviations

AA	Alternatives Assessment
ABA	Australasian Bioplastics Association
AS	Australian Standard
ASTM	American Society for Testing and Materials
BPI	Biodegradable Products Institute
CBI	Confidential business information
CEH	Center for Environmental Health
CHA	Chemical hazard assessment
CIC	Combustion Ion Chromatography
C*n*	PFASs with *n* carbon-fluorine bonds, e.g. C6 refers to PFAS substances with 6 C-F bonds
DWR	Durable water repellent
FPI	Foodservice Packaging Institute
GS	GreenScreen for Safer Chemicals
GS LT	GreenScreen List Translator
HPLC	High performance liquid chromatography
IC2	Interstate Chemicals Clearinghouse
ISO	International Organization for Standardization
LC	Liquid chromatography
LC-MS/MS	Liquid chromatography with tandem mass spectrometry
LCA	Life cycle assessment
LCT	Life cycle thinking
LOD	Limit of detection
LOQ	Limit of quantification
MS	Mass spectrometry
NDA	Non-disclosure agreement
NGC	Northwest Green Chemistry
NMR	Nuclear magnetic resonance
OR DEQ	Oregon Department of Environmental Quality
PLA	Polylactic acid
PS	Polystyrene
PET	Polyethylene terephthalate
PFAA	Perfluoroalkyl acid
PFASs	Per- and poly-fluorinated alkyl substances
PFHxA	Perfluorohexanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PIGE	Particle-Induced Gamma Ray Emission
PP	Polypropylene
PPE	Personal protective equipment
SCIL	Safer Chemicals Ingredients List

TAPPI	Technical Association of the Pulp and Paper Industry
US EPA	United States Environmental Protection Agency
WA DOE	Washington State Department of Ecology

Executive Summary

This report provides a roadmap for conducting a full alternatives assessment (AA) for food packaging that is free of per- and poly-fluoroalkyl substances (PFASs) and identifies some currently available alternatives (see supplemental file). The roadmap follows the IC2 Alternatives Assessment Guide (2017) with additions from Northwest Green Chemistry's experience creating frameworks and conducting AAs, such as minimum ('showstopper') criteria defined for each module. The report includes ways to leverage modules completed by other entities, how to test for PFASs, and how to identify PFASs-free alternatives using state procurement policies. Strategic steps forward in a resource constrained and imperfect information environment will allow Oregon Department of Environmental Quality to make the most of the Roadmap.

NGC's priority selection criteria to scope an alternatives assessment based on the modules are:

- OR DEQ should employ best practices for **stakeholder engagement** to enable improved problem definition, information gathering, results, and adoption of results. Key stakeholders provide insight from their perspectives that may not be initially apparent to researchers. Key stakeholders include representatives from food packaging manufacturers, users, retailers, and innovators. Government agency staff, industry/trade groups, nonprofits, and politicians will also bring a unique set of concerns and knowledge to the issues.
- Based on NGC's work identifying AA best practices, we recommend a **decision analysis** method similar to the IC2 hybrid method. This method presents acceptable alternatives in a selection guide to promote informed decision-making based on stakeholder's varying application needs. Acceptable alternatives are those that meet minimum criteria for each module. Once these criteria are met, then the options should be subject to user preferences and needs.
- **Hazard** module recommendations include information on how to scope a chemical inventory, using a tiered approach to chemical hazard assessment, and with special considerations for polymers. The hazard module also includes showstopper criteria and guidance for identifying safer alternatives.
- NGC recommends setting a limit on **exposure** based on the hazards of the chemicals in question to eliminate unacceptable alternatives. A comparative exposure approach should be used to address exposure to workers, customers, and environmental receptors.
- **Cost and availability** module recommendations include comparing the retail price of PFASs-containing products and the alternatives. Cost should not be used to eliminate alternatives as any product currently available on the market is at a reasonable price point for at least some users. Cost should be considered across the life cycle to include costs from waste management. Economic analysis across the life cycle would present the full picture of hidden costs, e.g. cleanup and health impacts of PFASs, though it is likely cost prohibitive for the initial AA.
- We recommend using stakeholder input to define **performance** criteria for different uses that include minimum requirements and performance tests. Diverse users should be engaged, including from restaurants, cafeterias, caterers, hospitals, schools, prisons, and consumers, etc.
- The goal of the **social impact** module is to ensure that the product(s) preferred by the alternatives assessment do not shift the burden from one community of people to another unduly. Organizations that should be involved in the social impact module in Oregon are OPAL Pdx, Beyond Toxics, and the Environmental Justice Task Force, among others
- To address the **materials management** module, a holistic consideration of the product from feedstock to end of life should be conducted. This includes impacts from feedstocks used and

wastes generated and managed, as well as a consideration of how the product may fit into the circular economy.

- The overall goal of the **life cycle** module is to take a comprehensive view of product impacts across the life cycle, to identify opportunities for innovation and improvement, and to avoid burden-shifting. This module builds on results from previous modules and considers how the product fits within the broader system. Life cycle thinking helps to identify hot spots and opportunities for innovation. Life cycle assessment is important for verifying assumptions.

This report does not include gathering data and reporting the results of an alternatives assessment. However, the researchers have compiled information on alternatives gathered by NGC and building on the work of other groups. A variety of alternatives exist for each packaging technology type and are laid out by material types, molded fiber technologies and coatings and other treatments. The report includes a technology map, a table of alternatives representing each technology a supplemental Excel file with extensive detail on the product, its manufacturer, and PFASs screening test results if available.

Some Recommended Next Steps:

An AA report is a snapshot in time and should be accompanied by an implementation plan. The plan should include strategies and resources for ongoing identification and evaluation of emerging alternatives, for driving and measuring adoption of alternatives, and for integrating other important information. Novel information may emerge over time including new toxicology studies, changes in economics, and new waste management methods. Oregon should consider collaborating with other governmental agencies and key stakeholders to create an implementation plan for the proposed AA. Additional recommendations for next steps include:

- Publicly state Oregon's priorities for PFASs free products. For example, as with a waste hierarchy, and consistent with OR's materials management vision, OR DEQ could state that its priorities are 1) to avoid products with hazardous chemicals to which people and the environment will be exposed across the product life cycle and 2) to promote a circular economy that eliminates waste at the source and recovers materials at the highest possible value for reuse. This will clarify how existing statements on sustainability apply to food packaging.
- Develop promotional and educational materials for diverse users explaining the issue and describing how to select PFASs-free alternatives.
- Identify additional classes of chemicals to eliminate. For example, ortho-phthalates have been identified by the Food Packaging Forum as a priority for replacement in food packaging.
- Create or revise procurement policies to purchase PFASs-free food packaging. Appendices A, B and C in this report provide detailed information, including pros and cons, of test methods, standards and certifications. Some certifications exclude PFASs and others do not. The European standards based on EN13432, generally exclude PFASs due to a 100 ppm fluorine limit, while US standards do not. However, some US standards (i.e. BPI certified compostable) are being updated to address this issue.
- Identify products as PFASs-free by:
    - Testing and making a list of PFASs-free options available in Oregon.
    - Using the CEH list as a starting point, but keep it updated, as products change over time.
    - Using compostability/biodegradability certifications such as TÜV AUSTRIA Seedling Logo or post-2019 BPI compostable that also include limits for fluorine.
    - Consider supporting or developing a certification for simply PFASs-free products, as the compostability/biodegradability portion of these certifications is not relevant to Oregon currently due to Oregon composters declining compostable food packaging.

Introduction

The Oregon Department of Environment (OR DEQ) initiated the Roadmap for Evaluating Alternatives to Food Packaging Containing Per- or Polyfluorinated Substances (PFASs) to gain insights that will inform applied research and agency policies. OR DEQ strives to eliminate waste and toxics via its policies and to avoid adoption of regrettable alternatives. Preferred alternatives are those consistent with agency objectives, are based on information derived from credible science, and optimize the well-being of Oregon residents, the environment, and stakeholders throughout the value chain. Inclusion of workers and businesses involved, from resource extraction through manufacturing and end of life, ensures that this AA is practical and avoids burden shifting. Several other states have taken, or are in the process of taking, action to drive procurement of food packaging materials that are free of PFASs including Washington, Minnesota, and New York.

In this report, we synthesize previous work by Northwest Green Chemistry (NGC) and others identifying currently-used food packaging products that have been found to contain PFASs and available alternatives that are PFASs-free and potentially safer alternatives. Food packaging products containing PFASs are primarily plant-fiber-based, single use products including but not limited to wraps, liners, take-out clamshell containers, bags, bowls/soup containers, trays, and pizza boxes. Available alternatives provide the same services as the PFASs containing products but are free of all PFASs. The alternative products may be derived from completely different types of materials such as plastic, metal, or clays, or they may be plant-fiber based but treated mechanically or with non PFAS additives to meet performance requirements. The feasibility of different use scenarios should be considered, such as transitioning from disposable single-use products to multi-use products.

Alternatives assessment (AA) is an applied research process that supports the substitution of chemicals of concern in products or processes with inherently safer alternatives, thereby protecting and enhancing human health and the environment (IC2, 2017). At its best, it provides a balanced and comprehensive approach to considering the impacts and tradeoffs associated with various existing and emerging options to help users make informed decisions and to drive the adoption of safer alternatives. It can also inform product design and drive innovation. AA can be done at different levels of comprehensiveness. The more comprehensive the assessment, the more data and resource intensive it becomes. However, the use of AA does not guarantee success in substituting safer alternatives. First, safer alternatives must be available; second, those alternatives must be acceptable with respect to cost, performance, and social perspectives; and third, there must be drivers to move the market toward adoption of the alternatives.

Sustainable materials cannot be reduced to a single attribute. For example, a product that is bio-based may have lower environmental impacts, but it is still not a sustainable material if it contains toxic chemicals and generates problematic wastes. Sustainable materials approximate the ideal laid out in the principles of Green Chemistry and Green Engineering and in the Materials Management in Oregon 2050 Vision and Framework for Action (OR DEQ, 2012). Identifying sustainable materials using AA should be based on the Commons Principles for Alternatives Assessment (2012, p.1):

- REDUCE HAZARD: Reduce hazard by replacing a chemical of concern with a less hazardous alternative. This approach provides an effective means to reduce risk associated with a product or process if the potential for exposure remains the same or lower. Consider reformulation to avoid use of the chemical of concern altogether.

- MINIMIZE EXPOSURE: Assess use patterns and exposure pathways to limit exposure to alternatives that may also present risks.
- USE BEST AVAILABLE INFORMATION: Obtain access to and use information that assists in distinguishing between possible choices. Before selecting preferred options, characterize the product and process sufficiently to avoid choosing alternatives that may result in unintended adverse consequences.
- REQUIRE DISCLOSURE AND TRANSPARENCY: Require disclosure across the supply chain regarding key chemical and technical information. Engage stakeholders throughout the assessment process to promote transparency in regard to alternatives assessment methodologies employed, data used to characterize alternatives, assumptions made, and decision-making rules applied.
- RESOLVE TRADE-OFFS: Use information about the product's life cycle to better understand potential benefits, impacts, and mitigation options associated with different alternatives. When substitution options do not provide a clearly preferable solution, consider organizational goals and values to determine appropriate weighting of decision criteria and identify acceptable trade-offs.
- TAKE ACTION: Take action to eliminate or substitute potentially hazardous chemicals. Choose safer alternatives that are commercially available, technically and economically feasible, and satisfy the performance requirements of the process/product. Collaborate with supply chain partners to drive innovation in the development and adoption of safer substitutes. Review new information to ensure that the option selected remains a safer choice.

This report is not an alternatives assessment. Rather, it is a roadmap for using AA based primarily on the Interstate Chemicals Clearinghouse Alternatives Assessment Guide. This report does the initial work of scoping the AA and identifying alternatives. It also recommends which attributes to consider based on the modules in IC2 AA Guide. It helps prioritize information needs, including information on key test methods. Finally, it recommends an approach for decision analysis that results in identifying functional and cost-effective products that are inherently safer but that also mitigate waste, life cycle, and negative social impacts. As a roadmap, it is designed to help OR DEQ integrate information being generated by other organizations and jurisdictions working to eliminate PFASs containing food packaging and to prioritize information needs to meet OR priorities. This AA roadmap also provides a test case for applying AA in support of Oregon's Sustainable materials framework (OR DEQ, 2012).

The Alternatives Assessment Roadmap

The Interstate Chemicals Clearinghouse (IC2, 2017), in its Alternatives Assessment Guide, states that "The objective of an alternatives assessment is to replace chemicals of concern in products or processes with inherently safer alternatives, thereby protecting and enhancing human health and the environment" (p. 3). Alternatives assessment (AA) is a new and evolving field at the nexus of science and policy. Northwest Green Chemistry (NGC) recently completed one of the first AAs using the IC2 AA Guide (2017) to identify alternatives to copper-based recreational boat paints, which are slated for phase-out in the recreational boat market in Washington. The AA included assessment of available alternatives using the lens of hazard, exposure, cost, availability, and performance. Alternatives ranged from coatings with alternative biocides, to biocide-free coatings to non-coating technologies. Based on this work, NGC identified promising practices for AA and identified key needs for further work in the field.

The process of an AA can be broken down into six steps (Figure 1), including 1) identifying chemical(s) of concern 2) conducting an initial evaluation or exploratory research of the subject being investigated 3) defining the scope of the AA 4) identifying alternatives to the chemical(s) of concern, 5) assessing the alternatives and determine any viable options that do not lead to regrettable substitutions, and 6) taking action on the results. The IC2 Guide describes steps 1-5; step 6 has been identified by NGC as necessary for the AA to impact human and environmental health. This roadmap fulfills steps 1-4 and defines the data needs and criteria for step 5, but it stops short of data collection for the assessment process. It is important to note that steps 3 and 4 require additional stakeholder input.

Figure 1. The six steps of the OR DEQ Roadmap for Alternatives Assessment (AA).

Step 1. Identifying the Chemical of Concern

Goal: Specify the chemical(s) of concern that are the focus of the AA, reason(s) for concern (e.g. hazard, risk, waste/litter, emissions), and their usage.

Though identifying the chemical of concern is listed as the first step, it is common that the chemicals of concern (CoCs) have already been identified outside of the AA process. For this work, OR DEQ identified PFASs as a chemical class of concern in food packaging.

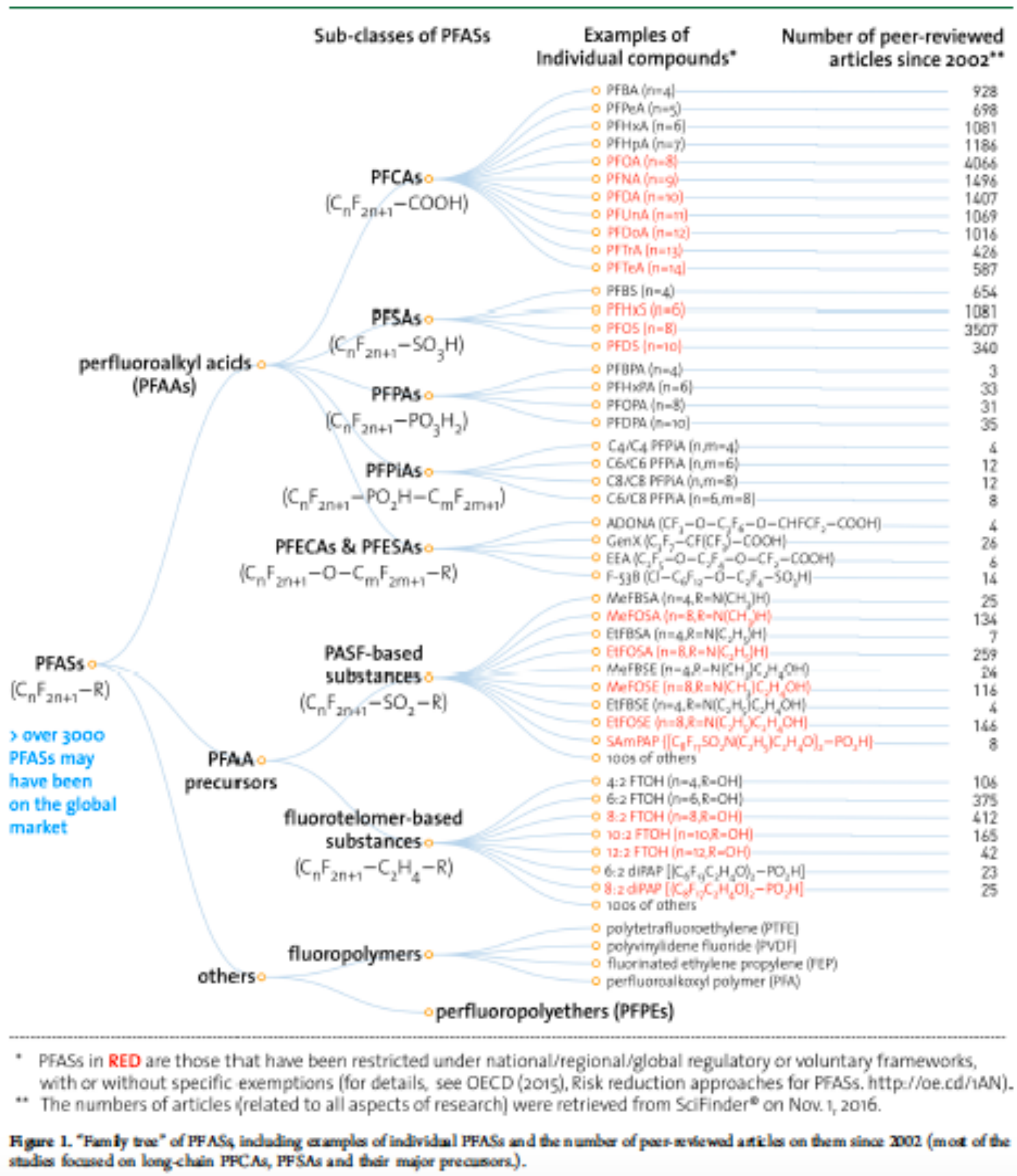


Figure 2. PFAS class and subclasses with examples of individual compounds within each subclass (Wang et al., 2017, p. 2510).

Buck (2011) defines PFASs as a chemical class, with several subclasses, characterized by the strong carbon-fluorine bond. PFASs are organic chemicals containing at least one fully fluorinated carbon atom (Scientific Guidance Panel Biomonitoring California, 2018). Estimates of the number of PFASs currently in products or the environment from previous manufacturing range from 3000-5000 (Buck, 2011; DeWitt, 2015; OECD 2018). Based on concerns about harm to human and environmental health, major U.S. chemical manufacturers ceased production of high profile PFASs, PFOS (perfluorooctanesulfonic acid) and PFOA (perfluorooctanoic acid), though production continues outside the U.S. (Lau, 2015). In this report, the term PFAS is used to apply to all chemicals in the class including precursors, metabolites and environmental degradation products that may degrade to form PFASs of concern (DeWitt, 2015). Figure 2 shows the class and subclass categorization completed by Wang, DeWitt, Higgins, and Cousins (2017) and indicates which substances have been subject to regulatory or voluntary phase-out action.

PFASs in Single-use Food Packaging

Fluorinated chemicals have been used for the past several decades as non-stick, grease, oil, and water-resistant coatings on a variety of products including food packaging. Fluorinated chemicals provide advanced chemical and physical properties, particularly related to heat, water and grease resistance, while being highly stable compounds. High heat resistance makes them function as fire suppression fluids. Their slick surface has warranted use for non-stick surface applications. Because they resist both water and oil, they have been used for clothing, equipment, carpets and much more to provide moisture and stain resistance. For single-use food packaging, heat and fluid (oil and water) resistance is a useful property that allows a variety of hot and cold foods to be contained for short durations without having the container fail, enabling consumers to store their un-eaten foods for later consumption.

Multiple methods for applying PFASs to food packaging materials exist (Trier 2018). The base material for most food packaging that contains PFASs is molded fiber. In these applications, PFASs are typically mixed in to the bulk material as an additive, rather than as a coating, which is more common for paper and paperboard. This process requires less steps and equipment than alternatives, decreasing costs and time. For post-production application, paper can be exposed to a solution of PFASs prior to pressing through rolls or against a hot steel drum, followed by drying (Trier 2018).

PFASs in food packaging are not necessarily bound tightly to the matrix. Researchers found that PFAS additives in food packaging paper migrate into food during package use (Begley, Hsu, Noonan, & Diachenko, 2007; De Witt, 2015; US FDA, 2007). Users can be exposed if the PFASs leach out of the food packaging into the food, and these chemicals can leach into the environment when the food packaging is composted, littered, or otherwise disposed of. While the rest of the packaging may break down, the PFASs will not in standard environmental conditions, or even the optimized conditions in an industrial composter. Migration of PFASs into food or other media is dependent on the amount, type, and chain length of the PFASs used, the contact time, the type of food or other media (e.g. predominantly fat - or water-based), and the temperature. Notably, even brief contact times can result in significant migration if the temperature is high and the media contains emulsified fats. In general, shorter-chain PFASs have been found to have higher migration efficiencies than long-chain analogues (Schaider et al., 2017). A comparison of PFASs exposure via other sources (air, water, dust, treated carpeting, and apparel) suggested that diet is an important source of these compounds (Tittlemier et al., 2007).

The problem of PFASs in food packaging is associated with compostable food service ware. Oregon does not currently compost food service ware and its composters have taken a strong stance against ever composting non-food products like these (Oregon Composters, 2019). The composters claim nine points on why composting food service ware may be detrimental, either to the environment or to their business model:

1. Products do not always compost, as expected.
2. Contamination happens.
3. Products hurt resale quality.
4. Composters cannot sell to organic farmers if products included.
5. Products may threaten human and environmental health.
6. Products increase costs and makes composters' jobs harder.
7. Just because something is compostable does not make it better for the environment.
8. In some cases, the benefits of recycling surpass those of composting.
9. Good intentions are not being realized.

Some of these points do not include a full consideration of the system, ignoring potential benefits of the diversion to compost of additional food from food service ware or lack of infrastructure for cleaning and recycling food service ware. Other points are currently being addressed by compostability certifiers, the push for product ingredient transparency, and by the proposed alternatives assessment work here. Until these issues are addressed, it is unlikely that Oregon's composters will change their stance. Regardless of their lack of acceptance by Oregon composters, compostable food service ware products are still used in Oregon. The use of these products results in exposure to workers and consumers. Disposal of these products in landfills results in PFASs exposing humans and the environment by:

- leaching to the subsurface and contaminating groundwater (Hamid, 2018).
- volatizing into air and contributing to elevated PFASs concentrations in the air near landfills (Hamid, 2018).
- leaching and subsequent treatment in a wastewater treatment plant, where they are not effectively removed and are released with treated wastewater and as part of biosolids (Hamid, 2018), which may be applied to agricultural land and taken up by plants (Lee, 2014).

Quantities emitted are small compared to a firefighting training ground, measured at ug/g space in soil at a firefighting training group (Baduel, 2015) versus ng/L to ug/L in landfill leachate (Hamid, 2018) or ng/g measurements for a specific PFAS sub-class in biosolid amended soil (Lee, 2014). These measurements are hampered by detection methods, which look at specific species or classes without taking a holistic view of all PFASs present (Hamid, 2018). However, even the emission of small quantities poses a risk when the substance is persistent and bio accumulative; 100 ng/g to 58 ug/g measurements were found bioaccumulated in plants grown in soil in the 0.1 – 138 ng/g range (Lee, 2014). Without considering the alternatives via an alternatives assessment, regrettable substitutions may occur. Further, no clear solution to the waste generated from food service ware exists in Oregon, and an alternatives assessment may be an avenue for identifying preferable materials and products with beneficial end of life programs.

Scope of Packaging for the Alternatives Assessment Roadmap

Fluorinated chemicals are found in a small subset of single-use food packaging products. Any molded fiber single-use food container without a plastic liner is likely to have fluorinated chemicals present. Researchers tested approximately four hundred fast food packages across the United States and found more than half of the dessert and bread wrappers contained PFASs (Schaider, et al., 2017); see Figure 3.

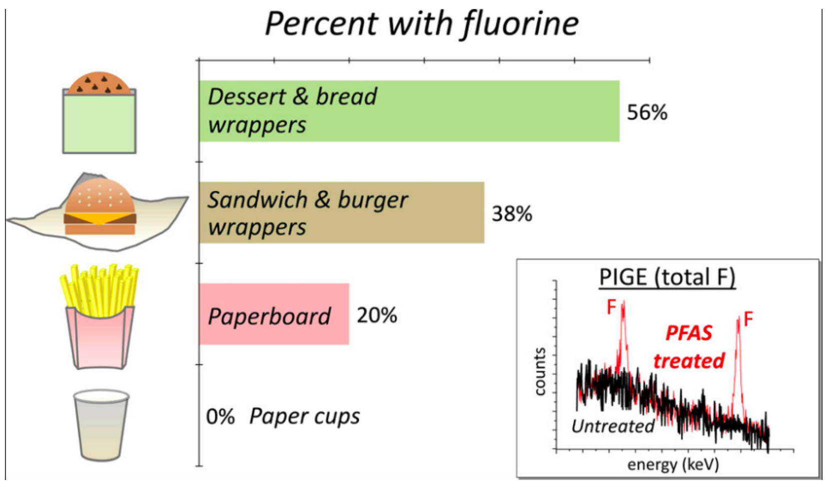


Figure 3. Percent of food packaging with fluorine from nationwide study (Schaider et al., 2017 p. 105).

A recent request for proposals for alternatives assessment work put out by the Washington Department of Ecology included the following (non-exhaustive) list of food packaging products where PFASs are likely to be used (Table 1).

Table 1. Examples of food packaging where PFASs may be used.

<table>
<tr><th>MARKET SEGMENT</th><th>PACKAGE TYPE</th><th>BASE MATERIAL</th></tr>
<tr><td rowspan="4">Quick Service Restaurants (QSR):
such as national brands
or local chains</td><td>Wraps/Liners</td><td>Paper</td></tr>
<tr><td>Pinch Bottom Bags</td><td>Paper</td></tr>
<tr><td>Flat Bottom Bags</td><td>Paper</td></tr>
<tr><td>Clam Shells</td><td>Corrugated</td></tr>
</table>

MARKET SEGMENT	PACKAGE TYPE	BASE MATERIAL
		Board
		Molded Fiber
	Cartons	Board
		Molded Fiber
	Bowls/Soup Containers	Board
	Pizza Boxes	Corrugated
Food Service (FS): such as private restaurants, hospitals, institutions, or groceries	Trays	Board
		Molded Fiber
		Corrugated
	Cartons	Board
	Take Out Packages	Board
		Molded Fiber
		Corrugated
	Pizza Boxes	Corrugated
	Boxes	Board
		Corrugated
	Bowls/Soup Containers	Board
	Bakery Packaging (bags/liners)	Paper
	Deli Packaging (wraps/liners/interleaves)	Paper
	Bread Bags	Paper
	Prepared/Ready-to-eat Food Containers	Board
Consumer Packaged Goods (CPG): such as items sold in retail stores	Confectionary/Candy Wrap	Paper
	Snack Bags	Paper

MARKET SEGMENT	PACKAGE TYPE	BASE MATERIAL
	Microwave Popcorn Bags	Paper
	Pet food bags	Paper

(WA DOE, 2018, p. 6)

In addition to its use in the product, PFASs may be used in the manufacturing process as a mold release agent (Wang, 2007). A recent screen of food packaging products found high fluorine levels in a bowl made from polylactic acid (PLA), which normally does not contain PFASs. The manufacturer traced this contamination to the fluorinated mold release agent used in its production (CEH, 2018).

Human Health and Environmental Impacts

In May of 2015 a group of approximately 200 scientists signed The Madrid Statement on Poly- and Per-fluoroalkyl Substances (PFASs) to address mounting concerns about fluorinated chemicals (Blum et al., 2015). The statement reports adverse human and environmental health effects found to date, while addressing the need for scientists, government bodies, industrial manufacturers, and consumers to take part in creating solutions to this problem. Within the last few decades, sufficient evidence has emerged to convince manufacturers and other decision makers that these chemicals are hazardous. In addition, PFASs and their transformation products are highly persistent and bio-accumulating, with longer chain PFASs having a higher bioaccumulation potential than shorter chain (DeWitt, 2015). PFASs that are transformed in the environment biodegrade into other PFAS species that are persistent. As a result, a voluntary ban of the chemical degradation product known as perfluorooctanoic acid (PFOA), typically found in highly fluorinated chemical products, went into effect as part of the US EPA's PFOA Stewardship Program (US EPA, 2017). This program required a 95% reduction in product content and facility emissions of PFOA, precursors to PFOA, and related higher homologues by 2010, and a commitment to eliminate these chemicals from products and emissions by 2015. PFASs range in chain length with most academic literature published on the toxicity, persistence, and bioaccumulation associated with the C8 (8 carbon-fluorine bonds) chemicals. The impacts of C6 fluorinated chemicals (6 carbon-fluorine bonds) that have emerged as the alternatives chosen by some in industry to replace C8 fluorinated chemicals have been less studied. However, there is a growing body of research that indicates that short and long chain PFASs pose similar environmental and public health hazards (CEH, 2018; DeWitt, 2015).

Bioaccumulation and Routes of Exposure

Haukås, Berger, Hop, Gulliksen, and Gabrielsen (2007) reported that "multivariate analyses showed that the degree of trophic transfer of PFASs is similar to that of PCBs, DDT and PBDEs, despite their accumulation through different pathways" (p. 360). As a proteinophilic substance, PFASs do not bind to lipids like other chemicals of concern but are still passed up the food chain by binding to proteins (Xia, Dai, Rabearisoa, Zhao, & Jiang, 2015). Long-chain PFASs compounds bioaccumulate to the top of the food chain, as do the shorter-chain compounds, but to a lesser degree. However, there is one significant difference between the routes of exposure for the longer-chain compounds and the shorter-chain compounds; longer-chain compounds are less mobile compared to shorter-chain compounds. The primary route of exposure for both compounds for humans is through ingestion. Shorter-chain compounds can travel and enter through contaminated drinking water and are harder to remove (Lau, 2015). Longer -chain PFASs have a lower tendency to bioaccumulate through drinking water but a higher tendency to accumulate through other direct oral routes of exposure (CEH, 2018).

Breakdown products of fluorinated compounds, such as the short chain breakdown product perfluorohexanoic acid (PFHxA) has a half-life of 32 days, whereas the long chain breakdown product PFOA has a half-life of 3.8 years in a human system (Lau, 2015). The biological half-life of a chemical is the time required for the amount of that substance in that biological system to be reduced by half (PAC, 1994). Other studies involving both animal and human testing have shown that shorter chain PFASs have lower bioaccumulation potential than long chain PFASs, as well as shorter half-lives in human blood (Allen, 2016). While this constitutes a reduction in bio-persistence, it does not make the chemical a good choice for use in food contact materials.

Persistence

The perfluorylalkyl moiety of PFASs is highly resistant to degradation and transformation. Due to the high electronegativity of fluorine, carbon-fluorine bonds are both shorter and stronger than carbon-hydrogen and other carbon-halogen bonds and are considered the strongest bond in organic chemistry (O'Hagan, 2008). This further influences neighboring carbon-carbon bonds, such that the bond between carbons in the perfluoroalkyl chain is stronger than similar carbon-carbon bonds in a fully hydrogenated chain (Trier, Taxvig, Rosenmai, & Pedersen, 2017). Fluorine is a poor leaving group, and requires high ionization energy for extraction (Kissa, 2001). Together, these properties make the perfluoroalkyl moiety of PFASs resistant to chemicals, such as acids and bases, heat, and abrasion (Trier et al., 2017).

While the perfluorylalkyl moiety is stable, the functional groups on it may undergo transformations once in the environment. The net result is not the biodegradation of PFASs, but rather the interconversion of one PFAS species to another PFAS species with no net loss of PFASs. For example, fluorotelomer alcohols (FTOHs) are converted to corresponding perfluorylalkyl acids (PFAAs), which are extremely persistent (Trier et al., 2017). This lack of complete biodegradation contributes to its interest as a class of chemicals of concern.

Toxic Effects to Humans and the Environment

Commonly used PFASs have been dispersed globally through use and are detectable in water, soil, sediment, wildlife, and human blood samples (DeWitt, 2015). This means that any toxic effects that are present in these chemicals can be found in a range of environmental media. PFASs in blood are ubiquitous, found in almost all humans around the world, even in isolated areas in the Arctic, but in higher levels in urban areas (Lau, 2015). Exposed workers have up to 100 times the level of concentration of PFASs in their blood as the general population (Mundt, Mundt, Luippold, Schmidt, & Farr, 2007).

Toxic effects associated with PFOA and PFOS, found through epidemiological studies, include decreased average birth weight; kidney and testicular cancer; thyroid disease; decreased sperm quality; pregnancy-induced hypertension; and immunotoxicity in children (Bach, Bech, Brix, Nohr, Bonde, & Henriksen, 2015; Ballesteros, Costa, Iniguez, Fletcher, Ballester, & Lopez-Espinosa, 2017; Hekster, Laane, & de

Voogt, 2003). Other studies have reported that PFASs can cause human health effects such as increased cholesterol, increased uric acid, increased liver enzymes, lowered vaccine response, thyroid disease, osteoarthritis, diabetes, and ulcerative colitis (DeWitt, 2015). Toxicological studies in animals have linked these chemicals to "altered mammary gland development, reproductive and developmental toxicity, testicular cancer, obesity, and immune suppression" (Schaider, et al., 2017, p. 105). PFASs also cause animal toxicity that includes liver, immune system, developmental, endocrine, metabolic, and neurobehavioral toxicity (Hekster et al., 2003). These products were voluntarily phased out, but they can still be found in environmental media and are still being produced by global manufacturers outside the US.

Regulation

Since 2006, US EPA has reviewed 294 new PFASs and has regulated 191 through a combination of orders and Significant New Use Rules (SNURs). The US EPA is beginning the necessary steps to propose designating PFOA and PFOS as 'hazardous substances' through one of the available statutory mechanisms, possibly CERCLA Section 102 (US EPA, n.d.).

Washington State has enacted a multi-stage legislative effort that prohibits the manufacture and sale of food packaging with PFASs in any concentration starting in 2022. However, the State cannot enforce the law until the Washington State Department of Ecology (WA DOE) conducts and publishes an alternatives assessment that demonstrates safer choices are available. The AA will follow the guidelines of IC2 (2017) and include at least the chemical hazards, exposure, performance, and cost and availability modules. Alternatives must also be previously approved for food contact by the FDA (WA 2018 c 138 § 2).

Step 2. Initial Evaluation

Goal: Determine whether or not an AA is necessary. Can the chemical of concern be removed without replacement, and the product still functions?

Not all single-use food packing is likely to contain PFASs. Anything that is made with plastic or has a contact surface that is lined with plastic should not contain fluorinated chemicals. This is because the surfaces have inherent non-stick and grease, oil, and water resistance; or are not designed to contact food, thereby eliminating the need for these properties (CEH, 2018). Generally, the types of single-use food packaging that do not contain fluorinated chemicals of any kind are (CEH, 2018; Schaider, 2017):

- Coffee Sleeves
- Cold and Hot Beverage Cups and Lids
- Napkins
- Plastic (PLA) and Non-Molded Fiber Bowls and Plates; including Paper Soup Containers
- Plastic and Non-Molded Fiber Take-Out Containers
- Wooden Stirrers
- Cutlery

Testing to Ensure Products are PFASs-free

Recent reports exposing PFASs in food service ware used product testing to identify which products may contain intentionally added PFASs by screening for fluorine. For example, the Center for Environmental Health (CEH, 2018) conducted a study that identified food packaging with fluorine content using a technique known as PIGE (see Appendix A for detailed descriptions of test methods). Products with no or low fluorine were considered free of intentionally added PFASs, while products with high fluorine were suspected of containing intentionally added PFASs.

Products without fluorine were considered PFASs-free. Products with low fluorine were considered free of intentionally added PFASs; levels of PFASs in these products are sufficiently low that it would not provide water or grease proof properties to the final product. One possible explanation for the fluorine in these low fluorine products is contamination. The final category, high fluorine, was consistently ten times higher than the low fluorine category. These products were presumed to contain intentionally added PFASs for water/grease resistance, which was confirmed in a subset using standard liquid chromatography with tandem mass spectrography (LC-MS/MS) methods. The 2018 CEH study results appear in the accompanying Excel spreadsheet attached to the report and delimit the no, low, moderate, and high PFAS results of testing.

General Considerations for Testing

Test methods can be divided into two groups: Those that detect and quantify specific PFASs, and those that detect and quantify fluorine content. In general, methods that detect and quantify specific PFASs rely on mass spectrometry, typically tandem mass spectrometry, and the use of standards. The advantage of these methods is that each individual specific PFAS is identified and quantified, typically with a low limit of detection/quantification (LOD/Q). A survey of PFASs methods in 2013 found that the best LOD for waters was 0.4-5.2 pg/L, though LOQs of 0.28-0.58 ng/L were more common (Trojanowicz & Koc, 2013). The disadvantage of these methods is the time and resources required to run samples, the lack of detection of PFASs that aren't explicitly searched for, and the inability to quantify PFASs for which there is no available standard.

On the other hand, methods that detect and quantify fluorine content do not distinguish between different PFAS species, nor do they distinguish between organic fluorine in PFASs and organic fluorine in other molecules or inorganic fluorine. The advantage of these methods is typically the low cost and rapid testing time. The disadvantage is that lack of specificity of which molecules are present, and potential misattribution of fluorine to PFASs when other fluorinated organic compounds are present. When considering food service ware, PFASs are the expected fluorinated organic compound that would be present.

The preferred method for determining PFASs in diverse samples has been LC-MS/MS (Kempistry, Xing, & Racz, 2018; Valsecchi et al., 2013), and this is the only method for which standard methods have been developed by ASTM (ASTM D7979), US EPA (Method 537 for drinking water, unofficial modified Method 537 for other media), and ISO (ISO 25101) (ASTM, 2017; Shoemaker, 2018; US EPA, 2018; ISO, 2014). Unfortunately, it is limited by the number of PFAS species that can be identified and quantified in the same run.

Particle-Induced Gamma Ray Emission (PIGE) is a newer technique that measures total fluorine as a proxy for PFASs that does not require the destruction of the sample and is significantly less time and resource intensive (CEH, 2018). PIGE, with some samples confirmed by Combustion Ion Chromatography (CIC), was used by CEH in a recent scan of food packaging materials. Both of these methods simply measure total fluorine and require follow-up studies to confirm that the fluorine results from PFASs or knowledge that other sources of fluorine are not used with these products. Notably, the CEH (2018) only found one product out of 137 in which a high fluorine result came from PFASs from the manufacturing process as opposed to intentionally added PFASs. Similar techniques were successfully applied by Safer Chemicals Healthy Families and Toxic-Free Future (2018).

Despite the current lack of a standard method, we recommend using PIGE to scan for PFASs in food packaging materials. PIGE was confirmed as a valid rapid screening method for food packaging materials by Schaider et al. (2017). As needed with positive samples, PIGE could be followed with a standardized LC-MS/MS test to verify which PFASs are present, and to identify and quantify those PFASs. A non-targeted approach may be necessary if the PFASs used are not the ones currently covered by the standardized methods. PIGE is less resource and time intensive than other methods, and is suitable for food packaging, given the lack of false PFAS positives found by CEH (2018). All of the standard test methods use LC-MS/MS currently, though US EPA is working to develop additional standard tests, particularly for other sample types (US EPA 2018). ASTM D7968 is suitable for PFASs in food packaging, and the modified methods US EPA is currently working on are worth considering once they are developed. However, any of these follow-up methods require understanding which PFASs are present in order to select the correct method and standards; if common PFASs are present, this will not be a major barrier. PIGE would also be suitable for validating claims that food packaging materials are PFASs-free; a negative result would require no follow-up and would verify that the food packaging material is PFASs-free to the detection limit.

Standards and Certifications for Procurement

Rather than relying on testing by the Oregon, the state could require an independent certificate of analysis verifying that the product is fluorine-free or PFASs-free. In order to do so, the state would need to identify which testing methods and labs are suitable for this, and/or identify which certifications are suitable. In the recent CEH (2018) work, they observed that many products certified as compostable in industrial composting facilities tested high for fluorine. Standards and certifications that exclude PFASs include a 100 ppm limit on fluorine. These include:

- Standards
  - EN 13432
  - AS 4736
- Certifications
  - TÜV AUSTRIA, OK compost HOME/INDUSTRIAL, OK biodegradable SOIL/WATER/MARINE, Seedling Logo
  - DIN CERTCO, Seedling Logo, DIN-Geprüft test mark for industrial compostability
  - ABA, Seedling Logo, home compostable

- BPI (starting Jan. 1, 2020)
- Cedar Grove (starting Jan. 1, 2020)

For a detailed description of these standards and certifications, as well as common ones that do not exclude PFASs, see Appendices B and C. While these certifications can be used for procurement, their use would involve over-specifying, as compostability is not necessarily desired by Oregon. Setting a 100 ppm limit, verified by 3rd-party testing, would ensure that products are free of intentionally added PFASs. We would further recommend requiring a declaration that the final products are PFASs free and the manufacturing process is PFASs free to ensure other PFAS sources, such as mold release agents, are avoided. In order to avoid overburdening manufacturers, we recommend identifying materials and product types that do not contain PFASs that could be exempted from product testing. For example, PFASs are not used in the production of thermoformed plastics.

Existing Government Procurement Policies

Other states have enacted procurement policies for food packaging, including both the states of New York and Minnesota, which are compared in Table 2 (certifications) and 3 (procurement differences). This comparison may change in the coming months, as Minnesota's compostable food service ware contract specifications are in the process of being updated. While committee work has confirmed the desire to move to PFASs free ware in NY, updates to the policy are not yet available. Notably, these policies focus on compostable food service ware, which Oregon does not currently compost in industrial facilities.

Table 2. Certifications used for Minnesota and New York procurement.

<table>
<tr><th>MN Procurement</th><th>NY Procurement</th></tr>
<tr><td>AIB Vincotte Inter: OK Compost (Belgium)
Australian Environmental Labeling Association
Japan BioPlastics Association
DIN CERTCO (European Union)
Cedar Grove Commercially Accepted Items</td><td>ASTM 6400-04 – Standard Specification for Compostable Plastics
ASTM 6868-03 – Standard Specification for Biodegradable Plastics Used as Coatings on Paper and Other Compostable Substrates</td></tr>
<tr><td colspan="2">Biodegradable Products Institute (BPI)</td></tr>
</table>

Table 3. Minnesota and New York procurement differences.

MN Procurement	NY Procurement
Procurement is for compostable food, beverage, and storage products	Procurement is for single use food containers (plates, bowls, hot & cold cups with lids, food trays & hinged containers)
When reusable food service containers are unavailable, compostable containers should be used, despite availability of infrastructure	When reusable food service containers are unavailable, compostable containers should be used (as long as there is a composting facility to accommodate)
Composting Specifications: None	Composting Specifications: All single use food containers (excluding hot and cold containers and lids) to the maximum extent be composted under ASTM 6400-04 for plastics and ASTM 6868-03 when coated, or if not applicable shall be biodegradable.
Composting Exception Specifications: None	Composting Exception Specifications: Hot and cold containers and lids shall meet one of the following: 1. Manufactured from bio-based material that is compostable or biodegradable 2. Manufactured from polymeric material (plastics/resins? With a minimum of 30% post-consumer recycled content (unless content is not allowed by USFDA) 3. Recyclable through a local or commercial program and labeled with a visually legible Resin Identification Code
Labeling Requirements: All compostable plastic products offered must bear a clearly visible, easily distinguished label or marking indicating the product's ability to be composted Text of the label or marking must include "COMPOSTABLE" Label and marking must be present on each individual item The State prefers the label or marking to be green in color and to include the logo of the certifying body	Labeling Requirements: If bio-based container is manufactured with polyethylene coated material, it is not compostable, and each container shall be marked to indicate it is not compostable, biodegradable, or recyclable.

MN Procurement	NY Procurement
Excluded Compounds: Per- and polyfluoroalkyl substances (PFASs) must not be added to products. To comply with this requirement, Contract Vendor must submit test results demonstrating that each proposed fiber-based product contains less than 100 ppm of fluorine. Information on testing protocol and recommended labs is available, upon request. If the revised price list does not contain fiber-based products, Contract Vendor does NOT need to submit test results. Only future proposed fiber-based products will need to be accompanied by test results.	Excluded Compounds: In accordance with Environmental Conservation Law section 37-0205, packaging shall not contain inks, dyes, pigments, adhesives, stabilizers, or any other additives to which any lead, cadmium, mercury or hexavalent chromium has been included as an element during manufacture or distribution in such a way that the sum of the concentrations levels of such lead, cadmium, mercury or hexavalent chromium exceed the following concentration level: 100 parts per million by weight (0.01%).
Other: None	Other: All packaging materials shall be made from reusable or recycled materials. All paper based packaging shall contain 30 percent post-consumer fiber by fiber weight. No foil or mylar packaging or excessive inner packing shall be used

Step 3. Scoping the AA

Stakeholder Engagement

Goal: Ensure stakeholders' concerns are addressed, disseminate information to stakeholders, improve acceptance and adoption of results by stakeholders, improve criteria and metrics to ensure relevance to stakeholders.

The stakeholder engagement module in the IC2 (2017) AA framework allows for varying levels of involvement, ranging from a simple thought experiment by researchers to an open stakeholder engagement process. Stakeholder engagement enables improved problem definition, information gathering, results, and adoption of results. Key stakeholders provide insight from their perspective that may not be initially apparent to researchers (Nestler & Heine, 2018). However, stakeholder engagement can be time and resource intensive.

For this project, we recommend using the IC2 Guide (2017) Level 2 formal stakeholder process. It requires OR DEQ to seek identified stakeholder input in a structured process. The formal process allows the agency to ensure, "pertinent AA information is provided for stakeholder review and comment (and that) all comments are collected and responded to" (IC2, 2017, p.24). Stakeholders should be contacted as soon as possible in the AA process. It is particularly important early on to gather stakeholder input on which products should be included in the AA, and on gain consensus on the criteria for each module.

Stakeholders should include:

- Users: food trucks, restaurants, caterers, hospitals, schools, and prisons
- Waste management professionals: composters, recyclers, waste-to-energy, landfills, compost sellers, and users
- Manufacturers: of PFAS-containing food packaging products
- Manufacturers: of PFASs-free food packaging products
- Manufacturers and suppliers throughout the supply chain: of materials and coatings or other substances used in food packaging, e.g. paper manufacturers, converters, etc.
- Retailers
- Distributors of food packaging products
- Innovators: Researchers, entrepreneurs, and businesses creating disruptive innovations
- Local community members: Local politicians, community leaders, and environmental/social justice groups (see social impact section for more information)
- Representatives of the environment: Environmental non-profits
- Government representatives: Local, county, regional, and state representatives
- Industry/trade associations

All stakeholders invited should be asked to identify other relevant stakeholders, who should then be invited to join the process. Contact can primarily be on-line and over-the-phone using conference calls for large group discussions, but some in-person contact at relevant events (e.g. restaurant, food truck, or food packaging related conferences or events) can assist with reaching additional stakeholder perspectives (Nestler & Heine, 2019). Interviews should supplement large-group meetings, particularly focusing on stakeholders who have not spoken up during the large-group meetings.

To inspire and motivate stakeholders involved in collaboration, it is important to designate a champion according to best practices in stakeholder engagement (Bryson, 2018; Intersector Project, n.d.; McDermott, Moote, & Dank 2011). This champion can be an individual or an entity, and the role of this champion is to build buy-in, credibility, and support for working together (Auwarter, Holly, Mareld, & Montgomery, 2016). Champions should be able to work with people in a way that brings out others' creativity and desire for change and have a network of experts to call upon (Auwarter et al., 2016). Groups also need an internal facilitator considered to be trustworthy, approachable, and impartial by participants (Ansell & Gash, 2008; Reed, 2008). Trusted facilitation is especially important in situations in which conflict is likely, for example, between chemical companies and environmental advocates, or between competing companies (Reed, 2008).

Stakeholder engagement should be used to further define the scope of the AA while ensuring that the results will be practical and increase the likelihood of adoption of results. For example, stakeholders should be involved in identifying alternatives and determining which alternatives are assessed. Numerous alternatives exist, and stakeholders can assist in narrowing the scope to the most viable. If the alternatives stakeholders are most interested in are not considered, they may choose to use those regardless of the lack of information.

This module can be made less resource intensive by limiting 1:1 and in-person engagement. We do not recommend eliminating active stakeholder engagement or changing to level 1 in the IC2 Guide (2017), which is a thought experiment and does not involve actually speaking with stakeholders. Rather, contact can be limited to conference calls, workshops and webinars to minimize resource use. Focus groups for particular topics or groups of stakeholders can also provide insight quickly and replace larger stakeholder input sessions, where appropriate.

This module can be made more resource intensive by involving stakeholders more directly in the decision-making process, such as by forming committees or working groups that advise on every step of the process. Some subgroups or committees may be desired for certain special interests. For example, this project may warrant an in-depth discussion of compostability vs recycling and the challenges posed by consumer sorting, collection, professional sorting, composting/recycling, and the sale/usage of the resulting compost/recycled material.

Decision Analysis

Goal: Guide assessors through the analysis of large amounts of often conflicting data to select preferred alternatives and empower users to make informed decisions about chemical or whole-product substitution.

The IC2 Guide (2017) describes three options for decision analysis: sequential, simultaneous, and hybrid. In the sequential method, assessors assess modules one at a time, and based on the results, eliminate some products before proceeding to the next module. In the simultaneous method, assessors assess all modules at the same time, and use the results in concert using a multi-parameter analysis to eliminate products. In the hybrid method, certain modules are prioritized and completed first using the sequential method, followed by simultaneous assessment of remaining modules using a multiparameter analysis. For example, assessors may complete the hazard module and eliminate some alternatives before proceeding to assess performance, cost & availability, and exposure simultaneously.

We recommend the hybrid approach to decision analysis with a variation used by NGC as part of its work to evaluate alternatives to copper-based recreational boat anti-fouling coatings. This approach establishes ‘showstopper’ criteria in individual modules similar to the sequential approach. However, from there it diverges from the sequential approach in a useful way. Instead of making decisions for stakeholders and assuming all stakeholder needs are similar, the assessment results for each product are presented in a matrix or other user-friendly Selection Guide (SG) format that is designed to help diverse users make an informed decision about the product(s) they select. Products would need to be separated into those that are specific final products versus those that are alternative coatings or treatments that could be applied to a final product. The group conducting the AA does not evaluate the options that make it through the first pass/showstopper criteria. This hybrid approach allows for different users to apply their own values, performance needs, and preferences. All of the available options will have met minimum criteria to ensure that they are inherently safer and more sustainable than the alternatives they will substitute.

For example, some stakeholders will value reusables over single-use disposable products and will prefer products such as the GO Box where infrastructure exists. Others may prefer single-use disposables that are commercially compostable for use in closed events with composting capacity. Still others may prefer products that are bio-based or recyclable in order to reduce their carbon footprints; others may require that products with such claims are backed by life-cycle assessments confirming that they do actually represent a reduction in emissions. Others may be especially cost sensitive or may be constrained by product availability. This process is related to the approach used by Consumer Reports (2018). Consumer Reports evaluates products based on what it deems to be the most relevant and discriminating criteria. In AA, those criteria are defined by the modules in the IC2 AA Guide (2017). For example, while Consumer Reports may report durability, energy consumption and cost for refrigerators, it does not rank them by space capacity or whether or not the freezer is on the top or the bottom or whether it has two doors or one. The final decision about product fit is left to consumer preference and need.

Stakeholder input should be used to ensure that the Selection Guide covers all of the important and discriminating attributes needed to support decision making about this set of products, or if it would be more useful to develop Selection Guides for different product uses. For example, there could be Selection Guides specific to each product (e.g. soup bowls, clamshells, etc.) or specific to certain use parameters (e.g. acceptable for hot food vs cold-food only, or microwaveable, etc.). This hybrid decision approach method preserves the greatest choice for users while still eliminating unacceptable options.

Driving innovation with AA: For some functional uses, there may be no products that currently exist that meet the first pass requirements. The assessors should clearly identify these as innovation opportunities. Funding entities, such as government agencies or foundations may consider offering incentives, in the form of grants or loans, directed at these innovation opportunities. Other funding entities could consider setting up a competition similar to the X Prize to encourage innovation. Investors may decide to invest in emerging start-up companies that seek to take on the innovation challenge.

Step 4: Identifying Alternatives

Goal: Broadly identify the universe of alternatives to the chemical of concern, including direct chemical substitutes, whole-product substitutes, and potentially disruptive innovations that approach product function differently.

Based on NGCs prior AA experience, we recommend that the scope of possible alternatives considered should be broad and include both existing and emerging options. Inclusion of a broad range of alternatives increases the likelihood that alternatives are found. It also increases the likelihood that the alternatives will not only be PFASs free, but that they will provide benefits across the full product life cycle. If the scope is too narrow, then innovative alternative materials and even innovative business models that mitigate impacts from food packaging products may be missed. While AA may be used to identify opportunities for incremental improvement, it can also help define specific challenges for chemical, engineering, or business model innovation. In coordination with OR DEQ's Toxics and Materials Management teams this AA roadmap provides a test case for applying AA in support of Oregon's Sustainable Materials Management Vision and Framework (OR DEQ, 2012).

The down side of broader inclusion is that less information may be available on new or emerging options. For example, users of new product types may have less experience with their performance; their initial costs may be higher than those for incumbent products, not reflecting future costs when brought to scale, and they may not be readily available in all locations.

AA is a snapshot in time and additional options may be identified as more stakeholders are engaged and new products are developed. Therefore, we advocate for consideration of both existing and emerging options including:

- Alternative bio-based materials, with or without coatings or additives to enhance performance (plant fiber, PLA)
- Alternative non bio-based materials that do not require PFAS additives to achieve performance specifications (e.g. aluminum, plastics, clays, etc.)
- Biodegradable, recyclable and reusable products

For example, Vibers (www.vibers.nl), a company based in the Netherlands, recently developing food service ware using locally grown elephant grass. If included and determined to be a preferable option, OR DEQ could use these results to encourage further development of this alternative in Oregon. Figure 4 provides a visual flowchart or map of available food packaging technology types. The supplemental file contains a compiled list of existing product, material and coating options from CEH (2018), CFE/CPA (2018), and NGC (2018) for this report.

Currently Identified PFASs-Free Food Packaging

There are numerous alternatives that may be sorted based on different attributes. A good first step is to consider the base material platform and the product functional uses. Not all materials will support all applications and it is useful to know the availability of alternatives for each functional use. Figure 4 (with parts a, b, and c) lays out a schema for comparing food packaging technologies broken out by 1) materials, 2) molded fiber feedstocks, and 3) coatings and treatments. The supplemental file links those categories to specific products. All technologies listed include examples that are suspected or known to be PFASs-free. This includes some examples of fiber-based products that claim to be PFASs-free. However, all molded fiber products tested by CEH contained PFASs. PFAS-free food packaging products may be sorted further based on material types, feedstocks, process treatments, and end of life management options.

Materials

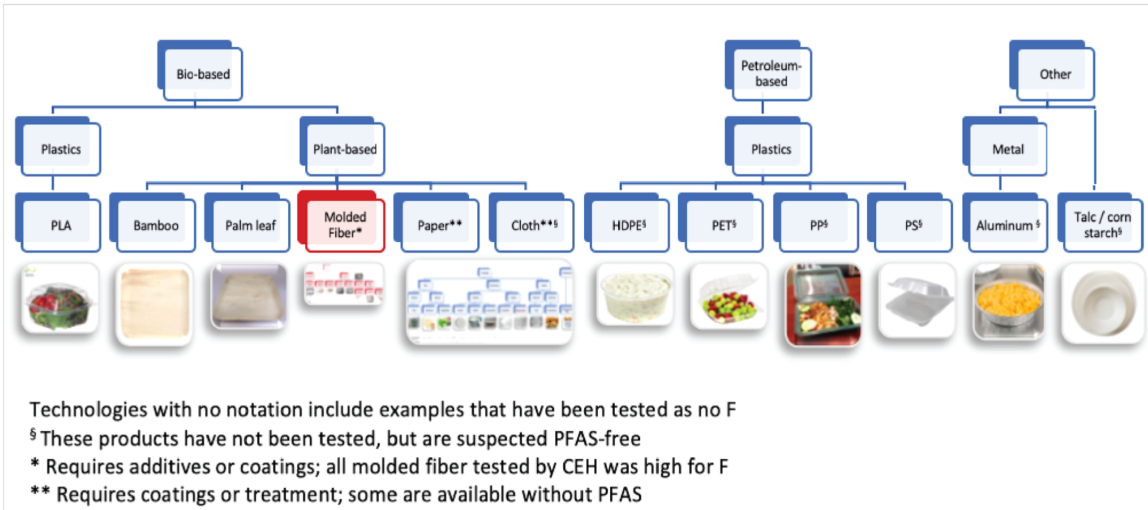


Figure 4a. Technologies used for food service ware: Materials

Molded Fiber Feedstocks

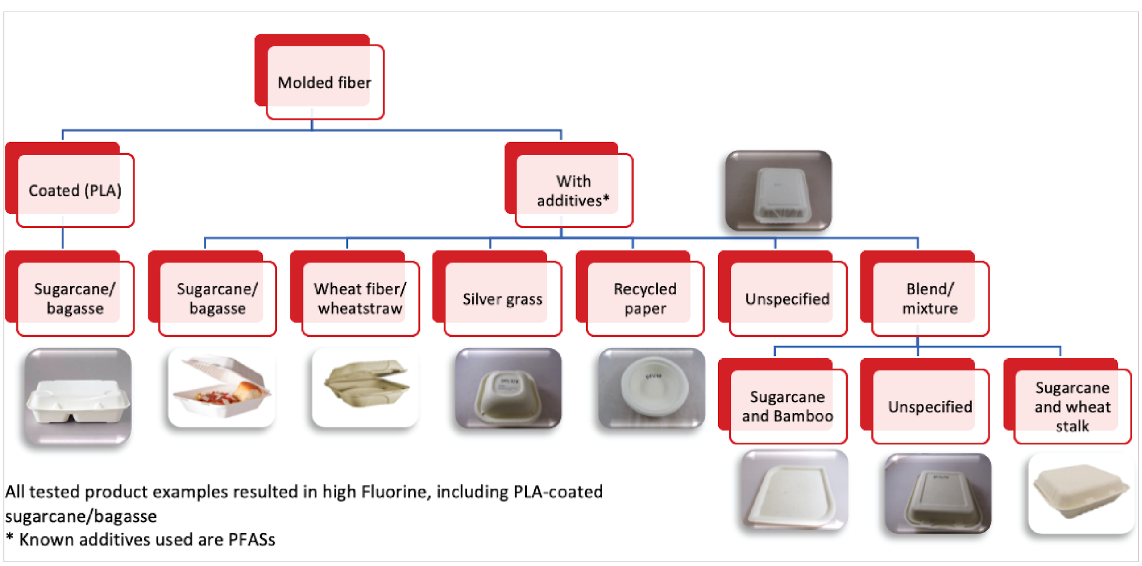


Figure 4b. Technologies used for food service ware: Molded fiber feedstocks

Coatings & Treatments 4

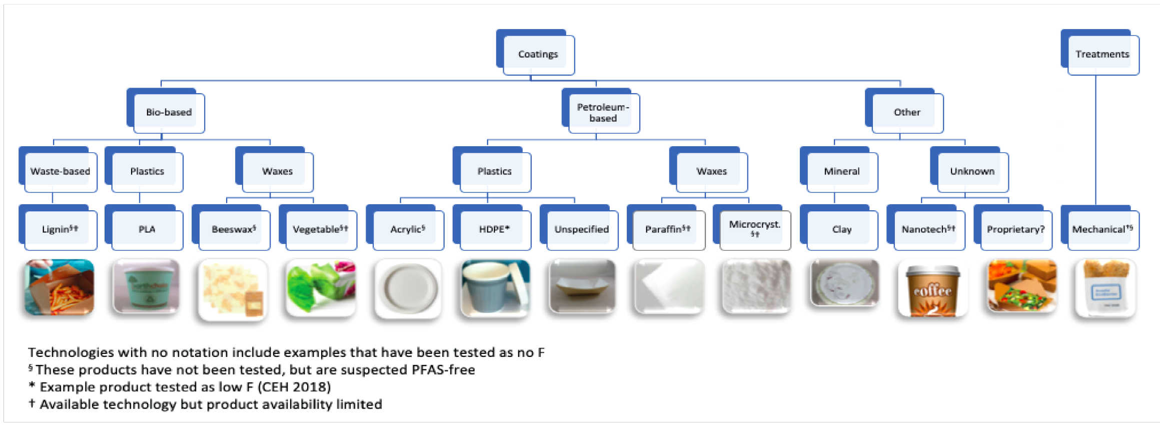


Figure 4c. Technologies used for food service ware: Coatings and treatments

Step 5: Proposed Selection Criteria to Narrow the Scope of the AA

NGC recommends the use of modules for stakeholder engagement, materials management, life cycle, and social impacts, in addition to the four mandatory AA modules hazard, exposure, cost & availability, and performance. For each module, we created priority selection criteria to ensure that alternatives to products with highly fluorinated chemicals are not regrettable substitutions.

As discussed, we propose using a modified hybrid framework for decision-making. In this framework, an initial screening assessment is done with a defined set of modules using 'showstopper' criteria to eliminate unacceptable alternatives. For example, showstopper criteria in performance can set a minimum standard of acceptable performance. Further analysis of performance will distinguish between higher and lower performers. The showstopper step exists to rapidly eliminate unacceptable alternatives and save time and resources by not fully assessing eliminated alternatives.

Hazard

Goal: Ensure preferred alternatives are comprised of chemicals that are inherently less hazardous than the chemical/product of concern.

The hazard module allows for a comparison between the inherent chemical hazards of the chemical of concern (here, PFASs) and alternatives. *Reduce hazard* is the first principle in the Commons Principles for Alternatives Assessments (2012). It is also at the heart of the green chemistry and engineering – to *eliminate toxics in products and processes.* This module allows for the selection of inherently less hazardous options and guards against regrettable substitutions, a situation where the alternative is equally or more hazardous, than the original chemical or product of concern.

A recent report from Safer Made identifies numerous chemicals of concern currently used in food packaging (Mulvihill, 2019):

- 53 chemicals of concern intentionally added to plastic food packaging
- 20 chemicals of concern intentionally added to fiber food packaging, 12 of which are PFASs
- 12 chemicals of concern intentionally added to metal food packaging, 2 of which are PFASs
- 72 non-intentionally added chemicals of concern

The authors also noted greater transparency of the supply chain and greater disclosure of additives are essential for driving the adoption of safer alternatives. Without a robust assessment of the ingredients and hazards of alternatives to products containing PFASs, regrettable substitutions may occur.

This section covers:

- Building a chemical inventory
- Taking a tiered approach to chemical hazard assessment (CHA)
- Criteria to eliminate (showstopper) unacceptable alternatives, and to identify safer products

For this module, we recommend a tiered approach as opposed to following a specific level in the IC2 Guide.

Chemical Inventory

Goal: Identify chemicals relevant to each product across the product lifecycle.

A chemical inventory is a critical step in applying both the hazard and exposure modules and is used to determine which chemicals will be assessed. This involves defining the scope of the chemicals of interest, determining how chemicals will be identified, and setting clear thresholds for disclosure and assessment. Identifying all relevant chemicals will require cooperation from manufacturers and may require the use of non-disclosure agreements (NDAs) to protect confidential business information (CBI). Transparency and public disclosure should be preferred when possible.

The chemical inventory should be completed for all products that are currently available as well as for emerging technologies of interest. At a minimum, the chemical inventory includes all substances that are likely to be retained in, or migrate from, the food packaging. This includes any monomer(s), oligomer(s) and any known additives and residuals (impurities), including catalysts and performance additives (anti-oxidants, colorants, plasticizers, UV stabilizers, flame retardants, compatibilizers, etc.). Ideally, the inventory should provide insight into occupational hazards as well. Knowing the residuals provides information on the chemicals used in manufacturing. A more complete assessment requires inventorying chemicals used and generated across the product life cycle in order to assess hazard, exposure, life cycle and disposal/recycling impacts. Assembling a complete chemical inventory for each life cycle stage can be challenging because formulations are often proprietary, and information for all life cycle stages may not be available, even to manufacturers throughout the supply chain.

We recommend inventorying all intentionally added chemicals as well as residuals present in the use phase of the product life cycle, and all intentionally added or used chemicals during the manufacturing stage. *Residuals* as defined by the USEPA Safer Choice Program (Safer Choice) are 'trace amounts of chemicals that are incidental to manufacturing. Residuals are not part of the intended chemical product but are present because of factors such as the nature of the synthesis and engineering pathways used to produce the chemical. Residuals include: unintended by- products of chemical reactions that occur in product formulation and chemical synthesis, impurities in an ingredient that may arise from starting materials, incompletely reacted components, and degradation products' (US EPA 2012).

Depending on the product, some residuals are more problematic than others. For example, due to the use of PFASs as mold release agents, PFASs may end up in a products due to manufacturing, even though they are not added to provide grease or water repellency. Such residuals are referred to as 'residuals of concern'. *Residuals of concern* as defined by Safer Choice are 'residuals that fails to meet the criteria in the General Standard for carcinogenicity, mutagenicity, reproductive toxicity and other human health effects, or fails to meet the criteria for persistence, bioaccumulation and toxicity, as defined by the Final PB&T Rule' (US EPA 2012).

Most chemicals have multiple names and need to be identified clearly using conventions such as Chemical Abstract Services Registration Numbers (CASRN), International Union of Pure and Applied Chemistry numbers (IUPAC) and others (EINECs, INCI). In theory, these identifiers are unique. However, some identifiers apply to general classes or groups of chemicals and more nuanced identification may be needed, such as for different forms of a chemical or molecular weight ranges. Additional data such as molecular structure and physical form help to refine the compound's identity. The chemical inventory includes the precise chemical identity, the chemical function, and concentrations or amounts (exact or ranges). We recommend using CASRNs to identify and distinguish all chemicals as a baseline, but to include additional specifications when available. This information may be used to determine that certain hazards do not apply to the specific form used in the product.

Clear thresholds are needed to determine which chemicals to include in the inventory and which to assess. One strategy is to set a concentration threshold, or de minimus level, at, or above which, a chemical constituent will be evaluated. Selecting a threshold may depend in part on the chemical's hazard characteristics. For example, endocrine disrupting substances are hazardous at very low exposure levels and thus a low threshold is appropriate. Safety Data Sheets provide precedent for using different disclosure levels for chemicals with different hazard traits. Carcinogenic chemicals above 0.1% must be reported while non-carcinogenic hazardous chemicals are disclosed above 1% (US EPA 2018). Some certification programs (e.g. Cradle to Cradle) link certification levels to the weight percent of chemicals disclosed. Example disclosure thresholds and criteria include:

- Specific chemicals known **not** to be present in a product.

- All intentionally used or added chemicals at any concentration for limited life cycle stages (e.g. use phase only).
- All intentionally used or added chemicals at any concentration at all life cycle stages.
- All intentionally added chemicals plus residuals at or above a concentration threshold.
- All intentionally added chemicals plus residuals present at or above a concentration threshold, plus residuals of concern at any concentration.

We recommend identifying all chemicals intentionally used or added along with residuals above 0.01% and residuals of concern at any concentration for assessment. Some people use a tiered and iterative approach to inventorying chemicals, starting with higher disclosure thresholds, and working to gather additional information at lower thresholds as feasible and relevant. The overall goal of this module is a comparison of materials based on hazard, so chemicals shared between all products may not need to be assessed. We recommend following a tiered and iterative approach that considers the kinds of comparisons desired. For example, alternative substances that function as a direct replacement to PFASs, using the same base material as PFASs-containing food packaging (e.g. alternative is a coating used on molded fiber), need only those intentionally used or added chemicals that are *different* between the PFAS packaging and the alternative packaging to be assessed. Chemicals that are shared between the PFAS packaging and the alternative packaging do not discriminate between products. However, all chemicals will need to be assessed to compare products outside of this limited scenario. The chemical inventory can be made more or less resource intensive by limiting or expanding the scope as follows.

- Life cycle stages included
    - Minimum: Use phase
    - Preferred: Use and manufacturing
    - Ideal: Use, manufacturing, and disposal/EOL
- Inventory thresholds
    - Minimum: All intentionally added ingredients. Residuals at or above 0.1%.
    - Preferred: All intentionally added ingredients. Residuals present at or above 0.01%
    - Ideal: All intentionally added ingredients, residuals at or above 0.01%, and all residuals of concern at any concentration, as defined in the US EPA Safer Choice standard (US EPA 2012).
- Disclosure
    - Minimum: Obtain publicly available information only.
    - Preferred: Companies provide ingredient disclosure under an NDA.
    - Ideal: Companies publicly disclose, providing full transparency.

Unfortunately, obtaining the same level of disclosure for every product is challenging. A mixture of disclosure levels further complicates decision analysis, as a lack of disclosure is not evidence of low hazard. Identifying all intentionally added ingredients, without identifying residuals, can result in regrettable substitutions, particularly if the manufacturing phase is not considered. For example, PFASs used as mold release agents can contaminate the final product despite not being intentionally added.

We recommend encouraging companies to provide full disclosure by rewarding them for disclosure in the AA process. For example, insufficient disclosure may be used as a criterion to exclude products from advancing in the AA towards the decision analysis.

Polymers

Polymers require special consideration. The United States, the European Union and others have established criteria and methods to screen for polymers of low concern (European Commission 2015). Polymers are generally unreactive, and their large size prevents them from crossing biological membranes. Hazards associated with polymers are usually tied to non-polymeric substances within the polymeric matrix including unreacted monomers, partially reacted oligomers, additives, etc. It is important to know the molecular weight (MW) ranges of substances in a polymer including residual monomers and oligomers. Lower molecular weight substances are more likely to migrate from plastic and, if toxic, will result in exposure. Therefore, MW is a screening criterion for identifying polymers of low concern. Typical thresholds used are < 500, > 500 and < 1,000, > 1,000 and < 5,000, > 5,000 and < 10,000, > 10,000 Daltons (Da). These thresholds are for screening purposes and cut off ranges may be shifted if warranted. For instance, ranges may be different for fluoropolymers (< 1,500 Da) or for higher molecular weight substances if accompanied by permeation enhancing substances commonly found in food contact materials (Geueke, Groh, & Muncke, 2018). When the perfluorinated moiety is present on a side-chain, degradation products may include mobile PFASs that need to be considered separately from the higher MW polymer. For polymers, we recommend identifying the molecular weight ranges of substances in the polymer, as well as the monomer, catalyst(s), any additives and processing aids used, and degradation products, particularly cleavable fluorinated side-chains.

Cooperation from manufacturers is necessary to generate a complete product inventory. However, even manufacturers may find it challenging to identify all chemicals involved in the production of a given product. Perfect information is not possible and there is no one single right way to set disclosure requirements. By communicating to manufacturers that their participation will influence future purchasing decisions, stakeholders who purchase products can be invaluable partners in convincing manufacturers to participate fully.

Transparency is important because information about what is known, and not known, about the chemicals used in production and manufacturing will support informed decision-making. We recommend preferring companies that provide full disclosure. Public disclosure is preferred over NDA-sealed disclosure; and more complete disclosure (e.g. including residuals as well as intentionally added ingredients, to a lower threshold, or covering more life cycle stages) over less complete disclosure. This aligns with the Commons Principles for Alternatives Assessment (2012), which recommends requiring disclosure and transparency.

This module can be made more or less resource intensive by limiting or expanding the scope of chemicals inventoried.

- Life cycle stages included
    - Minimum: Use phase
    - Preferred: Use and manufacturing
    - Ideal: Use, manufacturing, and disposal/EOL
- Inventory thresholds
    - Minimum: All intentionally added ingredients including monomers, MW range of oligomers, and catalysts. Residuals at or above 0.1%.
    - Preferred: All intentionally added ingredients including monomers, MW range of oligomers, and catalysts. Residuals present at or above 0.01% in final product.
    - Ideal: All intentionally added ingredients including monomers, MW range of oligomers, and catalysts, residuals at or above 0.01%, and all residuals of concern at any concentration, as defined in the US EPA Safer Choice standard (US EPA 2012). Clear identification of processing aids and other chemicals used in manufacturing.
- Disclosure
    - Minimum: Obtain publicly available information only.
    - Preferred: Companies provide ingredient disclosure under an NDA.
    - Ideal: Companies publicly disclose, providing full transparency.

Tiered Approach to Chemical Hazard Assessment

Goal: Efficiently and effectively assess hazard of chemicals on the inventory.

We recommend a tiered approach that begins by screening all chemicals using rapid and inexpensive chemical hazard assessment (CHA) methods, followed by progressively more resource intensive methods, as necessary. In this approach, the easiest sources are utilized first to eliminate products using “showstopper” criteria, and more detailed, resource-intensive assessments are used to further eliminate products using “showstopper” criteria and to distinguish between lower-hazard products. This process identifies products with acceptable hazard profiles while reducing costs.

Tiered assessment method:

1. Search for existing comprehensive chemical hazard assessments (CHAs). See the IC2 AA Guide for more detail on the different CHA methodologies (IC2 2017)
    a. Search for:
        i. Full chemical hazard assessments using the GreenScreen for Safer Chemicals (GS) methodology (Clean Production Action 2018) or the Design for the Environment Program Alternatives Assessment Criteria for Hazard Evaluation (US EPA 2011)
        ii. Partial GS assessments or assessments done using the WA DOE Quick Chemical Assessment Tool (QCAT) method (WA DOE, 2016)
    b. Search at:
        i. IC2 CHAD: http://www.theic2.org/hazard-assessment
        ii. GS Store: https://www.greenscreenchemicals.org/gs-assessments
        iii. Data commons: https://commons.healthymaterials.net/

    iv. ToxFMD Screened Chemistry™ Library (free for BM1 chemicals, others for sale): https://database.toxservices.com
2. If none are found, use GreenScreen List Translator via the Data Commons or ToxNot.
3. Assess results for data completeness and determine if more in depth assessments are necessary for any endpoints.
    a. If sufficient information is available to accurately and confidently distinguish between products, no further CHAs are necessary at this time.
    b. If information is not sufficient, complete QCATs as needed.
    c. If further information is needed, complete full chemical hazard assessments.

Criteria for Assessing Hazard in Food Packaging

Goal: Eliminate alternatives that are more hazardous than products with the chemicals of concern and distinguish between products with more moderate or even low hazard.

Showstopper criteria: Eliminate products with chemicals with PBT characteristics or classified as high for any of the Group I Human Hazards (carcinogenicity, mutagenicity, reproductive and development toxicity, and endocrine disruption). Chemicals with PBT characteristics are 1) very persistent and very bioaccumulating; 2) persistent, bioaccumulating and aquatically toxic; 3) very persistent and toxic; 4) very bioaccumulating and toxic. GreenScreen Benchmark 1 criterial can be used as a guide.

After products are eliminated due to showstopper criteria, the remaining alternatives can be compared. When comparing single chemicals, a direct comparison following the GreenScreen for Safer Chemicals method is appropriate. But we recommend using caution when using GS Benchmarks (BM). The GS BM system overly aggregates hazards into broad benchmarks that can impede informed decision making. It is better to compare chemicals based on the hazard summary table and to consider what is known about hazards tied to specific exposure routes.

When comparing whole products with chemical additives or chemical mixtures, it is useful to look at the individual chemicals and also to consider mixture rules such as those defined in the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Mixture rules are particularly useful for hazards that can be 'diluted out' at the product level. For example, glacial acetic acid is very hazardous to handle, but when dilute in a product it is not hazardous. In contrast, we do not recommend applying mixture rules to PBTs and Group 1 hazards. Unlike with acids or bases, the hazardous properties do not go away with dilution, there is simply less of the hazardous chemical present.

General criteria for single-chemical alternatives:

1. Directly compare chemicals for GS Benchmark (BM) scores. Higher values are preferred over lower values. Rule out chemicals/products that score BM 1.
2. If the GS BM scores fall into the range of BM2, or if the chemical scores are equivalent, then the chemicals/products should be compared based on the specific hazards identified in the hazard tables.

3. Make sure to determine the exposure route that drives the hazard. This information will be needed for the exposure module. If people are exposed via the oral route but there are data only for dermal exposure, then we recommend treating that hazard endpoint as a data gap.

General criteria for whole products and mixtures as alternatives:

- Prefer alternatives that contain no GS BM 1 (GS LT 1) chemicals. That would include:
  - chemicals classified as high for any of the Group I Human Hazards (carcinogenicity, mutagenicity, reproductive and development toxicity, and endocrine disruption)
  - chemicals classified with PBT characteristics
- Prefer alternatives without data gaps for key hazard endpoints and for key exposure routes.

The purpose of each AA module is to make meaningful distinctions between the alternatives. In some cases, it may be desired to use a more sophisticated break-out of even highly hazardous chemicals, such as chemicals that score GS BM 1 and GS LT 1. It is possible to tell whether or not this is warranted by considering the typical lifecycles of the product and when these alternatives are used, particularly phases in which exposure cannot be controlled or cannot be predicted.

Driving innovation with AA:

1. Tradeoffs are likely between chemicals with different hazard profiles and varying amounts of data gaps. Some data gaps can be filled by qualified toxicologist using modeling tools and inference methods called 'read across'. The goal is not necessarily to have perfect information, but to have sufficient confidence that the alternatives do not have undesirable hazard characteristics. Partner with innovators and manufacturers, unions and representatives of exposed communities to 1) drive demand for completion of research and development work to build comprehensive hazard profiles and 2) to inform decisions about tradeoffs in the face of uncertainty. Encourage manufacturers confident in the low hazard of the chemical ingredients they use to fund publicly available comprehensive CHAs.
2. Separate the chemical inventory of whole products into: 1) Water/grease-proofing performance additives 2) Non water/grease-proofing performance additives (e.g. UV stabilizers, whiteners); and 3) Chemicals used to make the base materials (e.g. processed wheat fiber, polymers such as PLA). This separates technologies used for water/grease-proofing from chemicals used for the base material and any other additives and can identify opportunities for innovation. For example, an otherwise preferable water/grease-proofing technology may be currently available only in products that also use an unacceptably hazardous UV stabilizer. This technology could be eliminated in the AA due to the UV stabilizer even though the rest of the chemistry is preferable. However, it may be possible to substitute or eliminate the UV stabilizer. By considering chemicals based on these functional uses, this opportunity is identified and encouraged.
3. Consider using AA to find alternatives for other chemical classes. For example, the Food Packaging Forum identified four phthalates commonly found in food contact materials (and in food) as top priorities for substitution (Food Packaging Forum 2018).
4. Develop information specific to processing aids and additives used in food packaging modeled after the Safer Choice Criteria for Processing Aids and Additives (US EPA nd). The US EPA Safer

Choice program treats processing aids and additives as a class. Similar guidance could be developed for processing aids and additives commonly used in food packaging materials.

5. Screen chemicals based not on hazard but also based on how they impact recyclability.

Comparative Exposure

Goal: After completing the hazard module, exposure is considered to reduce risk based on how the products are used.

The exposure module provides an opportunity to identify alternatives with lower exposure to chemicals that have moderate or low hazard properties, following the Commons Principles for Alternatives Assessment (2012) to minimize exposure. Preferred alternatives will not contain chemicals of high concern based on screening first with the hazard modules. However, most chemicals currently in use have some inherent hazards and it may be necessary to consider how the chemicals are used and their resulting exposure to people and the environment. We recommend starting with comparative exposure assessment rather than a full exposure assessment, focusing on exposure differences rather than exposure quantification. Some chemicals may be hazards in one life cycle stage due to their physical form rather than their inherent chemical toxicity. For example, powdered whiteners may be hazardous in the workplace but not bound within a polymer. It is not important what the total quantified exposure to a population is, but rather, the relative exposure between the alternatives.

Relevant exposure scenarios for food packaging include:

- Worker manufacturing food packaging
- Worker filling food packaging and providing it to customers
- Customer consuming food that was contained or stored in food packaging
- Worker handling food packaging end of life (e.g. recycling, composting, waste collection)
- Environmental exposure based on use scenarios
- Environmental exposure based on end of life of food packaging (e.g. landfill leachate, incineration products, unmanaged waste (litter))

As a first pass, we recommend assuming that any additives and residuals present in the food packaging product will result in maximum exposure (e.g. 100% leaches into food, 100% volatizes during manufacturing, 100% leaches from landfill). This is the worst-case scenario. If alternatives are considered acceptable under this exposure scenario, then no further work is necessary. For example, a product comprised entirely of chemicals of low hazard may be acceptable under this worst-case scenario. Any alternatives that raise concerns for worker, consumer or environmental health based on worst case scenarios should be evaluated further with modeling or testing. For more advanced assessment, we recommend an approach similar to that described in Greggs et al. (2018).

Worker Exposure

Workers in certain contexts are known to have higher PFASs serum levels, including workers at a PFASs production plant (Emmett, 2006), professional ski wax appliers (Freberg 2010), and workers at a textile manufacturing plant (Heydebreck, 2016). The extent of worker exposure to other constituents of food packaging will need to be estimated using modeling if testing results are not publicly available in the scientific literature. Personal protective equipment (PPE) may be considered but relying on protection from chemicals of concern by using PPE is not recommended.

Customer Exposure

It is important to carefully consider the potential uses and misuses of each alternative. Migration modeling or testing should mimic the most severe potential exposure condition, i.e. the highest temperature and longest exposure time anticipated. We recommend that initial considerations treat all food packaging equally, as if high temperatures and longest exposure times are expected. Food packaging only intended for cold or room temperature food contact that fails using these parameters could be reconsidered under more limited conditions and given a provisional pass.

Migration of food contact additives and other chemicals can be modeled mathematically. There are a number of different approaches to modeling including 1) deterministic or mechanistic models based on the physical chemical mechanisms driving the migration; 2) empirical models based on fitting modeling equations to actual data sets; 3) stochastic models that use probability distributions of migration; and 4) probabilistic models that take into account variables that occur with migration of chemicals and the probability of their occurrence. A useful summary of information on migration models and needs has been compiled by the Food Packaging Forum.

Migration of food contact additives and chemicals can also be tested directly. Performing migration testing would be more resource intensive. In a migration test, the food packaging is exposed to food or a food simulant for a specified period of time at a specified temperature, mimicking the most severe conditions of use. The US FDA provides detailed guidance for regulatory migration testing that can be followed (US FDA, 2007). Another option for gaining access to migration test data is to engage with manufacturers. All food contact materials must pass FDA criteria, which can include migration and compliance testing. By engaging with manufacturers, possibly under a Non-Disclosure Agreement (NDA) to protect Confidential Business Information (CBI), the results of this existing work may be shared with the assessors. This relies on the willingness of the manufacturers to participate.

Environmental Exposure

Comparative exposure of chemicals to the environment may be based on use patterns of the food packaging products and physical chemical properties of the chemicals (Greggs et al 2018). We recommend creating exposure maps to determine where environmental exposures may differ between products typically used in the same way. Exposure through end of life management should be linked to infrastructure currently available or reasonably anticipated to be available in Oregon.

Driving innovation with AA:

1. Partner with innovators, manufacturers, and unions to drive decreasing exposure across the product life cycle. Unions provide workers, who face increased exposure during manufacturing,

with a collective voice that can influence employers and reduce occupational illness and injury rates (Yi, 2011).

2. Consider how waste management infrastructure improvements and business models using food packaging products could meaningfully impact exposure results.

Cost and Availability

Goal: Ensure alternative products will be available in sufficient quantities to replace the products with the chemicals of concern and ensure that they are not cost prohibitive.

The cost and availability module ensures that alternatives are price-competitive and available in sufficient quantity. Inclusion of this module helps ensure that preferred alternatives can realistically be adopted by industry. Care should be taken to avoid biasing the module towards established technologies that have already been brought to scale. Cost should be considered across the life cycle of the products. For example, a reusable container may cost more up front but may become cost effective after a few uses.

Food packaging products are low-cost products and alternatives must have similar cost profiles to be readily adopted. We recommend researching the retail price of PFASs-containing products and the alternatives. However, this should not be used to eliminate alternatives within a reasonable cost range. Stakeholder engagement is recommended to help define a reasonable cost range; especially given regional variability, competition and expected cost reductions with scale. In addition, any product currently being used and purchased in the marketplace is at a reasonable price point for at least some users. Unfortunately, this criterion is not applicable to emerging products. It is worth acknowledging that the actual cost to businesses who provide take-out containers may be different from the retail price, but this information is not publicly available.

Food packaging products are fast-moving consumer goods, with a short lifespan and constant consumption. Assessors should discuss current production and the potential for future scaling of alternatives in order to understand the potential future costs and availability of these products for substitution. Availability of alternatives should be broken into functional categories, as defined in the performance module below, in order to understand if sufficient product(s) are available to match each function currently assumed by PFASs-containing food packaging.

Given Oregon's investment in the health of its people, its economy, and its natural resources, a more intensive full economic analysis is appropriate. Advanced cost assessment should include broader externalities such as societal impacts, human health, waste management, and litter. This would significantly increase the resources required for completing this module but would address other expenses that Oregon may incur. Cleaning up contamination is an expensive proposition so reducing the amount of toxic chemicals used and disposed of in Oregon may impact future costs. Costs from health impacts from PFASs exposure and exposure to other hazardous chemicals in alternatives would also be considered in a full economic analysis.

Performance

Goal: Ensure alternatives function for the desired application and that they meet minimum requirements.

The performance module is designed to ensure that alternative products will perform the same core function as the chemical or product of concern. Inclusion of this module helps ensure that alternatives that do not work are not recommended based on the AA. We recommend using stakeholder input to define a suite of performance criteria for different uses and to identify available performance metrics. We recommend a four-step process to this module, with stakeholders engaged at every stage:

1) Define the functions of currently-used PFASs-containing food service ware
2) For each function, define minimum/showstopper and stretch criteria and metrics
3) Match each product to appropriate function(s)
4) Assess products according to function

Actively engaging stakeholders in this module will improve criteria and metrics, as well as acceptance and adoption of the results of the alternatives assessment. By providing a voice to those who use food packaging containing PFASs, the assessors ensure that their concerns and needs are represented. If only users who have already substituted with alternatives are included, key functional parameters that are not covered by currently available alternatives may be overlooked and not considered, leaving these users without any functional alternatives. Diverse users should be engaged, including restaurants, food trucks, cafeterias, caterers, hospitals, schools, prisons, and consumers. For this module, in particular, it is vital that the assessors do not proceed without consulting stakeholders.

Food service ware covers a variety of functions, ranging from holding low-density room-temperature dry food to high-density hot and greasy liquids. The minimum water and grease resistance and strength of a bowl used to hold hot, greasy soup is different for a bowl used to hold cold, undressed salad. While a single PFASs-containing product may be capable of handling these diverse functions, multiple alternative products may be necessary to handle all of the same functions. It will be important to consider situations in which products currently using PFASs are overengineered for the function they provide.

Products are overengineered when they are designed to be more durable or have additional performance characteristics beyond what is necessary. In some cases, overengineering provides an additional safety factor or permits for minor manufacturing defects without compromising the product. overengineering is not an issue when it does not result in compromise in other modules. However, overengineering can also result in erroneously concluding that no functional alternatives are available due to the extraordinarily high-performance criteria.

One example comes from the use of PFASs in durable water repellents (DWRs) for apparel (Schellenberger, 2019). DWRs provide water and stain proofing to apparel. While alternatives to PFASs in DWRs for water proofing are commercially available today, many brands do not believe they are sufficient due to the lack of robust stain resistance. A detailed analysis of actual performance requirements and consumer expectations revealed that stain proofing is unnecessary for many garments. Outdoor apparel users are primarily concerned with water-proofing. These users ranked stain resistance as the lowest priority in purchasing decisions. One response highlighted that stain repellency is "not crucial to preventing hypothermia on the mountains" (Schellenberger, 2019, pp. 140-141). The use of PFASs in outdoor apparel results in overengineering the product by conferring additional performance benefits that are not central to users' needs or expectations. Before PFASs were recognized as chemicals of concern, this was not problematic.

Overengineering may occur in food packaging as well. For example, overengineering may result from the use of the same packaging for diverse food products. A restaurant may use the same bowls for hot and greasy soup, cold salads, and dry bread. The bowls in this example are overengineered for the cold and dry uses but needed for the hot and greasy soup. The bowls may be overengineered for all uses if they are sufficiently durable and leak-proof to last longer than about a week while filled.

Performance criteria should include showstopper limits and stretch criteria. Showstopper criteria are used to eliminate products that simply do not perform. For example, soup bowls that leak or clamshells with low tensile strength that collapse when loaded. Stretch criteria are used to distinguish between products that perform above and beyond their basic function. Stretch criteria should not be used to eliminate any product that meets the minimum criteria. Stretch criteria can help identify products that may be overengineered for a given function, but that overengineering is useful in reducing the number of different containers a given business must have available for use. It may be convenient to be able to use the same bowls for hot and greasy soup as for dry bread.

This module can be made less resource intensive by setting the minimum criteria for performance as the product being available on the market. Any product currently being used and purchased on the market must meet at least some user requirements. Emerging products cannot be assessed using this method and will require further consideration or comparison to existing alternatives. Another strategy to reduce resources necessary for this module is to limit the number of different functions assessed. Stakeholder input should be used to identify the most common and widespread functions. Stakeholders could also help identify where no PFASs-free alternatives are considered to be available.

This module can be made more resource intensive by performing actual testing of products to determine if they meet performance criteria. TAPPI, the Technical Association of the Pulp and Paper Industry, maintains standards and methods for used in the measurement, evaluation, and description of pulp, paper, and related products. While food packaging materials comprise more than just pulp and paper, these methods may be useful for paper-based alternatives and potentially for non paper-based alternatives as well.

The Kit Test (TAPPI T559) describes a method for measuring the degree of repellency/anti-wicking of a paper or paperboard treated with PFASs (TAPPI). It involves testing the treated paper with a series of liquids of varying surface tension and viscosity and observing which remains on the surface of the paper without causing failure. It is unknown if this test would be appropriate for alternatives, such as barrier coatings, mechanical treatments, or alternative materials.

The Foodservice Packaging Institute (FPI), is a North American trade association for the foodservice packaging industry that provides information on some test methods on their Resources webpage (https://fpi.org/Resources), including:

- Harmonized hot oil test for printed, finished foodservice products. This test exposes the use side of the product to hot corn oil containing red dye for 20 minutes. The oil is then removed with a spatula followed by a paper towel, after which the back side of the product is immediately examined for red marks.
- Leak test for poly coated hot cups. This test exposes the inside of the cup to a mixture of coffee and wetting agent (approximately 0.3% Triton X-100 final) for 20 minutes, during which the cups are inspected for leakers.

FPI also produces a rigidity tester for testing rigidity of single-use foodservice packaging products and maintains a standard operating method for its use.

While testing of products would add value to the resulting alternatives assessment, it will also result in an increase in cost, both time and resources. Testing may be necessary to overcome bias and increase adoption of alternatives. We recommend consulting with relevant stakeholders before committing to testing. It may be that no single test is sufficient to cover all stakeholder concerns.

Social Impacts

The goal of the social impact module is to ensure that the product(s) brought forward by the alternatives assessment do not result in unduly shifting a burden from one community of people to another. It is important to broadly consider the full life cycles of the products and to identify relevant stakeholders throughout. While the focus of this module is social justice, environmental justice organizations are critical in connecting social justice concerns with relevant impacts.

Stakeholder engagement is critical for this module. Stakeholders will identify burden-shifting and impacts that are not readily apparent to the assessors. Stakeholders should include the Oregon Environmental Justice Task Force, and representatives from OPAL Pdx and Beyond Toxics, two non-profits focused on environmental justice in Oregon, as well as representatives from environmental justice communities in Oregon, such as the Coalition of Communities of Color. Environmental justice communities in Oregon include racial/ethnic communities, low-income communities, tribal communities, and underrepresented communities (such as youth, elderly, or mental disabled) (Oregon Environmental Justice Task Force, 2016). While we specifically recommend these stakeholders for a focus group on the social impact module, it is necessary to include them in stakeholder discussions throughout the project in order to ensure that social and environmental justice is fully integrated in all modules of the alternatives assessment.

We recommend following Level 2 of the IC2 Guide (2017) for this module. This includes a consideration of impacts in Oregon during the use and end of life of the products and impacts globally from the manufacture of the food packaging products.

Suggested showstopper criteria for this module include:

- Use of child labor to manufacture or transport product
- Use of forced labor or slavery to manufacture or transport product
- Extraction of resources that contribute to unhealthy societies such as support of unethical military actions, genocide, etc. (e.g. conflict minerals)
- Extraction of resources or manufacturing that contributes to environmental degradation (e.g. unsustainably harvested palm oil, over-extraction of key resources).

We strongly recommend working closely with stakeholders to develop appropriate showstopper criteria for Oregon.

Results from this module may be used to alter assessment results from other modules. For example, if recycling of the product occurs primarily at an overseas plant that uses child labor, the product may be considered merely potentially recyclable as opposed to realistically recyclable.

Driving innovation with AA:

1. Some of the harmful impacts identified in this module involve practices that are broadly considered unacceptable by the average American consumer, such as child labor, slavery, shifting burdens to vulnerable populations, and genocide. Documentation of these practices could be shared with relevant stakeholders, such as environmental justice organizations and advocacy groups, in order to develop campaigns that lead to the voluntary elimination of these practices. Simply including the information in a report may not call it to the attention of the appropriate organization, and simply sharing with media is insufficient to generate the long-term support necessary for effective social change.
2. Guidance exists for companies interested in ensuring they are acting in a socially responsible manner. Companies that perform poorly in this module could be directed to existing resources:
    - ISO 26000 provides guidance for businesses and organizations to help them translate principles into effective actions and describes best practices relating to global social responsibility.
    - The SA8000® standard is a certification standard based on conventions of the International Labour Organization, the United Nations, and national laws.
    - The Global Reporting Initiative's Sustainability Reporting Guidelines include guidance for reporting on issues such as climate change, human rights, and corruption.

Materials Management

Goal: Reduce impacts on natural resources across the life cycle. Preserve natural capital by eliminating waste and maximizing value recovery from products after use.

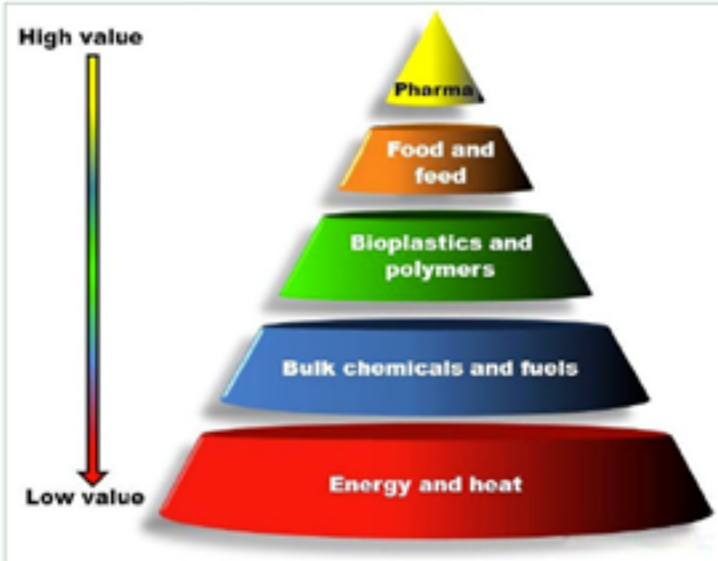
Materials management considers how the selection of different products may impact natural resource preservation/depletion and the potential for eliminating waste and maximizing material recovery value from products after use. It considers both the quantity and quality of wastes and how chemicals in materials can impact opportunities for recycling, composting, and other forms of recovery. It allows for a consideration of compatibility with, and progress towards, a circularity economy and identification of innovation needs. These parameters must be balanced with an assessment of measured impacts from the other modules, such as the LCA impacts in the Life Cycle Thinking module.

Sustainable materials management of food packaging products is necessary. Ideally, a circular material flow system will be efficient and will minimize negative impacts across the life cycle. Tools such as life cycle assessment (LCA), discussed in the next section, are valuable for assessing efficiencies and life cycle impacts. However, LCA does not typically address impacts such as propensity of a product to become litter, the flexibility of some products to undergo different waste management treatment processes, and geographical differences in societal waste management practices. Care must be taken to avoid focusing on single attributes of materials such as recyclability, compostability, or circularity that may drive undesirable tradeoffs across the lifecycle. At the same time, overall life cycle benefits should not result in tradeoffs that are unacceptable to a society. LCA is always useful for checking assumptions and identifying hot spots and opportunities for improvement and innovation.

Feedstocks: Products are not using sustainable feedstocks if they are based on 1) non-renewable, non-recycled/recyclable resources, 2) feedstock that degrades or consumes renewable resources faster than they can regenerate, or 3) materials that degrade the environment or compete with food production.

Sustainable materials management provides guidance for using fewer materials and materials that are reusable or recyclable numerous times. There is a general preference for recycling of 'permanent' materials, i.e. a material whose "inherent properties do not change during use and, through solid-liquid transformation, it can revert to its initial state" (Conte, Dinkel, Kägi, & Heim, 2014, p.12). Permanent materials used in food packaging include glass and metal, while non-permanent materials include paper and some plastics. Recycling of non-permanent materials typically requires input of virgin materials to overcome the degradation or impurities of the recyclate (Geueke et al., 2018).

Bio-based feedstocks are typically considered as having positive attributes as they are not based on fossil fuel resources. However, actual decreases in fossil fuel usage are challenged by LCA (Mistry et al., 2018). When bio-based materials are used, this usage may compete with other, possibly more valuable uses. The Biomass Value Pyramid in Figure 5 depicts a cascading approach to preferred biomass use with the highest priority given to the uses at the top of the pyramid (Devaney, Henchion, & Regan, 2017). Assumptions about key attributes should be verified with life cycle assessment.



Source: Peter Westermann, taken from Lange *et al.* (2012: 88)

Figure 5. The Biomass Value Pyramid shows a general preference for bio based feedstock usage: Pharma > food & feed > bioplastic & polymers > bulk chemicals & fuels > energy and heat (Lange et al., 2012).

The following rules of thumb may be useful in selecting feedstock for materials. But assumptions should be checked using LCA:

- When comparing like materials, use less material
- If based on renewable feedstock, prefer products based on agricultural waste versus renewable materials grown for use in food packaging. Prefer feedstock that are derived from sustainably managed crops, that are locally sourced, and that do not compete with "higher" uses (i.e. social, ecological, or food production value on the local, regional, and/or global scale).
- If based on recycled content, prefer alternatives that:
  - Use more recycled content over those that use less recycled content (when comparing like materials)
    - Use virgin feedstock within a defined material flow system that will result in the use of recycled content on the next cycle
    - Use 'clean' recycled content

Manufacturing:

Prefer alternatives that minimize consumption of resources and the generation of wastes during manufacturing. Prefer alternatives that do not require hazardous processing aids or additives that could interfere with material recovery.

Use:

Prefer alternatives with optimized product/packaging design for cleaning, reuse or recycling as well as other life cycle benefits (e.g. decreased packaging mass).

End of life:
The product's compatibility with preferred end of life options requires that the infrastructure exists to collect, sort, and process the product in that manner. Alternatives that can be composted in industrial facilities cannot provide their intended benefits when there are no industrial composting facilities in the region, or if facilities will not accept food service ware. Alternatives that can be recycled cannot provide their intended benefits when collection, sorting, and cleaning infrastructure is not available; or if a recyclable material is not wanted for recycling when contaminated with food. The possibility (or likelihood) that the packaging product may end up as litter must also be included in the assessment. Neither commercial compostability nor recyclability are beneficial if the product is frequently littered.

Products should include having a plan for recovering and recycling the material after use that accounts for regional differences. The plan may take advantage of publicly accessible waste management infrastructure or it may involve a closed and privately managed materials system based on product stewardship. In additional to optimizing design to account for other life cycle impacts, product design should be optimized for recovery and recycling of the material and instructions should be detailed, going beyond labels that say, 'please recycle'. For example, Green Blue Institute developed the How2Recycle Labeling program to optimize proper product and recycling management of packaging (How2Recycle Program, 2018). Unfortunately, this system used national recovery averages and may not hold up well for some regions in Oregon; greater specificity should be encouraged. Products managed with product stewardship like this should be preferred.

Some products may be suitable for multiple waste management/material recycling pathways. Products should be designed to facilitate recycling and other forms of material recovery. For example, some chemical additives may be benign from the toxicity perspective but may interfere with successful recycling. Such additives could range from certain fillers to colorants. Products should also be designed to minimize negative impacts from all feasible waste management pathways. For example, some additives (i.e. halogens) may transform into problematic pollutants when incinerated. The potential for toxics to contaminate the end of life pathway must be a consideration.

Prefer alternatives that generate less waste; particularly those that generate less hazardous waste / less waste with negative impacts. Avoid waste generation first, and secondly optimize material value recovery. Ideally products will be designed to account for regional differences in waste management infrastructure, allowing for flexibility in waste management options and reducing impacts from all likely waste management pathways. Prefer alternatives that do not contain chemicals that will interfere with end of life pathways, or that may contaminate end of life pathways.

Prefer alternatives that are recyclable, particularly those that are up-cyclable (can be recycled into similar or higher value products) over those that are only down-cyclable (can be recycled only into lower value products); can be recycled multiple rounds; and that are realistically recycled. Keep in mind available infrastructure and necessary preparation for recycling; food service ware is commonly contaminated with food waste and cannot be realistically recycled using available infrastructure. Check assumptions of recycling benefits using life cycle assessment (see Life Cycle Thinking).

Prefer alternatives that are biodegradable; particularly if they biodegrade in a way that has less of an impact if unintentionally 'leaked' out of the waste management system or littered. For example, paper fiber degrades far more quickly in wet environments than plastic. Litter is a worst-case scenario and products should not be designed or marketed in a way that might encourage littering. Nevertheless, prefer alternatives that are home/backyard compostable and marine degradable if available.

Products that are industrially compostable may be preferable in a region that encourages industrial composting. However, due to the lack of acceptance of food packaging at local Oregon composters, this attribute should be weighted lower than biodegradability and recyclability. For regions that encourage industrial composting, prefer alternatives that have certifications and/or 3rd party testing verifying their biodegradability/compostability. These alternatives should not degrade the resulting quality of the compost. Rather, they should enhance the resulting quality of the compost and help capture desirable compost feedstock (e.g. food scraps). See Test Methods and Certifications section below.

Prefer products managed under product stewardship principles including product takeback. At a minimum, products should come with clear instructions for managing them after use. Instructions and product design should both support correct sorting (e.g. redesign an item so that users can recognize it as a different material and help to ensure that it is not mis-sorted into the wrong recovery stream).

Metrics look at the % of each product matching the preferred attribute (e.g. % recycled content). When considering actual rates of disposal using different EOL pathways or comparing products based on available infrastructure, assign percentages of product to each disposal pathway for comparison, as well as comparing them based on their likelihood of undergoing worst-case waste disposal scenarios.

Opportunities to Mitigate Negative Impacts and Advance Sustainable Materials Management

Engage stakeholders to understand how they use the products and the waste management systems that exist in their regions. Collaborate with them to identify opportunities to mitigate negative impacts and advance circularity. What are different usage scenarios for these products? Could changes in packaging design, materials, or weight mitigate negative impacts? Are there opportunities to advance circularity by utilizing less virgin material? Focus on major hotspots for each product technology type in addition to differences between products of similar type. How might a different business model mitigate impacts?

For example, Taco Time Northwest in Washington State converted to 100% commercially compostable packaging in 2014. Prior to that, 90% of their waste had been going to landfill due to contamination of the recycling bin at their restaurants, despite intended sorting into garbage, recycling, and compost (Campbell, 2014). By switching to 100% commercially compostable packaging, Taco Time Northwest was able to create a closed and controlled waste management system. A restaurant with complete control over the packaging offered and waste management streams available can mitigate negative impacts from mis-sorting by simplifying the process.

An innovative alternative to disposable food take-out containers has been embraced by some food trucks and restaurants in downtown Portland (Baker, 2018). The GO-Box is food take-out packaging as a service. Reusable polypropylene containers are distributed to participating businesses. Consumers sign-up on an app, and check-out a container when they pick up food. Consumers then return the container to participating locations, after which GO-Box employees pick up the containers, wash them, and redistribute them. Life cycle impacts are reduced further by using bicycle transportation (Maus, 2018).

Driving innovation with AA:

1. Available infrastructure for end-of-life management determines the relative preference of different end-of-life options. Outside of Oregon, many groups, including MN and NY, prefer compostable food packaging in part because contamination by food waste is not an issue with composting, as it is with recycling. What can be done to prevent mixing of non-compostable packaging with fully commercially compostable packaging? Are there improvements to how we collect and process materials for recycling that would elevate recycling's position relative to composting? Can novel recycling methods be developed that are compatible with food waste? We recommend ongoing engagement with composters, recyclers, waste collectors, and manufacturers who use recycled material to discuss the benefits and drawbacks of allowing food packaging materials in industrial composting, and the possibilities of increased recycling.
2. Are there unused opportunities to utilize waste food packaging products? Partner with innovators and manufacturers to spur development of opportunities to add value to these underutilized resources.
3. Is there an opportunity for a disruptive innovation to replace a product's function? Can single use, disposable food packaging be avoided? Convene users of the product with innovators to discuss alternative methods of achieving the product's function. The best alternative products may not be products at all. They may be innovative business models or wisely engineered reuse or recovery programs.
4. Could use of reusables be promoted by requiring restaurants and food trucks to charge a fee for disposables, similar to plastic bag fees? Convene a focus group to discuss the possibilities.

Test Methods and Certifications

Multiple methods are used to test and indicate the type of degradability/compostability associated with materials and products and thresholds for contaminants. In this section, we review 1) test methods for assessing environmental biodegradability, and 2) standards and certification programs that assess material degradability. Some of these methods are useful for identifying food packaging products that are PFAS-free, even if biodegradability is not the priority.

We summarize information below on organizations that have developed standards and certifications for degradability and compostability (Figure 7).

In addition, we evaluate the standards for whether or not they consider PFASs (Table 6).

Appendices A, B and C provide more detailed information on each test method, standard and certification program.

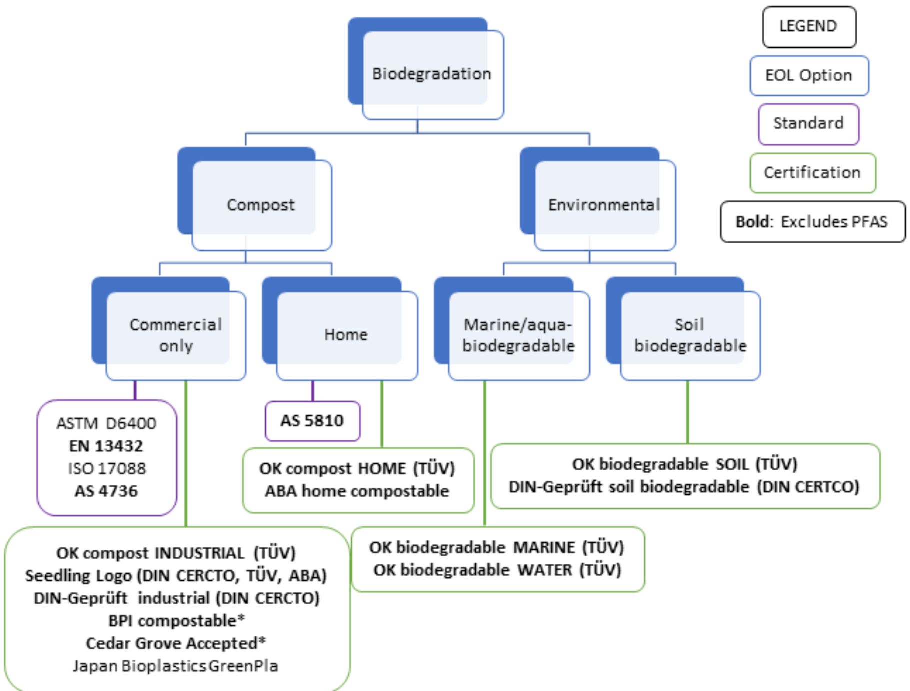


Figure 6. Standards and certifications for biodegradation end of life pathways for food packaging.

Standards and certifications in bold (ASTM D6400, ISO 17088, and Japan Bioplastics GreenPla) do not include a 100 ppm fluorine limit. Certifications in italics (BPI compostable, Cedar Grove) are phasing in a 100 ppm fluorine limit by 2020.

Table 4. Standards and certifications for compostable and biodegradable food packaging and PFASs considerations (via 100 ppm fluorine limit).

Standard		**Excludes PFAS (100 ppm fluorine limit)**
ASTM D6400		N
ISO 17088		N
EN 13432		Y
AS 4736		Y
Certification	**Related standard(s)**	**Excludes PFAS (100 ppm fluorine limit)**
BPI	ASTM D6400	N through 2019, Y post-2020 on new items, renewals, and existing inventory
Cedar Grove	ASTM D6400	N through 2019, Y post-2020 on new items and renewals
TÜV AUSTRIA OK compost INDUSTRIAL	EN 13432	Y
TÜV AUSTRIA, OK compost HOME	mod. EN 13432	Y

Certification	Related standard(s)	Excludes PFAS (100 ppm fluorine limit)
TÜV AUSTRIA, OK biodegradable SOIL/WATER/MARINE	varies	Y
TÜV AUSTRIA, Seedling Logo	EN 13432	Y
Standard		**Excludes PFAS (100 ppm fluorine limit)**
DIN CERTCO, Seedling Logo	EN 13432	Y
DIN CERTCO, DIN-Geprüft test mark for industrial compostability	EN 13432	Y
ABA, Seedling Logo	AS 4736	Y
ABA, home compostable	AS 5810	Y
JBA, GreenPla	custom	N

In determining if the product is compostable, a functional standard must define the conditions under which it degrades include the temperature needed and the time required for composting. The standard must also distinguish between fragmentation/disintegration and true biodegradation. IUPAC defines *disintegration* as fragmentation to particles of a defined size, with the limiting size typically defined by sieve conditions (Vert et al., 2012). On the other hand, *biodegradation* is degradation caused by enzymatic process resulting from the action of cells, which has been modified from former definitions by the exclusion of abiotic enzyme processes (Vert et al., 2012). The separation of these processes is clearly demonstrated in most plastics, which first fragment with physical processes into smaller and smaller plastic pieces, increasing the surface area and availability of molecules for biodegradation. The fragments may then biodegrade into minerals, water, and carbon dioxide over time.

While the stability of the non-fluorinated moieties in PFASs vary, the perfluoryl moiety of PFASs resists biodegradation and is very stable (Liu, 2013). Some PFAS classes, like the perfluorylalkyl acids (PFAAs), a class that includes PFOS and PFOA, are resistant to microbial biodegradation and are therefore considered recalcitrant (Liu, 2013; Ochoa-Herrera, 2016). Some PFASs undergo primary degradation whereby the parent compound degrades into a daughter compound that is recalcitrant. PFAAs are common biodegradation products of other PFASs (Liu, 2013). As the food packaging material breaks down, some PFASs may bio-transform into other PFASs, but the expectation is that the overall PFAS burden remains constant. PFAS levels in compost from facilities that accept residential and commercial food waste and compostable food packaging and service ware are higher than PFAS levels in compost from facilities that only accept yard waste (Lee & Trim, 2018). PFASs are taken up from soil by crops, and have been shown to accumulate in edible portions, though the bioaccumulation of PFASs depended strongly on PFAS species and concentration, soil properties, and the type of crop (Blaine, 2013).

Some certifications could be used to indicate products that do not contain PFASs. The European standard EN 13432 limits PFASs by limiting fluorine content to 100 ppm. This would exclude intentionally added PFASs for water/grease resistance. Certifications based on EN 13432, like TÜV AUSTRIA's OK compost INDUSTRIAL certification, should also appropriately exclude PFASs-containing food packaging products. The ASTM standard D6400 does not consider fluorine content and would permit PFASs. Certifications based on D6400, like BPI's compostability certification, permitted PFASs (CEH, 2018). However, BPI has adopted the 100 ppm limit from EN 13432 and is currently phasing it in with full adoption planned beginning in 2020 (BPI, 2017).

Life Cycle Thinking and Life Cycle Assessment

Goal: Holistic and quantitative comparison of products for impacts across defined life cycles,

The overall goal of the Life Cycle module is to take a comprehensive view of product impacts across the life cycle, to identify opportunities for innovation and improvement, and to avoid burden-shifting. Life cycle thinking is not exclusive to life cycle assessment. It is necessary for every module in an AA. For example, hazard must be addressed during manufacture, use and end of life. The same is true for exposure, social impacts, etc. Therefore, we do not recommend a separate module for life cycle thinking. It is germane to every module.

The goal of this module is to present a more holistic picture of the product system. We recommend a Level 3 assessment with LCA following ISO 14040 guidelines. Life cycle assessment is important for identifying hot spots, particularly between different types of technologies (e.g. reusable plastic packaging versus commercially compostable fiber packaging). Identifying hotspots can help to inspire ideas about how to mitigate impacts from those hotspots. For example, while bio based does not guarantee life cycle benefits, some bio based feedstocks have more benefits than others depending on requirements for energy, water, pesticides, etc. And in LCA, use of agricultural wastes can result in life cycle benefits because the impacts associated with the crop are not ascribed to the wastes. LCA is not likely to be the best tool for comparing products of similar design with minor differences, such as different versions of a functional chemical additive; unless differences result in different use or end of life pathway options.

LCA is also important for checking and verifying assumptions about environmental impacts associated with different product attributes. (Mistry, Allaway, Canepa, & Riven, 2018). A summary of challenges to assumptions about health and environmental benefits associated with common sustainability related attributes follows.

Challenges with Attribute-based Assessments

In a recent review of the literature, results of LCAs of packaging and food service ware were analyzed (Franklin Associates, 2018). They researchers reviewed LCAs that included comparisons relevant to four material attributes commonly associated with decreased environmental impacts and presumed to advance circularity. OR DEQ further summarized this work and made recommendations on the utility of each attribute, summarized below (Mistry et al., 2018):

- Bio-based - limited utility for predicting reduced environmental impacts, generally preferable/mixed.
    - Production of all current bio-based materials involves combustion of fossil fuels

        - Comparing bio-based and fossil fuel-based for the same material: Bio-based almost always reduces fossil fuel use.
        - Comparing bio-based against non-bio-based: Results are mixed.
    - Often conflated with other attributes, like compostable or biodegradable.
    - Tradeoffs exist with other impacts such as acidification and eutrophication.
    - Recommends calculating energy required for materials instead of using bio-based as a metric.
- Compostable - poor indicator
    - Often results in higher environmental impacts than non-compostable.
        - Higher burdens associated with feedstock production.
        - Low value recovery in composting compared to other options, e.g. recycling.
    - Poor user compliance and poor certifications/standards.
        - Certified compostable materials do not necessarily compost well in existing facilities.
        - Acceptance of compostable materials that appear similar to common non-compostable materials increases contamination of the compost.
        - Current certifications and standards are insufficient at managing emerging chemicals of concerns, like PFASs. See the section, *Test methods and thresholds used and indicate the type of degradability/compostability associated with materials and products,* for details.
        - Compostable may be confused with environmentally biodegradable, increasing litter.
    - Recommends against using this attribute in isolate, and instead using LCA.
- Recyclable - poor indicator
    - While recycling is typically beneficial when compared with alternatives like landfilling, the attribute of recyclable covers a distinct concept: Does use of readily recyclable materials lead to lower environmental impacts?
    - Mixed results for different packaging materials and tradeoffs do not easily fit into patterns; limited studies of food service ware show lower impacts but avoided key issue of food contamination.
    - Increasing recycling rates typically decreases negative impacts but requires infrastructure investment and user compliance.
    - Recommends against using this attribute in isolation, and instead using LCA.
- Recycled content - poor indicator
    - Once a material is selected, increasing recycled content almost always reduces negative impacts.
    - When comparing different materials, recycled content does not necessarily track with reduced impacts.
    - Recommends first optimizing profile via the use of materials and formats with the lowest impacts, then increasing recycled content to minimize negative impacts.

Driving innovation with LCA: LCA should be used to identify hotspots associated with different product types and to verify assumptions about differences between products based on their attributes. How could these hotspots be addressed using currently available technology? What research and development is necessary to mitigate the impacts? It can also be used to identify truly disruptive technologies that provide overarching life cycle benefits versus incremental improvements. For example, LCA could be used to verify whether or not a reuse model has more life cycle benefits than recycling; and how many reuse cycles would be necessary to provide those benefits. Likewise, it can be used to demonstrate incremental improvements within a technology such as demonstrating benefits from increasing amounts of recycled content.

Step 6: Take Action

Integrating with Existing and Ongoing AA Efforts

We recommend coordinating with existing and ongoing AA efforts to address PFASs and other chemicals of concern in food packaging and communicating with the other groups engaged in AA to avoid duplication of efforts. Ideally, each AA group would assess the same products but use different modules. This ensures that the results will be comparable and complementary, and that work is not duplicated unless necessary. However, we know that Washington State will conduct an AA in 2019 that is limited to consideration of hazard, exposure, cost & availability, and performance; and that the scope of products to be considered will be established by the assessor in collaboration with WA Department of Ecology (WA DOE). Nuances to the WA State law banning PFASs may require that the assessors narrow the focus of the products evaluated in the AA to demonstrate the availability of alternatives to key PFASs containing products.

OR DEQ can build on the WA AA work (beginning Fall 2019) to update this Roadmap and determine what additional work should be done. In order to build on an existing alternatives assessment of food packaging, the relevance, quality, breadth, and depth of the assessment must be ascertained. The quality of the assessment is tied to how well the criteria help to discriminate between products and to identify a preferable product as defined by the scope of the AA. Did hazard criteria overlook key endpoints, such that certain types of regrettable substitutions may not have been caught? Did hazard criteria overreach, resulting in the elimination of products that may be otherwise preferable? Did performance criteria consider all relevant use cases, or were some overlooked? Were performance criteria too stringent, promoting overengineered products in order to excel in the performance module? And so on. For any area in which criteria were too lax or too stringent, it may be necessary to re-evaluate the decision on which products are preferable, or to re-assess the module.

If reevaluation or reassessment of a module is necessary, and the existing AA used a sequential decision analysis method, it may be necessary to assess products that were dropped early. The goal is to ensure that the results are relevant to Oregon. Oregon’s regulations and infrastructure may result in the use of different decision criteria than those used for other regions.

OR DEQ should first determine if all products of interest have been assessed; and if not, which products should be added. Are these products unique, using a different base material or grease/water resistance chemistry than the products that have been assessed? If so, are these products likely to be preferable? Are there known showstopper criteria that these products fail? If necessary, complete a cursory screening assessment in select key modules. From there, OR DEQ will need to determine if the additional work of assessing the additional product(s) is worth the cost.

Implementation Plan

An AA report is a snapshot in time and should be accompanied by an implementation plan. The plan should include strategies and resources for ongoing identification and evaluation of emerging alternatives, for driving and measuring adoption of alternatives, and for integrating other important information. Novel information may emerge over time including new toxicology studies, changes in economics, and new waste management methods. Oregon should consider collaborating with other governmental agencies and key stakeholders to create an implementation plan for the proposed AA. Additional recommendations for next steps towards setting the stage for substitution include:

- Publicly state Oregon's priorities for PFASs free products. For example, as with a waste hierarchy, and consistent with OR's materials management vision, OR DEQ could state that its priorities are 1) to avoid products with hazardous chemicals to which people and the environment will be exposed across the product life cycle and 2) to promote a circular economy that eliminates waste at the source and recovers materials at the highest possible value for reuse. This should clarify how existing statements on sustainability apply to food packaging.
- Develop promotional and educational materials for diverse users explaining the issue and describing how to select PFASs-free alternatives.
- Identify additional classes of chemicals to eliminate. For example, ortho-phthalates have been identified by the Food Packaging Forum as a priority for replacement in food packaging.
- Create or revise procurement policies to purchase PFASs-free food packaging. Appendices A,B and C in this report provide detailed information, including pros and cons, of test methods, standards and certifications. Some certifications exclude PFASs and others do not. The European standards based on EN13432, generally exclude PFASs due to a 100 ppm fluorine limit, while US standards do not. However, some US standards (i.e. BPI certified compostable) are being updated to address this issue.
- Identify products as PFASs-free by:
    - Testing and making a list of PFASs-free options available in Oregon.
    - Using the CEH list as a starting point, but keep it updated, as products change over time.
    - Using compostability/biodegradability certifications such as TÜV AUSTRIA Seedling Logo or post-2019 BPI compostable that also include limits for fluorine.
    - Consider supporting or developing a certification for simply PFASs-free products, as the compostability/biodegradability portion of these certifications is not relevant to Oregon currently.

Adoption of safer, more sustainable alternatives is a process that requires changes in behaviors by key stakeholders. Identifying viable alternatives is only the first part of an ongoing initiative. Collaboration can include identifying goals and priority targets; agreeing on criteria for inclusion on green lists; and gathering information about stakeholder's values to improve adoption rates and outcomes. As goals become more specific, a program that encourages targeted behavior through incentives will form. The behaviors desired determine the overall learning objectives that will drive change and that shape the intervention activities required. It is important that OR DEQ set outcome metrics at the start of the AA process to evaluate whether change is occurring and to identify ways to improve its implementation strategy to achieve ongoing goals. In this way, OR DEQ and its collaborators can improve human, environmental, and economic health while avoiding unintended consequences, perverse incentives, or regrettable substitutions.

References

Allen. (2016, March 18). *Are short-chain polyfluoroalkyl substances (PFAS) safe substitutes for long-chains?* Retrieved from Nordic Institute: http://nipsect.dk/are-short-chain-polyfluoroalkyl-substances-pfas-safe-substitutes-for-long-chains/

Ansell, C., & Gash, A. (2008). Collaborative governance in theory and practice. *Journal of Public Administration Research and Theory, 18*(4), 543-571.

ASTM. (2011). *Standard specification for labeling of end items that incorporate plastics and polymers as coatings or additives with paper and other substrates designed to be aerobically composted in municipal or industrial facilities. ASTM D6868-11.* West Conshohocken, PA: ASTM International.

ASTM. (2012). *Standard specification for labeling of plastics designed to be aerobically composted in municipal or industrial facilities. ASTM D6400-12.* West Conshohocken, PA: ASTM International.

ASTM. (2017). *Standard Test Method for Determination of Per- and Polyfluoroalkyl Substances in Water, Sludge, Influent, Effluent and Wastewater by Liquid Chromatography Tandem Mass Spectrometry (LC/MS/MS)*. D7979-17. West Conshohocken, PA: ASTM International. Retrieved March 27, 2019 from https://www.astm.org/Standards/D7979.htm

Auwarter, C., Holly, B., Mareld, A., & Montgomery, A. (2016). *Intersectoral collaboration and stakeholder engagement: Northwest Green Chemistry*. Unpublished capstone project report, University of Southern California Sol Price School of Public Policy. Los Angeles, CA.

Bach, C. C., Bech, B. H., Brix, N., Nohr, E. A., Bonde, J. P. E., & Henriksen, T. B. (2015). Perfluoroalkyl and polyfluoroalkyl substances and human fetal growth: a systematic review. *Critical Reviews in Toxicology, 45*(1), 53-67.

Ballesteros, V., Costa, O., Iniguez, C., Fletcher, T., Ballester, F., & Lopez-Espinosa, M. J. (2017). Exposure to perfluoroalkyl substances and thyroid function in pregnant women and children: a systematic review of epidemiologic studies. *Environment International, 99*, 15-28.

Baker, L. (2018, June 6). Maker of reusable takeout containers sells business as awareness of plastics waste grows. Retrieved from https://www.oregonbusiness.com/article/restaurants-retail/item/18367-go-box-founder-sells.

Bartlett, S. A., & Davis, K. L. (2018). Evaluating PFAS cross contamination issues. *Remediation Journal, 28*(2), 53–57. https://doi.org/10.1002/rem.21549

Begley, T. H., Hsu, W., Noonan, G., & Diachenko, G. (2008). Migration of fluorochemical paper additives from food-contact paper into foods and food simulants. *Food Additives and Contaminants, 25*(3), 384-390.

Biodegradable Products Institute (BPI). (2017). Fluorinated Chemicals and BPI Certification. Retrieved on December 6, 2018, from https://bpiworld.org/BPI-Blog.html/6650181

Biodegradable Products Institute (BPI). (2018). Position on fluorinated chemicals. Retrieved on December 6, 2018, from https://www.bpiworld.org/Fluorinated-Chemicals.

Blaine, A. C.; Rich, C. D.; Hundal, L. S.; Lau, C.; Mills, M. A.; Harris, K. M.; Higgins, C. P., Uptake of perfluoroalkyl acids into edible crops via land applied biosolids: field and greenhouse studies. Environ Sci Technol 2013, 47, 14062-14069.

Blum, A., Balan, S. A., Scheringer, M., Trier, X., Goldenman, G., Cousins, I. T., ... & Peaslee, G. (2015). The Madrid statement on poly-and perfluoroalkyl substances (PFASs). *Environmental Health Perspectives*, *123*(5), A107.

Bryson, J. M. (2018). *Strategic planning for public and nonprofit organizations: A guide to strengthening and sustaining organizational achievement.* John Wiley & Sons.

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., De Voogt, P., … Pj Van Leeuwenkk, S. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management, 7,* 513–541. https://doi.org/10.1002/ieam.258

Campbell, K. (2014, November 19). Sorting Out a 'Fast food' waste problem. Retrieved from https://kcts9.org/programs/in-close/environment/sorting-out-fast-food-waste-problem.

Cedar Grove. (2019). Accepted Commercial Items. Retrieved on March 27, 2019, from https://cedar-grove.com/compostable/accepted-items

Cedar Grove. (2019). Compost manufacturing Alliance-(PSA-1)- Profile submittal addendum related to fluorinated chemicals. Retrieved on March 27, 2019, from https://cedar-grove.com/docs/CMA_-_Fluorinated_Chemicals_Policy_-_12-26-18.pdf

Center for Environmental Health (CEH). (2018). *Avoiding hidden hazards: A purchaser's guide to safer food ware.* Oakland, CA: CEH.

Center for Environmental Health (CEH). (2017, October 17). *Toxic chemicals in disposable food service ware.* Retrieved from http://www.ceh.org/wp-content/uploads/toxics_food_service_ware_webinar_101717_MASTER-Final.pdf

Clean Production Action. GreenScreen for Safer Chemicals. https://www.greenscreenchemicals.org. Accessed 2018.

Commons Principles for Alternatives Assessment. (2012). *Addressing chemicals of concerns to human health or the environment.* Retrieved from https://www.bizngo.org/static/ee_images/uploads/resources/commons_principles_AA_2013_10_14.pdf

Consumer Reports (2018). Retrieved from https://www.consumerreports.org/cro/index.htm.

Conte, F. Dinkel, F. Kägi, T., & Heim, T. (2014). *Permanent materials*. Carbotech. Retrieved from https://carbotech.ch/cms/wp-content/uploads/Final_PeM_Report_Carbotech.pdf.

Devaney, L., Henchion, M., & Regan, A. (2017). Good governance in the bio-economy. *Agricultural Economics Society and European Association of Agricultural Economists*. DOI: 10.1111/1746-692X.12141.

DeWitt, J. C. (Ed.). (2015). *Toxicological effects of perfluoroalkyl and polyfluoroalkyl substances.* Springer International Publishing.

Emmett E.A., Shofer F.S., Zhang H., Freeman D., Desai C., & Shaw L.M. (2006). Community exposure to perfluorooctanoate: relationships between serum concentrations and exposure sources. *Journal of Occupational Environmental Medicine 48*:759–70. doi:10.1097/01.jom.0000232486.07658.74. [accessed 2018 Nov 19]. http://www.ncbi.nlm.nih.gov/pubmed/16902368.

European Commission (EC). (2015). Technical assistance related to the review of REACH with regard to the registration requirements on polymer: Final report, written by BIO at Deloitte.

Food Packaging Forum. Phthalates. https://www.foodpackagingforum.org/food-packaging-health/phthalates. Accessed December 2018

Food Packaging Forum. Migration modeling. https://www.foodpackagingforum.org/food-packaging-health/migration-modeling. Accessed December 2018

Franklin Associates. (2018). The significance of environmental attributes as indicators of the life cycle environmental impacts of packaging and food service ware. Retrieved from https://www.oregon.gov/deq/FilterDocs/MaterialAttributes.pdf.

Freberg, B.I., Haug, L.S., Olsen, R., Daae, H.L., Hersson, M., Thomsen, C., Thorud, S., Becher, G., Molander, P., & Ellingsen, D.G. (2010). Occupational exposure to airborne perfluorinated compounds during professional ski waxing. *Environmental Science and Technology 44*:7723–

7728. doi:10.1021/es102033k. [accessed 2018 Nov 16]. http://pubs.acs.org/doi/abs/10.1021/es102033k.

Fujii, Y., Harada, K. H., & Koizumi, A. (2013). Occurrence of perfluorinated carboxylic acids (PFCAs) in personal care products and compounding agents. *Chemosphere, 93*(3), 538–544. https://doi.org/10.1016/J.CHEMOSPHERE.2013.06.049

Greggs, W., Burns, T., Egeghy, P., Embry, M.R., Fantke, P., Gaborek, B, Heine L., Jolliet, O., Lee, C., Muir, D., et al. (2018) Qualitative approach to comparative exposure in alternatives assessment. *Integrated Environmental Assessment and Management.* doi:10.1002/ieam.4070. [accessed 2018 Nov 20]. http://doi.wiley.com/10.1002/ieam.4070.

Geueke, B., Groh, K., & Muncke, J. (2017). Substances of Very High Concern in Food Contact Materials: Migration and Regulatory Background. *Packaging Technology and Science. 28 February.*

Geueke, B., Groh, K., & Muncke, J. (2018). Food packaging in the circular economy: Overview of chemical safety aspects for commonly used materials. *Journal of Cleaner Production.*

Groh, K.J. et al .(2017). Food contact materials and gut health: Implications for toxicity assessment and relevance of high molecular weight migrants. *Food Chemical Toxicology 109*(Pt 1):1-18.

Hamid, H., Li, L. Y., & Grace, J. R. (2018). Review of the fate and transformation of per-and polyfluoroalkyl substances (PFASs) in landfills. Environmental Pollution, 235, 74-84.

Haukås, M., Berger, U., Hop, H., Gulliksen, B., & Gabrielsen, G. W. (2007). Bioaccumulation of per-and polyfluorinated alkyl substances (PFAS) in selected species from the Barents Sea food web. *Environmental Pollution, 148*(1), 360-371.

Hekster, F. M., Laane, R. W., & de Voogt, P. (2003). Environmental and toxicity effects of perfluoroalkylated substances. In *Reviews of environmental contamination and toxicology* (pp. 99-121). New York, NY: Springer.

Heydebreck F., Tang J., Xie Z., Ebinghaus R. (2016). Emissions of per- and polyfluoroalkyl substances in a textile manufacturing plant in China and their relevance for workers' exposure. *Environmental Science Technology 50*:10386–10396. doi:10.1021/acs.est.6b03213. [accessed 2018 Nov 16]. http://pubs.acs.org/doi/10.1021/acs.est.6b03213.

Houtz, E. F., & Sedlak, D. L. (2012). Oxidative conversion as a means of detecting precursors to perfluoroalkyl acids in urban runoff. *Environmental Science & Technology Letters*, 9342-9349. doi:10.1021/es302274g.

How2Recycle Program. (2018). Retrieved from http://greenblue.org/work/how2recycle/.

International Organization for Standardization (ISO). (2014). ISO 25101:2009, Water quality -- Determination of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) -- Method for unfiltered samples using solid phase extraction and liquid chromatography/mass spectrometry. Retrieved on March 27, 2019 from https://www.iso.org/standard/42742.html

Intersector Project. (n.d.). *The intersector toolkit: Tools for cross-sector collaboration.* Retrieved from http://intersector.com/wp-content/uploads/2014/10/The-Intersector-Project-Toolkit2.pdf.

Interstate Chemicals Clearinghouse (IC2). (2017). *Interstate Chemicals Clearinghouse alternatives assessment guide, version 1.1.* Retrieved from http://theic2.org/article/download-pdf/file_name/IC2_AA_Guide_Version_1.1.pdf.

Kempistry, D. M., Xing, Y., & Racz, L. (2018). *Perfluoroalkyl substances in the environment: Theory, practice, and innovation.* CRC Press. Retrieved on November 5, 2018 from https://books.google.com/books?id=0QhpDwAAQBAJ&lpg=PT55&ots=uHxde-KaJX&lr&pg=PT55#v=onepage&q&f=false.

Kissa, E. (2001). *Fluorinated surfactants and repellents.* Marcel Dekker, Inc.

Lang, L. R., Allred, B. M., Peaslee, G. F., Field, J. A., & Barlax, M. A. (2016). Release of per- and polyfluoroalkyl substances (PFASs) from carpet and clothing in model anaerobic landfill reactors. *Environmental Science & Technology Letters*, 5024-5032.

Lau, C. Perfluorinated compounds: An overview. (pp.1-22) In DeWitt, J. C. (Ed.). (2015). *Toxicological effects of perfluoroalkyl and polyfluoroalkyl substances.* Springer International Publishing.

Lee, H., Tevlin, A. G., Mabury, S. A., & Mabury, S. A. (2013). Fate of polyfluoroalkyl phosphate diesters and their metabolites in biosolids-applied soil: biodegradation and plant uptake in greenhouse and field experiments. Environmental science & technology, 48(1), 340-349.

Lee, L., Trim, H. (2018). Evaluating perfluoroalkyl acids in composts with compostable food service ware products in their feedstocks. Retrieved from https://cswab.org/wp-content/uploads/2018/09/PFAS-Compost-Summary-Sheet-March-2018.pdf.

Liu, J., & Mejia Avendaño, S. (2013). Microbial degradation of polyfluoroalkyl chemicals in the environment: A review. *Environment International, 61*, 98–114. https://doi.org/10.1016/J.ENVINT.2013.08.022

Martin, J. W., Kannan, K., Berger, U., de Voogt, P., Field, J., Franklin, J., … & van Leeuwen, S. (2004). Analytical challenges hamper perfluoroalkyl research. *Environmental Science & Technology, 38*(13), 248A–255A. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15296292.

Maus, J. (2018, August 10). Islabikes and Go Box are the latest Portland businesses to add electric cargo bikes to their fleet. Retrieved from https://bikeportland.org/2018/08/10/islabikes-and-go-box-are-the-latest-portland-businesses-to-add-cargo-bikes-to-their-vehicle-fleet-287247.

McDermott, M. H., Moote, M., & Danks, C. (2011). Effective collaboration: Overcoming obstacles. In E.F. Dukes, K. E. Firehock, & J. E. Birkhoff (Eds.), Community-based collaboration: Bridging socio-ecological research and practice (pp. 81-110). Charlottesville, VA: University of Virginia Press.

Mistry, M. Allaway, D., Canepa, P., and Riven, J. (2018). Material attributes: Bio-based content, compostable, recyclable, and recycle content - How well does it predict the life cycle environmental impacts of packaging and food service ware? *State of Oregon Department of Environmental Quality*. Portland, OR.

Miyake, Y., Yamashita, N., So, M. K., Rostkowski, P., Taniyasu, S., Lam, P. K., & Kanna, K. (2007). Trace analysis of total fluorine in human blood using combustion ion chromatography for fluorine: A mass balance approach for the determination of known and unknown organofluorine compounds. *Journal of Chromatography A, 1154*(1-2), 214-221 doi:10.1016/j.chroma.2007.03.084.

Moody, C. A., Kwan, W. C., Martin, J. W., Muir, D. C., & Mabury, S. A. (2001). Determination of perfluorinated surfactants in surface water samples by two independent analytical techniques: liquid chromatography/tandem mass spectrometry and 19F NMR. *Analytical Chemistry, 73*(10), 2200–6. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11393841

Mulvihill, M., and Horotan, A. (2019). Safer Materials Innovation in Food Packaging. Retrieved from https://www.safermade.net/packaging-report

Mundt, D. J., Mundt, K. A., Luippold, R., Schmidt, M., & Farr, C. (2007). Clinical epidemiological study of employees exposed to surfactant blend containing perfluorononanoic acid (PFNA). *Occupational and Environmental Medicine 64*(9): 589–594.

Nestler, A. & Heine, L. (2019, forthcoming). Promising practices for alternatives assessment: Lessons from a case study of copper-based antifouling coatings. *Integrated Environmental Assessment and Management (IEAM).*

O'Hagan, D. (2008). Understanding organofluorine chemistry. An introduction to the C–F bond. *Chemical Society Reviews*, *37*(2), 308-319.

Ochoa-Herrera, V., Field, J. A., Luna-Velasco, A., & Sierra-Alvarez, R. (2016). Microbial toxicity and biodegradability of perfluorooctane sulfonate (PFOS) and shorter chain perfluoroalkyl and polyfluoroalkyl substances (PFASs). *Environmental Science: Processes & Impacts, 18*(9), 1236-1246.

Ohya, T., Kudo, N., Suzuki, E., & Kawashima, Y. (1998). Determination of perfluorinated carboxylic acids in biological samples by high-performance liquid chromatography. *Journal of Chromatography, Biomedical Sciences and Applications, 720*(1–2), 1–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9892060

Oregon Department of Environmental Quality (OR DEQ). (2012). Materials management in Oregon: 2050 vision and framework for action. Retrieved from https://www.oregon.gov/deq/FilterDocs/MManagementOR.pdf.

Oregon Environmental Justice Task Force. Oregon Environmental Justice Task Force Handbook, 2016. https://www.oregon.gov/gov/policy/environment/environmental_justice/Documents/2016%20Oregon%20EJTF%20Handbook%20Final.pdf

Organisation for Economic Co-operation and Development (OECD). (2018). Toward a New Comprehensive Global Database of Per-and Polyfluoroalkyl Substances (PFASs): Summary Report on Updating the OECD 2007 List of per-and Polyfluoroalkyl Substances (PFASs). http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

PAC, 1994, 66, 2513. Nomenclature for radioanalytical chemistry (IUPAC Recommendations 1994), doi:10.1351/pac199466122513

Poboży, E., Król, E., Wójcik, L., Wachowicz, M., & Trojanowicz, M. (2011). HPLC determination of perfluorinated carboxylic acids with fluorescence detection. *Mikrochimica Acta, 172*(3–4), 409–417. https://doi.org/10.1007/s00604-010-0513-z

Project Management Institute. (2013). *A guide to the project management body of knowledge (PMBOK® Guide).* Newton Square, PA, USA: Project Management Institute.

Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation, 141*, 2417-2431.

Rexius Compost & Organics, Dirt Hugger Organic Compost Co., Recology Organics Oregon, Republic Services Pacific Region Compost, Lane Forest Products, Deschutes Recycling Compost Facility, Pendleton Sanitary Serivces, Inc., Rogue Compost, Waste Pro (Oregon Composters). 2019. A Message from Composters Serving Oregon: Why We Don't Want Compostable Packaging and

Serviceware. Retrieved on March 27, 2019 from https://static1.squarespace.com/static/5a7a30710abd046ac76433a4/t/5c786b9b6e9a7f493fd62185/1551395742210/compostable_packaging_and_serviceware.pdf

Ritter, E. E., Dickinson, M. E., Harron, J. P., Lunderberg, D. M., DeYoung, P. A., Robel, A. E., . . . Peaslee, G. F. (2017). PIGE as a screening tool for per- and polyfluorinated substances in papers and textiles. *Nuclear Instruments and Methods in Physics Research, 407*, 47-54. doi:https://doi.org/10.1016/j.nimb.2017.05.052

Schaider, L. A., Balan, S. A., Blum, A., Andrews, D. q., Strynar, M. J., Dickinson, M. E., . . . Peaslee, G. F. (2017). Fluorinated compounds in U.S. food packaging. *Environmental Science Technology Letters*, 105-111. Retrieved November 5, 2017 from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6104644/.

Schellenberger, S., Hill, P. J., Levenstam, O., Gillgard, P., Cousins, I. T., Taylor, M., & Blackburn, R. S. (2019). Highly fluorinated chemicals in functional textiles can be replaced by re-evaluating liquid repellency and end-user requirements. *Journal of Cleaner Production*.

Shoemaker, J., Tettenhorst, D. (2018) Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC. Retrieved March 27, 2019 from https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=537290&Lab=NERL.

Scientific Guidance Panel Biomonitoring California. (November 18, 2015). Potential Priority Chemicals: Perfluoroalkyl and polyfluoroalkyl substances (PFASs). https://biomonitoring.ca.gov/sites/default/files/downloads/PotentialPriority_PFASs_111815.pdf.

TAPPI. Grease resistance test for paper and paperboard, Test Method T 559 cm-12. Retrieved from https://imisrise.tappi.org/TAPPI/Products/01/T/0104T559.aspx.

Tittlemier, S. A., Pepper, K., Seymour, C., Moisey, J., Bronson, R., Cao, X. L., & Dabeka, R. W. (2007). Dietary exposure of Canadians to perfluorinated carboxylates and perfluorooctane sulfonate via consumption of meat, fish, fast foods, and food items prepared in their packaging. *Journal of Agricultural and Food Chemistry, 55*(8), 3203-3210.

Tokranov, A. K., Nishizawa, N., Amadei, C. A., Zenobio, J. E., Pickard, H. M., Allen, J. G., ... & Sunderland, E. M. (2018). How Do We Measure Poly-and Perfluoroalkyl Substances (PFASs) at the Surface of Consumer Products?. *Environmental Science & Technology Letters*, *6*(1), 38-43.

Trier, X., Taxvig, C., Rosenmai, A. K., & Pedersen, G. A. (2017). *PFAS in paper and board for food contact - options for risk management of poly- and perfluorinated substances*. Copenhagen K, Denmark: Nordic Council of Ministers. (TemaNord; No. 573, Vol. 2017).

Trojanowicz, M., & Koc, M. (2013). Recent developments in methods for analysis of perfluorinated persistent pollutants. *Mikrochimica Acta, 180*(11–12), 957–971. https://doi.org/10.1007/s00604-013-1046-z

US EPA. No date (n.d.). EPA's Safer Choice Criteria for Processing Aids and Additives. https://www.epa.gov/sites/production/files/2013-12/documents/dfe_criteria_processing_aids_additives_0.pdf. Accessed Dec. 2018.

US EPA. (2017, December 13). *Assessing and managing chemicals under TSCA*. From www.epa.gov: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfass.

US EPA. (2011). *Design for the environment program Alternatives Assessment criteria for hazard evaluation*, Version 2.0, https://www.epa.gov/sites/production/files/2014-01/documents/aa_criteria_v2.pdf.

US EPA. (2012). EPA's Safer Choice Standard. https://www.epa.gov/sites/production/files/2013-12/documents/standard-for-safer-products.pdf

US EPA. (2018). EPA Drinking Water Laboratory Method 537 Q&A. Retrieved March 27, 2019 from https://www.epa.gov/pfas/epa-drinking-water-laboratory-method-537-qa

US EPA. (2018). *Toxics Release Inventory (TRI) Basis of OSHA carcinogens.* https://www.epa.gov/sites/production/files/2018-08/documents/osha_carcinogen_basis_august_2018.pdf.

US EPA. (2018). *Perfluoroalkyl and polyfluoroalkyl substances (PFAS): Methods and guidance for sampling and analyzing water and other environmental media.* Retrieved from https://www.epa.gov/sites/production/files/2018-04/documents/pfas_methods_tech_brief_02Apr18_revison.pdf

US FDA. (2007). *Guidance for industry: Preparation of premarket submissions for food contact substances (chemistry recommendations).* Retrieved from https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/IngredientsAdditivesGRASPackaging/ucm081818.htm

Valsecchi, S., Rusconi, M., & Polesello, S. (2013). Determination of perfluorinated compounds in aquatic organisms: a review. *Analytical and Bioanalytical Chemistry, 405*(1), 143–157. https://doi.org/10.1007/s00216-012-6492-7

Vert M., Doi Y., Hellwich, K. H., Hess, M., Hodge, P., Kubisa, P., Rinaudo, M., & Schué, F .(2012). Terminology for bio-related polymers and applications (IUPAC Recommendations). *Pure and Applied Chemistry. 84* (2): 377–410. doi:10.1351/PAC-REC-10-12-04.

Wagner, A., Raue, B., Brauch, H. J., Worch, E., & Lange, F. T. (2013). Determination of absorbable organic fluorine from aqueous environmental samples by adsorption to polystyrene-divinylbenzene based activated carbon and combustion ion chromatography. *Journal of Chromatography A*, 1295, 82-89.

Wang, C. F., Chiou, S. F., Ko, F. H., Chen, J. K., Chou, C. T., Huang, C. F., ... & Chang, F. C. (2007). Polybenzoxazine as a mold-release agent for nanoimprint lithography. *Langmuir, 23*(11), 5868-5871.

Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A never-ending story of per-and polyfluoroalkyl substances (PFASs)? *Environmental Science and Technology, 51*, 2508−2518.

Washington Department of Ecology (WA DOE). (2018). PFAS in food packaging alternatives assessment project summary. Retrieved from https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS/PFASFoodPackagingAAProjectSummary110618.pdf.

Washington Department of Ecology (WA DOE). (2016). Quick Chemical Assessment Tool. Retrieved from https://fortress.wa.gov/ecy/publications/SummaryPages/1404033.html

Xia, X., Dai, Z., Rabearisoa, A. H., Zhao, P., & Jiang, X. (2015). Comparing humic substance and protein compound effects on the bioaccumulation of perfluoroalkyl substances by Daphnia magna in water. *Chemosphere*, *119*, 978-986.

Yi, K. H., Cho, H. H., & Kim, J. (2011). An empirical analysis on labor unions and occupational safety and health committees' activity, and their relation to the changes in occupational injury and illness rate. *Safety and Health at Work*, *2*(4), 321-327.

Yuan, G., Peng, H., Huang, C., & Hu, J. (2016). Ubiquitous occurrence of fluorotelomer alcohols in eco-Friendly paper-made food-contact materials and their implication for human exposure. *Environmental Science & Technology Letters*, 942-950. doi:10.1021/acs.est.5b03806.

Appendix A: Test Methods for identifying PFASs in Products

Most PFAS methods can be divided into 1) extraction, concentration, or derivatization, 2) separation, and 3) detection and quantification. While these steps are linked and are not interchangeable between methods, certain steps are commonly shared. For example, HPLC is the most common separation method.

Regardless of the test method employed, it is important to minimized fluorinated chemical contamination and analyte loss and ensure standards are well characterized (Martin et al., 2004). Personal protective equipment, such as insect repellent necessary for collecting certain environmental samples, and personal care products may contain PFASs that could contaminate samples (Bartlett & Davis, 2018; Fujii, Harada, & Koizumi, 2013). Teflon™, comprised of PFASs, is commonly used in laboratory supplies and equipment, such as stir bars, sample container caps, pipette tips, tubing, tape, seals, septa, chemical containers and caps, and even seals and linings within analytical equipment and instruments (Kempistry, 2018). Post-injection contamination on HPLC systems, presumably due to internal fluoropolymer components, is common (Martin et al., 2004). Glassware should be avoided due to potential analyte loss due to adsorption (ISO 25101:2009). All sample containers should be rinsed thoroughly with water and methanol prior to use and should be checked for possible background contamination before use (ISO 25101:2009). Commercially available standards vary in purity and isomer profiles, confounding accuracy as well as inter-lab comparisons (Martin et al., 2004; Valsecchi, Rusconi,& Polesello, 2013). An analysis of commercially available standards revealed that purity ranged from 86% to >= 97%, which could potentially cause a significant over-estimation of PFASs in samples (Naile, 2010). Additionally, not all labeled standards had the same response as unlabeled versions, depending on the matrix, and the use of primarily linear-only standards could result in underestimation of PFASs in samples (Naile, 2010).

Standard Test Methods

A small selection of standard test methods for detection of PFASs exist, but they are limited by their use of liquid chromatography with tandem mass spectrometry (LC/MS-MS) for PFASs detection. This means that only the specific PFAS species of interest are detected; any other PFASs are overlooked.

The International Organization for Standardization (ISO) method ISO 25101:2009 specifies a method for detection and quantification of two PFASs species: PFOA and PFOS. PFASs are extracted and concentrated with solid phase extraction using commercially available copolymer cartridges, then separated with HPLC. Detection is via MS/MS. The standard is designed to work with unfiltered samples of drinking water, ground water, and surface water (fresh water and sea water).

US EPA method 537.1, updated in November 2018, quantifies up to 18 PFAS analytes including PFOS, PFOA, and PFHxS via LC-MS/MS and is designed for drinking water samples. The recent update increased the number of PFAS analytes from 14 to 18, adding GenX (hexafluoropropylene oxide dimer acid, HFPO-

DA) (ChemWatch, 2018). PFASs are extracted and concentrated with solid phase extraction using commercially available copolymer cartridges, then separated with HPLC and detected with MS/MS.

Some laboratories offer a modified US EPA Method 537 for other media, such as soils or ambient water (US EPA 2018). These modifications are not approved by the US EPA and have not undergone the same rigor as a standard US EPA test method. There are no standard EPA methods for analyzing PFASs in surface water, non-potable groundwater, wastewater, or solids, though US EPA is further developing methods for PFAS detection and quantification (US EPA, 2018).

ASTM offers two methods, D7979 for non-drinking-water aqueous samples and D7968 for soil/biosolid samples. Both methods us LC-MS/MS to separate, identify, and quantify PFAS analytes.

ASTM D7979-17 (ASTM, 2017). For non-drinking-water aqueous samples. Detection is via LC-MS/MS. Reporting ranges are listed on the website here https://www.astm.org/Standards/D7979.htm .
ASTM D7968. For soil/biosolid samples detection is via LC-MS/MS.

Particle-Induced Gamma Ray Emission (PIGE) Spectroscopy
Multiple groups have used Particle-Induced Gamma ray Emission (PIGE) spectroscopy to measure total fluorine as a proxy for PFASs (CEH, 2018; Lang, 2016; Safer Chemicals Healthy Families 2018; Schaider, et al., 2017). PIGE is a rapid and inexpensive method to measure total fluorine in solid-phase samples that has been validated with LC-MS/MS methods (Ritter, et al., 2017). A negative result is indicative that no PFASs are present at or above the detection limit, as all PFASs contain fluorine. Positive results indicate that PFASs or other fluorine-containing molecules are present. In Schaider (2017), the LOD was ~16 nmol F/cm^2, and the LOQ was ~50 nmol F/cm^2.

Both the CEH (2018) and the Safer Chemicals Healthy Families and Toxic Free Futures partnership (SCHF/TFF, 2018) used PIGE to screen food packaging materials for fluorine. In both works, they divided results into three classes:

- No detectable fluorine- both surfaces register total fluorine counts per microcoulomb of beam of less than ~150 (CEH) or 125 (SCHF/TFF)
- Low fluorine content - at least one surface registers total fluorine counts per microcoulomb of beam of greater than ~150 and less than ~500 (CEH) or greater than 125 and less than 450 (SCHF/TFF); fluorine must be statistically significant at 3x above background
- High fluorine content - at least one surface registers total fluorine counts per microcoulomb of beam of greater than ~500 (CEH) or 450 (SCHF/TFF); fluorine must be statistically significant at 3x above background

High fluorine content had statistically significantly higher (on average 10x higher, CEH, or 5x higher, SCHF/TFF) levels of fluorine than those identified as low fluorine. Low fluorine content could have resulted from clay containing naturally-occurring fluorine, or from low levels of contamination in the product manufacturing process.

In the CEH (2018) work, there was only a single instance out of 137 products assessed with a suspected false PFAS positive fluorine result due to the bulk material used; it was not expected for PFASs to be needed for PLA plastics. The manufacturing process for this product, a black rigid PLA plate, used a fluorinated chemical as a “mold release agent”. The company has indicated that they have requested a non-fluorinated substitute for this use. However, this mold release agent was most likely a PFAS or a mix of PFASs as PFASs are known to be used for this function (Kissa, 2001). It is not truly a false positive if PIGE detects both unintentionally present PFASs and intentionally added PFASs; in both cases it is detecting PFASs present in the final product. It is possible that some of the other high fluorine results from the CEH (2018) work or SCHF/TFF (2018) work is the result of non-PFAS fluorinated chemicals, but a selection of results was validated with LC-MS/MS, and this did not reveal high fluorine PFASs-free samples.

Combustion Ion Chromatography (CIC)

Combustion ion chromatography (CIC) measures both total fluorine and organic fluorine. In this method, the sample is extracted, the sample is combusted at high temperatures (e.g. >900°C) to break down organic molecules, and the resulting ions are analyzed using an ion chromatograph. Different sample extraction methods select for organic, inorganic, or total fluorine. Additional experiments are necessary to distinguish which organofluorine molecules are present; CIC alone does not distinguish between different PFASs or even confirm that the organofluorine is in PFASs. This approach was initially described by Miyake et al. (2007) with a LOD of 1 ng F/L with water samples and 1 ug F/L with blood samples. In Wagner et al. (2013), the limit of quantification (LOQ) was 0.3ug/L with wastewater samples when extraction was performed by the adsorption of organofluorine chemicals on a synthetic polystyrene-divinylbenzene based activated carbon. CIC was used by CEH (2018) to validate results obtained using PIGE.

Total Oxidizable Precursor (TOP) Assay

In this method, fluorotelomer precursors are oxidized using persulfate in the presence of base to produce perfluorinated alkyl acids (PFAAs), such as PFOA and PFHxA; this technique only applies to precursors with an oxidizable CH2 carbon (Houtz & Sedlak, 2012). The PFAAs are then quantified using targeted LC-MS/MS. Total precursors are calculated based on the increase in PFAAs present in the initial sample compared to those present in the derivatized sample. Due to the derivatization step, the precise identity of the fluorotelomer precursors is unknown using this method. Any PFAS species not looked for, or without an oxidizable CH2 carbon that results in a PFAS species looked for, is not detected with this method.

Fluorescence-based Methods

Other than mass spectrometry, one of the most sensitive detection options is fluorometric (Trojanowicz & Koc, 2013). In this method, PFASs are derivatized with a fluorophore, separated, and detected fluorometrically (Ohya, Kudo, Suzuki, & Kawashima, 1998; Poboży, Król, Wójcik, Wachowicz, & Trojanowicz, 2011). Paired with HPLC for separation, the LOD for this method is 43 to 75 ng PFASs/L (Poboży et al., 2011). These requires derivatizable PFASs, and does not identify specific species.

Nuclear Magnetic Resonance (NMR) Spectroscopy

19F nuclear magnetic resonance (NMR) spectroscopy can detect total fluorine in a sample. This technique was used by Moody, Kwan, Martin, Muir, & Mabury (2001) in conjunction with LC-MS/MS to identify and quantify PFASs in aqueous environmental samples following a spill of 22,000 liters of PFASs-containing fire-fighting foam at L.B. Pearson International Airport in Toronto, ON (Moody et al., 2001). The LOD was 10 ug/L for a 100 mL sample.

X-ray photoelectron spectroscopy (XPS)

XPS detects total fluorine on the surface (0.01 µm) of a product, and has been applied to both textiles and food contact materials (Tokranov, 2019). This is the region that is directly in contact with food or skin. PIGE also detects surface fluorine, but at a much greater depth (100 - 250 µm). A high resolution XPS scan provides unique peaks for CF2 and CF3 groups, confirming the presence of organofluorine. The LOD was ~1.6 wt% F, assuming the rest of the material is carbon.

Mass spectrometry (MS) Methods

Mass spectrometry (MS) can be used to detect and quantify specific PFAS species. It is limited to detecting known PFAS species, and requires a standard for quantification. The matrix can interfere with ionization of the PFAS analytes, either suppressing or enhancing it, which can cause difficulties when detecting and quantifying PFASs in diverse samples (Martin et al., 2004). Isotopic standards, if available, can address this issue, though may result in decreased sensitivity (Martin et al., 2004). Specific interference effects have been described for phospholipids and fatty materials (Valsecchi et al., 2013). The use of tandem mass spectrometry, or MS/MS, allows for by high sensitivity and selectivity of specific PFAS species.

MS is typically preceded by a separation step. HPLC is suitable for most PFASs, though gas chromatography (GC) is more suitable for volatile species (Martin et al., 2004). Gas chromatography requires derivatizing ionic PFASs to convert them to volatile species, while neutral species can be directly analyzed due to their semi-volatile nature (Kempistry et al., 2018). Liquid chromatography is generally preferred over GC when possible because the derivatization step required for GC is time consuming and a source of uncertainty (Valsecchi et al., 2013).

One downside of MS techniques is that limited specific species of PFASs are analyzed. The choice of extraction, liquid chromatography, and mass spectrometry conditions defines which species are resolved, identified, and quantified in MS; not all PFAS species are quantified simultaneously. Certain species, such as fluorotelomer alcohols, are volatile and form adducts with LC modifiers, meaning that there are additional challenges to the measurement of this subclass of PFASs using LC/MS (Schaider, et al., 2017). As these species are commonly detected in food contact materials (Yuan, Peng, Huang, & Hu, 2016), it is important to ensure that fluorotelomer alcohols are included among the species accurately quantified by the test method.

Another downside of LC/MS is that it requires destruction of the sample. However, only a small sample is required, and this is not a barrier to its use with disposable food packaging materials.

Appendix B: Standards for Environmental Biodegradation and Composting

Multiple standards bodies have developed relevant standards for PFASs and food packaging around composting:

- ASTM
- CEN
- ABA
- ISO

The relevant ASTM compostability standards is D6400, Standard Specification for Labeling of Plastics Designed to be Aerobically Composted in Municipal or Industrial Facilities (ASTM, 2012). It does not consider PFASs.

ASTM D6400 has three requirements for compostability, none of which consider PFASs directly (ASTM, 2012):

- Disintegration during composting: Product must disintegrate such that remaining product fragments are not readily distinguishable from the other organic materials in the compost. Up to 10% of the product by weight can remain intact on a 2.0 mm sieve.
- Biodegradation: Specified tests (ASTM D5338, ISO 14855-1, or ISO14855-2) must demonstrate biodegradation, defined as conversion of ninety percent of organic carbon to carbon dioxide by the end of the test period.
- No adverse impacts on ability of compost to support plant growth: Compost generated with the product does not adversely impact the ability of the compost to support plant growth, relative to compost generated without the product; certain chemicals are red-listed. Concentration of regulated metals must be less than 50% of those prescribed for sludges or composts; in the US, regulated metals include arsenic, cadmium, copper, lead, mercury, nickel, selenium, and zinc (Table 3 of 40 CFR Part 503.13). Following OECD Guideline 208, the germination rate and the plant biomass of the sample composts must be no less than 90% for two different plant species.

The European Committee for Standardization (CEN) offers EN 13432, a harmonized European standard for industrial compostability that is similar to ASTM D6400. It requires:

- Disintegration: At least 90% of product must disintegrate to fit through a 2x2mm mesh.
- Biodegradation: Conversion of at least 90% of the material into CO_2, water, and minerals following ISO 14855 (controlled aerobic composting), ISO 14851 (aerobic in water, oxygen demand), or ISO 14852 (aerobic in water, evolved CO_2)
- Quality of the final compost and ecotoxicity: Compost generated with the product does not adversely impact the ability of the compost to support plant growth, relative to compost generated without the product. Following OECD Guideline 208, the germination rate and the plant biomass of the sample composts must be no less than 90%. Further, the composted material must not have an adverse effect on the bulk density, pH, salinity, volatile solids, total nitrogen, total phosphorus, total magnesium, total potassium, and ammonium nitrogen

characteristics of the compost (according to http://www.bpf.co.uk/topics/standards_for_compostability.aspx).

- Chemical analysis: Low levels of certain chemicals, mostly heavy metals: zinc, copper, nickel, cadmium, lead, mercury, chromium, molybdenum, selenium, arsenic, and fluoride. Fluoride is limited to 100 mg/kg dry sample (100 ppm) (http://www.bpf.co.uk/topics/standards_for_compostability.aspx).

While it does not explicitly consider PFASs, the fluorine limit of 100 ppm is sufficient to exclude intentionally added PFASs for water/grease resistance.

Standards Australia offers AS4736 for industrial composting and AS5810 for home composting. AS4736 was based on EN 13432 and AS5810 was based on the OK compost HOME label offered by Vinçotte (currently offered by TÜV AUSTRIA). AS4736 has requirements in the same four areas as EN 13432 with the same or very similar specifications; the primary divergence is the addition of a worm ecotoxicity test. Both use the 100 ppm limit on fluorine from EN 13432, which excludes PFASs.

The International Organization for Standardization (ISO) offers ISO 17088, specifications for compostable plastics. Similar to ASTM D6400 and EN 13432, ISO 17088 requires 90% biodegradation and disintegration (limited by a 2mm sieve), and OECD 208 for the quality of the resulting compost. ISO 17088 is aligned with ASTM D6400 with regards to chemical analysis and relies on the country-of-sale’s regulations for metals; this means that ISO 17088 would permit PFASs like ASTM D6400.

Appendix C: Certification Programs for Environmental Biodegradation and Composting

Multiple organizations certify products as compostable in industrial or home composting or environmentally biodegradable. Here, we summarize the following certifications:

- Biodegradable Products Institute (BPI) certified compostable
- Cedar Grove Accepted
- TÜV AUSTRIA (formerly run by AIB Vinçotte International) - OK Compost INDUSTRIAL, OK Compost HOME
    - OK compost INDUSTRIAL
    - Seedling label
    - OK compost HOME
    - OK biodegradable SOIL
    - OK biodegradable WATER
    - OK biodegradable MARINE
- DIN CERTCO
- Japan Bioplastics Association GreenPla

Biodegradable Products Institute (BPI) certifies products as compostable in industrial facilities based on ASTM D6400 and D6868. Currently, PFASs are allowed in products labeled and sold with this compostability certification. However, in a November 2017 statement, BPI declared that they are adopting the 100 ppm fluorine limit from EN 13432 for all future certifications and requiring a declaration that no fluorinated chemicals have been intentionally added (BPI, 2017). By December 31, 2019, companies must confirm that any inventory with fluorine above 100 ppm will no longer be labeled or marketed as BPI certified compostable (BPI, 2018).

Cedar Grove maintains a list of compostable products, including food packaging, based on ASTM D6400 and D6868 and further requiring a field test of compostability. Currently, PFASs are allowed in products labeled and sold with this certification. Cedar Grove has recently updated their standard to match BPI, adopting a 100 ppm fluorine limit that goes into effect on January 1, 2020 (Cedar Grove, 2019). However, unlike BPI, they have no explicit requirement that existing inventory must also be compliant by that date. Starting January 1, 2019, Cedar Grove requires an addendum to any submissions that asks for information such as fluorine content (> or < 100 ppm), the range of fluorine found, laboratory methods used, future R&D work that may involve fluorine or fluorine alternatives, and whether those alternatives are being assessed for hazard (Cedar Grove, 2019).

TÜV AUSTRIA offers certification of biodegradability (soil, water, marine) and compostability (home and industrial). In order to achieve the OK compost INDUSTRIAL label, the product must pass EN 13432, and comply with EU Packaging Directive (94/62/EEC); OK compost HOME uses similar methodology but modifies EN 13432 to mimic the lower temperature conditions in a home compost pile (http://www.tuv-at.be/certifications/ok-compost-industrial-ok-compost-home/). Due to the use of EN 13432 and its 100 ppm limit on fluorine content, OK compost INDUSTRIAL prohibits PFASs.

TÜV AUSTRIA offers certification for biodegradability in soil, water, and marine environments. Each has individual requirements for biodegradation, disintegration, and environmental safety/ecotoxicity, and chemical analysis. Effort is made to ensure that the resulting labels do not promote littering. All three certifications reference EN 13432 for the chemical analysis; this means the 100 ppm limit on fluorine applies to these certifications as well, and all three certifications would prohibit PFASs as a result.

DIN CERTCO and TÜV AUSTRIA both offer the Seedling Logo, which is also based on EN13432. As with OK compost INDUSTRIAL, due to the use of EN 13432 and its 100 ppm limit on fluorine content, the Seedling Logo excludes PFASs. The requirements are very similar to the OK compost INDUSTRIAL requirements. In addition to the Seedling Logo, DIN CERTCO also offers the DIN-Geprüft test mark for industrial compostability following EN 13432, which excludes PFASs, and biodegradability in soil following EN 17033 for biodegradable mulch films.

The Seedling Logo is also offered by the Australasian Bioplastics Association (ABA), following Australian Standard (AS) 4736, Biodegradable plastics - biodegradable plastics suitable for composting and other microbial treatment. AS4736 is based on EN 13432 with the additional requirement of a worm test, and does include the 100 ppm limit on fluorine, and thus, PFASs. ABA also offers the Home Compostable Verification logo, based on AS5810, which also includes the 100 ppm limit on fluorine and thus PFASs.

Japan Bioplastics Association certifies plastics as biodegradable under GreenPla using its own scheme that is similar to EN 13432 and ASTM D6400:

- Disintegration: Resulting compost must filter through a 2mM sieve
- Biodegradation: Test must follow ISO 16929 or ASTM D5338 (following restrictions from ASTM D6400)
- Compost quality/ecotoxicity: OECD 208 or following “Plant Tests Using Komatsuna (Brassica rapa var. pervidis)” prescribed in General Administrative Agency Bulletin No.5005 (Silkworm Farming)

As noted previously, while PFASs content and toxicity could be sufficient to result in a fail of OECD 208, the results from the recent CEH (2018) study reveal that at least some PFASs-containing food packaging can pass OECD 208. It is expected that PFASs-containing food packaging could pass this certification.

Loopholes and Barriers

Several loopholes and barriers allow for materials containing highly fluorinated chemicals. Two requirements in standards and certifications could address the presence of PFASs in food packaging products: The compost quality/ecotoxicity test OECD 208 and the chemical analysis requirements that include fluorine. However, only the chemical analysis requirements actually exclude PFASs.

OECD 208 is a ubiquitous test method in these schemes. OECD Guideline 208 is the Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test (OECD, 2006). Seeds are plants in control compost and compost containing the product. Seeds are evaluated 14-21 days after 50% emergence of seedlings in the control compost. Assessment endpoints include:

- Visual assessment of seedling emergence
- Dry or fresh shoot weight or height
- Visible detrimental effects on parts of the plant

While it is possible that this would disqualify some products due to PFAS toxicity, it is known that many products containing PFASs have passed this test (CEH, 2018). The guideline requires that the compost is at least 10% product. PFAS concentrations in food packaging is relatively low. Regulations limit fluorochemical concentration, typically allowed to range from 0.2 to 1.5%, though industrial technical application papers mention concentration ranges from 0.1-4% (Trier et al., 2017). We identified one study that followed OECD 208 to test toxicity of seven different PFASs, using Lactuca sativa (lettuce) and the endpoint of root elongation. In this study, the NOECs ranged from 0.1 - 3 mm and EC50s ranged from 0.142 - 4.186 mm Given a compost density of ~400 g/L (and knowing that compost density can range significantly), the final concentration of PFASs in PFASs/food packaging compost would be in the single digit mm range, which falls within the EC50 for root elongation, leading to an expectation that PFASs-containing food packaging would be revealed using OECD 208.

However:

- Not all PFASs share the same toxicity. The PFASs used in food packaging may be less toxic to plants than the PFASs used in this study.
- Not all plants respond to PFASs in the same manner. The plants used in the OECD 208 tests for compost certification may not have used lettuce, which was used in this study, or may have used a different endpoint.
- Synergistic or antagonistic effects from PFAS mixtures and other chemicals present.

Given the results from the CEH (2018), it seems likely that OECD 208 is not sufficient for excluding PFASs from compost.

None of the chemical analysis requirements explicitly exclude PFASs. However, all of the standards and certifications based on EN 13432 include a 100 ppm limit on fluorine content. This corresponds to 0.01% of the food packaging. As mentioned above in the discussion on OECD 208, PFAS concentrations in food packaging may be 0.1% - 4% (Trier et al., 2017). Converting the percent PFASs to percent fluorine requires knowing the identity of the PFAS in question; 0.1% PFOA equates to almost 690 ppm fluorine, while PFOS corresponds to 650 ppm. As the size of the non-fluoro group increases, the corresponding ppm fluorine decreases. As the length of the perfluoro moiety increases, the corresponding ppm fluorine decreases. While a PFAS with a very large non-fluoro group could be present at 0.1% with fluorine levels below 100 ppm, the fluoro group is the functional group, and it would be expected that this particular PFAS requires a higher percentage to achieve the same water/grease-proofing. As a result, the 100 ppm fluorine limit is sufficient to exclude PFASs intentionally added for water/grease-proofing.