Per- and Polyfluoroalkyl Substances in Food Packaging Second Alternatives Assessment

Hazardous Waste and Toxics Reduction Program

Washington State Department of Ecology

Olympia, Washington

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Related Information

- The first PFAS in Food Packaging Alternatives Assessment Report to the Legislature[1]
- The first PFAS in Food Packaging Alternatives Assessment[2]

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[1] https://apps.ecology.wa.gov/publications/summarypages/2104007.html
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Department of Ecology's Regional Offices

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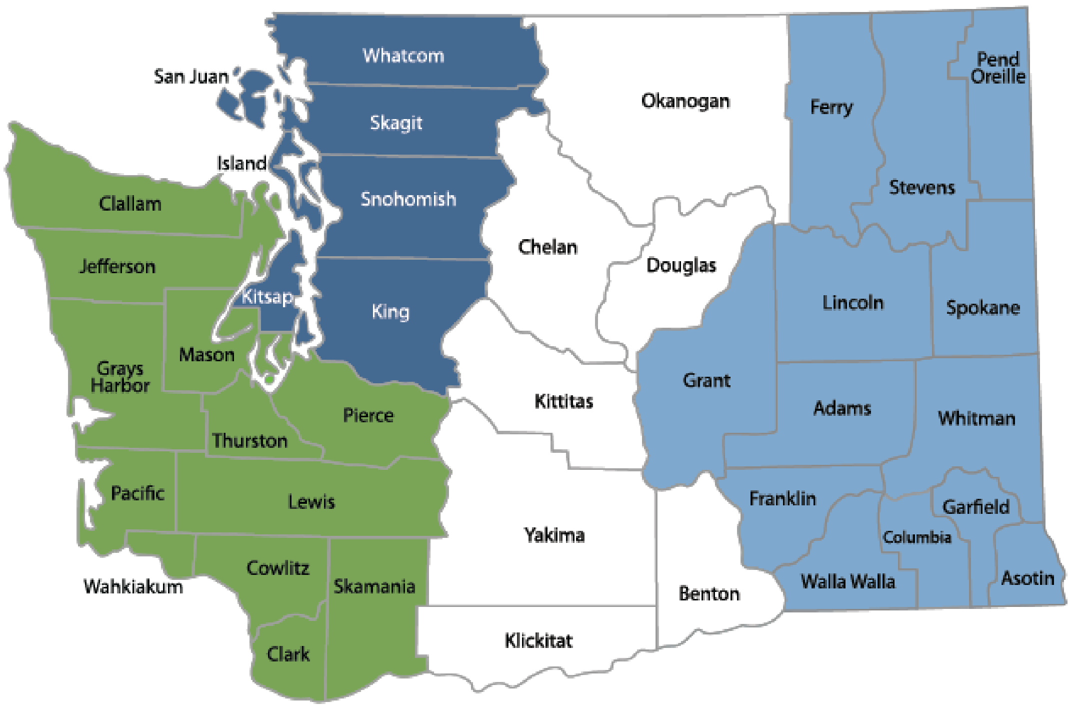

Southwest Region	Northwest Region	Central Region	Eastern Region
360-407-6300	425-594-0000	509-575-2490	509-329-3400

Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
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Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
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State of Washington

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Acronyms

Table 1. Acronyms found in this alternatives assessment.

Acronym	Definition
AA	Alternatives assessment
CAP	Chemical Action Plan
CASRN	Chemical Abstracts Service Registry Number
CBI	Confidential Business Information
CFR	Code of Federal Regulations
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
EVOH	Ethylene vinyl alcohol copolymers
FCM	Food contact material
FCN	Food Contact Notification
FDA	U.S. Food and Drug Administration
FTOH	Fluorotelomer alcohol
GHS	Globally Harmonized System of Classification and Labeling of Chemicals
HDPE	High density polyethylene
IC2	Interstate Chemical Clearinghouse
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
MW	Molecular weight
NAS	National Academy of Sciences
NEWMOA	Northeast Waste Management Officials' Association
NGO	Non-governmental organization
OGR	Oil and grease resistance
PE	Polyethylene
PET	Polyethylene terephthalate
PFAA	Perfluoroalkyl acid
PFAS	Per- and polyfluoroalkyl substances
PFHxA	Perfluorohexanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PPM	Parts per million
PLA	Polylactide or polylactic acid
PP	Polypropylene
PTFE	Polytetrafluoroethylene
PVOH	Polyvinyl alcohol
RCW	Revised Code Washington
SCIL	Safer Chemical Ingredients List

Executive Summary

Overview

This is the second Washington State Department of Ecology (Ecology) alternatives assessment (AA) of per-and polyfluoroalkyl substances (PFAS) in plant-fiber-based food packaging. This AA is pursuant to the requirements of RCW 70A.222.070,[4] which restricts the manufacture, distribution, and sale in Washington of "food packaging to which PFAS chemicals have been intentionally added in any amount." PFAS are intentionally added to some paper food packaging products to provide oil and grease resistance, water repellency, and leak resistance. The restriction timeline depends on when we identify safer alternatives to PFAS in food packaging.

As RCW 70A.222.070(2) requires, Ecology, in partnership with the Washington State Department of Health (collectively, "we"), designed an AA process to identify safer alternatives. This AA:

- Evaluates less toxic chemicals and nonchemical alternatives to replace the use of PFAS in food packaging.
- Follows the guidelines for alternatives assessments issued by the Interstate Chemicals Clearinghouse (IC2).
- Includes, at a minimum, an evaluation of chemical hazards, exposure, performance, cost, and availability.

This process considers alternatives to PFAS in food packaging that are "intended for direct food contact and are comprised, in substantial part, of paper, paperboard, or other materials originally derived from plant fibers" (RCW 70A.222.010[5]). Safer alternatives meet improved hazard and exposure considerations and can be practicably and economically substituted for PFAS.

We published our first AA using this process in February 2021 (Ecology, 2021). In it, we reviewed alternatives to PFAS in food packaging used to hold and serve freshly prepared food. We identified alternatives that met the criteria for a safer alternative for the following food packaging applications:

- Wraps & liners.
- Plates.
- Food boats.
- Pizza boxes.

This second AA evaluates five food packaging applications:

- Bags & sleeves.
- Bowls.

[4] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.070
[5] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.010

- Flat serviceware (which includes products like plates and trays).
- Open-top containers.
- Closed containers.

We chose these food packaging applications by looking at food packaging used to hold and serve freshly prepared food, specifically where we did not identify safer alternatives in the first AA. The Introduction includes more details on how we chose these applications and their definitions.

We identified safer alternatives for all five of the food packaging applications assessed in this AA.

Alternatives assessment approach

RCW 70A.222.070 requires us to use guidelines from the Interstate Chemicals Clearinghouse for Alternatives Assessments (IC2 AA Guide) (IC2, 2017) to determine whether safer alternatives exist for PFAS in the types of food packaging we identified. We closely followed the first AA process in this second AA (Ecology, 2021).

To meet the requirements of RCW 70A.222.070(2), we used the following four assessment modules from the IC2 AA Guide:

- Hazard Module.
- Exposure Assessment Module.
- Performance Evaluation Module.
- Cost and Availability Module.

We summarize the methods and results of each assessment module below. Each assessment module is used to determine whether an alternative is favorable or not compared to PFAS. To be a safer alternative, the alternative must be favorable based on all four assessment modules.

We first evaluated alternative substances in the hazard module to identify those that are less hazardous than PFAS. If we identified an alternative substance as less hazardous than PFAS, we then assessed it in the remaining three modules simultaneously. Alternative substances that we either identified as not less hazardous than PFAS or that we could not evaluate in the hazard module were not assessed in other modules. See the Introduction for more detail on the structure and composition of alternative assessments.

We incorporated stakeholder input by completing a Level 2 Stakeholder Involvement Module based on the IC2 AA Guide. Following these guidelines ensured we considered stakeholders during the AA process and offered them opportunities to provide input into that process. Stakeholder input directly led us to adopt an accelerated timeline to issue the second AA and add several alternative substances.

Results from assessment modules

Hazard Module

We used a Level 2 Hazard Module from the IC2 AA Guide to evaluate the human and environmental health hazards of PFAS and candidate alternative substances in order to identify alternatives that are less hazardous than PFAS.

We used information from well-studied PFAS to characterize the hazards of PFAS as a class of chemicals—which included some PFAS currently identified in food packaging products. We then established what it would mean for an alternative substance to be less hazardous than PFAS. After collecting information about the hazards of each alternative substance, we compared them to PFAS and came to one of three conclusions for each:

- A favorable alternative (an alternative of low concern and/or less hazardous than PFAS).
- Not a favorable alternative (not less hazardous than PFAS).
- Not a favorable alternative (not enough information).

We removed substances that were not favorable alternatives from further evaluation in this AA. See the hazard assessment method and results in Section 4.

Exposure Assessment Module

To evaluate potential exposure risk, we completed a Level 1 Basic Comparative Exposure Assessment based on the IC2 AA Guide. We deemed alternative substances we identified as low concern in the hazard module to be favorable alternatives and did not evaluate them in this module.

For the three alternative substances we considered less hazardous than PFAS (versus low concern), we compared exposure between each substance and certain well-studied PFAS. Comparing the exposure risks of the alternative substance to PFAS determines if any alternatives had a higher exposure risk (and were therefore not favorable alternatives).

We found that one alternative substance evaluated in this module had similar or lower exposure potentials compared to PFAS, indicating it was a favorable alternative. The remaining two alternative substances have exposure pathways that are not well understood, but could be of significant concern. To be protective, we determined there was not enough information to compare their exposure potential to PFAS as this time. Find the exposure assessment method and results in Section 5.

Performance Evaluation Module

We completed a Level 1 Basic Performance Evaluation following the IC2 AA Guide to identify any alternative substances that could not perform as well as PFAS. We reviewed promotional materials of example food packaging products to evaluate whether each alternative substance provides oil and grease resistance and leak resistance (the two performance requirements identified in products than use PFAS).

All but two alternative substances met these performance requirements, and are therefore favorable alternatives for all general uses. Of the remaining two alternative substances, one can meet performance requirements, but only for cold or room temperature food. The other did not meet the performance requirements and is not a favorable alternative. See the performance evaluation method and results in Section 6.

Cost and Availability Module

Ecology conducted a Level 1 Basic Cost and Availability Evaluation from the IC2 AA Guide to determine whether any alternatives would not be readily available or cost competitive. In the first AA, we completed a modified Level 1 evaluation focusing on the cost and availability of food packaging products for end-users. Recognizing that this data is difficult to obtain and poorly reflects the market, we switched to an unmodified Level 1 evaluation. This approach assesses the cost and availability of alternative materials and chemical substances for food packaging manufacturers.

In a Level 1 evaluation, the IC2 AA Guide presumes that if a food packaging manufacturer uses an alternative substance instead of PFAS to make a food packaging product, then the alternative substance is both available and cost competitive with PFAS. This evaluation adopts that assumption.

We identified products made with less hazardous alternative substances for each food packaging application in this assessment. We did not find any evidence of significant industry concerns about the supply of these alternative substances. Therefore, we consider these alternative substances to be both available and cost competitive for food packaging applications where they are used. We also determined that reusable food packaging products are available and cost competitive alternatives for some food packaging applications. Find the cost and availability method and results in Section 7.

Determination of safer alternatives

In Section 8, we present the results of each assessment module for each alternative and food packaging application. We note when there was either insufficient information to evaluate an alternative, or some restriction on the use of an alternative. This report makes no assertion regarding the safety or feasibility of PFAS alternatives we did not evaluate, nor about those we determined have insufficient information.

We used the results from all four assessment modules to determine if an alternative met the criteria to be favorable—we refer to the collective criteria as the “criteria for safer” (Section 8). For each food packaging application, we determined whether the candidate alternative 1) met the criteria for safer, 2) did not meet the criteria for safer, or 3) had insufficient information in one or more modules, preventing a conclusion.

Based on the reviews RCW 70A.222.070(2) requires and the IC2 AA Guide directs, we determined the alternative substances in Table 2 met the criteria for safer alternatives for one or more food packaging applications.

Table 2. Summary of safer alternatives identified for specific food packaging applications.

Food packaging application	Densified paper	Wax-coated	Clay-coated	PLA-coated	PLA Foam	Aluminum	Reusable versions	Total number identified
Bags and sleeves	Yes	Yes	No	No	No	No	No	**2**
Bowls	No	No	Yes	Yes	Yes	No	Yes	**4**
Flat serviceware	No	No	Yes	Yes	Yes	No	Yes	**4**
Open-top containers	Yes	Yes	Yes	Yes	Yes	Yes	Yes	**7**
Closed containers	No	No	Yes	Yes	Yes	Yes	No	**4**

Reusable versions of bowls, flat serviceware, and open-top containers met the criteria for safer alternatives for end-users who can collect and clean them.

In this AA, Ecology identified safer alternatives (as detailed in RCW 70A.222.070) for all five food packaging applications identified. These five food packaging applications—combined with the four applications identified in the previous AA—cover the general uses of food packaging to hold, serve, and transport freshly prepared food. Future AAs will focus on other areas of the market where PFAS are still used in food packaging.

Introduction

In 2018, the Washington State Legislature passed legislation banning the use of per- and polyfluoroalkyl substances (PFAS) in "specific food packaging applications" if safer alternatives are available (RCW 70A.222.070[6]). The Washington State Department of Ecology (Ecology), in consultation with the Washington State Department of Health (Health) (jointly, "we"), followed requirements in the law to:

- Conduct an alternatives assessment (AA) to evaluate "less toxic chemicals and nonchemical alternatives," and
- Determine whether alternatives are "readily available in sufficient quantity and at a comparable cost, and perform as well as or better than PFAS chemicals."

The AA must follow the Interstate Chemical Clearinghouse Alternatives Assessment Guidelines v1.1 (IC2 AA Guide) (IC2, 2017).

RCW 70A.222.010[7] defines PFAS as "a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom." PFAS have been in commercial use since the 1950s. In food packaging, PFAS are used to provide oil-, grease-, and water-resistance to paper, paperboard, and molded fiber products (ITRC, 2020).

These applications typically use polymeric PFAS, which may contain non-polymeric impurities left over from production, and which may eventually degrade to perfluoroalkyl acids (PFAAs) (Buck, 2015; Kwiatkowski et al., 2020). Studies detect these chemicals in food packaging material in the U.S., and they can migrate into food (Schaider et al., 2017; Yuan et al., 2016).

PFAS are persistent in the environment. Many members of the class can build up in our bodies and the food-chain. That's a problem because several members of the class are associated with carcinogenicity, developmental toxicity, and other human and environmental hazards.

Some state, federal, and international governments restrict the use of PFAS in food packaging.

- In 2019, Maine passed L.D. 1433 (H.P. 1043), which prohibits intentionally added PFAS in plant-fiber-based food packaging beginning January 1, 2022, provided the Maine Department of Environmental Protection can identify readily available safer alternatives. In 2021, L.D. 1503 expanded this prohibition to cover PFAS used in all products sold in Maine beginning January 1, 2030, unless it is a "currently unavoidable use" of PFAS.
- In 2020, New York passed a ban on all plant-fiber-based food packaging that contains intentionally added PFAS (S.8817 and A.4739-C) beginning in 2023.
- In 2021, Vermont passed a ban on intentionally added PFAS in all food packaging intended for direct contact with food, beginning July 1, 2023 (S.20).
- In 2021, Connecticut passed a ban on intentionally introduced PFAS in all food packaging intended for direct contact with food, beginning in 2024 (S.S.B. 837).

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[6] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.070
[7] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.010

- In 2021, Minnesota passed a provision prohibiting intentionally added PFAS in all food packaging, beginning in 2024 (S.F. 20).
- In 2021, California passed a law that prohibits the distribution or sale of plant-fiber-based food packaging that contains intentionally added PFAS or that contains greater than 100 parts-per-million (ppm) fluorine, as measured by a total organic fluorine test (AB 1200).
- Denmark enacted a ban on PFAS in food packaging beginning July 1, 2020, based on a limit of 20 micrograms of organic fluorine per gram of paper. PFAS may still be used in the plant fiber if there is a functional barrier between the PFAS-containing material and food (DVFA, 2020).
- In July 2020, the Food and Drug Administration (FDA) announced PFAS manufacturers had agreed to a three-year voluntary phase out of 6:2 fluorotelomer alcohol (FTOH) in food packaging (both the chemical and all polymer compounds that incorporated 6:2 FTOH) beginning in 2021 (FDA, 2020).

Alternatives assessment

We completed this AA using the IC2 AA Guide. An expert committee developed the guide, and the Northeast Waste Management Officials' Association (NEWMOA) maintains it. The IC2 AA Guide standardizes the AA process by:

- Fostering the replacement of toxic chemicals and avoiding regrettable substitutes.
- Including reasonable criteria to conduct an AA.
- Recommending a minimum data set needed to conduct an AA.
- Allowing for flexibility to meet a wide range of user needs.

According to IC2, an alternatives assessment aims “to replace chemicals of concern in products or processes with inherently safer alternatives, thereby protecting and enhancing human health and the environment.” An AA differs from traditional chemical risk assessment, which estimates exposure and compares it to a hazard-based limit. Conversely, AAs focus on reducing chemical hazards and avoiding regrettable substitutions to reduce risk. Considering other factors (such as stakeholder concerns, product performance, and cost and availability) further reduces the chance of selecting a regrettable substitute.

The IC2 AA Guide outlines five distinct steps for the AA process:

1. Identify chemicals of concern.
2. Initial evaluation.
3. Scoping.
4. Identification of alternatives.
5. Evaluate alternatives.

RCW 70A.222.070 takes the places of steps one and two, by identifying PFAS as the chemical of concern and directing us to perform an AA. Step three involves scoping to identify the framework of the AA (see the Hybrid Decision Framework below) and the degree of stakeholder involvement needed. Scoping as used by the IC2 AA Guide is distinct from the scope of the AA.

The scope of the AA refers to the logistical and legal boundaries the statute identifies or Ecology determines for the purposes of guiding this AA.

As a part of scoping, we continued the Level 2 Stakeholder Involvement Module started during the first AA (see Section 1). This module ensures concerned parties understand what decisions are being made and why and can provide input on the process. We recruited and engaged stakeholders who have an interest in or experience with toxic chemicals or the food packaging supply chain.

In step four, we identified potential alternatives. Section 3 outlines our process for identifying food packaging applications and alternatives to PFAS. For the purposes of this AA, we define alternatives at two levels:

- The **chemical/material level** considers an alternative substance in terms of its chemical components, which can include both an alternative chemical that replaces PFAS in plant fiber-based food packaging and an alternative material that replaces the plant fiber-based packaging itself, when applicable.
- By contrast, the **product level** reflects the combination of an alternative substance and a product that meets one of the specific food packaging applications considered in this AA. Evaluating alternatives at the product level can help us understand how alternative substances are used in food packaging products.

We use the term alternative substance to talk both about the alternative at the chemical level and the material level. For example, we evaluate a PLA foam clamshell and a PLA-coated paper plate as the same substance on the chemical level, because they are both made using PLA. At the material level, however, they are distinct—one is a PLA foam while the other is a PLA-coated paper. They are also distinct at the product level, since plates and clamshells are unique food packaging applications. Our assessment is focused on alternative substances, and therefore the chemical/material level in this AA. However, at certain points in the assessment, we do collect information on alternatives at the product level.

Finally, in step five, we evaluate the alternatives using assessment modules. To meet the requirements of RCW 70A.222.070, we completed four assessment modules for this AA. The assessment module levels we chose reflect Ecology's recommendations for government organizations conducting AAs (Ecology, 2015) and are sufficient to evaluate the alternatives:

- **IC2 Level 2: Hazard Module (Section 4)**. The goal is to determine the hazards of the chemical of concern and how they compare to potential alternative substances (chemical/material-level assessment).
- **IC2 Level 1: Exposure Assessment Module (Section 5)**. The goal is to evaluate potential exposure scenarios and determine if alternative substances pose a greater exposure risk to human health and the environment (chemical/material-level assessment).
- **IC2 Level 1: Performance Evaluation Module (Section 6)**. The goal is to ensure the alternative substances under consideration meet the necessary performance requirements (chemical/material-level assessment).
- **IC2 Level 1: Cost and Availability Module (Section 7)**. The goal is to evaluate whether alternatives are available and cost competitive (product-level assessment).

Find additional information in the section for each module.

Hybrid decision framework

The IC2 AA Guide suggests three possible decision frameworks for conducting an alternatives assessment:

- Sequential decision framework.
- Simultaneous decision framework.
- Hybrid decision framework.

In all three frameworks, assessors determine the scope of the AA before collecting data. For this AA, we used a hybrid decision framework.

In the hybrid decision framework, certain assessment modules are initially performed in sequence, typically the hazard and performance evaluation modules. That removes low-performing and hazardous alternatives from consideration. Then, we simultaneously collect data for the remaining potential alternatives for all remaining modules and evaluate them at the same time.

We slightly modified the hybrid decision framework the IC2 AA Guide suggests to better accommodate our assessment needs (Figure 1). We first evaluated all alternative substances in the hazard module to identify alternative substances that are less hazardous than PFAS. We then simultaneously evaluated less hazardous alternative substances using the remaining three assessment modules—exposure, performance, and cost and availability. We considered any alternative substances that we did not identify as less hazardous than PFAS (due to data gaps or data indicating hazards of concern) as not safer alternatives and did not evaluate them further.

Figure 1. Alternatives assessment process using a hybrid decision framework.

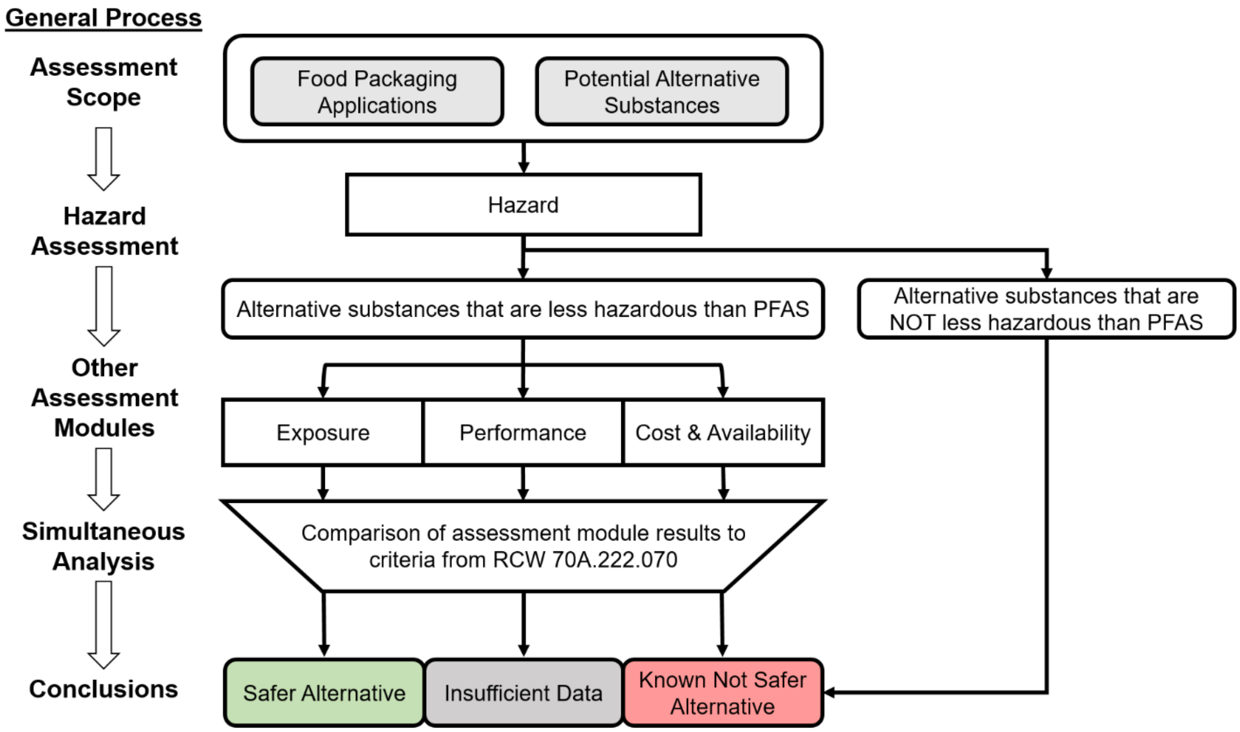

Figure notes:

- Access an accessible text description of this graphic.[8]

Sections 4 through 7 detail the process and results of the four assessment modules. We used results of these four modules to evaluate whether an alternative product made from a candidate alternative substance met the criteria for safer (as required by RCW 70A.222.070 and detailed in the IC2 AA Guide). To be a safer alternative, we must identify the alternative as favorable in all four assessment modules. We identified each alternative as either safer, not safer, or having insufficient data. Section 8 details these criteria and the results of this hybrid decision analysis.

Food packaging applications

This AA considers alternatives to PFAS in food packaging that are "intended for direct food contact and is comprised, in substantial part, of paper, paperboard, or other materials originally derived from plant fibers" (RCW 70A.222.010[9]). Food packaging is a multibillion-dollar market including products designed for quick service, foodservice, and consumer-packaged goods (Freedonia, 2017).

[8] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS-Food/TextDescriptions_Figures_SecondPFAS_FoodPackaging_AA.pdf
[9] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.010

For the purposes of this assessment, we define a food packaging application as products with a similar physical structure that package food in a similar manner. Each application includes food packaging products, as defined by RCW 70A.222.010, to which manufacturers intentionally add PFAS to prevent oil, grease, and other leaks through the packaging (see Section 2 for more details). Each application also includes products that do not contain PFAS.

In the first AA, we identified and defined ten food packaging applications based on specific examples of food packaging products offered for sale in the U.S.

We found safer alternatives for four applications (Ecology, 2021):

- Wraps and liners.
- Plates.
- Food boats.
- Pizza boxes.

We did not find safer alternatives that met all the criteria in RCW 70A.222.070 for six food packaging applications (Ecology, 2021):

- Bags and sleeves.
- Bowls.
- Trays (including cafeteria trays).
- French fry cartons.
- Clamshells.
- Interlocking folded containers (also called food containers or pails).

This second AA focuses on food packaging applications where we did not identify safer alternatives. After publishing the first AA, stakeholders expressed that some of these definitions of food packaging applications were overly restrictive, while others expressed that they were not restrictive enough. We therefore reviewed and revised how we defined these six food packaging applications where we did not identify safer alternatives.

We determined that basing our original definitions of food packaging applications on specific examples of food packaging products was too restrictive for certain types of food packaging. The approach did not acknowledge that consumers use many specific food packaging products interchangeably for the same food products. One example is clamshells and interlocking folded containers, which can interchangeably package many types of food.

For this second AA, we updated how we defined some food packaging applications. These new definitions aim to focus less on specific examples of food packaging products, and more on the general functions of food packaging while serving and transporting freshly prepared food. Each of these applications includes food packaging to which manufacturers intentionally add PFAS to provide oil and grease resistance (OGR) and leak resistance (RCW 70A.222.010[10]).

As in the first AA, we are only considering versions of these food packaging applications intended for serving or short-term storing, transporting, or holding freshly prepared food. FDA and FoodSafety.gov recommend discarding leftover prepared food after three to four days

[10] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.010

(FoodSafety.gov, 2019). We consider any length of time beyond four days to constitute long-term storage or holding of food. These food packaging applications may still be used for long-term storage, but we did not evaluate long-term storage in this AA.

The five food packaging applications we defined for the second AA include multiple product types that can be used interchangeably. They are:

- **Bags & sleeves:** Containers made from flexible material. Flat-bottom bags are typically used to transport food from a foodservice establishment (bags). Sealed-end bags can hold food for service or can transport food from a foodservice establishment (sleeves). Sleeves are also referred to as pinch-bottom bags.
- **Bowls:** Open-topped containers with wide openings and bottoms that allow spooning of food. They are typically designed to hold foods for serving that have a substantial liquid component (such as soup). Portion cups are also included in this application.
- **Flat serviceware:** Shallow, flat-bottomed containers with large surface areas used for serving and transporting food. These products may have one large surface or multiple compartments to separate food items during food service. Examples include shallow trays, cafeteria-style trays, and plates.
- **Open-top containers:** Containers that enclose food on all but one side. They are designed to hold foods for serving or transportation. Examples include food boats, French fry containers, and paper cones.*
- **Closed containers:** Containers that enclose food on all sides. Interlocking pieces or overlapping walls hold the container closed for transport. Examples include clamshells, food pails, bakery boxes, and deli containers.

*Bowls and bags & sleeves may be considered types of open-top containers but are evaluated as separate food packaging applications. This is because not all open-top containers can serve the function of bowls, on the one hand, or of bags and sleeves, on the other.

We published these definitions in May 2021 and shared them with stakeholders. One chemical trade group felt that, similar to the first AA, these definitions were too broad. All other stakeholders either expressed support for the new definitions, or did not express concern.

General considerations for this AA

We structured this AA to meet the requirements of RCW 70A.222.070 and use the best, publicly available science relating to AAs, PFAS, and known alternatives to PFAS. Under this law, we do not have the authority to require information from manufacturers of PFAS, alternative substances, or food packaging products. All the information we used was either publicly available, or manufacturers or stakeholders voluntarily provided it. Statutory requirements and the availability of information impacted this AA in several ways.

Stakeholder involvement

During this process, we engaged many different stakeholder groups, who provided diverse opinions and perspectives. We consider this both a strength and a challenge of this project. For example, certain nongovernmental organizations and members of the public felt that we defined our food packaging applications too narrowly in the first AA. Conversely, one chemical trade group felt those same food packaging applications should be more narrowly defined. We noted these perspectives and others in the assessment where possible.

We aimed to involve consumers and end-users in this AA. Consumer and end-user input is important because this group is directly exposed to PFAS from food packaging, and will be directly impacted by the transition to non-PFAS alternatives (cost, availability, performance, etc.). We had limited success recruiting consumers or end-users as stakeholders for this AA.

Criteria not considered in the AA

Ecology was directed to identify safer alternatives to PFAS by considering the hazards, exposure potential, performance, cost, and availability of alternatives. Stakeholders suggested other criteria that we could not use to evaluate alternatives, such as the greenhouse gas potential, social impact, or material end-of-life (how the material is disposed of). While these are worthwhile criteria to include in an AA, we ultimately determined they fell outside the scope of our work.

However, we strongly encourage individuals or organizations replacing food packaging that contains PFAS to consider these and other criteria as appropriate. In our assessment, we consider any alternative that meets the criteria described in 70A.222.070 a safer alternative. We do not identify or recommend any safer alternatives as more favorable than others. We urge end-users seeking the best alternative for their purposes to consider these or other criteria in their decision-making process.

Data limitations

Product producers were apprehensive to disclose the chemical identity, formulation, and use of PFAS-free products. This was due to concerns about competitive market advantage, potential damage to their brand, or potential future liabilities. To encourage the sharing of information and to alleviate those concerns, Ecology developed a Confidential Business Information (CBI) protocol allowing those interested to apply for confidential treatment of data (under Chapter 43.21A[11] RCW).

CBI submissions for this AA were limited. When we did not receive CBI submissions for candidate alternative substances, we completed our assessment modules using the best publicly available information about alternative substances.

Intentionally added PFAS

RCW 70A.222.070 prohibits the sale or distribution of "food packaging to which PFAS chemicals have been intentionally added in any amount." Intentionally added is not further defined in the statute. Therefore, we focused our assessment on identifying alternatives for documented uses of PFAS in plant-fiber-based food packaging.

In our research, we identified many examples where manufacturers add PFAS to provide oil- and water-resistance to food packaging, which is the focus of our analysis (see Section 6 for

[11] https://app.leg.wa.gov/RCW/default.aspx?cite=43.21A

more details). Others noted that PFAS may also be added to some molded fiber products as a manufacturing process aid to prevent the product from sticking to the mold (DTSC, 2020). Absent evidence in our own research or confirmation from manufacturers, we are not evaluating alternative manufacturing process aids in this AA.

Some studies suggest that PFAS may contaminate food packaging through the use of recycled paper (Trier et al., 2017). This could introduce PFAS into the final product. However, PFAS contamination from recycled materials does not provide a function in these products, and therefore is not within the scope of this AA.

Active ingredient identification

Manufacturers are not required to publicly list the chemicals they use in their food packaging. Therefore, we relied on research, stakeholder input, and publicly available databases of food packaging products for information about food packaging. To include a product as an example, we first confirmed it does not contain intentionally added PFAS, then tried to identify the alternative substance used. When we could not determine the alternative used in a product, we did not include it in our assessment.

Although we did not assess all potential alternatives in this AA, we identified enough information to evaluate many alternative substances and example products.

Section 1. Stakeholder Involvement Module

Overview

Ecology completed an IC2 Level 2 Stakeholder Involvement Module for this AA. It aimed to ensure we considered stakeholders in the AA process, and provided a framework to inform concerned parties about decision-making and receive input in return.

A variety of parties have a stake in the transition from PFAS to non-PFAS alternatives in food packaging. They include chemical manufacturers (PFAS and non-PFAS), food packaging manufacturers, suppliers, non-governmental organizations (NGOs), government agencies, trade organizations, retailers, purchasers and users, and end-of-life managers.

Incorporating stakeholder interests is an important component of the AA process. Our stakeholder process for the second AA built on an established stakeholder group from the first AA (Ecology, 2021). In accordance with RCW 70A.222.070(2)(b),[12] this AA must use the IC2 AA Guide. Therefore, our process followed guidelines in the Stakeholder Involvement Module of the IC2 AA Guide. Like the first AA, we identified and addressed stakeholder concerns wherever possible in this assessment.

Choice of an IC2 AA Guide level

The IC2 AA Guide describes three levels assessors can use in the Stakeholder Involvement Module:

- **Level 1 Internal exercise:** Identifies potential stakeholders, their concerns, and how their concerns may be addressed in the AA. There is little external stakeholder involvement, unless specific questions are posed where external input is required or recommended.
- **Level 2 Formal stakeholder process:** Identifies potential stakeholders and seeks their input in a formal and structured process. Pertinent AA information is provided for stakeholder review and comment. All comments are collected and responded to.
- **Level 3 Open stakeholder process:** Identifies potential stakeholders invited to participate in all aspects of AA process. Involvement includes all aspects from scoping, development, participation in formal committees (steering, advisory, technical, etc.), and review of the final product.

We completed a Level 2 Stakeholder Involvement Module. It provides a clear structure to receive input from a diverse group of stakeholders, while still maintaining decision-making power. This decision aligns with Ecology's previous recommendations for government organizations performing AAs (Ecology, 2015).

[12] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.070

Methodology

The IC2 AA Guide for a Level 2 stakeholder involvement process includes five questions or steps:

1. Identify potential stakeholders who might be interested and concerned with the chemical, product, or process being considered.
2. Identify potential concerns of stakeholders.
3. Can the concerns identified be addressed or mitigated?
4. Incorporate stakeholder concerns into the decision-making process. Document how this has been done.
5. Are the concerns identified serious enough to identify the alternative as unfavorable?

Stakeholder process

Identify potential stakeholders

We established a stakeholder process with diverse representation across types of organizations and interests during the first AA. We built on this established process for the second AA, and continued to distribute information through multiple communication channels. Recruiting additional stakeholders was a continuous, open process.

Similar to the first AA, we identified that our stakeholder process needed more representation from consumers, purchasers, and retailers of food packaging products. We developed specific, tailored outreach to manufacturers and end-users to encourage their participation in the second AA. We contacted 30 organizations via email in June 2021. Over a third of these organizations were responsive to the individualized invitation, and later shared input.

To reach new potential audiences who were unaware of our process, we broadly announced the transition from the first AA to the second AA. We invited stakeholder participation through new communication mediums: media engagement, blog posts, and social media.

- **Media engagement**: To reach new potential audiences, we engaged with media organizations including Chemical Watch,[13] the Food Packaging Forum,[14] and the Seattle Times.[15]
- **Blog posts**: We published a blog post to announce the first AA[16] and inform stakeholders that we were starting the second AA immediately. We published another subsequent blog post to invite stakeholders to participate[17] in an interactive webinar in April 2021 (discussed below).

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[13] https://chemicalwatch.com/270851/washington-state-issues-draft-scope-for-next-pfas-alternatives-assessment

[14] https://www.foodpackagingforum.org/news/washington-state-draft-scope-for-second-pfas-alternatives-assessment

[15] https://www.seattletimes.com/seattle-news/environment/seattle-study-of-breast-milk-from-50-women-finds-chemical-used-in-food-wrappers-firefighting-foam/

[16] https://ecology.wa.gov/Blog/Posts/February-2021/Making-food-packaging-safer-with-alternatives-to-t

[17] https://ecology.wa.gov/Blog/Posts/March-2021/Help-us-make-food-packaging-safer-in-Washington

- **Social media**: To broaden the reach of our first blog post, we shared it on Ecology's Twitter,[18] Facebook,[19] and Instagram[20] pages. To encourage participation in the interactive webinar in April 2021, we also shared the second blog on Ecology's Twitter,[21] Facebook,[22] and Instagram[23] pages.

In some cases, interested parties reached out directly to express interest in engaging as a stakeholder. We directed them to the PFAS in Food Packaging AA website and email list for project updates. However, during this AA, more often we contacted these parties and encouraged them to provide feedback and information.

Nearly 80 companies and organizations participated as stakeholders in this AA. Table 3 shows the number of stakeholders by type. Some companies and organizations had more than one person interested in this AA. Several stakeholders followed the AA progress but did not directly provide feedback. We included them in the current representation.

Table 3. Stakeholder representation (by type of organization) during the second AA.

Stakeholder type	Number of organizations
Government	26
Packaging product manufacturer	6
Chemical manufacturer	4
Paper producer	4
Product coating applicator	1
Trade organization	2
Purchaser/end user	8
NGO	10
Composter, recycler, waste manager	4
Consultant	14

End-users were represented by:

- State/local government agencies from Washington, Oregon, and California.
- Institutional purchasers.
- Military purchasers and the Department of Defense.
- Brands, retailers, grocers, and other food service operators.
- NGOs, consumer organizations, and public education organizations.
- Trade organizations representing grocers, hospitality industries, and restaurants or food trucks.

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[18] https://twitter.com/EcologyWA/status/1364336734213976071
[19] https://www.facebook.com/EcologyWA/photos/a.174138749276294/3884890588201073/?type=3&theater
[20] https://www.instagram.com/p/CLpqcH0LkT6/?utm_source=ig_web_copy_link
[21] https://twitter.com/EcologyWA/status/1369052809572720642
[22] https://www.facebook.com/EcologyWA/photos/a.174138749276294/3926435704046561/?type=3&theater
[23] https://www.instagram.com/p/CMLLFp_AqHO/?utm_source=ig_web_copy_link

Identify stakeholder concerns

We identified potential stakeholder concerns in several ways, including through interactive webinars, focused input sessions, email updates, websites, submitted comments, and online meetings. Stakeholder concerns included (but were not limited to):

- Project communication and transparency.
- The comparator selection and assessment processes.
- Product scoping.
- Assessment methodologies.
- Proprietary information submittal.
- Project timeline.
- Consideration of plastic alternatives.
- Social impact concerns.
- Importance of recyclability and compostability.

Communication with stakeholders

Ecology developed a dedicated website for the PFAS in Food Packaging Alternatives Assessment.[24] This website contains general and background information for the project, current and archived updates and information, and contact information for the PFAS AA team. Past webinar presentation slides and recordings are also available.

In May 2020, we added an eComment page[25] to the PFAS in Food Packaging AA website where we archive comments, memos, and letters submitted from stakeholders for public review. We invited stakeholders to submit comments as an alternative to reaching out directly to the PFAS AA team.

We used email list updates, online meetings, and interactive webinars to encourage stakeholder participation. The website includes a link to the email list, which archives stakeholder email updates. Our email updates share project information, timelines, progress and approaches, and announce webinars and input opportunities.

Webinars

We hosted webinars to update stakeholders on the AA progress, discuss decisions, request information for data needs, solicit feedback as we develop methodologies, and provide a platform for discussion and to address questions.

Between the first and second AA, we hosted three webinars with stakeholders.

- In March 2021,[26] we focused on the results from the first AA.

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[24] https://www.ezview.wa.gov/site/alias__1962/37610/pfas_in_food_packaging_alternatives_assessment.aspx
[25] http://hwtr.ecology.commentinput.com/comment/extra?id=a8U4i
[26] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS-Food/PFASAA_March2021_WebinarPresentation.pdf

- In April 2021,[27] we transitioned to the second AA and focused on listening to stakeholder input to guide decisions for that AA.
- In May 2021,[28] we oriented stakeholders to the draft scope document (discussed below) and requested feedback and new information on certain topics.

We structured these webinars interactively. Participants asked questions and saw their feedback from the discussion captured live on the presentation screen during the webinar. Stakeholders calling via phone and joining via computer could both engage in the discussion. These webinars contributed to a constructive, two-way dialogue with stakeholders and helped ensure we accurately captured their concerns. The input on our approach contributed to our decision-making for this AA.

For more information about who attended these webinars, see the section above on identifying potential stakeholders.

Sharing the second AA scope

To share how we defined food packaging applications differently for the second AA compared to the first AA, we published a document outlining the scope for the second AA[29] in May 2021. We opened an informal comment period to offer stakeholders an opportunity to weigh in on the changes we proposed. Stakeholders could provide input:

- Through our comment form.[30]
- Via email to our team.
- During the interactive webinars.
- Through individual meetings with our team.

We received over 130 comments from a community-based organization and its members calling on us to prioritize removing PFAS from food packaging and accelerate our timeline. To address this stakeholder input and to return to the timeline set in the statute we are implementing, we adjusted our timeline to publish this second AA earlier in 2022.

Online meetings

During individual meetings, we gathered information to inform the AA. During numerous online meetings with stakeholders, we discussed:

- Information about specific PFAS or PFAS-free alternatives.
- Information on food packaging products.
- Developing the AA scope.
- Data needs overall and data specific to certain portions of the assessment.
- End-user engagement.
- CBI protocol for submitting data.

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[27] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS-Food/PFAS_AA_FeedbackWebinar_April2021.pdf
[28] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS-Food/PFASAA_May2021_WebinarPresentation.pdf
[29] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS-Food/PFASAA_SecondAA_DraftScope.pdf
[30] http://hwtr.ecology.commentinput.com/?id=a8U4i

- Timeline updates.
- Social impact concerns.
- Lifecycle issues (biosolids, recyclability, compostability, etc.).

Addressing stakeholder concerns in decision-making

Ecology provided stakeholders opportunities to communicate concerns, and we prioritized addressing them where possible. This report highlights several instances where we addressed stakeholder concerns, including:

- Project timeline.
- Definitions of specific food packaging applications.
- Addressing the hazard and exposure concerns of PFAS as a class.
- Greater consideration of plastic food packaging products as candidate alternatives.
- Methods used to assess cost and availability for alternative substances.

We published the scope for the second AA to share what we intended to change between the first and second AA process, and to offer stakeholders another chance to weigh in. Stakeholder concerns directly contributed to our decision-making and led to changes in our methods, including:

- Reconsidering how we defined food packaging applications to allow for broader application of alternatives that are suitable for multiple packaging types.
- Revisiting how we assess cost, particularly for alternatives food packaging manufacturers already use.

Some stakeholders requested a formal public comment period for this AA. In order to return to the project timeline set in the statute we are implementing, we decided to move forward with this report in 2021. That adjusted timeline prevented us from offering a formal public comment period for this AA. In future AAs, we plan to again solicit feedback and incorporate any stakeholder input we receive about our process.

Are the concerns identified serious enough to identify the alternative as unfavorable?

There were no concerns stakeholders raised that would inhibit identifying safer alternatives for this assessment. We aimed to identify and address stakeholder concerns wherever possible in this assessment.

Section 2. PFAS as a Chemical Class and Use in Food Packaging

Overview

RCW 70A.222.010[31] defines perfluoroalkyl and polyfluoroalkyl substances or "PFAS chemicals" as "a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom." Within this AA, we use the term "PFAS" generically to refer to any chemical that meets this class definition.

In this AA, we assess PFAS as a class of chemicals, as defined in the statute. Evaluating alternatives against the class of PFAS chemicals helps overcome the challenges associated with assessing individual PFAS used in food packaging. Companies do not have to disclose which PFAS they add to food packaging, and current techniques to identify PFAS are limited to a handful of chemicals. As a result, we do not know if consumers are primarily exposed to one PFAS chemical or many through food packaging. It is also difficult to determine the identities and exact amounts of PFAS impurities or degradation products found in food packaging treated with a specific, approved PFAS.

This section briefly overviews current PFAS use in plant-fiber-based food packaging. It also discusses the advantages of assessing PFAS as a class, and addresses how different assessment modules use information on the class.

PFAS approved for use in plant-fiber-based food packaging

Our AA aims to identify alternatives that can replace PFAS in plant-fiber-based food packaging. Manufacturers add PFAS to these products to impart oil-, grease-, and moisture-resistance. They are either incorporated within the food packaging material, or added to the surface as a coating. PFAS from recycled paper can also contaminate food packaging (Trier et al., 2017). Only a subset of chemicals that meet the definition of PFAS are approved for use in materials that come into contact with food. We discuss those specifically approved for use in plant-fiber-based products here.

Currently, there are 28 Food Contact Notifications (FCNs)—covering 17 distinct PFAS formulations—that the U.S. Food and Drug Administration (FDA) has approved for use in plant fiber-based food packaging (FDA, 2021). Appendix A contains the name, Chemical Abstracts Service registry number (CASRN), representative chemical structure, and FCN of these compounds.

All approved FCNs are for polyfluorinated polymers. A majority of these are categorized as C6 side-chain fluorinated polymers (see Appendix A, Figure 3 for an example structure). The rest are categorized as perfluoropolyethers (see Appendix A, Figure 7 for an example structure). Side-chain fluorinated polymers consist of a non-fluorinated carbon backbone, typically of acrylate, methacrylate, or urethane chemistry, with fluorinated side chains. Perfluoropolyethers

[31] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.010

consist of a carbon and oxygen polymer backbone where fluorine is directly bonded to the carbon atoms (Buck et al., 2011).

Two additional PFAS compounds are approved for use in food contact paper and paperboard but do not have registered FCNs. These compounds are:

- A chromium (Cr III) complex of N-ethyl-N-heptadecylfluoro-octane sulfonyl glycine.
- An undecafluorocyclohexanemethanol ester mixture of dihydrogen phosphate.

They are permitted for use in food packaging pursuant to the Code of Federal Regulations list of indirect additives (see 21 CFR 176.160 and 21 CFR 176.170).

Note that Appendix A includes 14 FCNs that cover 11 distinct side-chain fluorinated PFAS compounds which incorporate 6:2 fluorotelomer alcohol (FTOH) side chains. Manufacturers of these compounds committed to a three-year voluntary phase out of these substances in food packaging beginning January 2021 (FDA, 2020). We expect these compounds to still be used in food packaging when we publish this assessment. Also at the time of publication, we are unaware of any new PFAS registered for use in food contact materials with FDA since the publication of the first AA.

Assessing PFAS as a chemical class

Background

Although FDA approves a subset of PFAS chemicals for use in food packaging, RCW 70A.222.070 prohibits the use of any PFAS that meet the class-based definition in RCW 70A.222.010. If we identify safer alternatives for specific applications of food packaging, then any intentional addition of any chemical meeting the class-based definition of PFAS is prohibited in those applications. Many PFAS currently used were brought to market to replace other PFAS manufacturers phased out due to toxicity concerns (FDA, 2015). Addressing PFAS as a class avoids replacing current PFAS with other, similarly toxic PFAS.

Additionally, many of the PFAS FDA approved for use in food packaging are not well-characterized in the scientific literature, and so their specific toxic properties of concern are not well-studied (Kwiatkowski et al., 2020; Wang et al., 2017; Wang et al., 2020). However, studies do establish that the polyfluorinated compounds approved for use in food packaging are all sources of perfluoroalkyl acids (PFAAs). When polyfluorinated compounds are manufactured and when they degrade, they can release PFAAs into the environment (Dinglasan-Panlilio & Mabury, 2006; Li et al., 2017; Rice et al., 2020; Trier et al., 2017; Wang et al., 2017; Wang et al., 2020; Washington et al., 2009; Washington & Jenkins, 2015).

Several of these PFAAs, including those directly linked to PFAS approved for use in food packaging, are well-studied (Kabadi et al., 2018; Rice et al., 2020). Studies detect PFAAs globally and in many different environmental media—they are extremely persistent chemicals (Kwiatkowski et al., 2020). Examples include perfluoroalkyl carboxylic acids like perfluorooctanoic acid (PFOA) and perfluoroalkyl sulfonic acids like perfluorooctanesulfonic acid (PFOS). They may also include perfluoroether carboxylic acids like Gen X. PFAAs have not been shown to degrade or transform under any natural conditions (Ochoa-Herrera et al., 2016; Liou et al., 2010; Ecology, 2020).

In the first AA, we identified two specific PFAS to act as a comparator and represent the class of PFAS chemicals in hazard assessment. Using a class-based approach to assess PFAS in this AA, we can rely on the most well-characterized (or data rich) PFAS, like PFAAs, to understand the class. This means we use the chemical class as the comparator in the hazard module.

How we used information about PFAS as a class

In this AA, we used PFAS as a class as a comparator to assess whether alternative substances to PFAS are safer, feasible, and available. Here, we summarize the information we used about PFAS as a class in the four assessment modules. As we noted, the assessment modules consider the hazard, exposure, performance, and cost and availability of alternative substances to PFAS in plant-fiber-based food packaging.

In the hazard module, we to establish a baseline based on hazard characteristics of data rich PFAS. We use the baseline to compare identified alternatives and determine whether they are less hazardous. We did not exhaustively review all the data concerning the chemical class. Instead, we based our review on several PFAS with sufficient peer-reviewed data. This approach avoids the pitfalls of treating PFAS with limited or no data (such as perfluoropolyethers) as "not hazardous" and helps ensure the alternative substances are safer than the chemical class.

Similarly, in the exposure assessment module, we used literature concerning PFAS exposure through food packaging and physical and chemical property data of certain well-characterized PFAS that are linked to food and food packaging. We used this information to characterize the exposure concerns of PFAS. We focused on concerns that are relevant to the use of plant-fiber-based food packaging. We then assessed alternative substances to determine if they presented similar or lower exposure potentials than PFAS.

In the performance evaluation module, we researched the performance expectations for food packaging products that use PFAS. We used that information to determine how PFAS function at the chemical, material, product, and process levels. Our evaluation focused on confirming that candidate alternatives provide oil, grease, and leak resistance at the material level.

In the cost and availability module, we did not directly compare each alternative substance to PFAS on the basis of availability and cost. Regulators' and private companies' actions to restrict or remove PFAS from food packaging is driving demand for PFAS-free alternative products.

Find more detail on how we used PFAS information in the four assessment modules in Sections 4 to 7.

Section 3. Candidate Alternatives to PFAS in Food Packaging

Overview

RCW 70A.222[32] directs Ecology to evaluate "less toxic chemicals and nonchemical alternatives" for "specific food packaging applications." The statute does not specify which chemical or nonchemical alternatives should be included. Using a process similar to the first AA, we generated a list of specific chemical and nonchemical alternatives to PFAS (which we call candidate alternatives) to evaluate in the second AA.

This section briefly discusses each candidate alternative we considered. It also briefly explains why we did not consider certain alternatives. Alternatives that are likely more hazardous than PFAS or those that are not found in commercial products were unlikely to be included in this AA.

Candidate alternatives

Types of alternatives to PFAS in food packaging

This AA divides alternatives to PFAS in plant-fiber-based food packaging into three groups: chemical treatments, base materials, and system alternatives. In this assessment, they are defined as:

- **Alternative chemical treatments**: Dry-end coatings or wet-end additives that are applied to the plant-fiber base material to provide oil and grease resistance (OGR) to the product.
- **Alternative base materials**: Primary substrates that are manufactured to provide OGR to the product, either:
    - Plant-fiber based (such as densified paper or paperboard).
    - Non-fiber based (such as plastics and aluminum).
- **System alternatives**: Alternatives that package food in a manner consistent with a specific food packaging application and provide OGR, but are operationally distinct from alternative chemical treatments or base materials. The primary system alternative for this assessment is reusable packaging (such as washable dishes).

We collectively refer to alternative chemical treatments or base materials as alternative substances. The law does not require our AA to include all existing and emerging alternatives, but rather to evaluate "less toxic chemicals and nonchemical alternatives" (RCW 70A.222.070).

Like the first AA, to identify candidate alternatives most likely to meet the criteria for a safer alternative, we used the following principles:

- **Less hazardous alternatives:** We prioritized alternative substances found on the U.S. Environmental Protection Agency's (EPA) Safer Chemicals Ingredients List (SCIL) or

[32] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222

comprised of materials generally known to be of low concern (e.g., paper or other plant fibers).

- **Available alternatives:** We prioritized alternatives used in PFAS-free food packaging products that are widely available in Washington state or in the U.S. An alternative chemical treatment or base material may be used in one or many food packaging applications.
- **Transparency of information:** We prioritized alternative substances with publicly available information about hazard, exposure, performance, and availability.

We did not include end-of-life considerations in our final selection. The end-of-life of a food packaging product—particularly whether it can be composted or recycled—is an important consideration for many food packaging users. Some local governments regulate which food packaging businesses can use based on end-of-life considerations (Seattle, 2009).

Of the candidate alternatives we identified, only a few are designed to be compostable in commercial composting facilities. Others that cannot be composted can be recycled, but only at certain facilities and when the product is completely clean of any food waste. Many alternatives can only be practically disposed in landfills—especially certain chemical alternatives, like plastics that are applied directly to paper or paperboard. Composting and recycling facilities are not available consistently throughout the state, which makes evaluating the end-of-life of these materials difficult.

Addressing food packaging end-of-life is outside the scope of this AA. Instead, we strongly encourage any food packaging manufacturer or end-user aiming to stop using or producing PFAS-containing food packaging to think about disposal for alternative products. We urge those interested in knowing the end-of-life options for specific food packaging materials to contact their local solid waste management services.

Selected candidate alternatives

Using the above criteria, we identified candidate alternatives to evaluate in this AA. We considered the chemical treatment and base material alternatives we included in the first AA in this assessment. In response to stakeholder feedback, we assessed additional plastic base materials (Section 1). We also considered reusable food packaging products.

Chemical treatment alternatives

- Bio-based wax
- Paraffin wax
- Clay
- Polylactic acid (PLA)
- Polyvinyl alcohol (PVOH)
- Ethylene vinyl alcohol copolymers (EVOH)
- Polyethylene (PE)
- Polyethylene terephthalate (PET)
- Siloxanes

Base material alternatives

- Untreated paper (including other untreated plant fibers)
- Densified paper (such as glassine or vegetable parchment)
- Rigid PLA
- PLA foam
- Rigid PE
- Rigid polypropylene (PP)
- Rigid PET
- Aluminum

System alternatives

- Reusable food contact products
    - Reusable rigid plastics
    - Reusable dishware

The candidate alternative substances we propose for this assessment are not a comprehensive list of all possible PFAS-free alternatives available on the U.S. market. For example, several food packaging manufacturers recently introduced molded fiber food packaging products and promoted them as PFAS-free. The manufacturers consider the exact identity of the alternative chemical treatments used in these products proprietary. Without the company disclosing information about the alternative used, we could not assess the products, so we did not include them as potential alternatives.

Substances relevant to candidate alternatives

Certain candidate alternatives use the same alternative substance to replace the function of PFAS. We focused on evaluating the substances below in this AA. FDA has approved all these alternatives—we list relevant approvals for each substance.

- **Untreated paper:** Paper that is manufactured without mechanical or chemical OGR treatments. Products made with this alternative are frequently used to package or serve food. This alternative is approved for use in food packaging and was designated a low hazard concern in the first AA.
- **Densified paper:** We use this term for untreated paper that has OGR properties without the addition of a chemical barrier via the process of mechanical densification, glazing, or machine finishing (DTSC, 2021; Trier et al., 2017). This alternative is approved for used in food packaging and was designated a low hazard concern in the first AA. The paper can be used on its own (e.g. bags) or as the food contact surface of corrugated cardboard products (Ahlstrom Munksjö, n.d.).
- **Wax:** Aqueous dispersion of petroleum or bio-based waxes can be used as a coating on paper or paperboard as a chemical barrier (Trier et al., 2017). These compounds are approved for use in food packaging (21 CFR 176.170; 21 CFR 176.180). Both petroleum-based and bio-based waxes have been designated a low hazard concern in the first AA based on their listing on EPA's SCIL (U.S. EPA, 2021).
- **Clay:** Clay coatings are made using a mineral filler that can be applied as a barrier coating to paper and paperboard—either alone or with binding polymers that create a

matrix around the filler (Chiang et al., 2018; Imerys, 2020; Paltakari et al., 2009). This alternative is approved for use in food packaging, and was designated a low hazard concern in the first AA based on the listing of a common mineral filler, kaolin clay, on EPA's SCIL (21 CFR 176.170; U.S. EPA, 2021).

- **Siloxane compounds:** Siloxane compounds consist of a silicon-oxygen backbone with organic groups attached to the silicon atoms. Paper and paperboard can be coated in siloxane-based polymers to provide a chemical barrier (Trier et al., 2017). Siloxane-coated paper is commonly used in paper wraps and liners, particularly baking papers (Verschueren & Parein, 2018). This alternative is approved for use in food packaging (21 CFR 176.170).
- **Aluminum:** Aluminum metal is used to make many products that come into direct contact with food, including silverware, baking trays, and food packaging (Stahl, 2017a). In this AA, we assessed aluminum foil, which can be used to make food packaging products intended for short-term food storage and transport. Aluminum foil is approved for use in single-use food packaging (WAC 246-215-01115).
    - Certain aluminum products can be manufactured with an additional non-stick coating applied to the food contact surface. We are not evaluating this type of aluminum in this assessment.
- **PVOH:** Polyvinyl alcohol is a polymer made from vinyl acetate. The acetate groups are transformed after polymerization into alcohol functional groups. PVOH is approved for use as a coating on paperboard and in FCNs 1349 and 333 (FDA, 2021; 21 CFR 176.170; 21 CFR 176.180; Kuraray, 2020). PVOH was designated a low hazard concern in the first AA based on its listing on EPA's SCIL (EPA, 2021).
- **EVOH:** Ethylene-vinyl alcohol is a copolymer made from ethylene and vinyl acetate (Robertson, 2012). The acetate groups are transformed after polymerization into alcohol functional groups. EVOH is approved for use as a coating on paper and paperboard under FCN 1179 (FDA, 2021; Kuraray, 2020).
- **PLA:** Polylactic acid is a bio-based plastic made from lactic acid monomers, which can be produced through biomass fermentation (Robertson, 2012). PLA alternatives can be base materials, such as PLA bioplastic or foam, or chemical barriers such as PLA-coated paper and paperboard (Chiang et al., 2018). PLA is approved for use as a food contact material under FCNs 475 and 178 (FDA, 2021).
- **PE:** Polyethylene is a plastic formed from the polymerization of ethylene and includes both high-density PE (HDPE) and low-density PE (LDPE) (Robertson, 2012). In this AA, we assessed both rigid PE packaging and PE-coated paper. PE is approved for use as a food contact material alone, and as a paper coating (21 CFR 177.1520; 21 CFR 176.170).
- **PET:** Polyethylene terephthalate is a plastic formed from the polymerization of bis(2-hydroxyethyl) terephthalate (Robertson, 2012). In this AA, we assessed both rigid PET packaging and PET-coated paper. PET is approved for use as a food contact material alone, and as a paper coating (21 CFR 177.1630; 21 CFR 176.170).
- **PP:** Polypropylene is a plastic formed from the polymerization of propylene (Robertson, 2012). In this AA, we assessed rigid PP packaging, which is approved for use as a food contact material (21 CFR 177.1520).

It is possible some food packaging products made from plastic (such as PLA, PE, PP, or PET) could contain PFAS added to the product as processing aids. However, not all plastics used in food packaging contain PFAS (CEH, 2018). When collecting information about example food packaging products, we confirm with food packaging manufacturers that PFAS were not added as a processing aid.

Alternative substances not currently considered in this AA

Some products are made using multi-layer materials, meaning multiple types of material are laminated together. This is particularly common in packaging used for long-term storage of food, where the packaging must protect the food from moisture, oxygen, and other environmental conditions (Robertson, 2012). Unless noted, we did not consider multi-layer materials in this assessment. The one exception is for coatings manufacturers apply to paper, paperboard, or molded fiber products.

We considered some single-use plastics, but we did not consider polystyrene products. Polystyrene is made using styrene, which is currently listed on California's Prop 65 list as a carcinogen (OEHHA, 2021). Without detailed information on the amount of residual styrene in polystyrene food packaging, it would not pass our evaluation in the hazard module (see Section 4 for more details).

Furthermore, E2SSB 5022,[33] which Governor Inslee signed into law in May 2021, prohibits the sale and distribution of expanded polystyrene food service products beginning June 1, 2024. There is significant overlap between the food service products included in this new law and the food packaging applications included here. Even if we identified expanded polystyrene as a safer alternative, it would soon be banned from use in Washington state.

There are many other alternative substances we could not confirm are used in food packaging products (DTSC, 2019; Glenn et al., 2021; OECD, 2020). Additionally, some substances used in food packaging may contribute to OGR or moisture resistance, but we did not observe them being used instead of PFAS or other chemical treatments (Robertson, 2012; OECD, 2020). We may evaluate these substances in future AAs.

[33] http://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Session%20Laws/Senate/5022-S2.SL.pdf#page=1

Section 4. Hazard Module

Overview

Ecology completed an IC2 Level 2 Hazard Module to determine whether candidate alternatives show potential hazards to human health and the environment that are lower than PFAS. The IC2 Level 2 Hazard Module recommends assessors use GreenScreen® for Safer Chemicals. In this section, we compared PFAS and alternatives to PFAS on the chemical level (see the introduction for a brief definition).

For this hazard assessment, we evaluated substances that replace the function of PFAS, not the formulations of entire food packaging products.

Using assessments of well-characterized PFAS, we determined that PFAS as a class will not meet the GreenScreen® criteria for Benchmark 2 (BM-2) chemicals. Therefore, we consider any alternative substance that scores BM-2 or better in a GreenScreen® (or that earns an equivalent score in another hazard assessment) less hazardous than PFAS.

We developed a tiered approach to implement the IC2 AA Guide. Before completing GreenScreen® or other hazard evaluations, we screened each candidate substance using the GreenScreen List Translator™ methodology and EPA SCIL. We did this to determine whether that chemical was already known to be of high or low concern. We then evaluated all remaining alternatives using GreenScreen® or an equivalent hazard method.

Without information about specific proprietary versions of the candidate alternatives, we evaluated some substances using representative chemicals. This analysis isolates chemical hazards that are common in an alternative substance or previously identified in the substance. The hazard module is not an exhaustive evaluation of all chemical hazards associated with these alternative substances—there are many additives manufacturers can use.

We identified several candidate alternative substances with lower hazard concerns than the evaluated PFAS (Table 12). We list these at the conclusion of this section. We did not further consider candidate alternative substances we identified as not less hazardous than PFAS or those without enough information to assess.

Choice of IC2 AA Guide level

The IC2 AA Guide describes three levels for the Hazard Module:

- **Level 1 Basic Evaluation**: Utilizes the Quick Chemical Assessment Tool to determine if hazards exist for specific hazard criteria using well-defined, readily available data sources.
- **Level 2 GreenScreen® Evaluation**: Uses the GreenScreen® for Hazard Assessment tool (GreenScreen®) to conduct a thorough hazard evaluation. GreenScreen® is a free, publicly available hazard assessment tool.
- **Level 3 Expanded GreenScreen® Evaluation**: Expands on Level 2 by eliminating data gaps and requiring an independent, third-party verification.

Like the first AA, we chose a Level 2 hazard evaluation. This approach provides a thorough and transparent method to evaluate hazard concerns without generating new data (which is required in a Level 3 assessment). The IC2 Level 2 hazard evaluation recommends using GreenScreen®, which evaluates each substance for 18 hazard endpoints. Based on these endpoints, GreenScreen® issues a benchmark score of 1 to 4 for a chemical or substance—with 1 being most hazardous and 4 being least hazardous. To identify substances that are less hazardous than PFAS, we compare these scores (or scores from equivalent hazard assessments) to scores for data rich PFAS.

Hazard assessment methodology

Similar to the first AA, our hazard assessment first screened each candidate alternative substance to determine if it was previously identified as a chemical of low or high hazard concern. For any substance not identified as either, we collected GreenScreen® hazard assessments for relevant chemicals or mixtures to assess the alternative.

In this AA, we also identified additional chemical hazard assessment tools with methods and processes equivalent to GreenScreen®. We also evaluated chemical or substance hazard assessments created using these tools in this report.

Differently from the first AA, in this assessment we compared alternative substances against the hazards of PFAS as a class—rather than against a representative PFAS. In this module, we collected hazard assessments on well-characterized PFAS and used them to understand the hazards associated with PFAS as a class.

Initial search for substances of low or high hazard concern

The candidate alternatives we considered represent a large group of substances covering multiple types of functional alternatives, including alternative materials and chemical barriers. Therefore, we developed a tiered approach to implement the IC2 AA Guide.

First, we used the GreenScreen List Translator™[34] to screen chemicals (CPA, 2018b). This rapid screening tool identifies chemicals of high concern based on their status on authoritative lists—

[34] https://www.greenscreenchemicals.org/images/ee_images/uploads/resources/GS_ListTranslator_Factsheet.pdf

such as the U.S. EPA Priority PBTs chemical list (Annex 11, CPA, 2018a). These lists identify chemicals with human and ecological hazard concerns.

A List Translator score of "LT-1" means the hazard classifications for this chemical meet one or more of the GreenScreen® Benchmark 1 criteria. In this assessment, we designated any substance with a List Translator score of "LT-1" as high concern, and did not evaluate it further.

Next, we screened alternative substances against EPA Safer Chemical Ingredients List (SCIL).[35] SCIL contains chemicals that meet the Safer Choice Criteria for Safer Chemical Ingredients, which is a hazard-based assessment similar to GreenScreen®. Designation on SCIL is based on data-driven assessments conducted by third-party assessors who are verified by the U.S. EPA.

To meet the SCIL master criteria, a chemical cannot be a known or suspected carcinogen, mutagen, or reproductive or developmental toxicant. It cannot have endocrine disrupting properties associated with adverse health outcomes. Toxicity data from the other endpoints (such as systemic toxicity, acute toxicity, and skin and eye sensitization) are compared to thresholds established by the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) and other authoritative bodies.

SCIL also identifies chemicals as "best in class" for a functional use, using specific functional class hazard criteria. One example of this is the polymer criteria. While this criteria deviates slightly from the master criteria, it still does not allow for hazards that would be associated with Benchmark 1 chemicals. Part of the evaluation considers the quantities and known hazards of residual monomers and degradation products in addition to the polymer. These assessments go beyond the minimum data requirements when additional data is available and indicates a concern.

To be protective, we only considered SCIL designations of "green circle" as low concern. These substances did not proceed to a further chemical hazard assessment. SCIL chemicals designated as "half-green circle" or "yellow triangle" (which have specified use restrictions), or those listed under Specialized Industrial Products (SIP) were not considered supportive of low concern designation.

[35] https://www.epa.gov/saferchoice/safer-ingredients

Data needs for a hazard assessment

If we did not identify a substance as being of high or low concern, we evaluated it using GreenScreen® or an equivalent hazard assessment method. Whenever possible, we used publicly available information to conduct our evaluation. To fill gaps in the public dataset, we requested alternative chemical and product formulation information from manufacturers.

We used the following information about alternative substances to collect chemical hazard assessments:

- CASRN and systematic chemical names for alternative substances that provide oil- and grease-resistance function in food packaging.
- Chemical structure (simplified molecular-input line-entry system [SMILES], image) of substances that provide oil- and grease-resistance function in food packaging.
- Polymeric substance information, including:
  - Representative structure
  - Mole ratios of monomers
  - MW_n (molecular weight average)
  - Known residual monomers, oligomers, byproducts, additives, or impurities (>100 ppm [greater than 100 ppm] or 0.01%)
  - Indication as to whether the monomers are blocked
  - Oligomer characterization based on molecular weight (MW)
- Formulation information for barrier coatings, including:
  - Active ingredient or functional additives (substances providing oil- and grease-resistance function)
  - Known byproducts or impurities (>100 ppm [greater than 100 ppm] or 0.01%)

Most of the alternative substances we considered are polymer substances or mixtures of multiple chemicals. For these alternative substances, we used example chemicals or formulations. We also considered common chemicals used to make an alternative substance.

GreenScreen® for Safer Chemicals (GreenScreen®)

The IC2 AA Guide level 2 hazard module recommends using the GreenScreen®[36] methodology to obtain hazard assessments. GreenScreen® evaluates 18 hazard endpoints:

Group I Human

- Carcinogenicity
- Genotoxicity/mutagenicity
- Reproductive toxicity
- Developmental toxicity
- Endocrine activity

Group II and II* Human

- Acute toxicity
- Systemic toxicity (single)
- Systemic toxicity (repeat*)
- Neurotoxicity (single)
- Neurotoxicity (repeat*)
- Skin sensitization*
- Respiratory sensitization*
- Skin irritation
- Eye irritation

Ecotoxicity

- Acute aquatic toxicity
- Chronic aquatic toxicity

Fate

- Persistence
- Bioaccumulation

Physical

- Reactivity
- Flammability

GreenScreen® builds on existing frameworks for comparing chemical hazards, such as GHS and EPA's Design for the Environment (DfE) program, now called Safer Choice. A GreenScreen® assessment uses data from peer-reviewed science, authoritative bodies, and regulatory studies (e.g., studies following Organisation for Economic Cooperation and Development protocols) to assess toxicity. Toxicity data for chemical analogs (which are chemically or biologically suitable substitutes for the chemical under assessment) or modeling data (e.g., the Ecological Structure Activity Relationships Program (ECOSAR) tool) can help fill in data gaps.

The licensed GreenScreen® profiler compiles data and assigns a score for each endpoint based on criteria developed from the GHS and other health and environmental protection agencies (such as EPA). If there are conflicting reports, assessors use a weight of evidence approach based on guidance from the European Chemicals Agency to assign a score (ECHA, 2020). Assessors include the compiled data used to assign scores in the complete GreenScreen® report.

Assessors then use scores for each hazard endpoint to assign a benchmark (BM) score of 1 to 4 for the chemical. A BM-1 stands for "Avoid: Chemical of High Concern" while a BM-4 means "Prefer: Safer Chemical." A Benchmark-U (unknown) score reflects inadequate data to characterize the chemical under the benchmark criteria (CPA, 2018a). BM-2(DG) or BM-3(DG) scores reflect inadequate data to meet the data requirements of a higher benchmark score

[36] https://www.greenscreenchemicals.org/learn/guidance-and-method-documents-downloads

(CPA, 2018a). GreenScreen® assessments that result in scores of BM-U, BM-2, BM-3, or BM-4 expire five years after the assessment date, and the substance must be re-evaluated (CPA, 2019).

A complete GreenScreen® evaluation of a polymer substance requires the molecular weight and structural details of the substance (CPA, 2018a). This evaluation also assesses hazard concerns for breakdown products, impurities, functional additives, and residual monomers (if applicable) present above 100 ppm. The hazard characteristics of a polymer may be different from a monomer, because the polymerization reaction changes the physical characteristics. However, the hazards of the impurities, such as breakdown products and residual monomers, may also influence the benchmark score of the polymer substance if they are present above the concentration threshold.

Evaluating impurities and breakdown products is particularly relevant to this alternatives assessment because these are often the chemicals found in food (Bhunia et al., 2013; Muncke at al., 2020; Till et al., 1987; 21CFR 176.17). For example, food packaging uses PFAS polymers that may have residual chemicals, such as 6:2 FTOH, or degrade into products, such as PFHxA—both of which studies detect in food packaging and may migrate into food (Buck, 2015; Yuan et al., 2016).

Without detailed substance information, we determined whether there was sufficient information to perform a hazard assessment on polymer impurities or breakdown products. Monomers, in particular, are used to compare the relative polymer hazards (Lithner et al., 2011; Rossi & Blake, 2014). Without evaluating an alternative using GreenScreen® or an equivalent hazard assessment (for either the alternative substance or its key components), we could not determine whether it is less hazardous than PFAS.

Equivalent chemical hazard assessments to GreenScreen®

In the first AA, we used GreenScreen® as the only hazard assessment tool. However, in recent years, more hazard assessment methodologies and tools have been developed or revised that are similar to GreenScreen®. We developed a list of requirements to identify which hazard assessment tools provide a similar level of confidence and can be considered equivalent to GreenScreen®. Meeting this list of requirements did not guarantee we included the tool in the assessment.

Requirements for hazard assessment tools

To create these requirements, we reviewed the IC2 AA Guide Hazard Module to determine what elements of GreenScreen® are important for the module. Important elements of the hazard assessment tool include a transparent and standardized hazard assessment method, and scoring system to identify chemicals of high concern and account for data gaps. The IC2 AA Guide also emphasizes the importance of technical experts to conducting these assessments and completing periodic reviews of each.

Using the IC2 AA Guide, GreenScreen® hazard assessment methodology, and our own data transparency needs, we defined the following five requirements for hazard assessment tools:

- **Ingredient disclosure:** All hazard assessments should evaluate, at minimum, the chemicals used in food packaging to function like PFAS, as well as known breakdown products and residual monomers and impurities in concentrations above 100ppm (0.01%). Confidential business information should be reviewed as appropriate.
- **Hazard endpoint transparency and equivalency:** All hazard assessments must include scores for individual human and environmental health hazard endpoints, as well as an evaluation of environmental fate and ecotoxicity.
  - The individual hazard endpoints should be equivalent to the hazard endpoints included in the GreenScreen® method (Comparing hazard assessments using different tools).
  - Ecology must be able to include the individual hazard endpoint scores associated with a chemical or substance in the PFAS AA report. This will enable us to transparently compare hazard assessments generated using different hazard assessment tools.
- **Assessment method transparency and equivalency:** The method and criteria used to score hazard endpoints and chemicals must be publicly available in sufficient detail that it is possible for someone with experience in hazard assessments to replicate the method.
  - Criteria transparency ensures that the conclusions of individual chemical hazard assessments and any comparisons between them are understandable.
  - To be considered equivalent to GreenScreen®, the criteria used should be based on recognized hazard classification methods, such as EPA's DfE or GHS.
- **Transparency in the process for assessment and re-assessment:** The hazard assessment must be conducted by a technical expert. The assessment must clearly communicate who conducted the hazard assessment, when it was completed and if there is an expiration date.
  - An expiration date may not be required if there is sufficient data to determine that the chemical is a high hazard concern (consistent with a score of BM-1 or LT-1).
  - There may be no expiration date for the assessment if the hazard assessment tool includes a process for continually updating the hazard assessment, and Ecology can confirm that the hazard assessment was updated in the last five years.
- **Third-party review:** It must be possible for Ecology (or another government agency) to conduct a review of an unredacted version of the hazard assessment.
  - The assessment must include the individual hazard endpoint scores, along with citations for any data used and an explanation for the score assignment.
  - Unpublished data**:** A review of the assessment may include reviewing any unpublished toxicological data included in the report. (We may make an exception if the documents containing the unpublished data were reviewed in their entirety through a peer review or other independent verification process.)

We were likely to consider a hazard assessment tool equivalent to GreenScreen® if it met all five of these requirements. We identified Scivera GHS+[37] and ChemFORWARD[38] as hazard assessment tools that met the above requirements and have hazard assessment methods and scoring criteria equivalent to GreenScreen®.

Similar to GreenScreen®, the Scivera GHS+ method is based on DfE and GHS, while ChemFORWARD uses the Cradle to Cradle™ Material Health Assessment criteria and GHS to assess chemical hazards. All three tools use publicly available methods that assess individual hazard endpoints and components (including residual monomers and impurities) above a 100 ppm concentration threshold. Each tool derives an overall chemical hazard score from individual scores for multiple human and environmental health hazard endpoints. All three tools include a score for chemicals with too many data gaps for hazard endpoints.

Both ChemFORWARD and Scivera GHS+ store reports in online databases. ChemFORWARD imposes a five-year expiration date on all assessments. Scivera GHS+ updates hazard assessments as new information becomes available—we confirmed the hazard assessments we used in this AA were verified in the last five years (Scivera, 2021d). We also generated a time-stamped summary of the hazard assessment for our records after reviewing it.

Comparing chemicals assessed using different hazard assessment tools

For all chemical and material hazard assessments we used in this AA, we reviewed the full hazard assessment, including scores for individual hazard endpoints. To maximize consistency with the IC2 AA guide, we compared alternatives to PFAS using the GreenScreen® benchmark scoring system.

Similar to GreenScreen®, Scivera GHS+ and ChemFORWARD compare data for individual hazard endpoints against thresholds GHS and other authoritative bodies established. The GHS threshold values, and occasionally the authoritative lists, do not always correspond to the same score for an individual endpoint across the two hazard assessment tools. Therefore, we looked at the data used to score a single hazard endpoint as needed to determine the equivalent hazard endpoint score in the GreenScreen® method.

Whenever we used an equivalent hazard assessment to evaluate a chemical, we reported the individual hazard endpoint scores generated by the original tool and its equivalent hazard endpoint scores using the GreenScreen® methodology. If a correction to any individual hazard endpoint was necessary, we noted which endpoint and our rationale for correcting it in our analysis.

[37] https://www.Scivera.com/ghsplus/

[38] https://www.chemforward.org/our-approach

Assessing PFAS as a class

In this AA, we assessed the hazards of PFAS as a class instead of selecting one or two PFAS to act as chemical comparators. To characterize the hazards of PFAS as a class, we identified PFAS that are data rich, meaning their hazards are well-characterized. We did this to avoid assuming that no data for a PFAS indicates no hazardous properties. Using data rich PFAS, we can establish a threshold score any alternative substance must meet or exceed for us to consider it less hazardous than PFAS as a class.

Many data rich PFAS are perfluoroalkyl acids (PFAAs). PFAAs are extremely persistent chemicals. Studies detect them globally and in many different environmental media (Kwiatkowski et al., 2020). PFAAs have not been shown to degrade or transform under any natural conditions (Ochoa-Herrera et al. 2016; Liou et al., 2010). Several PFAAs demonstrate human and environmental health hazards in addition to extreme persistence (Kwiatkowski et al., 2020).

Although PFAS applied to food packaging are not PFAAs, they are still a source of PFAAs. Side-chain fluorinated polymers (like those currently being phased out of food packaging) are PFAA precursors, compounds that can degrade or metabolize into PFAAs (Balan, 2021). In particular, many of those polymers contain the 6:2 FTOH moiety, which can cleave from the polymer and break down into perfluoroalkyl acids (Li et al., 2017; Rice et al., 2020; Kabadi et al., 2018; Washington et al., 2009).

Some PFAS are less likely to release PFAAs, except under conditions of high heat (Feng et al., 2015; Schlummer et al., 2015). Perfluoropolyethers, which are approved for use in food packaging, are characterized as very stable and highly persistent in the environment (Wang, 2020). Similarly, we received a GreenScreen® assessment for a side-chain fluorinated polymer that referenced unpublished data claiming it was not a source of PFAAs—either due to residual polyfluorinated monomer or monomer precursors or through the degradation of the polymer. We could not review this unpublished data, so we couldn’t verify the claims made in this GreenScreen®, and did not include it in the assessment.

Even when PFAS do not act as a significant PFAA precursor, PFAAs used in the manufacture of these substances still contribute to overall PFAS environmental emissions (Lohmann et al., 2020; Rice et al., 2021). Therefore, although the data rich PFAS that are publicly available in the literature are predominantly PFAAs, we believe the hazards we identified for these compounds illustrate the class as a whole.

Hazard assessment results

Assessing hazards associated with PFAS as a class

Find list of data rich PFAS with existing hazard assessments in Appendix B. This is not meant to be a complete list of PFAS that are regulated. It only summarizes findings from existing hazard assessments of well-characterized compounds. We reviewed publicly available hazard assessments that included data for multiple hazard endpoints. The available information on data rich PFAS consistently show hazards in mammalian species and other organisms. There is inadequate data to suggest other PFAS would differ in this regard.

We identified seven GreenScreen® hazard assessments of PFAS in the ToxServices GreenScreen® Library.[39] All of the assessments were conducted by certified GreenScreen® Profilers and are publicly available. All of the PFAS included in these assessments scored BM-1 using the GreenScreen® methodology.

We identified an additional seven PFAS that are included on authoritative lists and are classified as LT-1 using the GreenScreen® List Translator methodology (Pharos, 2021). A score of LT-1 indicates that if a GreenScreen® assessment were conducted, the chemical would likely score as BM-1.

We included two of these data rich PFAS, 6:2 FTOH and PFHxA, in the first AA as representative PFAS because they are impurities and breakdown products of PFAS used in food packaging. Studies also detect them in food (Boucher et al., 2020; Rice et al., 2020; Yuan et al., 2016).

The data rich PFAS in Appendix B show a range of hazards. All score high or very high for persistence. In addition, the seven data rich PFAS identified as LT-1 are present on authoritative lists due to evidence that they are high human health hazards. The remaining PFAS in Appendix B all score BM-1 due to evidence of very high bioaccumulation or other toxicities (in addition to high persistence).

Persistence and bioaccumulation

High persistence is characteristic of PFAS as a class. All data rich PFAS we identified show high or very high persistence (EC, 2021; UNEP, 2019; ToxServices 2016a, 2016c, 2018a, 2019a, 2019b, 2020a & 2020b).

Certain PFAS, such as 1,1,2,2-Tetrahydroperfluorodecyl acrylate, have high bioaccumulation (ToxServices, 2016a). Others, like 3-Ethoxyperfluoro(2-methylhexane), score very high for bioaccumulation (ToxServices, 2020a).

Authoritative sources list PFOA, PFOS, perfluorononanoic acid, ammonium perfluorooctanoate, potassium perfluorooctanesulfonate, and ammonium perfluorooctanesulfonate as persistent, bioaccumulative, and toxic chemicals (UNEP, 2019).

[39] https://database.toxservices.com/Home/Home/Index

Carcinogenicity

Tetrafluoroethylene has been classified as "probably carcinogenic to humans" (Group 2A) by IARC (IARC, 2017). It is also listed on California's Prop 65 list for carcinogenicity (OEHHA, 2021). In a GreenScreen® hazard assessment, hexafluoropropylene scored high for carcinogenicity—but with low confidence because the score was based on its structural similarity to tetrafluoroethylene (ToxServices, 2018).

Reproductive and developmental toxicity

PFOA, PFOS, perfluorononanoic acid, ammonium perfluorooctanoate, potassium perfluorooctanesulfonate, and ammonium perfluorooctanesulfonate are all found on authoritative lists that indicate a high score for reproductive or developmental toxicity (ECHA 2019, 2021b, & 2021c).

The European Union Classification for the Labeling and Packaging of hazardous chemicals attaches the codes H360 and H362 to PFOA and PFOS, indicating that they may damage fertility or the unborn child, and may cause harm to breast-fed children (ECHA, 2021c). Perfluorononanoic acid is also flagged with the codes H362 and H360f, indicating that it may cause harm to breast-fed children and may damage fertility (ECHA, 2021c).

Systemic toxicity

1,1,2,2-Tetrahydroperfluorodecyl acrylate has been identified as having high repeat systemic toxicity and neurotoxicity, based on studies using surrogate data (ToxServices, 2016a). Polytetrafluoroethylene (PTFE or polytef) scored high for repeated systemic toxicity, based on the potential to cause lung overload following inhalation exposure. The score was based on human reports of occupational exposures to PTFE used in the manufacturing of nonstick cookware (ToxServices, 2019b).

6:2 FTOH scores high for repeated systemic toxicity (ToxServices, 2019a). European Union Classification for the Labeling and Packaging of hazardous chemicals labels PFOA, PFOS, perfluorononanoic acid, ammonium perfluorooctanoate, potassium perfluorooctanesulfonate and ammonium perfluorooctanesulfonate with the code H372, indicating they cause damage to organs through prolonged exposure (ECHA, 2021c).

Skin and eye irritation

Potassium perfluorobutanesulfonate scored high for eye irritation based on measured data from high quality animal studies (ToxServices, 2020b). PFHxA was previously assessed and scored BM-1 because it demonstrated very high skin and eye irritation (ToxServices, 2016c).

European Union Classification for the Labeling and Packaging of hazardous chemicals labels PFOA, perfluorononanoic acid, and ammonium perfluorooctanoate with the code H318, indicating they cause serious eye damage (ECHA, 2021c).

Aquatic toxicity

3-Ethoxyperfluoro(2-methylhexane) scored very high for chronic aquatic toxicity in a previous hazard assessment (ToxServices, 2020a). 6:2 FTOH scores high for chronic aquatic toxicity based on invertebrate data (ToxServices, 2019a).

Summary

The PFAS class contains multiple groups, but the presence of PFAAs as impurities, residuals, and breakdown products within each category unifies hazard concerns. Using this definition and reviewing the data rich chemicals in the class, we find that PFAS consistently demonstrate human and environmental health hazard concerns in addition to their environmental persistence. These health hazards align with a chemical hazard assessment score of BM-1.

There is inadequate data demonstrating other PFAS would not share the hazards identified in Appendix B. Therefore, we conclude that any alternative to PFAS that scores BM-2 or better (using GreenScreen® or an equivalent hazard assessment method) is less hazardous than PFAS as a class.

Substances of high concern identified through GreenScreen List Translator™

We did not identify any candidate alternative substances as LT-1 using the GreenScreen® List Translator™ (Pharos, 2021). This initial screening exercise indicated that all identified substances were eligible for further hazard evaluation.

Substances of low concern identified in the first AA

Several alternative substances were previously identified as low concern and were not evaluated with GreenScreen® (Table 12). Untreated and densified paper, which are non-chemical alternatives to PFAS, are of low concern because they consist of plant-fiber pulps. Three alternative substances, waxes, kaolin clay, and PVOH, are of low concern due to their designation on the U.S. EPA SCIL as a “green circle” (EPA, 2021; Ecology, 2021).

Additional substances of low concern identified

We identified additional alternative substances on SCIL with green circles, indicating they are of low concern. SCIL categorizes these substances as polymers or processing aids. They include polyacrylic acid (CASRN 9003-01-4), sodium polyacrylate (CASRN 9003-04-7), and polypropylene (CASRN 9003-29-6).

Using SCIL, we identified several substances that are relevant to clay coatings as low concern polymers and processing aids. For example, calcium carbonate (CASRN 471-34-1) is a mineral filler that can be used in place of or with clay in clay coatings.

We also identified the following acrylate-methacrylate and methacrylate-acrylate-styrene copolymers that SCIL lists as green circles and that FDA approved for use in paper and paperboard coatings:

- 2-Propenoic acid, 2-methyl-, polymer with butyl 2-methyl-2-propenoate, butyl 2-propenoate, ethenylbenzene and methyl 2-methyl-2-propenoate (CASRN 25950-40-7).
- 2-Propenoic acid, 2-methyl-, polymer with butyl 2-propenoate and ethenylbenzene (CASRN 25036-16-2).
- 2-Propenoic acid, 2-methyl-, polymer with butyl 2-propenoate and methyl 2-methyl-2-propenoate (CASRN 25035-69-2).

- 2-Propenoic acid, 2-methyl-, polymer with butyl 2-propenoate, ethenylbenzene and methyl 2-methyl-2-propenoate (CASRN 25987-66-0).
- 2-Propenoic acid, 2-methyl-, polymer with ethenylbenzene (CASRN 9010-92-8).
- 2-Propenoic acid, 2-methyl-, polymer with ethyl 2-propenoate (CASRN 25212-88-8).
- 2-Propenoic acid, 2-methyl-, polymer with methyl 2-methyl-2-propenoate (CASRN 25086-15-1).

The SCIL evaluation considers the residual monomers and degradation products for their potential hazard.

SCIL also identifies several modified starches or celluloses that may be used in clay coatings as low concern:

- Starch (CASRN 9005-25-8).
- Sodium starch glycolate (CASRN 9063-38-1).
- 2-hydroxypropyl ether starch (CASRN 9049-76-7).
- 2-hydroxyethyl ether starch (CASRN 9005-27-0).
- Carboxymethyl ether starch (CASRN 9057-06-1).
- Sodium carboxymethylcellulose (CASRN 9004-32-4).
- 2-hydroxypropyl methyl cellulose (CASRN 9004-65-3).
- Hydroxyethyl cellulose (CASRN 9004-62-0).
- Hydroxypropyl cellulose (CASRN 9004-64-2).

We discuss these in more detail in the following section.

Clay coatings

Manufacturers apply clay coatings to paper and paperboard to create a smooth and printable surface. They are typically composed of a mineral filler, typically kaolin clay and/or calcium carbonate, and at least one binder, which fills the voids between mineral particles (Andersson, 2008). Alternatively, hyper platy clay can be used without the addition of a binder (Triantafillopoulos & Koukoulas, 2020). When applied, these substances form a barrier on the surface.

We evaluated kaolin clay in the first AA using EPA SCIL, where it is identified as a substance of low concern. Similarly, calcium carbonate (CASRN 471-34-1) is also identified as a substance of low concern based on EPA SCIL listing. Talc (CASRN 14807-96-6) can also be used. Talc—which can be used as a filler alongside kaolin clay and calcium carbonate, but is not required—was previously assessed using the GreenScreen® methodology and scored BM-1 due to very high persistence and high systemic toxicity through repeat exposure (ToxServices, 2019c).

Manufacturers can use many potential binders (when required) to fill the void between filler molecules (Andersson, 2008; Paltakari et al., 2009; Triantafillopoulos & Koukoulas, 2020). Some—such as synthetic resins made primarily using styrene (CASRN 100-42-5) or maleic anhydride (CASRN 108-31-6) as a comonomer—may not be less hazardous than PFAS due to concerns associated with these monomers (Pharos, 2021). Many others—such as PVOH, certain modified starches, and acrylate-based polymers, including some acrylate polymers made with styrene comonomers—are listed on EPA SCIL as green circles, indicating they meet the functional class criteria for polymers and are of low concern. Others, like carboxymethylcellulose, are not well-characterized.

Depending on the clay coating, manufacturers add the filler in equal or larger amounts than the binder (Andersson, 2008; Paltakari et al., 2009). In the first AA, our evaluation found that clay coatings were less hazardous based on an analysis of kaolin clay as a filler. Here, we found further evidence indicating that even when a binder is required or other fillers are added, clay coatings can be manufactured using component chemicals identified as low concern. We therefore determined that clay coatings are still substances of low concern (Table 12).

Siloxanes

We identified siloxanes as a possible alternative substance in this AA. In the first AA, we used vinyl dimethylsiloxy-terminated polydimethylsiloxane (CASRN 68083-19-2) to evaluate siloxanes used in alternative food packaging products. A publicly available GreenScreen® scored this chemical Benchmark 1 (ToxServices, 2014). In the absence of new data on other siloxanes that are relevant to food packaging, we conclude that siloxanes are not less hazardous than PFAS (Table 12).

Aluminum

The aluminum metal used to make aluminum foil—which can be used in food packaging as either a flat sheet or formed in foil containers—is an alloy of aluminum and small amounts of other metals (Robertson, 2012). Alloys commonly used to make aluminum foil will make up less than one percent of the total metal, and include silicon, iron, zinc, or manganese (Robertson, 2012). Some rigid aluminum foil containers are 98 percent aluminum, with manganese making up the bulk of the alloying metal (Robertson, 2012). There is no publicly available hazard assessment for manganese (Pharos, 2021).

A GreenScreen® hazard assessment of aluminum metal (CASRN 7429-90-5) scored it as BM-1 (ToxServices, 2016b). The assessment characterized the element as having very high persistence, very high aquatic toxicity, and high respiratory sensitization. The respiratory sensitization endpoint was based on the occurrence of asthmatic reactions in aluminum workers, although these could not be linked conclusively to aluminum. A subset of toxicity studies done using powdered aluminum identify acute and chronic aquatic toxicity in (ToxServices, 2016b).

The exact species and solubility of aluminum depends highly on pH and other environmental factors, which complicates the interpretation of aquatic toxicity data (ECHA, 2021a). The REACH dossier on aluminum notes that when aluminum ions release to surface water, they should quickly form insoluble aluminum hydroxides in mixing zones. While these hydroxides can lead to toxicity, these mixing zones in water are not typical, which limits the relevance of these forms of aluminum to estimate intrinsic aquatic toxicity (ECHA, 2021a).

The REACH dossier on aluminum minimizes the importance of the studies used in this hazard assessment (ECHA, 2021a). If the aquatic toxicity score were lowered, then the hazard endpoints for aluminum would be consistent with a BM-2 chemical.

Data from surrogates—aluminum oxide (CASRN 1344-28-1) and aluminum hydroxide (CASRN 21645-51-2), two common insoluble salts of aluminum that were used in the aluminum GreenScreen®—did not indicate aquatic toxic properties of concern (ToxServices, 2016b). Aluminum oxide films form on the surface of aluminum in the presence of air or water, meaning aluminum oxide is the material that makes direct contact with food when rigid aluminum foil containers are used (Robertson, 2012). We reviewed a hazard assessment of aluminum oxide to add clarity to our evaluation of aluminum.

In 2018, a publicly available GreenScreen® hazard assessment of aluminum oxide scored it BM-2 (WAP Sustainability Consulting, 2018). This GreenScreen® expired in April 2021. However, aluminum oxide scored yellow in a Scivera GHS+ assessment which was verified in 2020 (Table 4) (Scivera, 2020a). The individual hazard endpoint scores also align with GreenScreen® BM-2 scores (Table 5). Both the GreenScreen® and Scivera GHS+ hazard assessments score aluminum oxide as low or moderate for aquatic toxicity, using the same REACH dossier data for aluminum aquatic toxicity (ECHA, 2021a).

Table 4. Scivera GHS+ hazard endpoint scores for aluminum oxide and polyolefin additives.

Chemical (CASRN)	Carcinogenicity	Genotoxicity/ Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Toxicity - Dermal	Acute Toxicity - Oral	Acute Toxicity - Inhalation	Systemic Toxicity (single and repeat dose)	Neurotoxicity (single and repeat dose)	Dermal Sensitization	Respiratory Sensitization	Dermal Irritation	Eye Irritation	Sensory Irritation	Aspiration Potential	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation	Reactivity	Flammability
Aluminum oxide (non-fibrous) (1344-28-1)	G	G	G*	G*	DG	G*	G	G	Y*	Y*	G	Y*	G	G	Y*	G*	G*	Y*	B*	G*	G*	G*
Butylated hydroxytoluene (128-37-0)	Y	G	Y	Y	Y*	G	Y	DG	B*	G	Y*	G*	G	Y	Y	G*	B	B	R*	R	G*	G
Cyclic neopentanetetrayl bis(octadecyl phosphite) (3806-34-6)	Y*	G*	G	G	DG	G	G	DG	G	DG	G	DG	G*	Y*	DG	G*	G	Y*	R*	G*	G*	G
Triisopropylamine (122-20-3)	G*	G	G	G	DG	G	G*	G*	Y	Y*	G	DG	Y	B	Y	G*	Y	Y*	Y*	G	Y*	G
1,3,5-trimethyl-2,4,6,-tris-(3,5-di-t-butyl-4-hydroxybenzyl)-benzene (1709-70-2)	G	G	G	G	DG	G	Y	DG	G	DG	G*	DG	G	G	Y*	G*	G	G	B	G	G*	G
Tris(2,4-di-tert-butylphenyl) phosphite (31570-04-4)	G*	G	G	G	DG	G	G*	G*	G	G	G	G*	G	G	G*	G*	Y*	Y*	B	G	G*	G

Chemical (CASRN)	Carcinogenicity	Genotoxicity/ Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Toxicity - Dermal	Acute Toxicity - Oral	Acute Toxicity - Inhalation	Systemic Toxicity (single and repeat dose)	Neurotoxicity (single and repeat dose)	Dermal Sensitization	Respiratory Sensitization	Dermal Irritation	Eye Irritation	Sensory Irritation	Aspiration Potential	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation	Reactivity	Flammability
Distearyl thiodipropionate (693-36-7)	G*	G	G*	G	DG	G	G	DG	G	DG	G	DG	G	G	DG	G*	G	G	Y	G*	G	G
Ethylene distearamide (110-30-5)	G*	G	G*	G*	DG	G	G	G	G	DG	G*	DG	G*	Y*	Y*	G*	G*	Y*	R*	G	Y*	G*

Table notes:

- We retrieved assessments from the Scivera database in October 2021.
- **Scores marked with an asterisk** = endpoint was scored using computer modeling, analogous data, and/or expert judgement by the Scivera toxicology team.

Table 5. Equivalent GreenScreen® hazard endpoint scores for aluminum oxide and polyolefin additives.

Chemical (CASRN)	Carcinogenicity	Genotoxicity/ Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Toxicity	Systemic Toxicity (single and repeat dose)	Neurotoxicity (single and repeat dose)	Skin Sensitization	Respiratory Sensitization	Skin Irritation	Eye Irritation	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation	Reactivity	Flammability	Benchmark Score
Aluminum oxide (non-fibrous) (1344-28-1)	L	L	L *	L *	DG	L	M*	M*	L	M*	L	L	L *	M*	vH *	L *	L *	L *	Consistent with BM-2
Butylated hydroxytoluene (128-37-0)	M	L	M	M	M*	M	vH *	L	M*	L*	L	M	vH	vH	H*	H	L*	L	Consistent with BM-1
Cyclic neopentanetetrayl bis(octadecyl phosphite) (3806-34-6)	M*	L*	L	L	DG	L	L	DG	L	DG	L*	M*	L	M*	H*	L*	DG	M*	Consistent with BM-2
Triisopropylamine (122-20-3)	L*	L	L	L	DG	L	M	DG	L	DG	M	vH	M	M*	M*	L	M*	L	Consistent with BM-2
1,3,5-trimethyl-2,4,6,-tris-(3,5-di-t-butyl-4-hydroxybenzyl)-benzene (1709-70-2)	L	L	L	L	DG	M	L	DG	L*	DG	L	L	L	L	vH	L	L*	L	Consistent with BM-2
Tris(2,4-di-tert-butylphenyl) phosphite (31570-04-4)	L*	L	L	L	DG	L	L	L	L	L*	L	L	M*	M*	vH	L	L*	L	Consistent with BM-2
Distearyl thiodipropionate (693-36-7)	L*	L	L*	L	DG	L	L	DG	L	DG	L	L	L	L	M	L*	L	L	Consistent with BM-3
Ethylene distearamide (110-30-5)	L*	L	L*	L*	DG	L	L	DG	L*	DG	L*	M*	L*	M*	H*	L	M*	L*	Consistent with BM-2

Table notes:

- **Scores marked with an asterisk** = endpoint was scored in Scivera using computer modeling, analogous data, and/or expert judgement by the Scivera toxicology team.
- The three exposure-based endpoints for acute toxicity were combined into one score.
- Systemic toxicity and aspiration potential endpoints were combined.
- The neurotoxicity endpoint for triisopropylamine (CASRN 122-20-3) was scored using data from single-exposure studies. The GreenScreen® methodology requires data for repeat-exposure neurotoxicity studies. In their absence, the endpoint is counted as a data gap.

Based on our review of aluminum oxide and additional considerations around the aquatic toxicity of insoluble aluminum, we conclude that the hazard endpoints of aluminum used in food packaging align with a BM-2 score. Aluminum containers are therefore a less hazardous alternative to PFAS (Table 12). We further evaluate this substance in the exposure module.

Plastics and bioplastics

Several candidate alternatives in this AA are plastics or plastic-coated paper, paperboard, or molded fiber. Plastics are a group of polymers that manufacturers can process into a variety of forms (Robertson, 2012). While most plastic polymers show high persistence, some plastics such as PLA are designed to degrade, particularly in certain environments (Hahladakis et al., 2018).

Like other polymers, plastics are a mixture of polymer chains, impurities such as unreacted monomers and oligomers, functional additives, and degradation products (Hahladakis et al., 2018; Lithner et al., 2011; Wiesinger et al., 2021). The identity and concentration of these chemicals varies between plastics, and sometimes between product formulations of the same plastic. Manufacturers consider the product formulations used to make plastics for food packaging applications trade secrets. Chemical information specific to the polymer, such as molecular weight (MW), is also considered proprietary.

Like all polymer substances used in food contact materials, the lower MW impurities, additives, and degradation products are of potential concern, because they can more easily migrate into food (Bhunia et al., 2013; Groh et al. 2019; Lithner et al., 2011; Till et al., 1987). Studies show monomers, oligomers, antioxidants (which reduce UV or oxidative damage to the plastic), and plasticizers (which improve the workability of a plastic) migrating from food contact plastic to food or food simulants (Aurisano et al., 2021; Bhunia et al., 2013; Muncke et al., 2020).

A recent effort to aggregate hazards associated with chemicals used in plastic packaging identified 906 chemicals likely associated with plastic packaging, and 3,377 substances potentially associated (Groh et al., 2019). The authors acknowledged many data gaps hindering a comprehensive hazard assessment of specific plastics.

Without specific product information, it is difficult to identify the exact polymer impurities, additives, or breakdown products that are present above the 100 ppm threshold used in GreenScreen® evaluations. Many impurities and additives that migrate from a specific food packaging material into food are not characterized, or the information is not publicly available (Groh et al., 2019; Muncke et al., 2020).

In the absence of specific plastic packaging formulations for some candidate alternatives, we assessed the hazards of chemical components of the polymers that are likely found in food packaging. In all cases, we considered the monomers and likely catalysts. We also included additives these alternatives use, which may migrate into food. We assumed all components of these generic formulations were present at concentrations above 100 ppm, unless available literature indicated otherwise.

Microplastic particles produced by plastic products are an emerging environmental health concern. Although there is no standard definition, microplastic is any piece of plastic between one nanometer and five millimeters along its longest axis (GESAMP, 2015). Plastic food packaging most commonly produces inadvertent microplastic particles after disposal, when the plastic is exposed to solar UV radiation and becomes brittle. If the plastic product becomes sufficiently brittle, a variety of environmental forces such as wind, waves, or gravity may fragment the plastic (GESAMP, 2015). These inadvertent microplastic particles can transport through the air or waterways and animals or people can ingest them.

Microplastic particles represent an additional exposure pathway, rather than an intentionally added chemical in a plastic substance. We did not identify any relevant inadvertent microplastic particles on any of the authoritative lists the GreenScreen® methodology recommends for unintentionally added substances. We consider microplastics further in the Exposure Assessment Module for those plastic substances that required the evaluation.

Polylactic acid

Polylactic acid is a bio-based plastic made from lactic acid monomers, which can be produced through biomass fermentation (Robertson, 2012). PLA alternatives can be base materials, such as PLA bioplastic or foam, or chemical barriers, such as PLA-coated paper and paperboard (Chiang et al., 2018; DTSC, 2021).

We assessed PLA in the first AA. PLA is a high MW polymer (typically greater than 100,000 Daltons (Da)) with low bioavailability (Ecology, 2021). Chemical exposure from plastic food packaging is likely to come from impurities, additives, and degradation products (Bhunia et al. 2013; Masutani & Kimura, 2014; Till et al. 1987). The hazard evaluation focused on chemicals used to make PLA that may migrate from the polymer into food.

Our hazard assessment of residual monomers, breakdown products, and potential additives of PLA found that these components are generally of low hazard concern (Ecology, 2021). A common catalyst of PLA was identified as a BM-1 chemical. However, it is used at a final concentration lower than would impact a hazard assessment for PLA. Looking at all components of PLA, we determined that the polymer would likely score BM-3 using the GreenScreen® methodology. This determination is consistent with the benchmark scores Natureworks reports for a number of their PLA polymer formulations, although Ecology did not review those hazard assessments.

We did not receive additional information regarding specific PLA formulations used in food packaging. However, in 2021, ChemFORWARD contracted a hazard analysis of a theoretical PLA polymer with a 250,000 Da molecular weight (NSF, 2021). For this hypothetical polymer, the assessors assumed:

- No monomers, additives, or impurities were present at concentrations above 100 ppm.
- No oligomers under 500 Da were present at concentrations above two percent by weight.
- No oligomers under 1000 Da were present at concentrations above five percent by weight.

The assessors used physical and chemical information about PLA, as well as toxicological evaluations of lactic acid, to evaluate the polymer. This assessment did not identify any hazard endpoints of concern, with the exception of persistence, since the polymer degrades only in certain specialized environments. PLA therefore scored as Band B, consistent with a BM-3 GreenScreen® score.

Based on information we collected in the first AA and ChemFORWARD's assessment of the PLA polymer, we find that PLA's known hazards align with a BM-3 score (Table 12).

Polyolefins

Polyolefins are a group of polymers made from hydrocarbon chains. Polyethylene (PE) and polypropylene (PP) are two types of polyolefin manufacturers commonly use in food packaging products. Owing to their chemical similarity, many of the same additives are used for these compounds. As part of our hazard assessment of PE and PP as alternative substances, we identified a number of monomers, catalysts, and additives that can be used in polyolefins. In this section, we evaluated the hazards of those chemical components, such as additives, that are likely found in both PE and PP.

The polyolefins we evaluated showed a MW range of 10,000 to 200,000 Da (ILSI, 2003). Although this is a wide range, we expect these polymers to have low bioavailability based on MW (EPA, 2013). Therefore, we focused our evaluation on those components of polyolefins that may be present in PE and PP, and that we expect to have molecular weights at or below 1,000 Da.

All forms of polyolefins are capable of producing oligomers below 1,000 Daltons (ILSI, 2003). These oligomers are produced both during the polymerization process and also as a result of polymer oxidation. Studies show that these oligomers are commonly branched or linear alkanes, and are capable of migrating from packaging into food (Biedermann-Brem et al., 2012; Pack et al., 2020).

The toxicity of these specific oligomers is not well-characterized (Hoppe et al., 2016). Without specific data, we compared these oligomers to mineral oil saturated hydrocarbons, which are similarly complex mixtures of saturated hydrocarbon chemicals (Biedermann-Brem et al., 2012).

Previous mineral oil assessments determined that for certain hazard endpoints, such as carcinogenicity, the hazard concern depends on how highly treated the mineral oil is (IARC, 2018). Untreated mineral oil contains larger amounts of polycyclic aromatic hydrocarbons and other impurities in addition to mineral oil saturated hydrocarbons, which increase the carcinogenic potential of the mineral oil (IARC, 2018). Polycyclic aromatic hydrocarbons are not expected to be representative of polyolefin oligomers (Biedermann-Brem et al., 2012; Lommatzsch et al., 2016).

Highly treated mineral oil has these polycyclic aromatic hydrocarbons and other impurities removed (IARC, 2018). EPA assessed this purified form of mineral oil as a solvent, and listed it as a green circle compound. With the understanding that oligomers produced by polyolefins are more similar to highly treated mineral oil than mineral oil that contains impurities or polycyclic aromatic hydrocarbons, we use this EPA SCIL classification to characterize the oligomers as low concern (Table 7).

Antioxidants are added to polyolefins to prevent polymer breakdown from exposure to UV light, typically at concentrations up to 5,000 ppm (21 CFR 178.2010). There are many antioxidants manufacturers can add to polyolefins for this purpose. We obtained chemical hazard assessments for several antioxidants. These compounds vary in terms of chemical hazard.

Certain antioxidants that are approved for use in polyolefins and that come into contact with food were previously identified as chemicals of concern. Tris(nonylphenyl) phosphite (TNPP, CASRN 26523-78-4) is an antioxidant identified as LT-1 (Pharos, 2021). Due to endocrine disrupting properties of concern, TNPP is included as a candidate on the Substances of Very High Concern list (ECHA, 2019).

Additionally, butylated hydroxytoluene (BHT) scored BM-1 in a GreenScreen® assessment (Pharos, 2021). We could not access the GreenScreen® evaluation, but we reviewed a Scivera GHS+ hazard assessment of the same chemical, which scored it red for high persistence and bioaccumulation and very high aquatic toxicity (Table 4; Scivera, 2020b). This score aligns with a BM-1 score (Table 5).

However, we also identified several other antioxidants used in polyolefins with chemical hazard assessments that are consistent with a score of BM-2 or BM-3 using either Scivera GHS+ or GreenScreen® (Groh et al., 2019).

Cyclic neopentanetetrayl bis(octadecyl phosphite), tris(2,4-di-tert-butylphenyl) phosphite, triisopropanol amine, and 1,3,5-trimethyl-2,4,6,-tris-(3,5-di-t-butyl-4-hydroxybenzyl)-benzene were all evaluated by Scivera GHS+ and scored yellow (Table 4) (Scivera, 2021a; Scivera, 2021e; Scivera, 2021f; Scivera, 2021g). We found the individual hazard endpoints for these chemicals to be consistent with BM-2 (Table 5).

We also reviewed a Scivera GHS+ chemical hazard assessment for distearyl thiodipropionate. This chemical scored yellow/green (Scivera, 2021b). After reviewing the hazard assessment, we identified it as consistent with BM-3 (Table 5).

Finally, we contracted GreenScreen® hazard assessments for two additional antioxidants that studies previously detected in polyolefins—octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate and dilauryl thiodipropionate (Groh et al., 2019). Using the GreenScreen® methodology, octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate scored BM-2 (ToxServices, 2021h; Table 6). Dilauryl thiodipropionate scored BM-3(DG) because its hazard endpoints aligned with a score of BM-4, but it had impermissible data gaps for endocrine activity and repeated dose neurotoxicity (Table 6) (ToxServices, 2021c).

Table 6. GreenScreen® hazard assessments of chemicals identified in PE and PP used in food packaging.

Chemical (CASRN)	Carcinogenicity	Genotoxicity/Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Toxicity	Systemic Toxicity (single)	Systemic Toxicity (repeat*)	Neurotoxicity (single)	Neurotoxicity (repeat*)	Skin Sensitization*	Respiratory Sensitization*	Skin Irritation	Eye Irritation	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation	Reactivity	Flammability	Benchmark Score
Ethylene (74-85-1)	M	L	L*	L*	DG	L	DG	L	M*	L	L*	L*	L*	L*	M*	M*	L*	vL	L*	vH	**BM-2**
Propylene (115-07-1)	L	L	L*	L	DG	L	L	L	M	DG	L*	L*	L*	L*	M*	M*	L*	vL	L*	vH	**BM-2**
Erucamide (112-84-5)	L*	L	DG	L	DG	L	L	L	L*	L	L	L*	L	L	L*	L	L	L*	L*	L	**BM-2(DG)**
Octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)proprionate (2082-79-3)	L	L	L*	M*	DG	L	L	M	M*	L*	L	L*	L	L	L	L*	vH*	M*	L*	L	**BM-2**
Dilauryl thio-diproprionate (123-28-4)	L*	L	L*	L	DG	L	L	L	L*	DG	L	L*	L	L	L	L*	L	vL*	L*	L	**BM-3(DG)**
Benzoyl peroxide (94-36-0)	L	L	L*	M*	DG	L	M	L	L*	DG	H	DG	L*	H	vH	vH	vL	vL	vH	L*	**BM-2**
2,2'-azoisobutyro-nitrile (78-67-1)	M*	L	L*	L	DG	M	DG	M*	DG	L*	L	L*	L	L	H	M*	H*	vL	H	L*	**BM-2**

Table 7 summarizes the findings of these hazard assessments. Based on available chemical hazard assessments for potential polyolefin antioxidants, several antioxidants can stabilize polyolefins without adding chemicals of high hazard concern. While a few chemicals show hazards consistent with BM-1 chemicals, we did not find any evidence that these antioxidants are required for certain uses of polyolefins. Since several other antioxidants show hazards that align with BM-2 or BM-3 chemicals, we conclude that manufacturers can incorporate antioxidants into polyolefins without making the plastic materials consistent with BM-1 substances.

Slip agents can also be added polyolefins to lubricate film surfaces and prevent sticking (Hahladakis, 2018). They may also function as anti-static agents. The slip agent and anti-static agent erucamide was previously found in polyolefin films (Cooper & Tice 1995; Dopico-García et al., 2007). Using the GreenScreen® methodology, erucamide scored BM-2(DG)—with hazard endpoint scores aligning with BM-4, but impermissible data gaps for reproductive toxicity and endocrine activity (Table 6) (ToxServices, 2021d).

Additionally, we reviewed a chemical hazard assessment for ethylene distearamide, another slip agent the Scivera GHS+ methodology assessed (Groh et al., 2019). This chemical scored yellow due to high persistence and moderate aquatic toxicity (Scivera, 2021c). We found the individual hazard endpoints in this assessment to be consistent with a BM-2 score using the GreenScreen® methodology (Table 7).

We used the results of these assessments for additives and oligomers of polyolefins to assess PE and PP in the next two sections.

Table 7. Oligomers and additives of polyolefins with current chemical hazard assessments.

Chemical (CASRN)	Relation to polyolefin	Hazard concern
Polyolefin oligomers (by analogy to highly treated mineral oil)	Oligomer	U.S. EPA SCIL Green Circle
Butylated hydroxytoluene (128-37-0)	Antioxidant	Consistent with BM-1
Tris(nonylphenyl)phosphite (26523-78-4)	Antioxidant	LT-1
Octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate (2082-79-3)	Antioxidant	BM-2
Cyclic neopentanetetrayl bis(octadecyl phosphite) (3806-34-6)	Antioxidant	Consistent with BM-2
Triisopropylamine (122-20-3)	Antioxidant	Consistent with BM-2
1,3,5-trimethyl-2,4,6,-tris-(3,5-di-t-butyl-4-hydroxybenzyl)-benzene (1709-70-2)	Antioxidant	Consistent with BM-2
Tris(2,4-di-tert-butylphenyl) phosphite (31570-04-4)	Antioxidant	Consistent with BM-2
Dilauryl thiodipropionate (123-28-4)	Antioxidant	BM-3(DG)
Distearyl thiodipropionate (693-36-7)	Antioxidant	Consistent with BM-3
Erucamide (112-84-5)	Slip agent	BM-2(DG)
Ethylene distearamide (110-30-5)	Slip agent	Consistent with BM-2

Polyethylene

Polyethylene (PE) is a type of polyolefin. In food packaging, manufacturers commonly turn it into thin films, blow it into bottles, or apply it as a coating to paperboard or other substrates (Robertson, 2012). The composition of monomers, catalysts, and additives used in PE will vary both with the type of PE and the final food packaging product. We did not evaluate polymer films or bottles in this AA.

PE in its simplest form is the polymerization of ethylene gas at elevated temperatures and pressures. PE is divided into categories based on the final density of the polymer. High density PE (HDPE), low density PE (LDPE), and linear low density PE (LLDPE) are the most commonly used in food packaging (Robertson, 2012). LDPE and LLDPE have similar densities, but LLDPE shows less branching within the polymer chain. HDPE and LLDPE are produced by polymerizing ethylene with longer chain alkenes (such as 1-hexene) to reduce branching (ILSI, 2003).

Certain forms of PE are more common in the food packaging applications we assess in this AA. HDPE is a common plastic used to package food, but we did not observe significant amounts of single-use HDPE food packaging intended for short-term storage or food service. Therefore, we focused our evaluation of PE on LDPE and LLDPE.

LDPE and LLDPE are both used to coat paperboard, although LDPE is more common (Robertson, 2012). In extrusion coating, plastic pellets are heated under pressure until they melt into a viscous substance that can be applied to paperboard. The plastic penetrates into pores in the paper, which helps to adhere the coating without additional adhesives. This process works best with rougher surfaces, such as those found on kraft board (Robertson, 2012, Qenos, 2015a). It is possible to use extrusion coating to create an LDPE barrier on paperboard without additives like antioxidants or slip agents, although it is unclear how often this occurs (Lyondell Basel, n.d.).

Low-density polyethylene (LDPE)

The molecular weight of LDPE used in food packaging ranges from 10,000 to 50,000 Daltons (ILSI, 2003). LDPE is typically formed by reacting ethylene gas with oxygen or a peroxide catalyst. Using GreenScreen® methodology, ethylene scored BM-2 (Table 6) (ToxServices, 2021e). We evaluated two common catalysts, benzoyl peroxide and 2,2'-azobisisobutyronitrile, using the GreenScreen® methodology, and both scored BM-2 (Table 6) (ToxServices, 2021a; ToxServices, 2021b).

Propylene may also be added to control the amount of branching and the average MW (Lithner et al., 2011). The GreenScreen® methodology scored propylene BM-2 (Table 6) (ToxServices, 2021g).

Generally, lower density PE has higher degrees of chemical migration, which could increase exposure to chemicals of high concern (Till, 1987; Bhunia et al., 2013). PE most commonly requires antioxidants and slip agents be added to the plastic (Groh et al., 2019; ILSI, 2003).

The antioxidants and slip agents in Table 7 could all be used in LDPE. Based on our assessment of the monomers, catalysts, oligomers, and additives, we find that LDPE aligns with a score of BM-2 (Table 8). Based on the available data, we conclude that LDPE polymers can be manufactured as a less hazardous alternative than PFAS (Table 12). We consider the relative exposure potential of LDPE in the exposure evaluation module.

Table 8. Additional components of PE with current chemical hazard assessments (see Table 7 for additives).

Chemical (CASRN)	Relation to PLA	Hazard Concern
Ethylene (74-85-1)	Monomer	BM-2
Propylene (115-07-1)	Chain transfer agent	BM-2
Benzoyl peroxide (94-36-0)	Catalyst	BM-2
2,2'-azobisisobutyronitrile	Catalyst (alternate)	BM-2

Linear low-density polyethylene (LLDPE)

LLDPE generally has a higher molecular weight that LDPE, ranging from 50,000 to 200,000 Da in food packaging products (ILSI, 2003). LLDPE is formed by reacting ethylene gas with a low percentage of an alkene co-monomer such as 1-butene, 1-hexene, or 1-octene (Lithner et al., 2011). LLDPE is expected to use similar additives to LDPE.

The reaction is catalyzed by a Ziegler-Natta catalyst, which can be formed from titanium tetrachloride (CASRN 7550-45-0) and triethyl aluminum (CASNRN 97-93-8) (Lithner et al., 2011). Metallocene catalysts—metal-organic complexes made using zirconium or titanium and further complexed with methylaluminoxane—may also be used to increase LLDPE molecular weight and decrease the presence of low molecular weight oligomers (Kaminsky, 2004).

Little toxicity information is publicly available for Ziegler-Natta or metallocene catalysts. Metallocene catalysts are used in concentrations well below 100 ppm, indicating toxicological data for metallocene catalysts would likely not influence an assessment of LLDPE (Kaminsky, 2004; Shamiri et al., 2014). However, it is unclear how often metallocene catalysts are used instead of Ziegler-Natta catalysts to polymerize LLDPE.

Although our analysis of LDPE suggests that the hazards of LLDPE additives and oligomers are likely consistent with a BM-2 substance, we could not evaluate the hazards of any potential alkene co-monomers for this report. Without this information and other details on the catalysts, we did not have enough information to assess LLDPE in this AA (other forms of PE; Table 12). Therefore, we did not evaluate this alternative in later evaluation modules.

Polypropylene (PP)

PP is a polyolefin plastic formed by the polymerization of propylene. The plastic consists of long saturated hydrocarbon chains with branching methyl groups at regular intervals. Typical molecular weights range from 50,000 to 200,000 Da (Shamiri et al., 2014), indicating low bioavailability. The configuration of methyl groups along the chain determines the physical properties of the plastic substance. Certain catalysts, such as Ziegler-Natta or metallocene catalysts, are required to ensure that isotactic PP (the form of PP used to manufacture food packaging) is formed (Robertson, 2012).

PP homopolymer (CASRN 9003-29-6) is listed on EPA Safer Chemicals Ingredient List as a green circle, indicating the polymer is of low concern. However, the PP used to make rigid containers often includes additives we identified for polyolefins above, which may impact its potential toxicity. We consider those here.

Similar to LLDPE, PP can be catalyzed using a Ziegler-Natta or metallocene catalyst. Manufacturers use metallocene catalysts more often in the production of PP for food packaging (Robertson, 2012; 21 CFR 177.1520). These catalysts are used in concentrations well below 100 ppm, indicating toxicological data for metallocene catalysts would likely not influence an evaluation of polymer hazard endpoints (Kaminsky, 2004; Shamiri et al., 2014).

Ethylene may be used as a co-monomer to make the plastic more malleable, particularly when the resulting polymer will be used in injection molding—where PP is heated to a molten state and cast into a 3D structure (ILSI, 2002). The GreenScreen® methodology scored ethylene BM-2 (Table 6). PP oligomers were found to be consistent with highly treated mineral oil, which is listed on EPA SCIL as a green circle substance (Table 7).

Additives like antioxidants and other UV stabilizers, slip agents, and sometimes anti-static agents are mixed in with PP to stabilize the polymer or make it easier to handle (Bhunia et al., 2013; Hahladakis et al., 2018; ILSI, 2002). The antioxidant and slip agents in Table 7 could all be used in LDPE. Based on our assessment of the monomers, oligomers, and additives, of PP, we conclude that the PP used in rigid food packaging aligns with a BM-2 score (Table 9). This score indicates that PP is a less hazardous alternative than PFAS (Table 12). We consider the relative exposure potential of PP in the exposure evaluation module.

PP-talc composite plastics

A subset of rigid PP containers use large quantities of talc (CASRN 14807-96-6) as a filler (PP-talc composites). Using talc both reduces the amount of PP needed, lowering costs, and also alters the mechanical properties (Jilken, Malhammar, & Selden, 1991). We noted PP containers intended for food contact with talc well in excess of 100 ppm. The GreenScreen® methodology scored talc BM-1 (ToxServices, 2019c). PP-talc composites are not less hazardous than PFAS. Therefore, we will not evaluate them in later evaluation modules.

Table 9. Additional components of PP with current chemical hazard assessments (see Table 7 for additives and oligomers).

Chemical (CASRN)	Relation to PLA	Hazard concern
Propylene (115-07-1)	Monomer	BM-2
Talc (14807-96-6)	Filler	BM-1

EVOH

Manufacturers typically apply EVOH as a barrier layer on paper, paperboard, or plastic food contact surfaces (FDA, 2021; Kuraray, 2020). For this AA, we are evaluating EVOH when it is used as an independent barrier layer on paper. We contracted an assessment of the Exceval HR-3010 coating film using the GreenScreen® methodology (ToxServices, 2021f). The coating scored BM-3, indicating it is of low concern (Table 10). The molecular weight of this polymer is over 40,000 Da. No catalysts or residual monomers are present at thresholds that require additional analysis, and no known degradation products are expected to impact the score (ToxServices, 2021f).

Table 10. GreenScreen® hazard assessment of an EVOH coating film.

Chemical (CASRN)	Carcinogenicity	Genotoxicity/Mutagenicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Toxicity	Systemic Toxicity (single)	Systemic Toxicity (repeat*)	Neurotoxicity (single)	Neurotoxicity (repeat*)	Skin Sensitization*	Respiratory Sensitization*	Skin Irritation	Eye Irritation	Acute Aquatic Toxicity	Chronic Aquatic Toxicity	Persistence	Bioaccumulation	Reactivity	Flammability	Benchmark Score
EVOH (Exceval HR-3010) (26221-27-2)	L	L	L	L	*L**	L	*L**	L	*L**	*L**	L	*L**	L	*L**	*L**	*L**	*M**	*vL**	*L**	*L**	**BM-3**

Polyethylene terephthalate

In this AA, we identified both polyethylene terephthalate (PET)-coated paperboard and rigid PET plastic as potential alternative materials that could replace PFAS. PET is a plastic made from the polymerization of the pre-polymer bishydroxyethyl terephthalate, which can be formed by reacting ethylene glycol with either terephthalic acid or dimethyl terephthalate (Lithner et al., 2011; Robertson, 2012). Two catalysts are used, one to form the pre-polymer and another to generate PET.

The GreenScreen® methodology previously assessed several components of PET using (Table 11). Zinc oxide and antimony trioxide are commonly used to catalyze the formation of the pre-polymer and PET, respectively. Zinc oxide scored BM-1 for very high aquatic toxicity, high systemic toxicity, and very high persistence endpoints (ToxServices, 2018b). An unverified GreenScreen® evaluation from 2014 scored antimony trioxide BM-1 due to high aquatic toxicity, high systemic toxicity, and very high persistence endpoints (Rosenblum Environmental, 2014). A 2018 National Toxicology Program Report on Carcinogens determined that antimony trioxide is "reasonably anticipated to be a human carcinogen," which aligns with a high carcinogenicity endpoint (NTP, 2018).

GreenScreen® hazard evaluations conducted in 2013 scored terephthalic acid, a PET monomer, as BM-2 (ToxServices, 2013c) and bis(2-hydroxyethyl) terephthalate, a PET intermediate, as BM-U (ToxServices, 2013a), although those GreenScreen® evaluations since expired. A GreenScreen® evaluation conducted at the same time for ethylene glycol, a required monomer of PET, noted high developmental toxicity, scoring the chemical BM-1 (ToxServices, 2013b). BM-1 scores do not expire (CPA, 2019).

Table 11. Components of PET with current chemical hazard assessments.

Chemical (CASRN)	Relation to PLA	Hazard Concern
Ethylene glycol (107-21-1)	Monomer	BM-1: Avoid – Chemical of High Concern
Zinc oxide (1314-13-2)	Catalyst	BM-1: Avoid – Chemical of High Concern
Antimony trioxide (1309-64-4)	Catalyst	BM-1: Avoid – Chemical of High Concern

Without specific information about a PET formulation used in food packaging, we evaluated available hazard assessments for the components of PET. We determined that these components cannot be considered less hazardous than PFAS as a class (Table 12). We did not consider additives or degradation products of PET, which may introduce additional hazardous substances. Therefore, we conclude that PET is not a less hazardous alternative than PFAS. We removed products made using PET from further consideration in this AA.

Summary

In this AA, we reviewed the hazards associated with data rich PFAS and used them to characterize the class. Each well-characterized PFAS shows evidence of toxic properties of concern that would cause the chemical to score BM-1 using the GreenScreen® methodology. Therefore, to assess the hazards of candidate alternative substances, we looked for toxicological data indicating the alternative substance would score BM-2 or better using the

GreenScreen® (or equivalent) methodology. Table 12 reports the results for each candidate alternative.

In the subsequent modules of this AA, we assess those alternative substances identified in Table 12 as BM-2, BM-3, or low concern (see hybrid decision framework for more details).

Table 12. Hazard assessment summary for alternative substances.

Substance name	CASRN	Approach	Result
Untreated or densified paper	65996-61-4	Non-chemical alternative	Low concern
Waxes (petroleum- or bio-based)	(Petroleum-based) 64742-43-4; 64742-51-4 (Bio-based) 8001-22-7; 67784-80-9; 8012-89-3; 8015-86-9	U.S. EPA SCIL	Low concern
Clay (coating of mineral filler or filler and binder)	(Filler) 1332-58-7; 471-34-1 (Binder, not exhaustive) 25035-82-9; 25035-69-2; 9010-92-8; 9004-32-4; 9005-25-8; 9002-89-5	U.S. EPA SCIL	Low concern
PVOH	9002-89-5 (fully hydrolyzed), 25213-24-5 (partially hydrolyzed)	U.S. EPA SCIL	Low concern
Siloxanes (by analogy to vinyl dimethylsiloxy-terminated polydimethylsiloxane)	68083-19-2	Evaluated in first AA using GreenScreen®	Benchmark-1: Avoid – Chemical of High Concern
Aluminum (by analogy to aluminum oxide)	1344-28-1	Evaluated using GreenScreen® and Scivera GHS+	Consistent with Benchmark-2: Use but Search for Safer Substitutes
PLA (by an evaluation of components)	9051-89-2	Evaluated in first AA using GreenScreen® and U.S. EPA SCIL	Consistent with Benchmark-3: Use but Still Opportunity for Improvement
LDPE (by an evaluation of components)	9002-88-4	Evaluated using GreenScreen® and U.S. EPA SCIL	Consistent with BM-2: Use but Search for Safer Substitutes
LLDPE (by an evaluation of components)	9002-88-4	Insufficient Information	Insufficient information
HDPE (by an evaluation of components)	9002-88-4	Insufficient Information	Insufficient information
PP (by an evaluation of components)	9003-07-0	Evaluated using GreenScreen® and U.S. EPA SCIL	Consistent with BM-2: Use but Search for Safer Substitutes

Substance name	CASRN	Approach	Result
PP-talc composite	(PP) 9003-07-0 (Talc filler) 14807-96-6	Evaluated using GreenScreen® and U.S. EPA SCIL	Consistent with Benchmark-1: Avoid – Chemical of High Concern
PET (by an evaluation of components)	25038-59-9	Evaluated using GreenScreen®	Consistent with Benchmark-1: Avoid – Chemical of High Concern
EVOH	26221-27-2 (based on FDA FCN 1179)	Evaluated using GreenScreen®	Benchmark-3: Use but Still Opportunity for Improvement

In this AA, we will not further assess the following alternative substances, which we did not find to be less hazardous than PFAS:

- Siloxanes.
- PET.
- Forms of PE other than LDPE.
- PP-talc composites.

Section 8 also reports these results.

Alternative substances that will be assessed further in this AA

Based on our evaluations of the human health and environmental hazards, we identified the following alternative substances as less hazardous than PFAS:

- Untreated or densified paper or other plant fibers
- Waxes (both natural and petroleum-derived)
- Clay coatings
- Aluminum
- PLA
- PVOH
- EVOH
- LDPE
- PP

The Section 8 summary includes the results from Table 12 for these candidate alternative substances. In the subsequent modules, we assess alternative substances for potential exposure concerns, performance in food packaging, and cost and availability.

Section 5. Exposure Assessment Module

Overview

The IC2 AA Guide Level 1 Comparative Exposure Assessment Module is a qualitative assessment. It uses readily available data “to identify whether material differences exist between the chemical of concern and potential alternatives.” A material difference means any meaningful difference between the physiochemical properties or exposure routes of PFAS and an alternative substance suggesting a differences in exposure potential. This section evaluates PFAS and alternatives to PFAS on the chemical level (see the introduction for a brief definition).

Similar to the hazard module (Section 4), we used a tiered approach to follow the IC2 AA Guide. We use preliminary questions to determine, based on the concerns identified in the hazard assessment, if an alternative should undergo a comparative exposure assessment. Subsequent questions compare PFAS and a potential alternative by evaluating differences in chemical properties, exposure pathways, and exposure concerns. If there are no material differences between PFAS and the alternative, a full exposure evaluation is not required.

Since the physical and chemical properties of PFAS vary, we used PFHxA and 6:2 FTOH as example PFAS that studies find in food from contact with packaging materials (Fengler et al., 2011; Yuan et al., 2016). PFHxA is also a persistent degradation product of other PFAS in the class, which means the long-term exposure potential is higher than other PFAS (Buck et al., 2011; Balan et al., 2021). The exposure pathways of PFAS in food packaging do not vary substantially.

Several alternative substances were of low concern in the hazard module and therefore do not require a comparative exposure evaluation. We evaluated the comparative exposure potential of aluminum, LDPE, and PP. We found no substantive differences between aluminum and PFAS.

LDPE and PP may produce microplastic particles as they degrade, which could lead to microplastic pollution in the environment. The impact of microplastic particles on the environment, particularly on marine environments, and the likelihood of food packaging releasing these microplastics is not well understood. We concluded we do not have enough information to complete a comparative exposure evaluation of LDPE or PP.

We summarize the results of this module in Table 19.

Choice of IC2 AA Guide level

The IC2 AA Guide describes three levels for the Exposure Assessment Module:

- **Level 1 Basic Comparative Exposure Evaluation**: This level utilizes a qualitative assessment of readily available data to identify whether material differences exist between the chemical of concern and potential alternatives. If material differences in exposure potential do exist, a separate exposure assessment is necessary for the alternative. Decisions in this level are based upon a qualitative assessment using readily available data.
- **Level 2 Expanded Comparative Exposure Evaluation**: Builds on the previous level by increasing the quality and quantity of information. More detailed quantitative data is required to evaluate the importance of exposure in the AA process.
- **Level 3 Detailed Exposure Evaluation**: This level builds on previous levels and requires detailed scientific studies as the basis for decisions. If these studies are not available, they are conducted, and the data is used to determine the importance of exposure in the AA process.

In the hazard module, we identified candidate alternatives that are less hazardous than PFAS and unlikely to be regrettable substitutes. We determined that a Level 1 Exposure Assessment Module, when combined with the Level 2 Hazard Module, would be sufficient to identify safer alternatives that meet the requirements of RCW 70A.222.070.[40]

Exposure considerations for PFAS

Stakeholders asked us to consider PFAS exposures from non-food packaging products in this module. This AA focuses on PFAS exposures from food packaging products. Cumulative exposures contribute to health risks, but are outside the scope of this analysis. Ecology and Health's Draft PFAS Chemical Action Plan[41] (CAP) discusses cumulative PFAS exposure and its sources in Washington state.

There is evidence that some PFAS in food packaging materials migrate into food products they contain (Fengler et al., 2011; Müller et al., 2012; Schaider et al., 2017; Trier et al., 2017; Yuan et al., 2016). How much PFAS migrate to food depends on the food composition, temperature, the presence of salts and emulsifiers, the concentration of PFAS, total surface area, and surface energy (Trier et al., 2017). PFAS tend to migrate more easily to proteins, starches, and ethanol (Trier et al., 2017).

Shorter-chain FTOHs show higher migration efficiencies than their longer-chain counterparts (Trier et al., 2017). PFAS used in food packaging contain C6 side chains and may break down to PFHxA (Kabadi et al., 2018; Rice et al., 2020). In addition, 6:2 FTOH is often used as a precursor to these polymers and can be present in food packaging as an impurity (Boucher, 2020).

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[40] https://app.leg.wa.gov/rcw/default.aspx?cite=70A.222.070

[41] https://apps.ecology.wa.gov/publications/summarypages/2004035.html

PFAS-containing food packaging contaminates waste streams, which can lead to environmental exposures. Choi et al. (2019) detected short-chain (C6 or less) PFAAs in commercial compost. The PFAA load in waste streams containing food packaging was notably higher (28.7 to 75.9 µg/kg) than the load from organic waste without food packaging (2.38 to 7.60 µg/kg). These PFAAs were leachable to pore water (25 – 49%) and were strongly correlated with the PFAA load (Choi et al., 2019).

Additionally, a recent study linked PFAS production (including those detected in food packaging applications) to the largest registered releases in the U.S. of HCFC-22, a greenhouse gas linked to ozone depletion (Schreder & Kemler, 2021).

A decrease in PFAS exposure from food packaging is expected with the increased use of PFAS-free alternatives. However, the magnitude of the decrease is difficult to predict. Other sources of PFAS will still contribute to exposure.

Environmental justice considerations of PFAS in food packaging

Environmental justice is defined as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations, and policies. Fair treatment means that no group of people should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental, and commercial operations or programs and policies" (EPA, 2018). A full Social Impact Assessment from the IC2 AA Guide is outside the scope of this AA. However, we used aspects of this approach to identify overburdened communities and those at highest risk of exposure to PFAS in food packaging.

Direct research on food packaging chemical exposure and environmental justice issues is limited. This lack of data may not mean there is no issue, but instead could indicate groups who have been historically overlooked (Nelson & Brooks, 2016).

Overburdened communities are more vulnerable to environmental hazards and experience a disproportionate risk for exposure to chemicals like PFAS (EPA, 2019). In Washington, certain communities have higher PFAS concentrations in the environment or in their drinking water, and some use fast food, take-out, or packaged food products more often than others (Health, n.d.).

Additionally, landfills, incinerators, composting, and illegal dumping or littering can release PFAS from food packaging into the environment. Populations who live near landfills, incinerators, and composting areas may experience more exposure to these PFAS. Waste disposal facilities are more frequently placed near low-income and minority communities (Dovey, 2015).

Certain populations may have higher concentrations of PFAS in their bodies. Studies associate higher PFAS concentrations in the body with consuming more microwavable popcorn and having the Gilbert syndrome phenotype (Fan, Ducatman, & Zhang, 2014; Susmann et al., 2019). Gilbert syndrome is prevalent in approximately 3 – 7% of the U.S. population, and is found more often in males than females across all races (Fan, Ducatman, & Zhang, 2014; Susmann et al., 2019).

Further, certain populations tend to consume fast food at higher rates, and may be more impacted by the ban. These populations will likely benefit from a decrease in PFAS exposure, although the magnitude of that benefit is unknown. We identified increased rates of fast food consumption for the following sub-populations:

- Food insecure children and youth (Chi et al., 2015; Widome et al., 2009).
- Obese adults, both generally and specifically among Hispanic/Latino adults (Anderson et al., 2011; Burgoine, et al., 2016; Fraser et al., 2012; Garcia, Sunil, & Hinojosa, 2012; McClain et al., 2018).
- Individuals working non-standard hours or schedules (Devine et al., 2009; Zagorsky & Smith, 2017).
- Individuals with increased levels of education (Hidaka et al., 2018; Paeratakul et al., 2003; Rydell et al., 2008).
- Certain racial and ethnic groups, including African American adolescents and pregnant or post-partum women, English-speaking Mexican Americans of higher socioeconomic status and educational levels, and young and employed Latino women (Arcan et al., 2009; Ayala et al., 2005; Harris et al., 2016; Langellier et al., 2015).
- Children and those of childbearing age (Fanning, Marsh, & Stiegert, 2010; Paeratakul et al., 2003).
- Individuals living, working, or attending a school in proximity to fast food outlets (Bernsdorf et al., 2017; Forsyth et al., 2012; Longacre et al., 2012; Simon et al., 2008).
- Neighborhoods lacking alternative options to fast food (predominantly impacting primarily African-American neighborhoods) (Hilmers, Hilmers, & Dave, 2012).

More research on the intersection between food packaging chemical exposure and environmental justice issues is needed help to fill current knowledge gaps. Increased understanding could help policymakers, regulators, and others address health disparities.

Exposure assessment methodology

Data needs for exposure assessment

We used physiochemical properties (or details supporting adequate estimation of physical-chemical properties using QSAR models) to characterize the exposure potential of alternative substances. We sought other available or relevant data to inform the potential for exposure. If needed to answer certain questions, additional information from bio- or environmental monitoring may be required.

Tiered approach to comparative exposure assessment

For this AA, the exposure assessment followed the IC2 AA Guide for a Level 1 Basic Comparative Exposure Assessment. This approach meets the U.S. National Academy of Sciences (NAS) “Path B” recommendations[42] for comparative exposure assessment (NAS, 2014). Our approach also incorporates elements of both EPA’s Sustainable Futures Interpretative Assistance Document for Assessment of Polymers (2013)[43] (SF Polymer Criteria) (EPA, 2013) and the Health and Environmental Sciences Institute’s (HESI) Sustainable Chemical Alternatives Technical Committee’s qualitative comparative approach[44] (HESI Exposure Guidance) (Greggs W et al., 2019).

The IC2 AA Guide organizes the Basic Comparative Exposure Assessment into a series of questions. The questions assess readily available data to identify whether material differences exist between the comparator and potential alternatives. If the properties and potential pathways are similar, we conclude the alternative has equivalent exposure potential to PFAS and further evaluation is unnecessary. If we identify material differences, we further evaluate the alternative using biomonitoring data, manufacturing criteria, or lifecycle information. Figure 2 illustrates this approach.

[42] https://www.nap.edu/catalog/18872/a-framework-to-guide-selection-of-chemical-alternatives
[43] https://www.epa.gov/sites/production/files/2015-05/documents/06-iad_polymers_june2013.pdf
[44] https://setac.onlinelibrary.wiley.com/doi/full/10.1002/ieam.4070

Figure 2. IC2 Basic Comparative Exposure Approach.

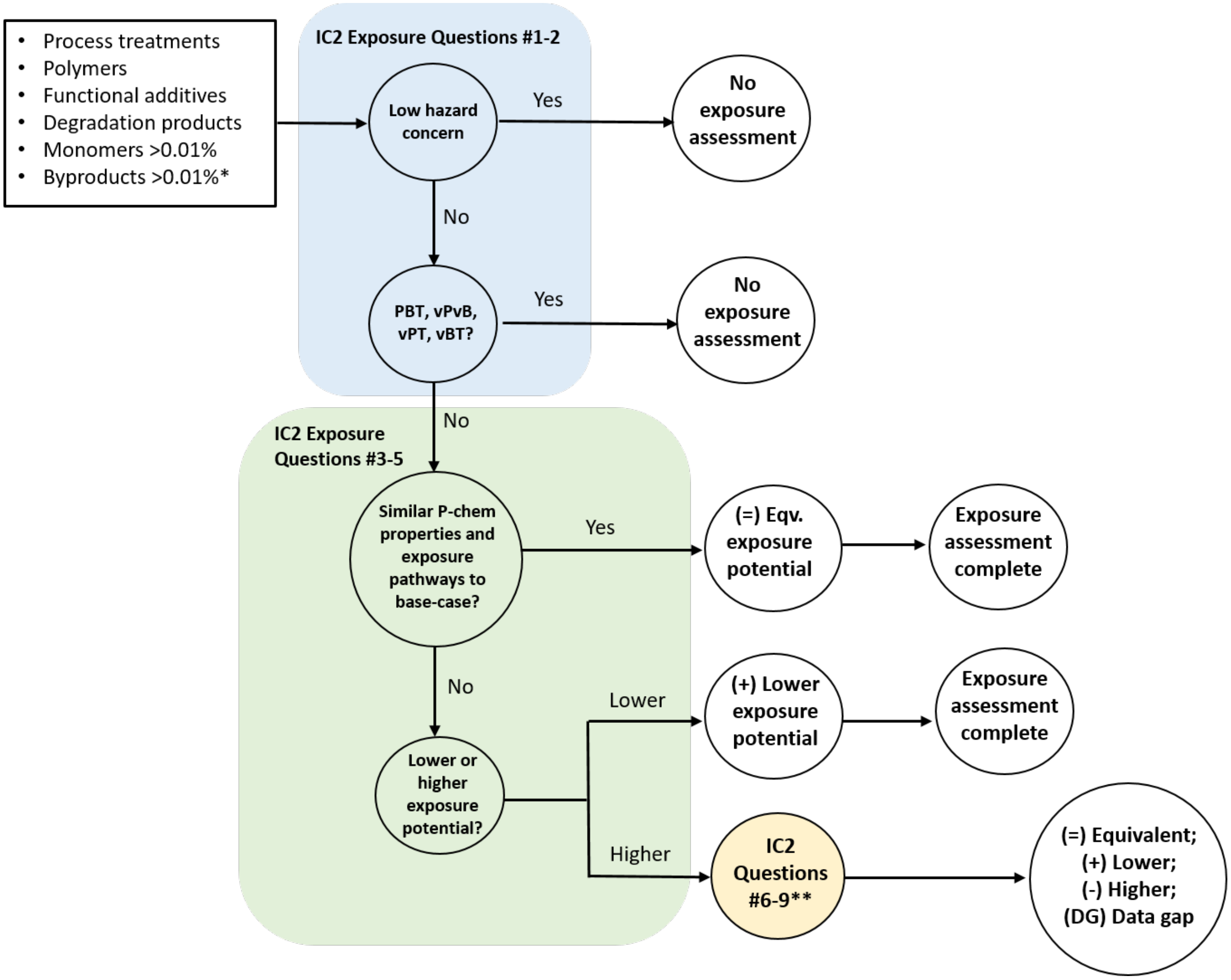

Figure notes:

- * We do not additionally evaluate polymer additives and degradation products if our assessment of the polymer substance finds exposure properties of concern.
- ** IC2 questions #6 – 9 incorporate biomonitoring studies, manufacturing criteria, and qualitative lifecycle information.
- Access an accessible text description of this graphic.[45]

[45] https://www.ezview.wa.gov/Portals/_1962/Documents/PFAS-Food/TextDescriptions_Figures_SecondPFAS_FoodPackaging_AA.pdf

Evaluation of exposure concerns

Initial screening questions

Question 1: Has the alternative been evaluated for hazard and determined to be of low concern (e.g., GreenScreen® BM-3 or BM-4)?

Substances we concluded are of low concern (e.g., listed with a green circle on SCIL), or BM-3 chemicals under the Tiered Approach to Hazard Assessment, did not undergo a comparative exposure assessment. We applied the exposure assessment to the candidate alternative substances we screened in the Level 2 Hazard Module and deemed are of moderate concern (BM-2 or equivalent).

Question 2: Does the alternative have persistence, bioaccumulative, and/or toxic properties of concern?

We removed highly persistent and/or highly bioaccumulative and/or toxic alternatives (vPvB, vPT, vBT, PBT) from consideration based on their hazard assessment. These alternatives did not undergo an exposure assessment.

Qualitative exposure assessment

Questions 3 – 5 represent a qualitative exposure assessment. Answers are recorded in an assessment template (IC2 AA Guide, page 112). Questions 3 – 5 use the following parts in the template:

1. Compare physicochemical properties between the chemical of concern and alternative.
2. Consider other inherent chemical properties of the alternative relevant to exposure.
3. Compare human exposure pathways between the chemical of concern and alternative.
4. Compare ecological exposure pathways between the chemical of concern and alternative.

Question 3: Are the chemical properties for the chemical of concern and alternative materially similar? Or do material differences exist?

We assessed pertinent properties and evaluated them using the endpoint criteria in the IC2 AA Guide. We included additional endpoints supplemented by the HESI Exposure Guidance,[46] summarized in Table 13 and Table 14 (Greggs et al., 2019).

[46] https://setac.onlinelibrary.wiley.com/doi/full/10.1002/ieam.4070

Table 13. IC2 Level 1 related properties.

Property	Reason	Guidelines (NAS, 2014)
Volatility and vapor pressure	Volatility and vapor pressure influence how likely the chemical is to be found in the air or how likely it is to enter the body.	$>10^{-8}$ mmHg (greater than 10^{-8} mmHg); considered likely to found in the air. $> 10^{-4}$ mmHg (greater than 10^{-4} mmHg); considered to be more likely to enter the body.
Molecular weight	Generally, as molecular weight and size increase, bioavailability decreases (leading to a lower toxicity potential).	>1000 amu (greater than 1000 amu) is less likely to be bioavailable
Solubility in water	Generally, a chemical that is highly soluble in water will have more bioavailability and toxicity. In addition, water soluble chemicals are more likely to be found in water bodies and precipitation.	<1 ppb (less than 1 ppb) generally have lower water solubility
Log K_{ow}	The log of the water-octanol coefficient (Log K_{ow}), is an indicator of potential for bioaccumulation,[1] as well as bioavailability.	Less than 5 for mammals Less than 4 for aquatic species
Boiling point	The boiling point determines if the chemical will be a liquid or gas at a certain temperature.	<25 C (less than 25 C) will be a gas at room temperature
Melting point	The melting point determines if the chemical will be a solid or liquid at a certain temperature.	<25 C (less than 25 C) will be a liquid at room temperature
Density and specific gravity	Has implications for where the chemical might partition when with other liquids or gases.	
pH	A measure of free hydrogen, with implication for water solubility and potential damage to cells.	For certain products, a pH of greater than 2 and less than 11.5 is safest for eyes and skin (Safer Choice, 2015).
Corrosivity	Associated with the ability to gradually destroy materials by chemical reaction.	GHS criteria used to determine level of concern. Typically, the more extreme the pH (either high or low), the higher likelihood of corrosivity issues whether it be to the eye, skin, respiratory system, etc. Typical pH values used are approximately below 3 and above 10. (See GHS criteria for more details.)
Environmental partitioning	A measure of how easily molecules or salts break apart under certain conditions (primarily in solution).	The higher the constant (K_d), the more likely the molecules or salts will break apart.

Property	Reason	Guidelines (NAS, 2014)
Use characteristics (binding properties) or synergistic effects	Other properties that can help determine the state of the chemical in the environment and biological compartments or interactions with other chemicals found in the environment.	The acid dissociation constant (pKa) is used to help identify availability of chemicals to bond. pKas of concern are typically less than 3 (acid) or greater than 11 (bases). Synergistic effects identify how other chemicals may impact availability of the chemical of concern. For example, dimethyl sulfoxide (DMSO) easily enters skin. Chemicals dissolved in DMSO can be more biologically available than chemicals dissolved in other solvents.

Table notes:

1. Higher log K_{ow} values indicate greater bioaccumulation potential.

Table 14. HESI exposure related properties (Greggs et al., 2019).

Property	Reason	HESI Exposure Guidance
Particle size	Addresses inhalation exposure related to particulates.	Likely to penetrate the alveolar region <10 µm (less than 10 µm). Likely to enter the nose or mouth and penetrate the tracheo-alveolar region ≥10 and ≤100 µm (greater than or equal to 10 and less than or equal to 100 µm). Not likely to be inhaled >100 µm (greater than 100 µm). Inhalable fraction (in mg/kg): • Firm granules, flakes, or pellets: ≤100 (less than or equal to 100) • Granules, flakes, or pellets: 100 – 500 • Course dust: 501 – 2000 • Fine dust: 2000 – 5000 • Extremely fine and light powder: >5000 (greater than 5000)
Volatility (Henry's Law Constant)	Henry's Law Constant is used to estimate the potential to volatilize from water surfaces.	• Very volatile from water: $>10^{-1}$ (greater than 10^{-1}) Volatile from water: $10^{-1} – 10^{-3}$ • Moderately volatile: $10^{-3} – 10^{-5}$ • Slightly volatile: $10^{-5} – 10^{-7}$ • Nonvolatile: $<10^{-7}$ (less than 10^{-7})
$LogK_{oc}$	Addresses the potential to migrate in soil, which could lead to groundwater contamination.	• Very strong sorption, negligible migration: greater than 4.5 • Strong sorption, negligible to slow migration: 3.5 – 4.4 • Moderate sorption, slow migration: 2.5 – 3.4 • Low sorption, moderate migration: 1.5 – 2.4 • Negligible sorption, rapid migration: less than 1.5

Property	Reason	HESI Exposure Guidance
Bioaccumulation[1]	Considers the potential for the target chemical to accumulate in organisms.	BCF/LogBCF or BAF/LogBAF: • Very high: greater than 5000 (3.7) • High: 5000 – 1000 (3.7 to 3) • Moderate: 1000 – 100 (3 to 2) • Low: less than 100 (2)
Persistence[2]	Addresses the potential for the target chemical to persist in environmental media.	Half-life in days: • Very high: greater than 180 (air: 2) • High: 60 – 180 • Moderate: 60 – 16 • Low: less than 16 or pass ready biodegradability test not including the 10-d window • Very low: pass biodegradability test with 10-d window

Table notes:

1. For bioaccumulation, higher BCF or BAF values are associated with increased bioaccumulation potential.
2. For persistence, longer half-lives are associated with increased persistence.

Polymers with low molecular weight (MW less than 1000; SF Category 1 in SF Polymer Criteria) were expected to be bioavailable and we would evaluate them using the same methods and approaches as for discrete substances. We used the SF Polymer Criteria to address the special considerations associated with evaluating polymers with high MW (MW greater than 1000; SF Category 2 & 3). Many of these substances vary in composition and lack adequate data sets, making it difficult to evaluate their physicochemical properties. The SF Polymer Criteria summarizes various approaches for assessing physical and chemical properties (EPA, 2013).

Question 4: Compare exposure pathways between the chemical of concern and the alternative(s). (Are there material differences?)

This question addresses the potential for ingestion, inhalation, and dermal exposures from using and disposing the chemical of concern and the candidate alternative.

Question 5: Are there substantive differences between the chemical of concern and the possible alternatives that are likely to increase exposure concerns for the any of the alternatives? Use comparative exposure decision rules.

After populating the assessment template (IC2 AA Guide, page 112), we completed an overall comparison of the proposed alternative to the chemical of concern applying the decision rules in Table 15. We briefly discuss supporting rationale for the key parameters we used to make the determination, as well as any uncertainties and data gaps.

Table 15. Decision Rules for IC2 comparative exposure assessment.

Exposure determination	Score	Assessment complete?
The potential exposure is likely to be equivalent to the chemical of concern	= (equal)	Yes
The potential exposure of the alternative is likely to be lower than the chemical of concern	+ (plus)	Yes
The potential exposure of the alternative is likely to be higher than the chemical of concern	- (minus)	No, proceed to Question 6
Data gap*	DG	Yes

Table notes:

- * = Only applied if initial comparison suggests higher exposure potential and there are insufficient data to address questions 6 – 9.

Additional considerations when potential exposure of the alternative is likely higher than PFAS

Questions 6 – 9 of the IC2 AA Guide were addressed if initial comparison suggested an alternative had higher exposure potential. These questions aim to clarify and confirm whether the exposure concern is justified. If the assessment proceeds to this level, we follow the IC2 Guidance exactly.

- Question 6 requires identifying any available bio- or environmental monitoring studies.
- Question 7 considers manufacturing criteria to evaluate exposure concern.
- Question 8 considers qualitative lifecycle aspects to evaluate exposure concern.
- Question 9 considers whether there are sufficient data to evaluate exposure or if exposure should be considered a critical data gap.

Exposure assessment module results

Determination of exposure assessment need based on identified hazard endpoints (Questions 1 and 2)

1. Has the alternative been evaluated for hazard and determined to be of low concern (e.g., EPA SCIL Green Circle, GreenScreen® Benchmark-3 or -4)?

In the exposure assessment module, we did not consider alternative substances that we did not identify as less hazardous than PFAS in the hazard module.

We evaluated untreated paper, densified paper, petroleum-based wax, bio-based wax, clay coating, PVOH, EVOH, and PLA (through analysis of its components) for hazard (see Section 4) and determined they are of low concern. According to the IC2 AA Guide, further exposure assessment for these substances is not required (Table 19).

2. Does the alternative have persistence, bioaccumulative, and/or toxic properties of concern?

In the hazard module, we identified alternative substances with persistence, bioaccumulative, and/or toxic properties of concern as consistent with BM-1. Since these substances were not considered less hazardous than PFAS in the hazard module, we did not further consider them in this AA.

Qualitative exposure assessment (questions 3 to 5)

In the hazard module, we identified aluminum, low-density polyethylene (LDPE), and polypropylene (PP) as BM-2 alternatives. We assessed these alternative substances further using questions 3 – 5.

We did not evaluate additives, such as antioxidants, used in LDPE and PP in the exposure module. This is because we found exposure concerns related to LDPE and PP and did not continue the analysis. If LDPE and PP showed no material difference in exposure compared to PFAS, we would have also evaluated the exposure potential of these additives. We identified enough uncertainties in LDPE and PP (due to a lack of conclusive information on microplastic particle formation and impact) that further considering additives would not have changed our conclusions.

Although we expect PFAS used in food packaging to have the same or similar exposure pathways, the chemical and physical properties of PFAS vary by substance. Therefore, although we compare alternatives to the class of PFAS in this AA overall, when comparing physiochemical properties we only used data for PFHxA and 6:2 FTOH, since these data-rich PFAS were previously used to represent PFAS used in food packaging (Ecology, 2021).

These PFAS are impurities in and degradation products of side-chain fluorinated polymers, which are used in food packaging (Buck, 2015; Li et al., 2017; Rice et al., 2020; Trier et al., 2017). A 2016 study by Yuan et al. identified 6:2 FTOH as the most common fluorotelomer detected in food packaging material in the U.S. This suggests that short chain (C6) PFAS are prevalent in food packaging and contribute to PFAS exposure (Yuan et al., 2016). PFHxA is a degradation product produced by several PFAS, including 6:2 FTOH (Kabadi et al., 2018; Rice et al., 2020; Washington et al., 2009).

Question 3: Are the chemical properties for the chemical of concern and alternative materially similar? Or do material differences exist?

This question asks if there are material differences, meaning any meaningful difference between the physiochemical properties of PFAS and an alternative substance suggesting a difference in the exposure potential.

Appendix C lists experimental and modeled values for chemical and other exposure properties of interest. The table in this appendix includes values for PFHxA, 6:2 FTOH, PP, LDPE, and aluminum oxide. We collected data from chemical databases, technical data sheets, and material safety data sheets.

To assess alternative substances, we searched for physiochemical and exposure information for the compounds we evaluated in the hazard module. For example, we assessed aluminum oxide instead of aluminum, since a thin coating of aluminum oxide forms on aluminum and makes direct contact with food or human skin (Robertson, 2012). Similarly, we assessed LDPE instead of another type of PE because we evaluated it in the hazard module. We assessed LDPE and PP as category 3 polymers according to the SF criteria (EPA, 2013).

Both LDPE and PP are expected to produce microplastics as they degrade (GESAMP, 2015). We determined that microplastic formation represents a meaningful difference in exposure based on the potential for new exposure pathways.

A microplastic is generally considered a plastic particle that is less than five millimeters along the longest dimension (GESAMP, 2015). We did not find conclusive information on the expected size and shape of the microplastics LDPE and PP food packaging would generate. Consequently, we cannot determine what fraction pose an inhalation or ingestion risk (UNEP, 2016). LDPE and PP both have densities under 1 gram per milliliter, so these particles are expected to float in waterways.

We did not have enough information to outline all physical and chemical properties of microplastics in Appendix C. As a result, we cannot conclude whether exposure is lower or equal to PFAS from food packaging. Therefore, based on exposure, we did not identify LDPE and PP as favorable alternatives.

Question 4: Compare exposure pathways between the chemical of concern and the alternative(s). (Are there material differences?)

Oral exposure is the primary pathway for chemicals used in food packaging, typically via contaminated food or water. Food is contaminated primarily from coming into contact with packaging that contains migratory chemicals. Food and water contamination may also occur when food packaging is improperly disposed, or when chemicals migrate into landfill leachate. For all the materials used in food packaging, we do not expect significant inhalation or dermal exposures. We reviewed known exposure pathways from food packaging made with PFAS, aluminum, LDPE, and PP to see if material differences exist.

Contaminated food is a significant route for PFAS exposure. PFAS in food packaging materials can migrate into food products they contain (Fengler et al., 2011; Müller et al., 2012; Schaider et al., 2017; Trier et al., 2017; Yuan et al., 2016;). How much PFAS migrate into food depends on the food composition, temperature, the presence of salts and emulsifiers, the concentration of PFAS, total surface area, and surface energy (Trier et al., 2017). PFAS tend to migrate more easily to proteins, starches, and ethanol (Trier et al., 2017).

There is some evidence that aluminum, LDPE, and PP may also migrate from food packaging materials to food. Studies identify the migration of polymer constituents and additives (including polymer microplastics) into food and drink as a source of exposure for the general population (Bhunia et al., 2013; Galloway, 2015; Ranjan et al., 2021). Acidic or hot liquids may increase the migration potential (Galloway, 2015; Ranjan et al., 2021). Contact with acidic foods can increase exposure to aluminum from packaging, because the lower pH increases the soluble aluminum leaching into food (Stahl et al., 2017a; Stahl et al., 2017b).

As noted, PFAS-containing food packaging also contaminates waste streams, including through compost contamination and landfill leachate, which can lead to drinking water contamination

(Choi et al., 2019; Hamid et al., 2018; Vestergreen & Cousins, 2009). Compost contamination is of particular concern, since molded fiber products containing PFAS are often labeled as compostable, even when composters do not accept these products (Chiang et al., 2018).

Food packaging products made with aluminum, LDPE, or PP could also contaminate compost if disposed improperly, although these products are not marketed as compostable. Aluminum may undergo undesirable reactions in landfills that generate water-soluble forms of aluminum, which can leach into the environment (Calder & Stark, 2010).

PP and LDPE may shed microplastics into the environment, both through improper disposal and potentially through landfill leachate (Golwala et al., 2021; Su et al., 2019; World Health Organization, 2019). These microplastics can transport in water and possibly through the air. Microplastic breakdown products from LDPE and PP food packaging represent an exposure pathway we do not expect from food packaging products that contain PFAS but do not contain plastic.

Studies link microplastic particle exposure with toxicological impacts in species that ingest the particles (Enyoh et al., 2020; GESAMP, 2015). The size and shape of the ingested particles and leeching of toxic chemicals that accumulated in the microplastics may influence toxicity (Enyoh et al., 2020). The degree of toxicity of these particles is currently not well understood. Similarly, while we know all LDPE and PP materials could produce microplastics, the amount and characterization of microplastics from food packaging produces is poorly understood.

In summary, all substances we evaluated have the potential to cause human and environmental exposures through water and food contamination. We find no material differences in the exposure pathways between PFAS and aluminum used in food packaging. We identified an additional exposure pathway (microplastics) for LDPE and PP used in food packaging.

Question 5: Are there substantive differences between the chemical of concern and the possible alternatives that are likely to increase exposure concerns for any of the alternatives?

Using the physiochemical property values we collected in Table 26 in Appendix C, we looked for meaningful differences in exposure potential between PFHxA, 6:2 FTOH, and candidate alternatives. Tables 16, 17, and 18 show results from these comparisons for aluminum, LDPE, and PP respectively. We compare the properties of each alternative to PFHxA and 6:2 FTOH separately. A positive label indicates that the potential exposure of the alternative is likely lower than the PFAS compound based on evidence for the physiochemical property. A negative label means the opposite. When we did not identify data for a PFAS compound or alternative substances, we stated there was not enough data.

Based on the available data, aluminum oxide did not have substantive differences from PFHxA or 6:2 FTOH. We could not identify values for all physiochemical properties suggested by the IC2 AA Guide or the HESI exposure guide. However, we identified enough information to compare vapor pressure, molecular weight, water solubility, and octanol-water partition coefficients, which help predict oral exposure risk. We conclude that aluminum does not have higher exposure concerns compared to PFAS (summarized in Table 19).

Table 16. Comparison of chemical properties of aluminum to PFAS.

Physicochemical properties	Comparison to PFHxA	Comparison to 6:2 FTOH
Volatility and vapor pressure	Positive	Positive
Molecular weight	Equal	Equal
Solubility in water	Positive	Equal
Log K_{ow}	Positive	Positive
Boiling point	Equal	Equal
Melting point	Positive	Positive
Density and specific gravity	Positive	Positive
pH	Not enough data	Not enough data
Corrosivity	Not enough data	Not enough data
Environmental partitioning	Equal	Equal
Use characteristics or synergistic effects	Not enough data	Not enough data
Particle size	Not enough data	Not enough data
Volatility (Henry's Law Constant)	Equal	Equal
LogK_{oc}	Equal	Negative
Bioaccumulation	Equal	Positive
Persistence	Equal	Negative

Similarly, based on the physiochemical properties we collected in Table 26 in Appendix C, we did not observe any physical or chemical properties of LDPE or PP as they are found in food packaging indicating a meaningfully higher exposure potential compared to PFAS (Table 17 and Table 18).

Table 17. Comparison of chemical properties of LDPE to PFAS.

Physicochemical properties	Comparison to PFHxA	Comparison to 6:2 FTOH
Volatility and vapor pressure	Positive	Positive
Molecular weight	Positive	Positive
Solubility in water	Positive	Equal
Log K_{ow}	Not enough data	Not enough data
Boiling point	Not enough data	Not enough data
Melting point	Positive	Positive
Density and specific gravity	Equal	Equal
pH	Not enough data	Not enough data
Corrosivity	Not enough data	Not enough data
Environmental partitioning	Not enough data	Not enough data
Use characteristics or synergistic effects	Not enough data	Not enough data
Particle size	Not enough data	Not enough data
Volatility (Henry's Law Constant)	Not enough data	Not enough data
LogK_{oc}	Not enough data	Not enough data
Bioaccumulation	Not enough data	Not enough data
Persistence	Equal	Equal

Table 18. Comparison of chemical properties of PP to PFAS.

Physicochemical properties	Comparison to PFHxA	Comparison to 6:2 FTOH
Volatility and vapor pressure	Positive	Positive
Molecular weight	Positive	Positive
Solubility in water	Positive	Equal
Log K_{ow}	Not enough data	Not enough data
Boiling point	Equal	Equal
Melting point	Positive	Positive
Density and specific gravity	Equal	Equal
pH	Not enough data	Not enough data
Corrosivity	Not enough data	Not enough data
Environmental partitioning	Not enough data	Not enough data
Use characteristics or synergistic effects	Not enough data	Not enough data
Particle size	Not enough data	Not enough data
Volatility (Henry's Law Constant)	Not enough data	Not enough data
LogK_{oc}	Not enough data	Not enough data
Bioaccumulation	Not enough data	Not enough data
Persistence	Equal	Equal

Based on this comparison, we do not anticipate that bulk LDPE or PP in food packaging will have different exposure pathways from PFAS. However, our findings do not extend to microplastics

LDPE or PP form from food packaging. We do not expect PFAS used in fiber-based food packaging to produce microplastic particles. As such, microplastic particles represent an additional exposure pathway compared to PFAS we must consider for LDPE and PP food packaging products.

We could not identify enough information about microplastic breakdown products from food packaging applications to analyze physical chemical properties for these products. Given the current data gaps in our understanding of how microplastic particles are formed and their impact on human and environmental health, we cannot determine the exposure potential of LDPE and PP microplastics, and thus we cannot determine the exposure potential of LDPE and PP. Until more studies are available about microplastic exposure, there is not enough information to complete a comparative exposure evaluation between PP and LDPE and PFAS (Table 19).

Summary

Table 19 summarizes the results of the exposure assessment module. In the hazard module, we determined some alternative substances had low hazard concerns. These substances did not require an exposure assessment.

We did not have enough information to assess LDPE and PP. Aluminum was evaluated and found to have similar exposure potential to PFAS used in food packaging. We consider substances with similar exposure potentials to PFAS favorable alternatives. The Section 8 summary includes these results.

Table 19. Results of exposure assessment module.

Substance name	CASRN	Result
Untreated or densified paper	65996-61-4	Low hazard concern—no exposure assessment required
Waxes (petroleum- or bio-based)	(Petroleum-based) 64742-43-4; 64742-51-4 (Bio-based) 8001-22-7; 67784-80-9; 8012-89-3; 8015-86-9	Low hazard concern—no exposure assessment required
Clay (coating of mineral filler or filler and binder)	(Filler) 1332-58-7; 471-34-1 (Binder, not exhaustive) 25035-82-9; 25035-69-2; 9010-92-8; 9004-32-4; 9005-25-8; 9002-89-5	Low hazard concern—no exposure assessment required
PVOH	9002-89-5 (fully hydrolyzed), 25213-24-5 (partially hydrolyzed)	Low hazard concern—no exposure assessment required
PLA	9051-89-2	Low hazard concern—no exposure assessment required
EVOH	26221-27-2 (based on FDA FCN 1179)	Low hazard concern—no exposure assessment required
Aluminum (by analogy to aluminum oxide)	1344-28-1	Similar exposure potential—favorable
LDPE	9002-88-4	Insufficient information to determine exposure potential
PP	9003-07-0	Insufficient information to determine exposure potential

Section 6. Performance Evaluation Module

Overview

We completed an IC2 Level 1 Performance Evaluation Module to determine whether the candidate alternatives "perform as well as or better than PFAS chemicals in a specific food packaging application" according to RCW 70A.222.070.[47] In this section, we evaluate alternative substances to PFAS on the chemical and material level (see the introduction for brief definitions).

For a Level 1 Performance Evaluation, we reviewed how manufacturers use each candidate alternative substance in food packaging products to determine if it provides the same function as PFAS. We compiled lists of example products that a) meet one or more of our definitions for food packaging applications and b) use a candidate alternative substance we identified as less hazardous than PFAS (see Section 4 for more detail). Find these lists in Appendices D through I. We reviewed promotional material for each example. This process determines whether the alternative substances meet the performance requirements of oil and grease resistance (OGR) and leak resistance. We define these as:

- **OGR:** Ability of a material to resist the permeation of grease through the substrate as evidenced by a reduction or lack of spotting, staining, or spreading.
- **Leak resistance:** Ability of a material to resist fluids by reduced permeation **and** transfer through the substrate, or the ability to resist leaks through folds or seals (such as in folded paperboard material).

We focus on the performance of alternative substances, not products. That means we can generally use evidence of OGR or leak resistance from one example product to evaluate the alternative substance for all food packaging applications. If we found no evidence an alternative substance met the performance requirements, then we concluded it does not perform as well as PFAS. For all but one candidate alternative substance, either promotional data or expert input identified the candidate alternatives as providing OGR and leak resistance (at least under some conditions of use).

[47] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.070

Choice of IC2 AA Guide level

The IC2 AA Guide describes three levels for the Performance Evaluation Module:

- **Level 1 Basic Performance Evaluation**: Identifies a few basic questions about whether the alternative performs the required function in the product. This level uses qualitative information readily available from manufacturers and other sources to evaluate alternatives.
- **Level 2 Extended Performance Evaluation**: Builds upon the information obtained in Level 1 to determine whether the alternative performs the required function in the product. It uses quantitative information from existing data reviewed by technical experts in the field to evaluate alternatives.
- **Level 3 Detailed Performance Evaluation:** Expands upon the previous levels. It uses quantitative information to evaluate alternatives based upon results of specified tests reviewed and validated by technical experts.

Ecology chose a Level 1 performance evaluation. We determined that a qualitative performance assessment was sufficient to meet the additional criteria from RCW 70A.222.070. Level 2 requires verifying performance via third-party laboratory testing, which is beyond the scope of this AA.

Performance assessment methodology

Identifying performance requirements

Potential performance requirements of food packaging that contain PFAS

Stakeholders communicated that OGR and leak resistance are the most important properties for selecting food packaging (Ecology, 2021). This is consistent with the Food Packaging Institute's 2019 U.S. Consumer Survey results—which reported "stopping oil and grease stains" and "leak/spill proofing" as the most important single-use item attributes (FPI, 2019a). These results were based on 800 respondents approximately split between the U.S. and Canada, ranging in a balance of age (18 – 60 plus), income, education level, gender, and region (FPI, 2019b). It also aligns with other studies of PFAS in food packaging, which suggest the primary function of PFAS is to improve oil, grease, and moisture resistance (DTSC, 2021; Nestler et al., 2018; OECD, 2020; Trier et al., 2017).

The IC2 AA Guide Level 1 performance assessment recommends considering PFAS performance requirements at four levels: the chemical level, the material level, the product level, and the process level. We combined these considerations with the information we gathered in the first AA to determine the performance requirements needed to identify technically feasible alternatives.

At the chemical level, PFAS repel both oily and watery substances. Manufacturers add PFAS to paper- and fiber-based food packaging to create a material that is oil, grease, and moisture resistant (the material-level performance). They can then use this material to create a single-use product which can hold oily or soupy foods without leaking or transferring oil or liquids to other surfaces (product-level performance). At the process-level, food packaging must hold food while it is served, stored, or transported without leaking food or staining other surfaces with oil or liquids.

Performance requirements evaluated in this AA

Based on stakeholder input and research from the first AA, we decided to use the material-level performance requirements to evaluate the technical feasibility of alternative substances. The material-level performance of PFAS or an alternative substance dictates whether a material can create food packaging products that successfully hold, serve, and transport wet or oily food. While one could argue that alternatives should be assessed at the product-level, there are other elements (such as product design or manufacture) unrelated to the alternative substance that can impact a product's ability to perform.

We used stakeholder input and research from the first AA to define the performance requirements of OGR and leak resistance at the material-level:

- **OGR:** Ability of a material to resist the permeation of grease through the substrate as evidenced by a reduction or lack of spotting, staining, or spreading.
- **Leak resistance:** Ability of a material to resist fluids by reduced permeation **and** transfer through the substrate, or the ability to resist leaks through folds or seals (such as in folded paperboard material).

An in-depth technical review of performance is outside the scope of this assessment. We did not use any one performance test to determine whether alternatives perform as well as PFAS. Instead, we use the performance requirements of PFAS-containing food packaging to establish a baseline of qualitative performance in order to evaluate alternatives.

Performance requirements beyond the scope of this AA

Other food packaging attributes may be advertised to end-users, such as visual aesthetics of the packaging. However, they are not relevant performance requirements for the food packaging applications we are assessing in this AA. This assessment intends to identify any gaps in performance—where alternative substances cannot provide the same primary function as plant-fiber-based materials that contain PFAS. Other performance requirements may be important to certain businesses, but we only focus on requirements that directly impact holding and serving freshly prepared food.

We also did not evaluate the performance of PFAS as processing aids used in manufacturing plant-fiber-based food packaging in this AA. We did not identify any plant-fiber-based products where PFAS was used as a processing aid and had to be replaced with a PFAS-free processing aid. Furthermore, we expect poor performance from processing aids to result in low quality or unusable products. Therefore, we consider product availability as evidence that processing aids meet manufacturer performance requirements.

Method to assess product performance

Like the first AA, an alternative substance can provide OGR in food packaging in three ways:

1. Create a surface barrier on the substrate (i.e., fiber) that can resist oil, grease, and moisture (Trier et al., 2017).
2. Act as an internal sizing agent to decrease the spaces between the substrate fibers and decrease permeability to oil and grease (Trier et al., 2017).
3. Create a foam, plastic, or metal solid substrate or material that is impermeable to oil, grease, and moisture.

We anticipate alternative substances that create a solid substrate using metal, plastic, or foam will provide OGR and leak resistance. Following IC2 Level 1 performance module guidance, we evaluated all other alternative substances using qualitative information to ensure they are capable of creating a barrier to oil, grease, and moisture

Identifying example food packaging products

The IC2 AA guide recommends evaluating promotional materials to confirm an alternative substance meets performance requirements. To do this, we compiled sets of example products that are PFAS-free and made using one of the less hazardous alternative substances we identified in Section 4. We first identified PFAS-free example products that food packaging manufacturers currently sell. We considered example products PFAS-free when they met one of the following criteria:

- Product was certified compostable through the Biodegradable Products Institute (BPI), Cedar Grove or Compost Manufacturer's Alliance (CMA), or OK Compost (BPI, 2021; CMA, 2021; TÜV AUSTRIA Belgium, 2021). These certifications require a measured total fluorinated chemical content of 100 ppm or less (BPI, 2018; CMA, 2020; Nestler et al., 2018; TÜV AUSTRIA Belgium, n.d.).
- Product manufacturers stated the product was PFAS-free.
- Product was made using aluminum or plastic as a base material, since these materials do not contain plant-based-fibers. We further confirmed this information by engaging manufacturers of these products.
- Product was made using plastic-coated paperboard. Third-party product testing data indicates plastic-coated paperboard products do not have intentionally added PFAS (CEH, 2021; Chiang et al., 2018). We further confirmed this information by engaging multiple manufacturers of products made using plastic-coated paperboard.

We screened all products to confirm they are not legacy products that manufacturers no longer make. Next, we identified the alternative providing the same function as PFAS in the product. We only included example products where we previously determined the alternative substance is less hazardous than PFAS in the hazard module.

We listed these example products by the relevant food packaging application in Appendix D through Appendix H. We included relevant promotional material for each product when available. Find additional examples of PFAS-free materials offered for sale in Appendix I.

- Appendix D: Examples of bags & sleeves made using less hazardous alternatives to PFAS.

- Appendix E: Examples of bowls made using less hazardous alternatives to PFAS.
- Appendix F: Examples of flat serviceware made using less hazardous alternatives to PFAS.
- Appendix G: Examples of open-top containers made using less hazardous alternatives to PFAS.
- Appendix H: Examples of closed containers made using less hazardous alternatives to PFAS.
- Appendix I: Examples of other less hazardous alternative substances to PFAS.

In each appendix, the example products are sorted into tables based on the candidate alternative substance used.

Questions used to assess alternative performance

Based on these promotional materials, we evaluated each alternative substance using questions from the IC2 AA Guide for a Level 1 Performance Evaluation Module. We paraphrased these questions from the IC2 AA Guide:

A. Is the alternative being used for the same or similar function?
B. Is the alternative available on the commercial market?
C. Do promotional materials for the alternative state it provides the desired function?
D. Based on A, B, and C is this a favorable alternative? [If yes, the assessment is complete, and the alternative substance is determined to be favorable.]
E. Has an authoritative body demonstrated the alternative functions adequately?
F. Are there indications that the alternative does not perform as well?
G. Has an expert identified the alternative as unfavorable for performance?

We answered these questions yes or no in order, based on qualitative descriptions and promotional materials. Using the IC2 AA Guide, the performance evaluation is complete if we answer the first three questions (A, B, and C) positively (question D). Conversely, if the answer to question D is negative, we continue with questions E through G.

Question E refers to an authoritative body that has demonstrated the alternative functions adequately. We did not identify an authoritative body that meets the IC2 definition for the food packaging industry. Therefore, the answer to this question for any alternative would be “no” or not applicable. If applicable, we incorporate publicly available data or information about performance into the assessment (Question F).

Question G refers to expert sources identifying this product as unfavorable. In this assessment, expert sources who can determine whether a product functions as required are the producers who make that specific product (not producers of competing products) and end-users who use it.

For the purposes of this assessment, end-users are businesses, individuals, or entities that purchase or use food packaging. This can include consumers, retailers, grocers providing prepared foods, cafes, restaurants (quick-service, fast-casual, and dine-in), cafeterias, government agencies, and others.

Qualitative data used to assess performance

To answer Question C, we looked for supportive language in promotional materials for the example products. Supportive language for OGR included phrases such as:

- Greaseproof.
- Oil and/or grease resistance.
- References to Kit Test levels (TAPPI test method T 559) or penetration rates.
- Described as "non-stick."

Supportive language for leak resistance included phrases such as:

- Moisture resistance.
- Leak resistance.
- References to wet strength.
- Products advertised as soup bowls or soup cups.

OGR is a performance requirement that product achieve on the material-level. We do not expect the product structure to alter the ability of a specific alternative substance to provide OGR. Therefore, evidence of OGR in any product that uses a candidate alternative substance meant the alternative met the performance requirements PFAS provide in any food packaging application.

Leak resistance is also a performance requirement that products achieve on the material-level. Leak resistance covers the ability of a material to resist fluid permeation. This includes both on the flat surface of the material, and when the material is folded or sealed during manufacturing. Folds and seals may be created to manufacture any food packaging product currently under assessment, but are particularly relevant to certain applications:

- Bags & sleeves
- Bowls
- Open-top containers
- Closed containers

If we identified example products that provide leak resistance and represent one of those four food packaging applications, then that was evidence that the alternative substance performs as well as PFAS.

In this AA, we did not use evidence of leak resistance in flat serviceware (like plates and trays) as the only positive evidence that an alternative substance provides leak resistance. We categorize the substance as favorable under certain conditions if:

- Evidence from flat serviceware is the only evidence available.
- There is no evidence indicating the substance does not perform as well from other example products.

If we did not identify any supportive information for any example food packaging products, we concluded the alternative is not favorable.

Possible outcomes for the performance evaluation

Appendices D to I include the sample inventories of products and the associated promotional language for each food packaging application. Each table entry contains promotional material language (if available), along with a yes or no response to the questions "does the product provide OGR?" and "does the product provide leak resistance?"

If we found evidence that the alternative substance provides both OGR and leak resistance, then we determined that it performs as well as PFAS. We then label the substance "favorable." For substances that meet one performance requirement (either OGR or leak resistance), or that only provide OGR and leak resistance under certain circumstances, we label them "favorable under certain conditions." Finally, if we identify evidence the product does not meet the performance requirements, we label it as "not favorable."

We also engaged experts about product use to determine alternative substance favorability. When those discussions contributed new information, we summarized it in the results section.

Performance assessment results

Alternative substances that are used for similar functions and offered for sale

Questions A and B of a Level 1 performance evaluation determine whether an alternative is being used for the same or a similar function and is available on the commercial market. Considering the example products (Appendices D through H) and the example substances (Appendix I), we conclude that all candidate alternative substances are offered for sale for the same or a similar function as PFAS.

Evaluation of alternative substances

Since all alternative substances are offered for sale and function similarly to PFAS, we prioritized information from expert sources and promotional materials to determine substance performance.

We categorized alternative substances as performing as well as PFAS ("favorable"), performing as well as PFAS under certain conditions of use ("favorable for some uses"), or not performing as well as PFAS ("not favorable"). We did this using information cited in Appendix D to Appendix I, and additional information from stakeholders as appropriate. These results are used in Section 8.

Because we changed our approach from evaluating alternative chemistries to evaluating alternatives as materials, we refined the alternatives slightly based on our research findings. For example, we determined PLA was a less hazardous substance in Section 4. In compiling lists of products, we identified that PLA could be used to coat paper or paperboard (PLA-coated), or as a foam or sheet to form three-dimensional products (PLA foam or rigid PLA). We determined the performance of each alternative material separately in this module.

Alternative substances we identified as "favorable"

Based on the performance data (Appendix D to Appendix I) from example food packaging products, we identified six alternative chemical treatments that provide both OGR and leak resistance according to promotional materials:

- Wax-coated paper
- Clay-coated paper
- PLA-coated paper
- PVOH-coated paper
- EVOH-coated paper
- LDPE-coated paper

The phrase "coated paper" can refer to coatings applied to either paper or paperboard. We expect these alternative substances to perform as well as PFAS.

Additionally, we identified four alternative base materials that we expect to perform as well as PFAS.

- Densified paper
- PLA foam
- Rigid PP
- Aluminum

We identified densified paper and PLA foam as favorable alternatives through information stakeholders provided and available promotional materials. We determined that aluminum metal (as used in aluminum foil containers) and PP (when used to make rigid containers) are favorable alternative materials given the inherent oil and water repellency of the metal or plastic.

Alternative substances we identified as "favorable for some uses"

Based on the performance data (Appendix D to Appendix I), we concluded that rigid PLAprovides both OGR and leak resistance for some uses.

PLA, when used in its rigid, unfoamed plastic form, is not recommended by manufacturers to hold hot food. The required safe holding temperature for hot food (135° F or higher) (WAC 246-215) is above the recommended temperature range for rigid PLA plastic food packaging products (105 – 110° F) (Pactiv, n.d.; World Centric, n.d.). This material therefore provides both OGR and leak resistance when packaging cold and room temperature foods, but not hot foods. We therefore determined it is only favorable for some uses.

Alternative substances we identified as "not favorable"

Some products we evaluated did not include supportive language for OGR or leak resistance in their promotional materials. Based on the performance data (Appendix D to Appendix I), we concluded that untreated paper or paperboard does not provide OGR or leak resistance.

We did not identify any contradicting expert sources indicating that untreated paper or paperboard met the performance criteria. Therefore, we identified this alternative substance as not favorable. This does not mean that products made with untreated paper or paperboard do not perform at all or are not a good choice for holding and serving certain types of food. It does suggest that products made with this alternative are not expected to perform as well with oily or high moisture foods compared to similar products containing PFAS.

Section 7. Cost and Availability Module

Overview

To evaluate whether alternatives are available and cost comparable, Ecology completed a Level 1 Basic Cost and Availability Module based on the IC2 AA Guide. RCW 70A.222.070[48] directs Ecology to use IC2 guidance to determine that an alternative is "readily available in sufficient quantity at a comparable cost." In this section, we evaluate PFAS and alternatives to PFAS at the product level (see the introduction for a brief definition).

The cost and availability module in the alternatives assessment determines if candidate alternatives that seem feasible are actually cost prohibitive or unavailable, rendering them unfavorable options. To make this determination, we looked at what alternative substances manufacturers use in place of PFAS in the food packaging applications under investigation.

In the first AA, we modified the Level 1 evaluation to focus on the cost and availability of food packaging products to end-users. Recognizing that this data is difficult to obtain and poorly reflects the market, we returned to the original Level 1 evaluation to determine whether the alternatives are readily available and cost comparable for food packaging manufacturers.

Following the rationale in the IC2 AA Guide, we presume that manufacturers using a less hazardous alternative in food packaging products is sufficient evidence that the alternative is both readily available in sufficient quantity, and that manufacturers can use it in products in a manner that is cost competitive with PFAS.

In this section, we identified available and cost competitive candidate alternatives that manufacturers use in all five food packaging applications we assessed. We did this by identifying example products that a) represent one of the five food packaging applications under assessment and b) use a candidate alternative substance we previously identified as less hazardous than PFAS. We identified three or more available and cost competitive alternatives for each food packaging application.

[48] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222

Choice of IC2 AA Guide level

The IC2 AA Guide describes four levels for the Cost and Availability Module:

- **Level 1 Basic Cost and Availability Evaluation**: This evaluation asks a few basic questions about whether the alternative is being used in cost-competitive products.
- **Level 2 Extended Basic Cost and Availability Evaluation**: This evaluation builds on the information obtained in Level 1 to determine if the alternative is both available and cost effective. This evaluation goes beyond whether or not the alternative is currently being used to determine if it could be available and cost effective if selected.
- **Level 3 Chemical and Material Cost and Availability Evaluation**: This evaluation expands on the previous level to include not only the cost and availability of the chemical, but also the material in which it will be used. It also introduces lifecycle costing (LCC), and requires an initial review of possible impacts due to LCC.
- **Level 4 Chemical, Material and Re-designed Cost and Availability Evaluation**: This level adds requirements to assess costs and benefits associated with product redesign to accommodate the use of an alternative. The focus is on private costs and benefits. It also includes a more detailed LCC evaluation.

A Level 1 cost and availability evaluation is a straightforward way to determine what alternative substances manufacturers can economically substitute for PFAS now. This is in contrast to higher levels, such as a Level 2 cost and availability evaluation, which includes forecasting alternative price and availability changes, and goes beyond the purpose of this AA.

RCW 70A.222.070[49] directs us to use IC2 guidance to determine if an alternative is "readily available in sufficient quantity at a comparable cost." The Level 1 Basic Cost and Availability Evaluation focuses on identifying alternatives that manufacturers currently use in relevant products. It represents a method to determine which alternatives are available and cost competitive with PFAS.

Cost and availability method

The purpose of the cost and availability module is to determine if less hazardous alternatives that seem feasible are actually cost prohibitive or unavailable, rendering them unfavorable options. For a Level 1 evaluation, the IC2 AA Guide provides two questions to determine the economic feasibility of an alternative.

1. Is the alternative currently used in the application of interest?
2. Is the alternative currently offered for sale for the application of interest? Is the price of the alternative close to the current?

According to the IC2 AA Guide, if the answer to either question is positive, the alternative is considered favorable for both cost and availability, and the AA process continues. Question one assumes that if an alternative is being used in products, then it is both available and cost competitive to replace the chemical of concern. Question two addresses availability and cost

[49] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.070

separately when an alternative is offered for sale but there is no evidence manufacturers use it for the application of interest.

New approach to availability and cost comparability

The information we need to positively answer questions one and two in a Level 1 cost and availability evaluation depends on how we define "currently used for the application of interest." Based on stakeholder feedback and an internal review of our first AA, we updated the definition we use.

We did not change how we define the "application of interest." As with the first AA, each "specific food packaging application" we identified for this AA represents one application of interest. This means that—unlike our approach to evaluating alternative performance—information indicating an alternative substance is used in one food packaging application, such as open-top containers, does not necessarily mean an alternative substance is used in another food packaging application, such as closed containers.

We re-evaluated how we think about whether an alternative is "currently used." In the first AA, we focused on evaluating whether end-users currently purchase alternative products, including food service businesses, institutions with dining services, and individual consumers. To identify an alternative substance as readily available and cost comparable, we identified products with candidate alternative substances end-users were purchasing (question one). Or, we confirmed these products were offered for sale to end-users and that the price was close to the current price of products containing PFAS (question two).

In the first AA, we collected product price information to demonstrate that the price of products using candidate alternatives was close to products with PFAS (question two). We also looked for information indicating that there was a substantial material shortage that would impact the availability of an alternative substance.

After the first AA, stakeholders shared feedback about how we evaluated costs associated with PFAS and alternatives. Several public health groups and environmental NGOs felt that we should consider costs beyond the cost to end-users—such as the cost of health or environmental impacts. They also felt that using product price information did not reflect a market that is moving away from food packaging products with PFAS. One industry group felt that considering the price of food packaging products was insufficient to demonstrate a lack of economic impact to end-users from switching products.

We agree with our stakeholders that there are many costs to food packaging users, and many other elements of food packaging influence a product's purchase price. We did not consider this when evaluating alternatives in the first AA. We also agree that using publicly available product price information poorly reflects the market. However, evaluating these additional environmental and health costs is beyond what is required in this AA.

Instead of adding these additional cost considerations in the second AA, we shifted our focus from finding alternatives that are cost comparable and available for end-users to finding alternatives that are cost comparable and available for manufacturers. Food packaging manufacturers rarely manufacture the raw materials used to make packaging. Therefore, these manufacturers select the materials and chemicals they will use in their packaging based, at least in part, on what materials and chemicals are readily available and can create cost competitive products.

The shift in focus also alters our approach. Rather than determining which alternative food packaging products end-users purchase, we determine which alternative substances manufacturers use to make food packaging products. The new approach presumes that manufacturers would not use an alternative substance that is not available and cost comparable. The IC2 Guide includes this approach, which is used in other AAs, as an example of how to conduct a Level 1 cost and availability evaluation (Ecology & Health, 2008; IC2, 2017).

Using this new approach, to identify which alternatives are currently used in the application of interest, we looked at what alternative substances manufacturers are using to make relevant food packaging products (question one). Our new approach is compatible with our general evaluation of alternative substances supply as another indicator of availability.

For each food packaging application we are assessing, we collected information on example products that a) represent one of the five food packaging applications under assessment and b) use a candidate alternative substance we previously identified as less hazardous than PFAS. For each food packaging application, we then had a list of alternative substances manufacturers use instead of PFAS. We combine this with general information about alternative substance supply to identify alternatives that are readily available in sufficient quantity at a comparable cost.

Identifying products using known alternative substances

Following the IC2 Guide Level 1 cost and availability analysis, we must assess alternatives at the product level instead of the chemical or material level. We looked for information indicating one of the less hazardous candidate alternative substances (identified in Section 4) is replacing PFAS in the five food packaging applications we are assessing. If at least one manufacturer is using an alternative in food packaging products, that indicates the alternative is both readily available to manufacturers and can be purchased at prices comparable with PFAS.

Identifying example PFAS-free products

To show that manufacturers are using candidate alternatives, we first identified PFAS-free example products that manufacturers currently sell. We conclude that example products are PFAS-free when they meet one of the following criteria:

- Product was certified compostable through the Biodegradable Products Institute (BPI), Cedar Grove or Compost Manufacturer's Alliance (CMA), or OK Compost (BPI, 2021; CMA, 2021; TÜV AUSTRIA Belgium, 2021). These certifications require a measured total fluorinated chemical content of 100 ppm or less (BPI, 2018; CMA, 2020; Nestler et al., 2018, TÜV AUSTRIA Belgium, n.d.).
- Product manufacturers stated the product was PFAS-free.
- Product was made using aluminum or plastic as a base material, since these materials do not contain plant-based-fibers. We further confirmed this information by engaging manufacturers of these products.
- Product was made using plastic-coated paperboard. Third-party product testing data indicates that plastic-coated paperboard products do not have intentionally added PFAS (CEH, 2021; Chiang et al., 2018). We confirmed this information through discussions with multiple manufacturers of products made using plastic-coated paperboard.

We screened all products to confirm they are currently available products made by the manufacturer in question. Next, we determined the alternative providing the same function as PFAS in the product. We only included example products using a candidate alternative substance we previously concluded is less hazardous than PFAS.

If we identified at least one example product for purchase to end-users, this is sufficient evidence that the less hazardous alternative is used, available, and cost comparable to PFAS. We list example products made using known alternatives in Appendices D to H.

Sorting example products by food packaging application

Each appendix includes example products for one of the five food packaging applications we are considering.

- Bags & sleeves
- Bowls
- Flat serviceware
- Open-top containers
- Closed containers

These applications focus on the general functions of food packaging during the serving and transport of freshly prepared food. Each application includes multiple food packaging product types that can be used interchangeably. We define these applications in the introduction.

For some of these applications, we identified products that met the definition of more than one application. For example, some products represent both a bowl and an open-top container. While we only included those products in the appendix focused on bowls, we used them to evaluate both open-top containers and bowls in the results.

Some closed container products have completely detachable lids. These products can be categorized as closed containers with lids, but as another food packaging application when used without lids. Food containers, for example, are open-top containers when lids are not used. We ultimately categorized the example product based on how it was advertised. If the container and lid were sold together, and the lid fit the correct criteria, we categorized the product as a closed container. If the bottom container was sold separately from the lid, we categorized it under open-top containers or bowls, but also included it in the results for closed containers.

Identifying available and cost competitive candidate alternatives

In each appendix, we sorted products into tables based on the alternative used, which includes the base material and, if applicable, the chemical treatment used in place of PFAS. If a manufacturer made multiple products with the same alternative and representing the same application, we only counted them once.

We concluded alternative substances are available and cost competitive with PFAS if we identified at least one manufacturer making a food packaging product that:

- Meets the definition of one of the five food packaging applications defined in this AA;
- Does not intentionally add PFAS as part of their manufacturing process; and
- Uses a known less hazardous alternative substance to manufacture the product;

We summarize our findings for each food packaging application in the results section.

Additional market considerations

The cost and availability evaluation for alternative substances aims to identify examples of alternative substance use in specific food packaging products. We also review general market information to confirm there are no obvious alternative substance supply shortages impacting alternative availability. As part of this review, we re-evaluated PLA supply information to determine if the potential PLA supply limitations identified in the first AA were still evident.

Cost and availability results

Increasing demand for PFAS-free food packaging products

Our analysis focused on identifying specific examples of relevant food packaging products made using known alternatives. During this analysis, we observed a general increase in demand for PFAS-free food packaging products. We cannot use this information to demonstrate the availability of specific alternatives, but it indicates a market shift away from food packaging that contains PFAS.

Several food service companies pledged to remove PFAS from some or all food packaging products used at their establishments, including (Safer Chemicals Healthy Families, 2021b):

- Wendy’s, which committed to removing PFAS from consumer-facing packaging by the end of 2021.
- Cava, which committed to removing PFAS from food packaging by mid-2021.
- McDonald’s, which committed to removing PFAS from guest packaging globally by 2025.
- Taco Bell, which committed to removing PFAS from consumer-facing packaging by 2025.

- Chipotle, Freshii, and Sweetgreen, which all committed to removing PFAS from molded fiber products by the end of 2021.

Panera Bread, Burger King, and Tim Hortons announced they are evaluating PFAS-free alternatives for their food packaging (Safer Chemicals Healthy Families, 2021a; Safer Chemicals Healthy Families, 2021b). Albertsons, Whole Foods, and 7-Eleven all disclosed that they removed PFAS from certain food packaging materials (Safer Chemicals Healthy Families, 2021b).

Several companies added PFAS to restricted substance lists for company-owned brands of food packaging (Safer Chemicals Healthy Families, 2021b):

- Amazon
- Office Depot
- Staples
- Rite Aid

Most of these companies made these announcements in the last two years. This demonstrates the rapid movement of many large food packaging end-users toward PFAS-free food packaging.

Reusable food packaging products are available and cost competitive for some food packaging applications

Reusable food packaging is a non-chemical alternative to PFAS that suits some businesses. While it cannot completely replace all single-use food packaging, we consider it another possibility to replace PFAS-containing foodservice products.

In the first AA, analyzed the cost and the availability of reusable food packaging. The food packaging application, industry type, and size of the business influenced whether a reusable version of a food packaging application was available or cost competitive (Ecology, 2021).

ReThink Disposable reported several case studies examining the cost for foodservice businesses to transition from single-use, disposable food packaging items to reusable dinnerware options like flat serviceware (plates and trays), bowls, and open-top containers (food baskets). Reusable products are widely available for purchase, and many end-users have access to facilities to clean and sanitize these products (ReThink Disposable, 2015). Therefore, we identified reusable products as a favorable alternative for bowls, flat serviceware, and open-top containers for end-users with access to necessary facilities.

In the first AA, we discussed options for businesses interested in reusable take-out container systems (Chiang et al., 2018; Ecology, 2021). Whether reusable take-out container businesses are available currently depends highly on location. Further, reusable take-out container programs may not be feasible for all businesses (ReThink Disposable, 2015). Therefore, at this time, we do not consider reusable take-out containers readily available throughout Washington state.

General availability of alternative substances

While collaborating with stakeholders and researching available products for this assessment, we noted any evidence indicating a specific alternative substance was in short supply. Our assessment presumes manufacturers would not use substances that are not available. However, substantial evidence of a supply shortage could indicate that an available substance is not readily available in sufficient quantity.

We found no evidence that the alternative substances we are considering would not be available in sufficient quantity. In the first AA, we determined that alternatives using PLA, including PLA-coated paperboard and PLA foam, were only available for some end-users. This was based on input from stakeholders that there was a PLA material shortage impacting the availability of the alternative. Some published literature supported this concern (Jem & Tan, 2020). PLA's increased use in food packaging and other industries (such as agriculture and industrial packaging) is believed to be the cause of the shortage.

As part of this AA, we revisited PLA availability. We consulted industry stakeholders, checked for product availability online, studied the status of global PLA production, and reviewed a Biodegradable Films Market report forecasting for 2025. Since the last AA, several PLA distributers announced expansions of their existing plants or creation of new ones.

- In 2020, NatureWorks, LLC, installed additional lactide monomer purification capacity at their flagship Ingeo biopolymer manufacturing facility located in Nebraska (Natureworks, 2020). The company announced a new PLA plant located outside Bangkok, Thailand, which is projected to open in 2024 and produce an additional 75,000 tons of PLA per year (Bioplastics Magazine, 2021; NS Packaging, 2021).
- Futerro started operation of a new plant in China in September 2020 that has a 30,000 ton per year capacity. Futerro plans to increase the capacity of the plant (Bioplastics Magazine, 2020).
- Total Corbion announced the first world-scale PLA plant in Europe, set to be operational by 2024 at a 100,000 ton per year capacity (Total Corbion, 2020).

The Biodegradable Films Market report did not mention this shortage nor its effect on the supply of PLA, stating that the biodegradable film supply is expected only to increase significantly in the near future (Research and Markets, 2020). Furthermore, the number of PLA-containing products we identified in this assessment that manufacturers produce indicates that products did not leave the market due to supply. This large list demonstrates that there is enough PLA supply to continue to offer these products.

Based on stakeholder input, the lack of evidence suggesting a shortage, and evidence suggesting an increase in PLA supply, we no longer believe the availability of PLA is a concern. Therefore, examples of food packaging products made using PLA, PLA foam, or PLA-coated paperboard will demonstrate that the PLA material is an available and cost competitive alternative to PFAS.

Favorable alternative substances used in bags and sleeves

Tables 26 through 28 in Appendix D list example products that meet the definition of a bag or sleeve and use a known less hazardous alternative substance in place of PFAS. Based on that information, we can conclude that the following alternative substances are readily available and cost comparable when used to make bags and sleeves:

- Densified paper (4 manufacturers identified); see Table 27.
- Untreated paper (3 manufacturers identified); see Table 28.
- Wax-coated paper (2 manufacturers identified); see Table 29.

Favorable alternative substances used in bowls

Tables 29 through 35 in Appendix E list example products that meet the definition of a bowl and use a known less hazardous alternative substance in place of PFAS.

- Clay-coated paperboard (1 manufacturer identified); see Table 30.
- LDPE-coated paperboard (2 manufacturers identified); see Table 31.
- PLA foam (2 manufacturers identified); see Table 32.
- PLA-coated paperboard (19 manufacturers identified); see Table 33.
- Rigid PLA (8 manufacturers identified); see Table 34.
- Rigid PP (2 manufacturers identified); see Table 35.
- Wax-coated paperboard (1 manufacturer identified); see Table 36.

We only identified wax-coated portion cups in this category. We therefore determined that wax-coated paper was only favorable for some uses. Additionally, we identified reusable bowls as an available and cost comparable option for some end-users.

Favorable alternative substances used in flat serviceware

Tables 36 through 40 in Appendix F list example products that meet the definition of flat serviceware and use a known less hazardous alternative substance in place of PFAS.

- Clay-coated paperboard (2 manufacturers identified); see Table 37.
- PLA foam (5 manufacturers identified); see Table 38.
- PLA-coated paperboard (1 manufacturer identified); see Table 39.
- Rigid PLA (1 manufacturer identified); see Table 40.
- Untreated paperboard (4 manufacturers identified); see Table 41.

Additionally, we identified reusable plates and trays as an available and cost comparable option for some end-users.

Favorable alternative substances that are used in open-top containers

Tables 41 through 47 in Appendix G list example products that meet the definition of open-top containers and use a known less hazardous alternative substance in place of PFAS.

Open-top containers can also include food packaging products that we would otherwise categorize as bowls or bags. Therefore, in addition to the alternative substances identified from example products in Appendix G, alternative substances identified in example bags and sleeves (Appendix D) or bowls (Appendix E) are also available and cost competitive alternatives for open-top containers.

- Aluminum (2 manufacturers identified); see Table 42.
- Clay-coated paperboard: 5 manufacturers identified
    - Open-top containers: 4 manufacturers identified; see Table 43.
    - Bowls: 1 manufacturer identified; see Table 30.
- Densified paper (4 manufacturers identified); see Table 27.

- LDPE-coated paperboard (2 manufacturers identified); see Table 31.
- PLA foam: 2 manufacturers identified
  - Open-top containers: 1 manufacturer identified; see Table 44.
  - Bowls: 1 manufacturer identified; see Table 32.
- PLA-coated paperboard: 20 manufacturers identified
  - Open-top containers: 2 manufacturers identified; see Table 45.
  - Bowls: 18 manufacturers identified; see Table 33.
- Rigid PLA: 9 manufacturers identified
  - Open-top containers: 3 manufacturers identified; see Table 46.
  - Bowls: 6 manufacturers identified; see Table 34.
- Rigid PP: 3 manufacturers identified
  - Open-top containers: 2 manufacturers identified; see Table 47.
  - Bowls: 1 manufacturer identified; see Table 35.
- Wax coated paper or paperboard: 3 manufacturers identified
  - Open-top containers: 1 manufacturer identified; see Table 48.
  - Bags & sleeves: 2 manufacturers identified; see Table 29.

Additionally, we identified reusable food boats and bowls as an available and cost comparable option for some end-users.

Favorable alternative substances that are used in closed containers

Tables 48 through 54 in Appendix H list example products that meet the definition of closed containers and use a known alternative substance in place of PFAS.

Certain bowls or open-top containers can function as closed containers when a lid is also purchased. Therefore, in addition to the alternative substances identified from example products in Appendix H, certain example bowls (Appendix E) or open-top containers (Appendix G) products are also included.

- Aluminum: 3 manufacturers identified
  - Closed containers: 2 manufacturers identified; see Table 49.
  - Open-top containers: 1 manufacturer identified; see Table 42.
- Clay-coated paperboard (1 manufacturer identified); see Table 50.
- LDPE-coated paperboard (6 manufacturers identified); see Table 51.
- PLA Foam (3 manufacturers identified); see Table 52.
- PLA-coated paperboard: 13 manufacturers identified
  - Closed containers: 5 manufacturers identified; see Table 53.
  - Bowls: 8 additional manufacturers identified; see Table 33.
- Rigid PLA: 9 manufacturers identified
  - Closed containers: 7 manufacturers identified; see Table 54.
  - Bowls: 2 manufacturers identified; see Table 34.
- Rigid PP: 4 manufacturers identified
  - Closed containers: 3 manufacturers identified; see Table 55.
  - Open-top containers: 1 manufacturer identified; see Table 47.

Summary

In this section, we identified available and cost competitive alternative substances for each food packaging application by collecting products that a) represent one of the five food packaging applications under assessment and b) use a candidate alternative substance that we previously identified as less hazardous than PFAS. These results are used in Section 8.

For certain alternative substances, we did not identify examples of manufacturers using the alternative in relevant food packaging products. This indicates that these alternatives may not be available and cost competitive in the five current applications at this time. Alternatively, manufacturers may use them in relevant food packaging products we did not identify. We labeled these alternatives as having “insufficient information” for this assessment module.

We identified several PFAS-free food packaging products that represented one or more food packaging applications, but we could not identify the alternative substance used. This includes several products advertised as having a “poly coating” or using an aqueous barrier coating. In future AAs, we will continue to work with chemical and food packaging manufacturers and paper converters to positively correlate less hazardous alternative substances with finished food packaging products.

Section 8. Identifying Safer Alternatives from AA Module Results

Overview

To complete our analysis, we looked at results from each assessment module for a specific alternative, and determined whether that substance met the criteria for a safer alternative. To meet the criteria for safer as defined by RCW 70A.222.070,[50] the alternative:

- Must be less hazardous than the comparator according to the Hazard Module (labeled as "low concern," "BM-3," or "BM-2" in the summary tables).
- Must have a similar or lower exposure potential than the comparator or be a sufficiently low hazard concern according to the Exposure Assessment Module (labeled as "favorable" or "not applicable" in the summary tables).
- Must perform as well or better than PFAS according to the Performance Evaluation Module (labeled as "favorable" in the summary tables).
- Must be readily available in sufficient quantity, and be cost comparable with PFAS, according to the Cost and Availability Module (labeled as "favorable" in the summary tables).

Sections 4 through 7 detail each module.

We used a hybrid decision framework for this AA, which involved first evaluating the hazards of candidate alternatives to identify those that are less hazardous than PFAS. In the hazard module, we identified several alternative substances that show fewer hazard concerns than PFAS as a class, indicating they are less hazardous alternatives. We identified the following alternative substances as either not less hazardous than PFAS, or as having insufficient hazard information to evaluate:

- Polyethylene terephthalate.
- Siloxanes.
- Other forms of PE that are not LDPE.
- PP-talc composites.

We removed these alternative substances from further consideration in this AA, and did not include them in this summary.

For candidate alternative substances we identified as less hazardous than PFAS, we concurrently analyzed results from the remaining three assessment modules to identify safer alternatives. We report the results for each candidate alternative substance according to both chemical and material type:

- Untreated paper.
- Densified paper.
- Wax-coated paper.

[50] https://app.leg.wa.gov/RCW/default.aspx?cite=70A.222.070

- Clay-coated paper.
- PVOH-coated paper.
- EVOH-coated paper.
- LDPE-coated paper.
- PLA-coated paper.
- PLA foam.
- Rigid PLA.
- Rigid PP.
- Aluminum.

Coated paper can refer to coated paper, coated paperboard, or coated molded fiber products. We collected the results from the Hazard Module, Exposure Assessment, Performance Evaluation, and Cost and Availability Module in Table 20 through Table 24. This section includes a table for each food packaging application, reporting conclusions from the four modules for each potential alternative substance.

If we could not assess an alternative in any module other than the hazard module, we labeled that alternative as having "insufficient information," and did not identify it as a safer alternative. This does not mean the alternative is not a safer alternative, only that we lacked enough data to us for this AA to make a determination.

Additionally, we identified certain alternatives that could meet the performance requirements of PFAS or were readily available to end-users except under certain conditions. We labeled these alternatives to acknowledge they meet the criteria for a safer alternative for most, but not all, circumstances.

Based on results from the four evaluations, we selected one of four outcomes for each alternative:

- Yes, this is a safer alternative.
- Yes, this is a safer alternative, with a restriction such as "for some end users" or "for some uses."
- No, this is not a safer alternative, or it does not meet the criteria for safer at this time.
- There is insufficient information to assess the alternative.

Table 20 to Table 24 summarize the assessment module outcomes for each food packaging application and all candidate alternatives.

Table 20. Summary of assessment modules outcomes for bags & sleeves.

Alternative substance	Hazard module	Exposure module	Performance module	Cost & availability	Safer alternative?
Untreated paper	Low concern – Favorable	Not applicable	Not favorable	Favorable	Not safer alternative
Densified paper	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Wax-coated	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Clay-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
PVOH-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
EVOH-coated	BM 3 – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
LDPE-coated	BM 2 – Favorable	Insufficient information	Favorable	Insufficient information	Insufficient information
PLA-coated	BM 3 – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
PLA Foam	BM 3 – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
Rigid PLA	BM 3 – Favorable	Not applicable	Favorable for some uses	Insufficient information	Insufficient information
Rigid PP	BM 2 – Favorable	Insufficient information	Favorable	Insufficient information	Insufficient information
Aluminum	BM 2 – Favorable	Favorable	Favorable	Insufficient information	Insufficient information
Reusable bags	Not applicable	Not applicable	Not applicable	Not favorable	Not safer alternative

Table 21. Summary of assessment modules outcomes for bowls.

Alternative substance	Hazard module	Exposure module	Performance module	Cost & availability	Safer alternative?
Untreated paper	Low concern – Favorable	Not applicable	Not favorable	Insufficient information	Not safer alternative
Densified paper	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
Wax-coated	Low concern – Favorable	Not applicable	Favorable	Favorable for some uses	Safer alternative for some uses
Clay-coated	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PVOH-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
EVOH-coated	BM 3 – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
LDPE-coated	BM 2 – Favorable	Insufficient information	Favorable	Favorable	Insufficient information
PLA-coated	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PLA Foam	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Rigid PLA	BM 3 – Favorable	Not applicable	Favorable for some uses	Favorable	Safer alternative for some uses
Rigid PP	BM 2 – Favorable	Insufficient information	Favorable	Favorable	Insufficient information
Aluminum	BM 2 – Favorable	Favorable	Favorable	Insufficient information	Insufficient information
Reusable bowls	Not applicable	Not applicable	Not applicable	Yes for some end users	Yes for some end users

Table 22. Summary of assessment modules outcomes for flat serviceware.

Alternative substance	Hazard module	Exposure module	Performance module	Cost & availability	Safer alternative?
Untreated paper	Low concern – Favorable	Not applicable	Not favorable	Favorable	Not safer alternative
Densified paper	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
Wax-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
Clay-coated	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PVOH-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
EVOH-coated	BM 3 – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
LDPE-coated	BM 2 – Favorable	Insufficient information	Favorable	Insufficient information	Insufficient information
PLA-coated	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PLA foam	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Rigid PLA	BM 3 – Favorable	Not applicable	Favorable for some uses	Favorable	Safer alternative for some uses
Rigid PP	BM 2 – Favorable	Insufficient information	Favorable	Insufficient information	Insufficient information
Aluminum	BM 2 – Favorable	Favorable	Favorable	Insufficient information	Insufficient information
Reusable flat serviceware	Not applicable	Not applicable	Not applicable	Yes for some end users	Yes for some end users

Table 23. Summary of assessment modules outcomes for open-top containers.

Alternative substance	Hazard module	Exposure module	Performance module	Cost & availability	Safer alternative?
Untreated paper	Low concern – Favorable	Not applicable	Not favorable	Insufficient information	Not safer alternative
Densified paper	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Wax-coated	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Clay-coated	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PVOH-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
EVOH-coated	BM 3 – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
LDPE-coated	BM 2 – Favorable	Insufficient information	Favorable	Favorable	Insufficient information
PLA-coated	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PLA foam	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Rigid PLA	BM 3 – Favorable	Not applicable	Favorable for some uses	Favorable	Safer alternative for some uses
Rigid PP	BM 2 – Favorable	Insufficient information	Favorable	Favorable	Insufficient information
Aluminum	BM 2 – Favorable	Favorable	Favorable	Favorable	Safer alternative
Reusable open-top containers	Not applicable	Not applicable	Not applicable	Yes for some end users	Yes for some end users

Table 24. Summary of assessment modules outcomes for closed containers.

Alternative substance	Hazard module	Exposure module	Performance module	Cost & availability	Safer alternative?
Untreated paper	Low concern – Favorable	Not applicable	Not favorable	Insufficient information	Not safer alternative
Densified paper	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
Wax-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
Clay-coated	Low concern – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PVOH-coated	Low concern – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
EVOH-coated	BM 3 – Favorable	Not applicable	Favorable	Insufficient information	Insufficient information
LDPE-coated	BM 2 – Favorable	Insufficient information	Favorable	Favorable	Insufficient information
PLA-coated	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
PLA foam	BM 3 – Favorable	Not applicable	Favorable	Favorable	Safer alternative
Rigid PLA	BM 3 – Favorable	Not applicable	Favorable for some uses	Favorable	Safer alternative for some uses
Rigid PP	BM 2 – Favorable	Insufficient information	Favorable	Favorable	Insufficient information
Aluminum	BM 2 – Favorable	Favorable	Favorable	Favorable	Safer alternative
Reusable closed containers	Not applicable	Not applicable	Not applicable	Not favorable	Not safer alternative

Conclusion

Summary of safer alternatives by application

To find that safer alternatives are available for each food packaging application, at least one alternative must meet the criteria for safer with no restrictions (we note these as a “safer alternative” in the tables in this section). We also included reusable products when we identified them, since they will only be unavailable products when a cleaning system is unavailable, which has less to do with the products and more to do with the food service business using the products.

We identified the following safer alternatives for each food packaging application:

Food packaging application: Bags & sleeves

- Densified paper.
- Wax-coated paper.

Food packaging application: Bowls

- Clay-coated paper.
- PLA-coated paper.
- PLA foam.
- Reusable bowls (for some end-users).

Food packaging application: Flat serviceware

- Clay-coated paper.
- PLA-coated paper.
- PLA foam.
- Reusable flat serviceware (for some end-users).

Food packaging application: Open-top containers

- Densified paper.
- Wax-coated paper.
- Clay-coated paper.
- PLA-coated paper.
- PLA foam.
- Aluminum.
- Reusable open-top containers (for some end users).

Food packaging application: Closed containers

- Clay-coated paper.
- PLA-coated paper.
- PLA foam.
- Aluminum.

Concluding comments

We focused on identifying alternatives to PFAS in five food packaging applications that met the criteria for safer alternatives outlined in RCW 70A.222.070. These five food packaging applications hold freshly prepared food, and if needed, store freshly prepared food for short periods of time. We chose these food packaging applications to cover the types of food packaging generally used to hold freshly prepared food where we did not identify safer alternatives during the first AA (Ecology, 2021). With this second AA, we identified safer alternatives for all general applications of food packaging intended to store or transport freshly prepared food.

Our goal in these AAs was not to prioritize safer alternatives or identify one alternative as the most favorable. This work is a general review of alternatives that, by necessity, cannot consider specific company or user needs. Individuals or organizations aiming to replace food packaging that contains PFAS are encouraged to use this AA as a starting point for their own evaluation of alternatives. We encourage food packaging manufacturers exploring alternatives to PFAS to consider all alternative substances that met hazard and exposure criteria because they may have access to performance or availability information that was not available in this assessment.

We encourage individuals and organizations to consider any specialized needs they have that might influence the criteria for a favorable alternative regarding hazard, exposure, performance, cost or availability. We also urge individuals and organizations to consider additional criteria, particularly regarding environmental equity, social impact or material end-of-life. Prioritizing alternative chemicals, materials, and products with a positive impact on the communities where they are made, used, and disposed, or that can be easily recycled or composted, helps ensure the most preferable alternatives replace PFAS.

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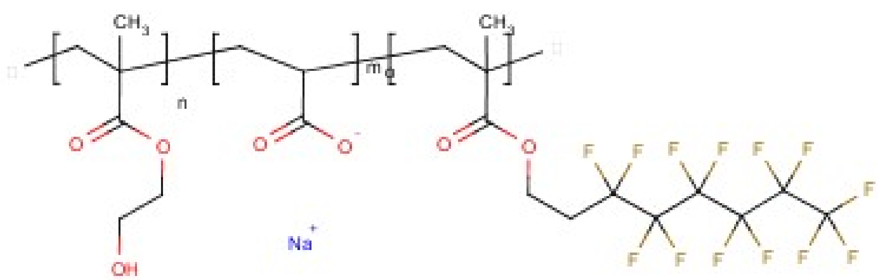
Appendix A. Representative Structures of PFAS that FDA Approved for Use in Food Packaging

2-propenoic acid, 2-methyl-, 2- hydroxyethyl ester, polymer with 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2- propenoate, sodium salt

- CAS Registration Number: 1878204-24-0.
- FCN or FCS number: 1676.
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.[51]

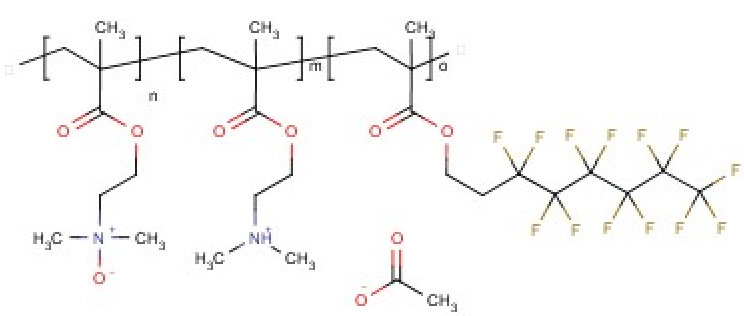
Figure 3. Representative structure of CAS 1878204-24-0.



Copolymer of 2- (dimethylamino) ethyl methacrylate with 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, N-oxide, acetate

- CAS Registration Number: 1440528-04-0.
- FCN or FCS number: 1493.
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

Figure 4. Representative structure of CAS 1440528-04-0.



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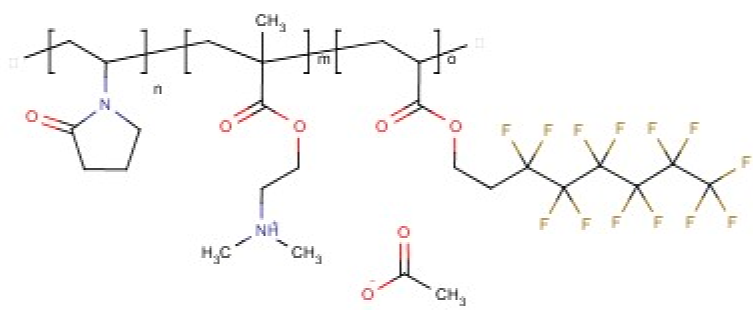
[51] https://www.fda.gov/food/cfsan-constituent-updates/fda-announces-voluntary-phase-out-industry-certain-pfas-used-food-packaging

2-Propenoic acid, 2-methyl-, 2- (dimethylamino)ethyl ester, polymer with 1-ethenyl-2-pyrrolidinone and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate, acetate

- CAS Registration Number: 1334473-84-5.
- FCN or FCS numbers: 1451 (1360).
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

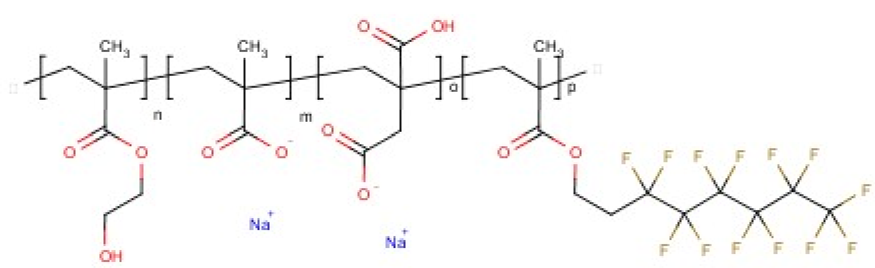
Figure 5. Representative structure of CAS 1334473-84-5.



Butanedioic acid, 2-methylene-, polymer with 2-hydroxyethyl, 2- methyl-2-propenoate, 2-methyl- 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, sodium salt

- CAS Registration Number: 1345817-52-8.
- FCN or FCS number: 1186.
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

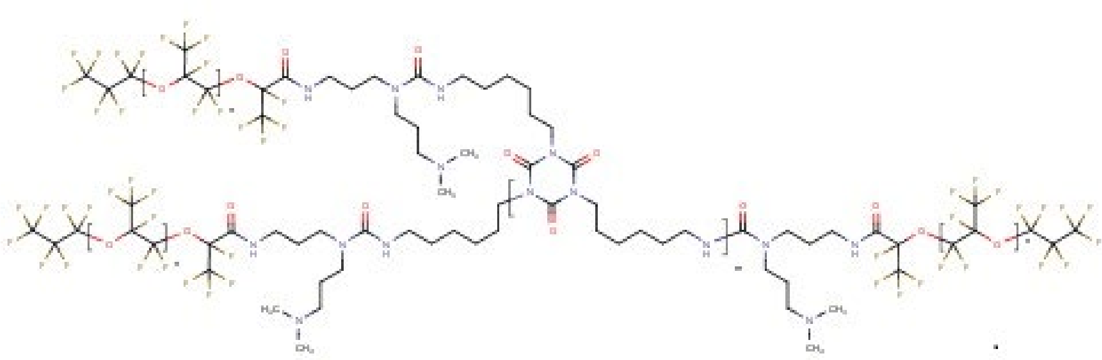
Figure 6. Representative structure of CAS 1345817-52-8.



Hexane, 1,6-diisocyanato-, homopolymer, α-[1-[[[3-[[3 (dimethylamino)propyl]amino]propyl]amino]carbonyl]-1,2,2,2- tetrafluoroethyl]-ω-(1,1,2, 2,3,3,3-heptafluoropropoxy) poly[oxy[trifluoro(trifluoromet-hyl)-1,2-ethanediyl]]-blocked

- CAS Registration Number: 1279108-20-1.
- FCN or FCS number: 1097.

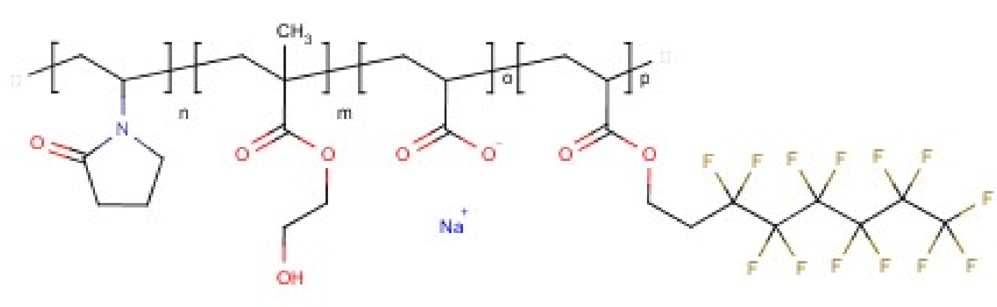
Figure 7. Representative structure of CAS 1279108-20-1



2-propenoic acid, 2-methyl-, 2- hydroxyethyl ester polymer with 1-ethenyl-2-pyrrolidinone, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate sodium salt

- CAS Registration Number: 1206450-10-3.
- FCN or FCS number: 1044.
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

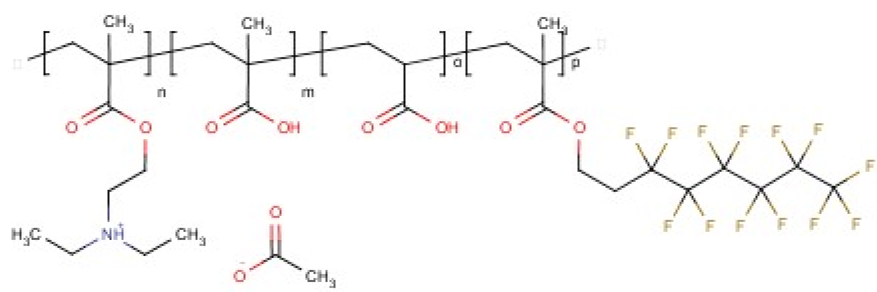
Figure 8. Representative structure of CAS 1206450-10-3.



2-propenoic acid, 2-methyl-, polymer with 2- (diethylamino)ethyl 2-methyl-2- propenoate, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2- propenoate, acetate

- CAS Registration Number: 1071022-26-8.
- FCN or FCS numbers: 1027 (885).
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

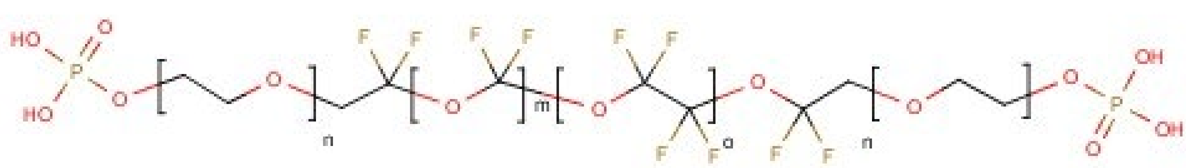
Figure 9. Representative structure of CAS 1071022-26-8.



Diphosphoric acid, polymers with ethoxylated reduced Me esters of reduced polymerized oxidized tetrafluoroethylene

- This substance is also known as: phosphate esters of ethoxylated perfluoroether, prepared by reaction of ethoxylated perfluoroether diol (CAS Reg. No. 162492-15-1) with phosphorous pentoxide (CAS Reg. No. 1314-56-3) or pyrophosphoric acid (CAS Reg. No. 2466-09-3).
- CAS Registration Number: 200013-65-6.
- FCN or FCS numbers: 962 (416 and 195).

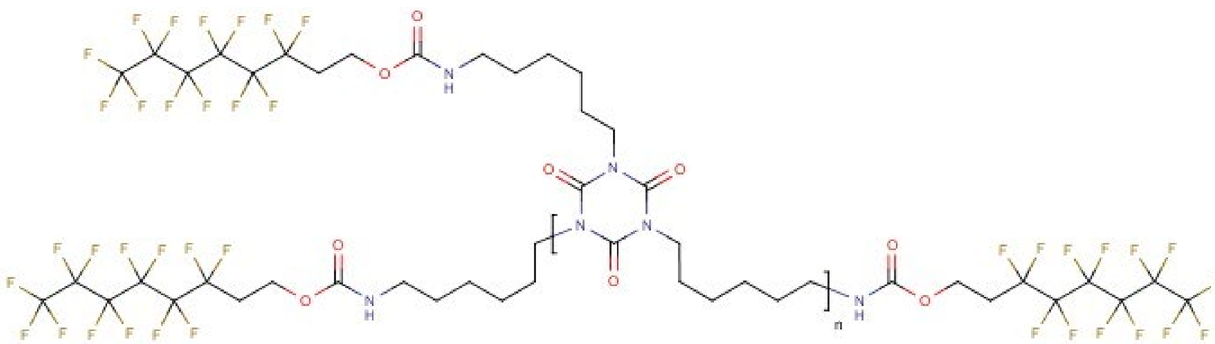
Figure 10. Representative structure of CAS 200013-65-6.



Hexane, 1,6-diisocyanato-, homopolymer, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol-blocked

- CAS Registration Number: 357624-15-8.
- FCN or FCS number: 940.
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

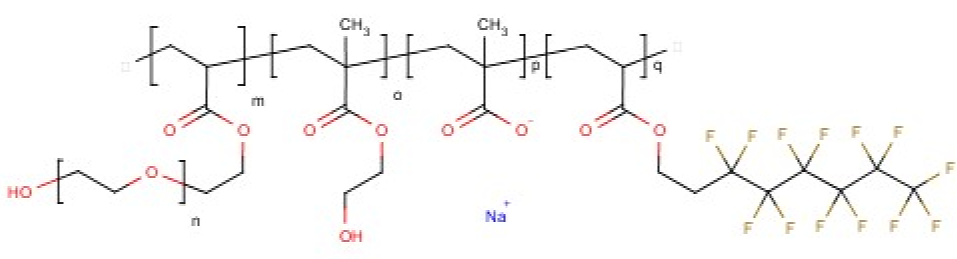
Figure 11. Representative structure of CAS 357624-15-8.



2-propenoic acid, 2-methyl-, polymer with 2-hydroxyethyl 2-methyl-2-propenoate, α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl) and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate, sodium salt

- CAS Registration Number: 1158951-86-0.
- FCN or FCS number: 933.
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

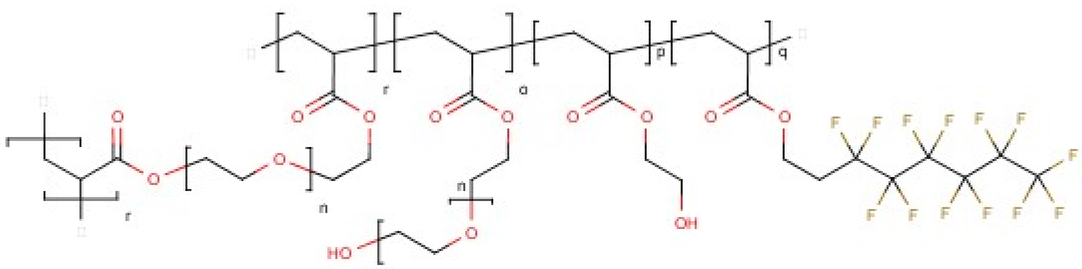
Figure 12. Representative structure of CAS 1158951-86-0.



2-propenoic acid, 2- hydroxyethyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2- ethanediyl), α-(1-oxo-2-propen- 1-yl)-ω-[(1-oxo-2-propen-1-yl)oxy]poly(oxy-1,2-ethanediyl) and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate

- CAS Registration Number: 1012783-70-8.
- FCN or FCS numbers: 888 (827).
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

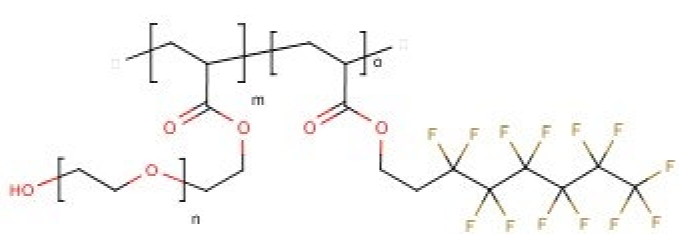
Figure 13. Representative structure of CAS 1012783-70-8.



2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω- hydroxypoly(oxy-1,2- ethanediyl)

- FCN or FCS number: 820.
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

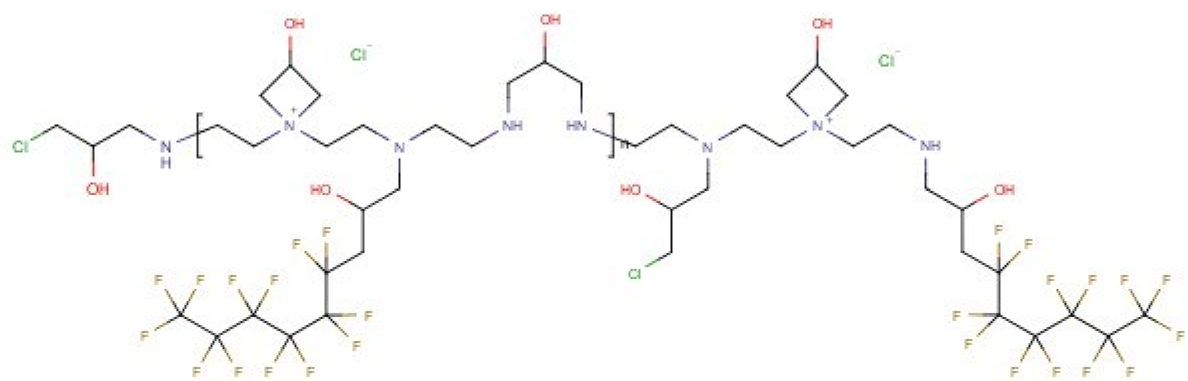
Figure 14. Representative structure of 2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω- hydroxypoly(oxy-1,2- ethanediyl).



2-propen-1-ol, reaction products with 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-6-iodohexane, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine

- CAS Registration Number: 464178-94-7.
- FCN or FCS numbers: 783 (746 and 542).

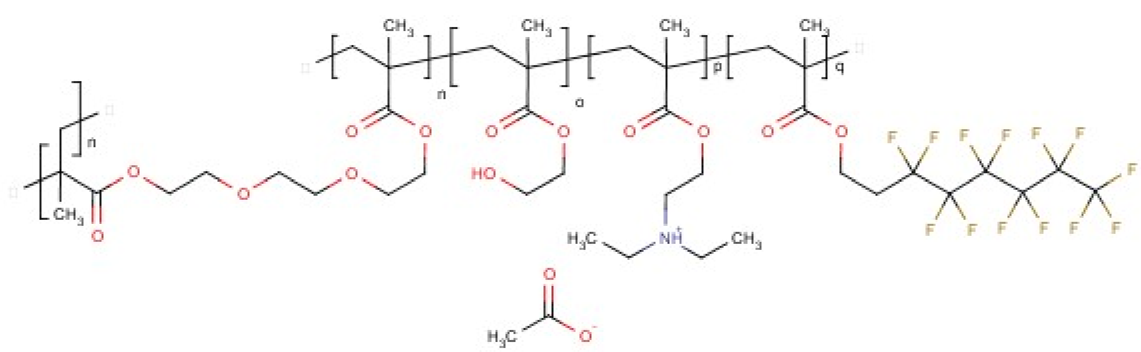
Figure 15. Representative structure of CAS 464178-94-7.



Copolymer of perfluorohexylethyl methacrylate, 2-N,N- diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, acetic acid salt

- CAS Registration Number: 863408-20-2.
- FCN or FCS numbers: 604 (599).
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

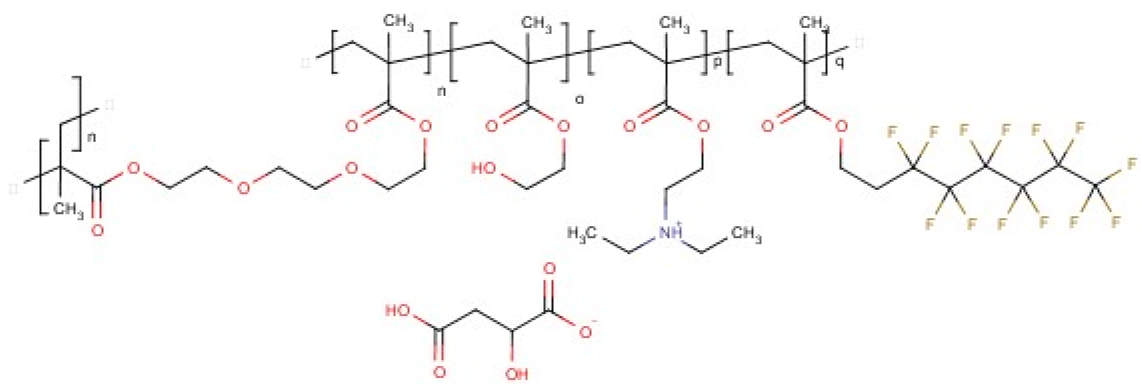
Figure 16. Representative structure of CAS 863408-20-2.



Copolymer of perfluorohexylethyl methacrylate, 2-N,N- diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, malic acid salt

- CAS Registration Number: 1225273-44-8.
- FCN or FCS numbers: 604 (599).
- This substance is being voluntarily phased out as per FDA agreement released July 31, 2020.

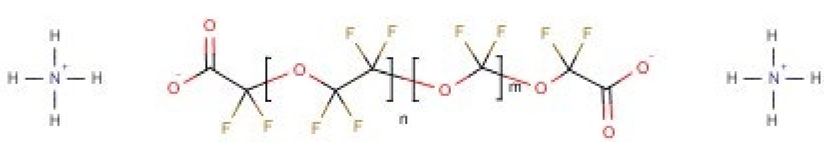
Figure 17. Representative structure of CAS 1225273-44-8.



Perfluoropolyether dicarboxylic acid, ammonium salt.

- CAS Registration Number: 69991-62-4.
- FCN or FCS number: 538 (398).

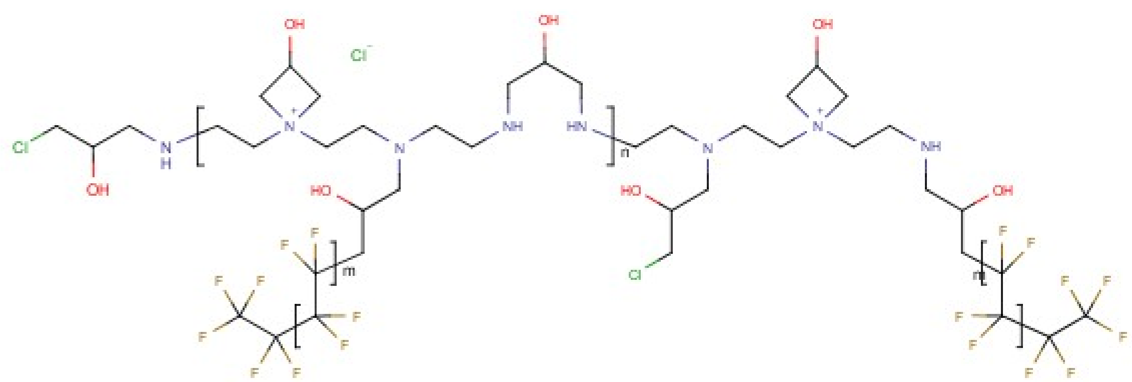
Figure 18. Representative structure of CAS 69991-62-4.



2-propen-1-ol, reaction products with pentafluoroiodoethane- tetrafluoroethylene telomer, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine (CAS Reg. No 464178-90-3)

- CAS Registration Number: 464178-90-3.
- FCN or FCS numbers: 518 (487, 314).

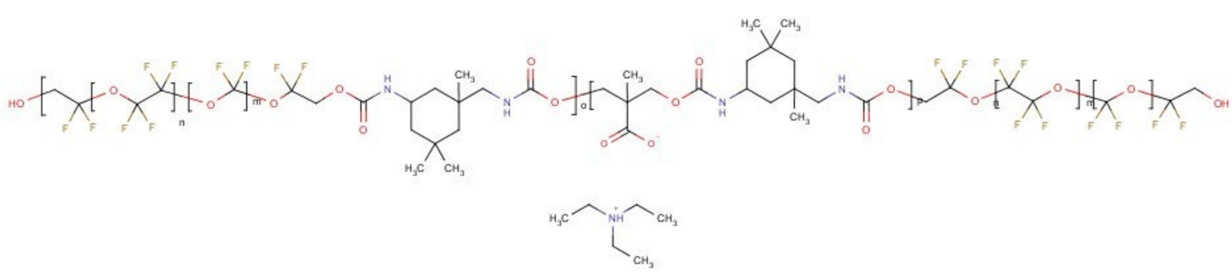
Figure 19. Representative structure of CAS 464178-90-3.



Fluorinated polyurethane anionic resin prepared by reacting perfluoropolyether diol (CAS Reg. No. 88645-29-8), isophorone diisocyanate (CAS Reg. No. 4098-71-9), 2,2-dimethylolpropionic acid (CAS Reg. No. 4767-03-7), and triethylamine (CAS Reg. No. 121-44-8)

- CAS Registration Number: 328389-91-9.
- FCN or FCS number: 187.

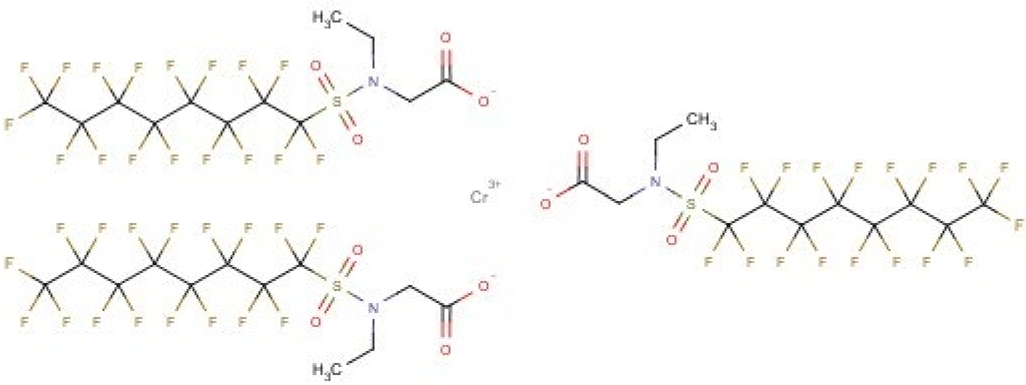
Figure 20. Representative structure of CAS 328389-91-9.



Chromium (Cr III) complex of N-ethyl - N -heptadecylfluoro- octane sulfonyl glycine containing up to 20 percent by weight of the chromium (Cr III) complex of heptadecylfluoro- octane sulfonic acid may be safely used as a component of paper for packaging dry food when used in accordance with prescribed conditions

- CFR section: 176.160.

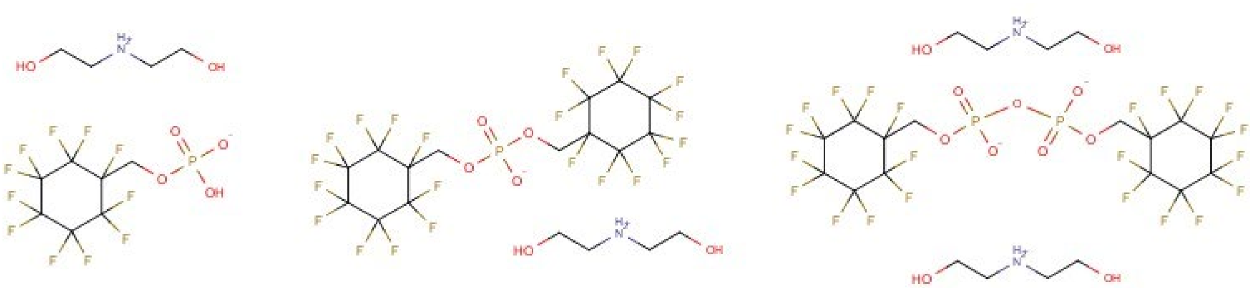
Figure 21. Representative structure of chromium (Cr III) complex of N-ethyl - N -heptadecylfluoro-octane sulfonyl glycine (drawn as 2.88% chromium (Cr III).



Undecafluorocyclohexanemethanol ester mixture of dihydrogen phosphate, compound with 2,2' iminodiethanol (1:1); hydrogen phosphate, compound with 2,2'- iminodiethanol (1:1); and P,P'- dihydrogen pyrophosphate, compound with 2,2'- iminodiethanol (1:2); where the ester mixture has a fluorine content of 48.3 pct to 53.1 pct as determined on a solids basis

- CFR section: 176.170.

Figure 22. Representative structure of undecafluorocyclohexanemethanol ester mixture of dihydrogen phosphate (drawn as 46.14% fluorine).



Appendix B. Common Hazards of Data Rich PFAS

This appendix contains a list of data rich PFAS with existing hazard assessments. We reviewed existing publicly available hazard assessments that included data from multiple hazard endpoints. The third column in each table highlights the GreenScreen® endpoints of concern for the compound, as well as its presence on any authoritative lists (CPA, 2018b).

Table 25. Hazard information for data rich PFAS.

Common Name (CASRN)	GreenScreen® assessment or List Translator score(s)	Endpoints of concern based on GreenScreen® score (high or very high) or authoritative listings
Hexafluoropropylene (116-15-4)	BM-1	Persistence, carcinogenicity, systemic toxicity (single and repeat), neurotoxicity (single), and skin and eye irritation (ToxServices, 2018a).
3-Ethoxyperfluoro(2-methylhexane) (297730-93-9)	BM-1	Persistence, bioaccumulation, and chronic aquatic toxicity (ToxServices, 2020a).
Perfluorobutanesulfonate, potassium salt (29420-49-3)	BM-1	Persistence and eye irritation (ToxServices, 2020b).
1,1,2,2-Tetrahydroperfluorodecyl acrylate (27905-45-9)	BM-1	Persistence, bioaccumulation, neurotoxicity (repeat), and systemic toxicity (repeat) (ToxServices, 2016a).
PTFE (9002-84-0)	BM-1	Persistence and systemic toxicity (ToxServices, 2019b).
PFHxA (307-24-4)	BM-1	Persistence, systemic toxicity (single), and skin and eye irritation (ToxServices, 2016c).
6:2 FTOH (647-42-7)	BM-1	Persistence, acute toxicity, systemic toxicity (single and repeat), and aquatic toxicity (acute and chronic) (ToxServices, 2019a).

Common Name (CASRN)	GreenScreen® assessment or List Translator score(s)	Endpoints of concern based on GreenScreen® score (high or very high) or authoritative listings
Perfluorooctanoic acid (335-67-1)	LT-1	**Developmental toxicity:** CA EPA Prop 65, EU GHS statement H360D & H362 (ECHA, 2021c; OEHHA, 2021). **Reproductive and/or developmental toxicity:** EU Annex VI CMRs Category 1B, EU REACH Annex XVII CMRs Category 2, EU SVHC Authorisation List Toxic to reproduction candidate list (ECHA 2019, 2021b, & 2021c). **Systemic toxicity:** EU GHS code H372 (ECHA, 2021c). **Eye irritation:** EU GHS code H318 (ECHA, 2021c). **PBT:** UNEP Stockholm Convention on Persistent Organic Pollutants (UNEP, 2019).
Perfluorononanoic acid (375-95-1)	LT-1	**Developmental toxicity:** EU GHS codes H362 and H360Df (ECHA, 2021c). **Reproductive and/or developmental toxicity:** EU Annex VI CMRs Category 1B, EU REACH Annex XVII CMRs Category 2, EU SVHC Authorisation List Toxic to reproduction candidate list (ECHA, 2019, 2021b, & 2021c). **Systemic toxicity:** EU GHS code H372 (ECHA, 2021c). **Eye irritation:** EU GHS code H318 (ECHA, 2021c). **PBT:** EU SVHC Authorisation List PBT Candidate (ECHA, 2019).
Perfluorooctanesulfonic Acid (1763-23-1)	LT-1	**Reproductive and/or developmental toxicity:** EU Annex VI CMR Category 1B, EU REACH Annex XVII CMRs Category 2 (ECHA, 2021a & 2021b). **Developmental Toxicity:** CA Prop 65, EU GHS codes H360D and H362 (ECHA, 2021c; OEHHA, 2021). **Systemic toxicity:** EU GHS code H372 (ECHA, 2021c). **PBT:** UNEP Stockholm Convention on Persistent Organic Pollutants (UNEP, 2019).

Common Name (CASRN)	GreenScreen® assessment or List Translator score(s)	Endpoints of concern based on GreenScreen® score (high or very high) or authoritative listings
Ammonium perfluorooctanoate (3825-26-1)	LT-1	**Developmental toxicity:** EU GHS codes H360 and H362 (ECHA, 2021c). **Reproductive and/or developmental toxicity:** EU Annex VI CMRs Category 1B, EU REACH Annex XVII CMRs Category 2, EU SVHC Authorisation List Toxic to reproduction candidate list (ECHA 2019, 2021b, & 2021c). **Systemic toxicity:** EU GHS code H372 (ECHA, 2021c). **Eye irritation:** EU GHS code H318 (ECHA, 2021c). **PBT:** UNEP Stockholm Convention on Persistent Organic Pollutants (UNEP, 2019).
Potassium perfluorooctanesulfonate (2795-39-3)	LT-1	**Developmental toxicity:** EU GHS codes H360D and H362 (ECHA, 2021c). **Reproductive and/or developmental toxicity:** EU Annex VI CMRs Category 1B, EU REACH Annex XVII CMRs Category 2 (ECHA, 2021b & 2021c). **Systemic toxicity:** EU GHS code H372 (ECHA, 2021c). **PBT:** UNEP Stockholm Persistent Organic Pollutant (UNEP, 2019).
Ammonium perfluorooctanesulfonate (29081-56-9)	LT-1	**Developmental toxicity:** EU GHS codes H360D and H362 (ECHA, 2021c). **Reproductive and/or developmental toxicity:** EU Annex VI CMRs Category 1B, EU REACH Annex XVII CMRs Category 2 (ECHA, 2021b & 2021c). **Systemic toxicity:** EU GHS code H372 (ECHA, 2021c). **PBT:** UNEP Stockholm Persistent Organic Pollutant (UNEP, 2019).
Tetrafluoroethylene (116-14-3)	LT-1	**Carcinogenicity:** CA EPA Prop 65, IARC Group 2A, MAK Group 2, US NIH Report on Carcinogens (IARC, 2017; MAK, 2021; NTP, 2016; OEHHA, 2021)

Appendix C. Exposure-Related Properties of PFAS and Alternatives

Table 26 contains experimentally determined or modeled values for the exposure-related properties used to compare PFAS and certain alternative substances in the exposure assessment module. The first column includes the units for each exposure-related property. See Section 5 for more details on the exposure assessment method and results.

Each column contains values from a single resource. More than one column for the same chemical indicates that we consulted multiple sources. An entry of "ND" (no data) means we did not identify any values from that source for that exposure-related property.

Table 26. Exposure-related property values for specific PFAS and alternative substances.

Property (Units)	PFHxA[1]	PFHxA[2]	6:2 FTOH[3]	Aluminum oxide[4]	LDPE[5]	PP[6]
Volatility/ vapor pressure (mm Hg)	ND	1.98	7.5E-2 – 6.57	0.75 at 2122 Celsius	ND	ND
Molecular weight (amu or Da)	ND	314.0499	364.104	101.961	Broad MW distribution >1000[7]	MW > 200,000[8]
Solubility in water (mg/L)	0.85273 – 4.703	Less than 29	4.84E-5	Insoluble	Insoluble	Insoluble
Log K_{ow}	4.37	ND	4.54 – 4.70	-0.83 (EPISuite[52]; WAP Sustainability Consulting, 2018)	ND	ND
Boiling point (Celsius)	157	ND	90 – 174	5396	ND	Decomposes above 300 C
Melting point (Celsius)	14	ND	-35.0	2030 – 3632	112	150 – 170
Density/ specific gravity (g/cm3)	1.759 – 1.762	1.762	1.54 – 1.59	3.97	0.915 – 0.928	0.880 – 0.913
pH	ND	ND	ND	Aluminum oxide is available as chromatography medium at pH 9.5, 4.5 and 7.0	ND	ND
Corrosivity	ND	GHS Category 1 (corrosive to metals)	ND	ND	ND	ND
Environmental partitioning	ND	Partition coefficient 3.12 – 3.26	ND	ND	ND	ND

[52] https://www.epa.gov/tsca-screening-tools/epi-suitetm-estimation-program-interface

Property (Units)	PFHxA[1]	PFHxA[2]	6:2 FTOH[3]	Aluminum oxide[4]	LDPE[5]	PP[6]
Use characteristics or synergistic effects	ND	pKa = 0.84	ND	ND	ND	ND
Particle size	ND	ND	ND	ND	ND	ND
Volatility (Henry's Law Constant)	0.174	ND	2.62E-10 (modeled)	9.18E-17 (EPISuite; WAP Sustainability Consulting, 2018)	ND	ND
$LogK_{oc}$	3.096	2.081 – 3.116 (EPISuite)	ND	1.907 (EPISuite; WAP Sustainability Consulting, 2018)	ND	ND
Bioaccumulation	BCF 3.162	BCF 100 – 500	ND	BCF 3.162 (EPISuite; WAP Sustainability Consulting, 2018)	ND	ND
Persistence	ND	Very high	ND	Very high	Very high	Very high
Flammability	ND	Moderate	ND	Nonflammable	Combustible	> 300 C flash point; flammable

Table notes:

1. PFHxA: CASRN 307-24-4 (RSC, 2021[53])
2. PFHxA: CASRN 307-24-4 (ToxServices, 2016c)
3. 6:2 FTOH: CASRN 647-42-7 (EPA, 2021[54])
4. Aluminum oxide: CASRN 1344-28-1 (NIH, 2021[55])
5. LDPE: CASRN 9002-88-4 (Qenos, 2015b)
6. PP: CASRN 9003-07-0 (Advanced Petrochem, 2016)
7. ILSI, 2003 gives a more generic MW range for LDPE of 10,000 to 50,000 Daltons.
8. Shamiri et al., 2014 gives a more generic MW range for PP of 50,000 to 200,000 Daltons.

[53] http://www.chemspider.com/Chemical-Structure.60864.html
[54] https://comptox.epa.gov/dashboard/dsstoxdb/results?search=647-42-7
[55] https://pubchem.ncbi.nlm.nih.gov/compound/Aluminum-oxide

Appendix D. Examples of Bags & Sleeves

This appendix includes example products made with less hazardous alternatives that meet the definition of bags and sleeves. We sorted products into tables based on the alternative they use. That includes the base material and, if applicable, the chemical treatment used in place of PFAS. Section 6 and Section 7 use this appendix to assess alternative performance or use.

Table 27. Example bags & sleeves made using densified paper.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Glassine Bags	Brown Paper Goods	Yes	No	Glassine will hold most grease but it will not hide it[56]	CMA, 2021
Glassine Bags	Fischer Paper Products	Yes	Yes	A thin, glossy paper that delivers moderate moisture protection. Plain glassine bags are made for exceptional grease resistance[57,58]	CMA, 2021
Sub/Mini-Baguette Sandwich Bags; Paper Snack & Sandwich Bags	If You Care	Yes	No	Greaseproof[59,60]	OK Compost (EN 13432)
Glassine bags with or without clear compostable window	Vegware	Yes	No	Great grease resistance[61]	CMA, 2021

[56] https://www.nmbakery.com/files/117093219.pdf
[57] https://fischerpaperproducts.com/products/glassine-french-fry-bag-609/
[58] https://fischerpaperproducts.com/branded-custom-packaging/materials/
[59] https://buyifyoucare.com/collections/baking-cooking/products/if-you-care-sub-mini-baguette-sandwich-bags
[60] https://buyifyoucare.com/collections/baking-cooking/products/sandwich-bags-fcs-certified
[61] https://www.vegwareus.com/us/catalogue/hot_bags_wraps/

Table 28. Example bags & sleeves made using untreated paper.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Plain Milly Bag; Kraft Merchandise Bag	AJM Packaging Corporation	No	No	None specific to OGR or leak resistance[62]	CMA, 2021
TruKraft™ Natural Kraft Bread Bag	Fischer Paper Products	No	No	None specific to OGR or leak resistance[63,64]	CMA, 2021
Recycled Kraft Gusset Bag	Vegware	No	No	None specific to OGR or leak resistance[65]	CMA, 2021
Paper PLA Window Bags	Vegware	No	No	None specific to OGR or leak resistance[66,67]	CMA, 2021

Table 29. Example bags & sleeves made using wax-coated paper.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Waxed Sandwich Bag	Fischer Paper Products	Yes	Yes	Provides superior grease and moisture resistance[68,69]	CMA, 2021
Waxed Sandwich Bags & Sleeves	McNairn Pkg.	Yes	Yes	Grease resistant; Dry wax application to this paper makes it grease and moisture resistant[70]	BPI, 2021

[62] https://www.walmart.com/ip/AJM-MBN105G8M-5-x-7-5-in-Plain-Milly-Bag-44-Kraft-Case-of-8000/668247302
[63] https://fischerpaperproducts.com/branded-custom-packaging/materials/
[64] https://fischerpaperproducts.com/products/bread-bag-bb-36/
[65] https://www.vegwareus.com/us/catalogue/bags_to_go/6_x_075_x_7in_recycled_kraft_gusset_bag/
[66] https://www.vegwareus.com/us/catalogue/bags_to_go/
[67] https://www.vegwareus.com/us/catalogue/bags_to_go/4_x_2_x_14in_kraft_pla_side_window_baguette_bag/
[68] https://fischerpaperproducts.com/products/waxed-sandwich-bag-514/
[69] https://fischerpaperproducts.com/branded-custom-packaging/materials/
[70] https://www.mcnairnpackaging.com/catalogs.html

Appendix E. Examples of Bowls

This appendix includes example products made with less hazardous alternatives that meet the definition of bowls. We also included some of these products in open-top containers and closed containers (with lids). We sorted products into tables based on the alternative they use. That includes the base material and, if applicable, the chemical treatment used in place of PFAS. Section 6 and Section 7 use this appendix to assess alternative performance or use.

Table 30. Example bowls made using clay-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Solo® Eco-Forward™/Solo® Paper Dinnerware	Dart Container Corporation	Yes	Yes	Solo® paper bowls have excellent moisture resistance, grease resistance, and strength to keep you serving in style.[71]	CMA, 2021

Table 31. Example bowls made using LDPE-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Single-Sided Poly Paper Soufflé Cup	Dart Container Corporation	No	Yes	Resistant to liquid penetration… poly-lined Paper options available for superior moisture resistance[72,73]	Stakeholder input; CEH, 2018
Solo® VS SSP Paper Food Containers	Dart Container Corporation	No	Yes	Single-sided, polyethylene-coated paper on the inside of the container acts as a moisture barrier to keep liquid inside[74,75]	Stakeholder input; CEH, 2018
Single Wall White Bowl	Gallimore Products Inc.	No	No	None specific to OGR or leak resistance[76]	N/A—material type CEH, 2018

[71] https://www.dartcontainer.com/products/foodservice-catalog/dinnerware-containers/dinnerware/paper/solo-paper-dinnerware/hb12-j8001/
[72] https://www.dartcontainer.com/products/foodservice-catalog/dinnerware-containers/containers/paper/solo-paper-portion-containers/
[73] https://www.dartcontainer.com/sustainability/about-our-products/coated-paperboard/
[74] https://www.dartcontainer.com/products/foodservice-catalog/dinnerware-containers/containers/paper/solo-paper-portion-containers/
[75] https://www.dartcontainer.com/sustainability/about-our-products/coated-paperboard/
[76] http://www.gallimoreproducts.com/cups--bowls.html

Table 32. Example bowls made using PLA Foam.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Customizable Bowls	BGF Ecobio	Yes—plastic	Yes—plastic	Superior mechanical properties—thermal resistance, durability, insulation and cushioning—for substitution of conventional single-serve products made with PS, PP, or pulp[77,78]	CMA, 2021
Earth Maize Compostable Bowls	Biodegradable Food Service, LLC	Yes	Yes	Moisture resistant; grease resistant[79]	BPI, 2021

Table 33. Example bowls made using PLA-coated paperboard or molded fiber.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Planet+® Compostable Food Containers	Asean Corporation	No	Yes	Outstanding hot or cold food serving performance, with all the same qualities as our Planet+® Compostable Hot Cups[80]	CMA, 2021
PLA Paper Soup Container	Besics Packaging Corporation	No	Yes	Perfect for hot drinks; soup container[81]	BPI, 2021
Earth Bowl To-Go Containers	Biodegradable Food Service, LLC	No	No	None specific to OGR or leak resistance[82]	BPI, 2021
Compostable Hot Paper Bowl with Bio Lining	BioGreenChoice	Yes	Yes	Strong and sturdy, they are useful for serving foods with and without sauces[83]	BPI, 2021

[77] http://www.koreabiofoam.com/en/tech/
[78] http://www.koreabiofoam.com/en/products/
[79] https://earth-to-go.org/earth-maize/earth-maize
[80] https://www.stalkmarketproducts.com/products/containers/food-containers/food-containers.html
[81] https://besics.ca/shop/public/product/soup-bowls
[82] https://earth-to-go.org/earth-bowl/compostble-soup-bowls
[83] https://www.biogreenchoice.com/products/12-oz-compostable-hot-paper-bowl-w-bio-lining-500-count

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Bare® by Solo® Eco-Forward® VS SSPLA Paper Food Containers	Dart Container Corporation	No	Yes	Plant-based resin moisture barrier preventing leaks and replacing petroleum-based lining typical of paper food containers[84,85]	CMA, 2021
Compostable Food Container or Bowl	EcoGuardian	Yes	Yes	Perfect size for larger sized portions of soup, stew, noodles, cereal, oatmeal, breakfast, lunch, dinner, desserts—organic waterproof lining[86]	CMA, 2021
Paper Soup Bowls with PLA Lining	ecoKloud	No	Yes	Ideal for hot soups[87]	BPI, 2021
World Art Paper Containers; Greenstripe Food Containers	Eco-Products	Yes	Yes	Without leaking; Paper coating alternatives Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[88,89]	BPI, 2021
Paper Soup Cup with PLA Lining	G2 Chef's Choice	No	Yes	Soup cup[90]	BPI, 2021
Ecotainer Food Containers (soup bowls)	Graphic Packaging International	Yes	Yes	Paper Coating Alternatives Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[91]	CMA, 2021
Sugarcane Soup Bowl	Hanchang Paper Co.	Yes	Yes	Using Ingeo by Natureworks LLC[92]	BPI, 2021
Karat Earth Eco-Friendly Paper Food Containers, multiple sizes	Lollicup USA Inc.	Yes	Yes	Holds liquid and hot food nicely, perfect for hot soups, ice creams, salads, and many more[93,94]	CMA, 2021

[84] http://embed.widencdn.net/pdf/plus/dart/mdsyq0i8mi/GS1418USES_Web.pdf?u=hsm95h
[85] https://www.dartcontainer.com/products/foodservice-catalog/dinnerware-containers/containers/paper/bare-by-solo-eco-forward-vs-sspla-paper-food-containers/
[86] https://www.ecoguardian.com/ecoguardian-products/16-oz-compostable-food-container%2Fbowl
[87] http://www.ecokloud.com/biodegradable/compostable/paper-pla-bowls.html
[88] https://www.ecoproductsstore.com/world_art.html
[89] https://www.natureworksllc.com/~/media/News_and_Events/NatureWorks_TheIngeoJourney_pdf.pdf
[90] http://www.g2bychefschoice.com/hot-cups-1
[91] https://www.graphicpkg.com/products/ecotainer-food-containers/
[92] http://www.greenus-eco.com/?doc_id=soup_bowl
[93] https://lollicupstore.com/ke-kdp16.html
[94] https://lollicupstore.com/ke-k504w.html

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Green Choice Compostable Soup Containers	Pacific Green Products	Yes	Yes	Lined with a Ingeo[95]	BPI, 2021
PLA Paper Soup Cup	Pactiv Evergreen	Yes	Yes	Paper/PLA (-40°F/-36°C - 400°F/184°C), soak-through-resistant cup[96,97]	CMA, 2021
Compostable Soup Cups	President Packaging Ind. Corp.	No	Yes	Fresh soup bowls are perfectly designed for deli foods and soups[98]	BPI, 2021
Hot/Cold Food Containers	PrimeWare	No	No	None specific to OGR/leak resistance[99]	BPI, 2021
PLA-Lined Soup Container	Vegware	Yes	Yes	Perfect for everything from hot soups and stews to ice cream sundaes; Paper Coating Alternatives Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[100,101]	CMA, 2021
Fiber Bowl PLA Lined	WorldCentric	Yes	Yes	Moisture and grease resistance, not grease proof[102,103]	BPI, 2021
FSC® Paper Bowl, White	WorldCentric	Yes	Yes	Lined with NatureWorks Ingeo, great for soup, ice cream, and snacks; bowls are suitable for liquids up to 220°F[104]	CMA, 2021
YesEco PLA (Lined) Bowls	YesEco	No	No	None specific to OGR or leak resistance[105]	BPI, 2021

95 https://www.pacificgreenproducts.com/pages/containers
96 https://www.pactiv.com/brochures/EC-0135.pdf
97 https://www.pactiv.com/products/PHSC12ECDI.htm
98 http://www.ppi.com.tw/en/products_page.php?G0=4&G1=38&G2=43
99 https://primewareproducts.com/products/12-ounce-food-containers-case-of-500
100 https://www.vegwareus.com/us/catalogue/bon_appetit_bowls/32oz_plalined_paper_food_bowl_185series/
101 https://www.natureworksllc.com/~/media/News_and_Events/NatureWorks_TheIngeoJourney_pdf.pdf
102 https://assets.brandfolder.com/q6sdrm-8dqtq8-a6ikdy/v/11751614/original/WC-NoAdded-PFAS-Products-2020(secure).pdf
103 https://store.worldcentric.com/1-oz-portion-cup-clear
104 https://store.worldcentric.com/12-oz-paper-bowl-white
105 http://www.yeseco.com/soup-bowls/

Table 34. Example bowls made using rigid PLA.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Salad Bowls	Asean Corporation	Yes—plastic	Yes—plastic	Jaya 100% Compostable PLA Salad Bowls[106]	CMA, 2021
Salad Bowls	Eco-Products	Yes—plastic	Yes—plastic	Made with PLA, a plant-based plastic[107,108]	CMA, 2021
GREENWARE® Portion Cups	Fabri-kal	Yes—plastic	Yes—plastic	Made from a PLA resin derived from plants[109]	CMA, 2021
Karat Earth PLA Portion Cups	Lollicup USA Inc.	Yes—plastic	Yes—plastic	PLA plastic is clear allowing easy visibility of contents, and it is durable and shatter-proof[110]	CMA, 2021
Compostable Printed Portion Cup	Pactiv Evergreen	Yes—plastic	Yes—plastic	PLA (0°F/-16°C - 105°F/37°C), secure any condiment[111,112]	CMA, 2021
Basic Nature 16 oz Round Clear PLA Plastic To-Go Bowls	Restaurantware	Yes—plastic	Yes—plastic	Great for serving cold dishes such as pasta salads, fresh green salads, and more[113]	CMA, 2021
PLA Salad Bowls, PLA Portion Pots	Vegware	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[114,115]	CMA, 2021
Clear Salad Bowls, Portion Cup	World Centric	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[116]	CMA, 2021

[106] https://www.stalkmarketproducts.com/products/containers/pla-containers/salad-bowls.html
[107] https://www.ecoproducts.com/salad_bowls.html
[108] https://www.ecoproducts.com/round_deli_and_portion_cups.html
[109] https://www.fabri-kal.com/products/Greenware-Portion-Cups
[110] https://lollicupstore.com/karat-earth-4-oz-pla-portion-cups-clear.html
[111] https://www.pactiv.com/brochures/PAC-0400.pdf
[112] https://www.pactiv.com/products/YSPLA200EC.htm
[113] https://www.restaurantware.com/disposables/take-out/food-containers-lids/basic-nature-16-oz-round-clear-pla-plastic-to-go-bowl-compostable-6-x-6-x-2-1-4-500-count-box/
[114] https://www.vegwareus.com/us/catalogue/bon_appetit_bowls/24oz_pla_salad_bowl_185series/
[115] https://www.vegwareus.com/us/catalogue/portion_pots/
[116] https://store.worldcentric.com/store/bowls-and-lids

Table 35. Example bowls made using rigid PP.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
PresentaBowls® Pro Square Bowls	Dart Container Corporation	Yes—plastic	Yes—plastic	None specific to OGR/leak resistance[117]	N/A—material type; Stakeholder input
Polypropylene Portion Cups	Pactiv Evergreen	Yes—plastic	Yes—plastic	Pack Condiments and Sauces To Go[118,119]	N/A—material

Table 36. Example bowls made using wax-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Wax Treated Paper Soufflé Cup	Dart Container Corporation	No	Yes	Resistant to liquid penetration[120,121]	CMA, 2021

[117] https://p.widencdn.net/a5klmv/MC207USE_PresentaBowlsPro_Print
[118] https://www.pactiv.com/brochures/PAC-0400.pdf
[119] https://www.pactiv.com/Pactiv/Marketing-Materials/PSBanCompliant.pdf
[120] https://www.dartcontainer.com/products/foodservice-catalog/dinnerware-containers/containers/paper/solo-paper-portion-containers/
[121] https://www.dartcontainer.com/sustainability/about-our-products/coated-paperboard/

Appendix F. Examples of Flat Serviceware

This appendix includes example products made with less hazardous alternatives that meet the definition of flat serviceware. We also included some of these products in closed containers (with lids). We sorted products into tables based on the alternative they use. That includes the base material and, if applicable, the chemical treatment used in place of PFAS. Section 6 and Section 7 use this appendix to assess alternative performance or use.

Table 37. Example flat serviceware made using clay-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Solo® Eco-Forward™/ Solo® Paper Dinnerware	Dart Container Corporation	Yes	Yes	Solo® paper plates, platters and bowls have excellent moisture resistance, grease resistance, and strength to keep you serving in style[122]	CMA, 2021
Compostable Pressware Paper Plate	Pactiv Evergreen	Yes	Yes	Durable and resistant to grease and moisture[123,124]	CMA, 2021

Table 38. Example flat serviceware made using PLA foam.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Foam trays	Anhui Hengxin	Yes—plastic	Yes—plastic	As a bio-based material, PLA can replace traditional plastics in many fields with good performance[125,126]	BPI, 2021
Trays, Revert Round Plates	BGF Ecobio	Yes—plastic	Yes—plastic	Superior mechanical properties—thermal resistance, durability, insulation, and cushioning—for substitution of conventional single-serve products made with PS, PP or pulp[127,128]	CMA, 2021

122 https://www.dartcontainer.com/products/foodservice-catalog/dinnerware-containers/dinnerware/paper/solo-paper-dinnerware/mp9r-j8001/
123 https://www.pactiv.com/brochures/EC-0360.pdf
124 https://www.pactiv.com/brochures/PAC-0201.pdf
125 http://www.hfhxin.com/List/?2-2006-0-1.html
126 http://www.hfhxin.com/About/?6-6001.html
127 http://www.koreabiofoam.com/en/tech/
128 http://www.koreabiofoam.com/en/products/

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Earth Maize Compostable Plates and Trays	Biodegradable Food Service, LLC	Yes	Yes	Moisture resistant; grease resistant.[129]	BPI, 2021
Dyne-a-pak Nature®	Dyne-A-Pak	Yes	Yes	Moisture barrier properties; Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[130]	CMA, 2021
NatureTRAY	Novipax	Yes—plastic	Yes—plastic	These foam trays are made from Ingeo™, an ingenious new plastic made from plants[131]	CMA, 2021

Table 39. Example flat serviceware made using PLA-coated molded fiber.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Fiber Tray PLA-Lined; Fiber Catering Pan PLA-Lined	WorldCentric	Yes	Yes	Moisture and grease resistance, but not grease proof[132]	BPI, 2021

Table 40. Example flat serviceware made using rigid PLA.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Round Tray	Chen's Container Industrial Corp.	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[133]	BPI, 2021

129 https://earth-to-go.org/earth-maize/earth-maize
130 http://www.dyneapak.com/en/nature.html
131 http://www.novipax.com/assets/NatureTray-Data-Sheet.pdf
132 https://assets.brandfolder.com/q6sdrm-8dqtq8-a6ikdy/v/11751614/original/WC-NoAdded-PFAS-Products-2020(secure).pdf
133 http://www.ccicorp.com.tw/product-list_1_8_9.html#product

Table 41. Example flat serviceware made using untreated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Untreated Green Label Paper Plate	AJM	No	No	None specific to OGR or leak resistance[134,135]	CMA, 2021
Dixie® 9" Untreated Paper Plates by GP Pro (Georgia Pacific)	Georgia Pacific (Dixie)	No	No	None specific to OGR or leak resistance[136]	CMA, 2021
Lunch Trays	Southern Champion Tray	No	No	None specific to OGR or leak resistance[137]	CMA, 2021
Carry Trays/Lunch Trays	Specialty Quality Packaging	No	No	None specific to OGR or leak resistance[138]	CMA, 2021

[134] https://www.ajmpack.com/buy-ajm/
[135] https://www.walmart.com/ip/AJM-017-PP9GREWH-Bag-100-9-Inch-White-Paperplates-Gre/147384330
[136] https://www.gppro.com/gp/gppro/USD/GP-PRO-Categories/Dixie%C2%AE-Paper-Plates%2C-Platters%2C-%20Bowls/DIXIE%C2%AE-9%22-UNCOATED-PAPER-PLATES-BY-GP-PRO-%28GEORGIA-PACIFIC%29%2C-WHITE%2C-%201%2C000-PLATES-PER-CASE/p/709902WNP9
[137] https://www.sctray.com/images/uploads/files/SCT_2019_ProductCatalog_small.pdf
[138] https://kariout.com/products/paper/

Appendix G. Examples of Open-top Containers

This appendix includes example products made with less hazardous alternatives that meet the definition of open-top containers. We also included some of these products in closed containers (with lids). We sorted products into tables based on the alternative they use. That includes the base material and, if applicable, the chemical treatment used in place of PFAS. Section 6 and Section 7 use this appendix to assess alternative performance or use.

Table 42. Example open-top containers made using aluminum.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Round Standard Weight Foil Take-Out Pan	Choice	Yes	Yes	Durable standard-weight aluminum material is leak-proof[139]	N/A–material
Aluminum Round Pans	Pactiv	Yes	Yes	Aluminum containers resist the greases and oils; these lids provide leak-resistance for all your takeout needs[140]	N/A—material type

Table 43. Example open-top containers made using clay-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Compostable Food Trays; Brown Disposable Boat	Eco-Products	Yes	No	Resilient to grease[141]	CMA, 2021
Food Boats	Southern Champion Tray	No	No	None specific to OGR or leak resistance[142]	CMA, 2021
Food Trays/Boats, Fry Scoop	Specialty Quality Packaging	No	No	None specific to OGR or leak resistance[143]	CMA, 2021
Food Trays	Vegware	Yes	No	Serve street food in sustainable style with our new grease resistant kraft food trays[144]	CMA, 2021

[139] https://www.webstaurantstore.com/choice-7-round-standard-weight-foil-take-out-pan-case/612527ST.html
[140] https://www.pactiv.com/products/401945U.htm
[141] https://www.ecoproductsstore.com/food_trays.html
[142] https://www.sctray.com/images/uploads/files/SCT_2019_ProductCatalog_small.pdf
[143] https://web.archive.org/web/20190507042841/http:/lancasales.com/LancaSales/Vendor%20Brochures/SQP/SQP%20Catalog%20-%202015.pdf
[144] https://docs.vegware.com/vegware_productlist_ed24.pdf

Table 44. Example open-top containers made using PLA foam.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Food Carriers and Trays	BGF Ecobio	Yes—plastic	Yes—plastic	Superior mechanical properties—thermal resistance, durability, insulation, and cushioning—for substitution of conventional single-serve products made with PS, PP, or pulp[145,146]	CMA, 2021

Table 45. Example open-top containers made using PLA-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Eco-Products Compostable French Fry Scoop	Eco-Products	Yes	Yes	Grease resistant; Paper Coating Alternatives Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[147,148]	CMA, 2021
Wide Kraft Bowls	Ningbo Futur Technology Co.	No	No	None specific to OGR or leak resistance[149]	BPI, 2021

[145] http://www.koreabiofoam.com/en/tech/
[146] http://www.koreabiofoam.com/en/products/
[147] https://www.ecoproducts.com/food_trays.html
[148] https://www.natureworksllc.com/~/media/News_and_Events/NatureWorks_TheIngeoJourney_pdf.pdf
[149] http://www.futurbrands.com/product/detail/45.html

Table 46. Example open-top containers made using rigid PLA.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Deli Round Containers	Asean Corporation	Yes—plastic	Yes—plastic	Jaya 100% Compostable PLA Round Deli Container[150]	CMA, 2021
Deli Containers	Good Natured Products	Yes—plastic	Yes—plastic	Uses PLA plastic[151,152]	CMA, 2021
PLA Bella pots	Vegware	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[153]	CMA, 2021

Table 47. Example open-top containers made using rigid PP.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
MicroGourmet® Plastic Deli Containers	Dart Container Corporation	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[154]	N/A—material type; Stakeholder input
Delitainer® Microwavable Containers	Pactiv Evergreen	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance; heavy gauge, microwaveable product[155]	N/A—material type

Table 48. Example open-top containers made using wax-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Eco-Forward® Paper Cone Cups	Dart Container Corporation	No	Yes	Pre-treated wax paper acts as a moisture barrier to keep liquid inside the cup[156]	Stakeholder Input

[150] https://www.stalkmarketproducts.com/products/containers/pla-containers/round-deli-containers.html
[151] https://goodnaturedproducts.com/products/16-oz-deli-container-9002
[152] https://goodnaturedproducts.com/pages/faq
[153] https://www.vegwareus.com/us/catalogue/deli_containers/
[154] https://p.widencdn.net/a5klmv/MC207USE_PresentaBowlsPro_Print
[155] https://www.pactiv.com/Pactiv/Marketing-Materials/PAC-0158.pdf
[156] https://dart.widen.net/view/pdf/fhphyxbjxm/MC2534USE_ConeCups_Web.pdf?t.download=true&u=ag1iq5

Appendix H. Examples of Closed Containers

This appendix includes example products made with less hazardous alternatives that meet the definition of closed containers. We sorted products into tables based on the alternative they use. That includes the base material and, if applicable, the chemical treatment used in place of PFAS. Section 6 and Section 7 use this appendix to assess alternative performance or use.

Table 49. Example closed containers made using aluminum.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Round Standard Weight Foil Take-Out Pan and Lid	Choice	Yes	Yes	Durable standard-weight aluminum material is leak-proof[157, 158]	N/A—material type
Foil Container—Round with Lid	Monogram	Yes—metal	Yes—metal	Perfect for storing and transporting hot and cold foods for carryout and catering[159]	N/A—material type

Table 50. Example closed containers made using clay-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Take-Out Barn & Boxes, Bakery Boxes, Sausage & Meat Boxes, Take-Out Containers	Southern Champion Tray	No	No	None specific to OGR or leak resistance[160]	CMA, 2021

[157] https://www.webstaurantstore.com/choice-7-round-standard-weight-foil-take-out-pan-case/612527ST.html
[158] https://www.webstaurantstore.com/choice-1-1-2-lb-oblong-deep-foil-laminated-board-lid-case/612LOB15LBD.html
[159] https://www.usfoods.com/great-food/featured-products/equipment-supplies/foil-container-round-with-lid.html
[160] https://www.sctray.com/catalog/foodservice

Table 51. Example closed containers made using LDPE-coated paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Solo® VS SSP Paper Food Containers	Dart Container Corporation	No	Yes	Single-sided, polyethylene-coated paper on the inside of the container acts as a moisture barrier to keep liquid inside[161,162]	Stakeholder input; CEH, 2018
Pactiv EarthChoice One Box; OneBox™ Paper Boxes	Pactiv Evergreen	Yes	Yes	Leak resistant coating prevents sauces and liquids from penetrating through the container; polycoated inside: leak and grease resistant applications[163,164]	N/A—material type; CEH, 2018
Evolution World™ Hot & Cold Food container[209]	Eco-Products	No	No	Outer coating protects against condensation[165,166]	N/A—material type; CEH 2018
Pack n' Eat Take Out Boxes—PE Lined	Gallimore Products Inc.	No	No	None specific to OGR or leak resistance[167]	N/A—material type; CEH 2018
Envy® Double Polyethylene Paper Food Container	Prime Source	Yes	Yes	Can be used for either hot or cold food applications; perfect for hot take-out items like soup or for storing ice cream in the freezer[168]	N/A—material type; CEH 2018
Bio-Pak® and Bio-Plus Earth® Interlocking Folded Containers	WestRock	Yes	Yes	Leak resistant, withstands sauces and gravies; suitable for all food types from hot to cold, wet to dry[169]	Stakeholder input; CEH, 2018

161 https://www.dartcontainer.com/products/foodservice-catalog/dinnerware-containers/containers/paper/solo-paper-portion-containers/
162 https://p.widencdn.net/np33pj/MC1543USE_Web
163 https://www.pactiv.com/Pactiv/Marketing-Materials/PSBanCompliant.pdf
164 https://www.pactiv.com/brochures/EC-0135.pdf
165 https://www.ecoproducts.com/evolution_world.html
166 https://www.ecoproducts.com/faqs-our_products.html
167 http://www.gallimoreproducts.com/take-out-boxes.html
168 https://www.primesourcebrands.com/product/envy-double-polyethylene-paper-food-container-vented-lid-combo/
169 https://www.westrock.com/-/media/pdf/folding-carton/fold-pak/biopak-product-brochure-2021.pdf?modified=20210519051615

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Fold-Pak®, Fold-Pak® Earth, SmartServ® by Fold-Pak®	WestRock	Yes	Yes	Interior moisture and grease barrier prevents leaking and allows storage of any type of food—cold, hot, wet or dry[170,171]	Stakeholder input; CEH, 2018

Table 52. Example closed containers made using PLA Foam.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Foam Lunch Box	Anhui Hengxin	Yes—plastic	Yes—plastic	As a bio-based material, PLA can replace traditional plastics in many fields with good performance[172,173]	BPI, 2021
Food Carriers	BGF Ecobio	Yes—plastic	Yes—plastic	Superior mechanical properties—thermal resistance, durability, insulation, and cushioning—for substitution of conventional single-serve products made with PS, PP, or pulp[174,175]	CMA, 2021
Brown 8" 3 Compartment Clamshell; 9”, 8”, 6” Clamshells	Biodegradable Food Service, LLC	Yes	Yes	Moisture resistant; grease resistant[176]	BPI, 2021

[170] https://www.westrock.com/products/folding-cartons/fold-pak
[171] https://www.westrock.com/products/folding-cartons/smartserv
[172] http://www.hfhxin.com/List/?2-2006-0-1.html
[173] http://www.hfhxin.com/About/?6-6001.html
[174] http://www.koreabiofoam.com/en/tech/
[175] http://www.koreabiofoam.com/en/products/
[176] https://earth-to-go.org/earth-maize/earth-maize

Table 53. Example closed containers made using PLA-coated paperboard or molded fiber.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Planet+ Food Container and Lid	Asean Corporation	Yes	Yes	Paper Coating Alternatives Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[177,178]	CMA, 2021
Emerald Compostable Paper Soup Cups and Lids	Emerald	No	Yes	Excellent for frozen yogurt, cereal, and more[179]	BPI, 2021
Compostable Innobox Edge	Inno-Pak	Yes	Yes	Great leak protection; hot food friendly; cold food friendly; Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[180,181]	CMA, 2021
Vegware Sandwich/ Wrap Boxes and Wedges	Vegware	Yes	Yes	Grease-resistant coating; Paper Coating Alternatives Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[182,183]	CMA, 2021
Hoagie Box—PLA lined	World Centric	Yes	Yes	9x6x3" fiber hoagie boxes are made from bamboo and unbleached plant fiber, an annually renewable resource, have a bio-based lining, and contain no added PFAS; bio-based lining prevents leaking of oil and moisture[184]	BPI, 2021
Hot Paper Ingeo™-Lined Soup Bowls	World Centric	Yes	Yes	Suitable for liquids; Paper Coating Alternatives Ingeo™ functions well, with good moisture, grease, and oil resistance (Ingeo Brochure)[185,186]	CMA, 2021

177 https://www.stalkmarketproducts.com/brands/planet.html
178 https://www.natureworksllc.com/~/media/News_and_Events/NatureWorks_TheIngeoJourney_pdf.pdf
179 https://www.emeraldbrand.com/1-000-Emerald-Commercially-Compostable-8oz.-Soup-Containers-.13-cents-Container
180 https://www.innopak.com/products/compostable_innobox_edge/
181 https://www.natureworksllc.com/~/media/News_and_Events/NatureWorks_TheIngeoJourney_pdf.pdf
182 https://www.vegwareus.com/us/catalogue/sandwich_wrap_boxes/
183 https://www.natureworksllc.com/~/media/News_and_Events/NatureWorks_TheIngeoJourney_pdf.pdf
184 https://store.worldcentric.com/9x6x3-fiber-hoagie-box-pla-lined-leaf
185 https://store.worldcentric.com/store/bowls-and-lids/paper-bowls
186 https://www.natureworksllc.com/~/media/News_and_Events/NatureWorks_TheIngeoJourney_pdf.pdf

Table 54. Example closed containers made using rigid PLA.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Jaya Sushi Food Tray with Lid Combo	Asean Corporation	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[187]	BPI, 2021
Jaya Bowls, Lids, Hinged Containers, Deli Containers (various sizes)	Asean Corporation	Yes—plastic	Yes—plastic	Jaya 100% compostable PLA[188,189,190]	CMA, 2021
Clear PLA Salad Bowls	Eco-Products	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[191]	BPI, 2021
Hinged Clamshell; PLA Sandwich Wedge Container	Eco-Products	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[192]	BPI, 2021
Rectangular and Round Deli Containers; Portion Cups	Eco-Products	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[193]	BPI, 2021
On-the-Go Boxes	Fabri-Kal	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[194]	CMA, 2021
Deli Containers	Good Natured Products	Yes—plastic	Yes—plastic	Uses PLA plastic[195,196]	CMA, 2021
Multipurpose Clamshell Packaging	Good Natured Products	Yes—plastic	Yes—plastic	Uses PLA plastic[197,198]	CMA, 2021
Compostable Deli Container with Lid	Pactiv	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[199]	CMA, 2021
Pactiv EarthChoice Clear Hinged Container	Pactiv	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[200]	CMA, 2021

[187] https://www.stalkmarketproducts.com/take-out-tray-with-lid-combo-9-x4-x1.html
[188] https://www.stalkmarketproducts.com/products/containers/pla-containers/round-deli-containers.html
[189] https://www.stalkmarketproducts.com/products/containers/pla-containers/hinged-containers.html
[190] https://www.stalkmarketproducts.com/brands/jaya.html
[191] https://www.ecoproductsstore.com/salad_bowls.html
[192] https://www.ecoproductsstore.com/6_inch_x_6_inch_x_3_inch_clear_hinged_clamshell.html
[193] https://www.ecoproductsstore.com/rectangular_deli_containers.html
[194] https://www.fabri-kal.com/products/greenware-on-the-go-boxes
[195] https://goodnaturedproducts.com/products/16-oz-deli-container-9002
[196] https://goodnaturedproducts.com/pages/faq
[197] https://goodnaturedproducts.com/products/24-oz-biodegradable-clamshell-container-9007
[198] https://goodnaturedproducts.com/pages/faq
[199] https://earthchoicepackaging.com/brochures/EC-0135.pdf
[200] https://earthchoicepackaging.com/brochures/EC-0135.pdf

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Salad Bowl + Lid	Vegware	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[201]	CMA, 2021
Hinged PLA Deli Containers, PLA Bella Pots, Round Deli Pots	Vegware	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[202]	CMA, 2021
World Centric Ingeo™ Rectangular Deli Containers	World Centric	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[203]	BPI, 2021
World Centric Clear to Go Ingeo™ Hinged Clamshells	World Centric	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance[204]	CMA, 2021

Table 55. Example closed containers made using rigid PP.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Clover Hinged To-Go Containers	Genpak	Yes—plastic	Yes—plastic	A 360° leak resistant food container[205]	N/A—material; Stakeholder input
Newspring Containers	Pactiv Evergreen	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance; heavy gauge, microwaveable product[206,207]	N/A—material type
Clear Deli Cup And Lid Combo	Prime Source	Yes—plastic	Yes—plastic	None specific to OGR or leak resistance; containers are tough and light[208]	N/A—material type

201 https://www.vegwareus.com/us/catalogue/bon_appetit_bowls/
202 https://www.vegwareus.com/us/catalogue/deli_containers/
203 https://store.worldcentric.com/store/take-out-containers/rectangular-deli-containers
204 https://store.worldcentric.com/7x7x3-hinged-clamshell-clear
205 https://www.genpak.com/product/clover-hinged/
206 https://www.pactiv.com/Pactiv/Marketing-Materials/PSBanCompliant.pdf
207 https://www.pactiv.com/Pactiv/Marketing-Materials/PAC-0158.pdf
208 https://www.primesourcebrands.com/product/clear-deli-cup-lid-combo/

Appendix I. Examples of Other Alternative Substances

This appendix includes example alternative substances that are offered for sale and can be used to manufacture food packaging products without PFAS. We used these examples to determine alternative substance performance only (see Section 6). We did not use them in this AA to determine which alternatives are available or cost competitive.

Table 56. Examples of densified paper.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
Servera® and Grease-Gard® FluoroFree® Papers	Ahlstrom-Munksjo	Yes	Yes	Providing grease and water resistance in addition to heat retention; FDA Compliant[209,210]	BPI, 2021
EcoBarrier® Plus Paper	Twin Rivers Paper Company	Yes	Yes	High performance grease resistance properties for demanding OGR applications; wet-strength and fiber certification upon request; FDA compliant for food contact[211,212]	Stakeholder input
EcoBarrier® Choice Paper	Twin Rivers Paper Company	Yes	Yes	High performance grease resistance properties for demanding OGR applications; wet-strength and fiber certification upon request; FDA compliant for food contact[213,214]	Stakeholder input

[209] https://www.ahlstrom-munksjo.com/products/food-packaging-baking-and-cooking-solutions/food-packaging-papers/QSR-Food-Service-Papers/
[210] https://www.ahlstrom-munksjo.com/products/technologies/genuine-vegetable-parchment-technology/
[211] https://www.twinriverspaper.com/products/packaging-paper/ecobarrier/
[212] https://www.twinriverspaper.com/uploads/pkg_insert_ecobarrier_2-8-21.pdf
[213] https://www.twinriverspaper.com/products/packaging-paper/ecobarrier-choice/
[214] https://www.twinriverspaper.com/uploads/pkg_insert_ecobarrier_2-8-21.pdf

Table 57. Example closed containers made using EVOH-coated paper or paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
KURARAY EXCEVAL; wide range of coating grades and versatility	Kuraray	Yes	Yes	Excellent barrier against oxygen and grease; FDA certified product and can be used in paper coating formulas and will be the best candidate of non-fluoro chemical barrier agents in the next generation of greaseproof papers; high water resistance[215]	Stakeholder input

Table 58. Example closed containers made using PVOH-coated paper or paperboard.

Product name	Company name	OGR?	Leak resistance?	Promotional language	PFAS-free source
KURARAY POVAL; wide range of coating grades and versatility	Kuraray	Yes	Yes	Polyvinyl alcohol is approved to be used in food packaging according to BfR and FDA; water-resistant and oil- and –grease resistant[216]	Stakeholder input

[215] https://kuraray.us.com/products/polymers/exceval/
[216] https://www.kuraray-poval.com/applications/barrier-films