PFAS Organics Recycling Literature Review and Data Audit

Prepared by:

Wood Environment & Infrastructure Solutions, Inc.
800 Marquette Avenue, Suite 1200
Minneapolis, Minnesota

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PFAS Organics Recycling
Literature Review and Data Audit

Submitted To:

Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, Minnesota 55155

Submitted By:

Wood Environment & Infrastructure Solutions, Inc.
800 Marquette Avenue, Suite 900
Minneapolis, Minnesota 55402

January 2021

Project No. 7311192044

September 30, 2020

Kayla Walsh, Tim Farnan
Project Managers, MPCA
520 Lafayette Road
St. Paul, MN 55155

Re: PFAS Organics Recycling Literature Review and Data Audit
Wood Project No. 7311192044

Dear Kayla and Tim;

Wood Environment & Infrastructure, Solutions, Inc. (Wood) is pleased to submit this per- and polyfluoroalkyl substances (PFAS) organics recycling literature review and data audit report to the Minnesota Pollution Control Agency (MPCA). The report summarizes the literature review, data gap evaluation by material type, a comparison to previously collected contact water samples, and a summary of findings and recommendations.

We appreciate the opportunity to assist you on this project. If you have any questions or concerns, please do not hesitate to contact us as identified below.

Sincerely,

Shalene Thomas
Project Manager
Tel.: 612-490-7606
shalene.thomas@woodplc.com

Hannah Albertus-Benham, PE
Technical Reviewer
Tel.: 612-252-3657
hannah.albertus@woodplc.com

David Woodward
PFAS Technical Director
Tel: 717-659-0434
david.woodward@woodplc.com

Emma Driver, PMP
MPCA Client Account Manager
Tel: 612-252- 3641
emma.driver@woodplc.com

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ACRONYMS AND ABBREVIATIONS

AOF	Absorbable Organic Fluorine
BPI	Biodegradable Products Institute
CAS	Chemical Abstracts Service
CIC	Combustion Ion Chromatography
COPCs	Chemicals of Potential Concern
DQR	Data Quality Review
diPAP	Fluorotelomer phosphate diester
ECF	Electrochemical Fluorination
EOF	Extractable Organic Fluorine
EFSA	European Food Safety Authority
FCM	Food Contact Material
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FTCA	fluorotelomer carboxylic acid
FTOH	fluorotelomer alcohol
HBV	Health Based Value
HRL	Health Risk Limit
ID	Identifier
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
MPCA	Minnesota Pollution Control Agency
MSW	Mixed Municipal Solid Waste
NEBRA	Northeast Biosolids and Residuals Association
OECD	Organization for Economic Co-operation and Development
PFAA	Perfluoroalkyl acids
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoate, perfluorobutanoic acid
PFBS	perfluorobutane sulfonate, perfluorobutane sulfonic acid
PFCA	perfluoroalkyl carboxylate, perfluoroalkyl carboxylic acid
PFDA	perfluorodecanoate, perfluorodecanoic acid
PFDoA	perfluorododecanoate, perfluorododecanoic acid
PFDoS	perfluorododecane sulfonate, perfluorododecane sulfonic acid
PFDS	perfluorodecane sulfonate, perfluorodecane sulfonic acid
PFHpA	perfluoroheptanoate, perfluoroheptanoic acid
PFHpS	perfluoroheptane sulfonate, perfluoroheptane sulfonic acid
PFHxA	perfluorohexanoate, perfluorohexanoic acid

PFHxS	perfluorohexane sulfonate, perfluorohexane sulfonic acid
PFNA	perfluorononanoate, perfluorononanoic acid
PFNS	perfluorononane sulfonate, perfluorononane sulfonic acid
PFOA	perfluorooctanoate, perfluorooctanoic acid
PFOS	perfluorooctane sulfonate, perfluorooctane sulfonic acid
PFOSA	perfluorooctane sulfonamide
PFPeA	perfluoropentanoate, perfluoropentanoic acid
PFPeS	perfluoropentane sulfonate, perfluoropentane sulfonic acid
PFSA	perfluoroalkyl sulfonate, perfluoroalkane sulfonic acid
PFTeDA	perfluorotetradecanoic acid
PFTeDS	perfluorotetradecane sulfonate, perfluorotetradecane sulfonic acid
PFTrDA	perfluorotridecanoic acid
PFTrDS	perfluorotridecane sulfonate, perfluorotridecane sulfonic acid
PFUnDA	perfluoroundecanoate, perfluoroundecanoic acid
PFUnDS	perfluoroundecane sulfonate, perfluoroundecane sulfonic acid
PIGE	Particle-Induced Gamma Ray Emission
PLA	Polylactic acid
ppm	Parts per million
ppt	Parts per trillion
QA/QC	Quality assurance/quality control
SAP	Sampling and Analysis Plan
SSOM	Source Separated Organic Materials
TOPS	Total Organic Precursor Assay
USEPA	United States Environmental Protection Agency
Wood	Wood Environment & Infrastructure Solutions, Inc.

EXECUTIVE SUMMARY

Per- and polyfluoroalkyl substances (PFAS) have been ubiquitously found in the environment globally. Ambient concentrations may be found in air, water and soil and several PFAS are still being used today in commerce. Composting yard and food wastes as well as compostable food packaging into a nutrient rich soil amendment can benefit soil health, reduce the need for chemical fertilizers, and reduce the amounts of wastes going to landfills or incineration. However, PFAS found in the environment and transferred to food, yard materials, or used in compostable packaging is leading to challenging circumstances for composting.

There are four objectives for this study:

1. More clearly define potential sources of PFAS at organic recycling sites (Source Separated Organic Materials (SSOM) sites and Yard Waste sites specifically) to allow proactive management and support policy development;
2. More clearly understand potential PFAS chemicals found in contact water and surface water at SSOM and Yard Waste sites to ensure appropriate mitigation measures are considered;
3. Define potential data gaps based on a completed literature review so recommendations may be made for additional research; and
4. Develop a list of products for testing/analysis consideration.

SSOM sites can be defined as those sites which accept a broad array of materials including food scraps, food packaging/compostable products and yard waste. SSOM sites only take material from residents or businesses that separate their organics from typical household garbage. Yard waste sites can be defined as those sites which accept only items like brush, leaves and grass clippings.

To meet the study objectives, a literature review was completed of more than 160 academic papers published on the topics of PFAS and food, food waste(s), food packaging, and yard waste(s). The literature review included a compilation of PFAS analytical measurements reported in the academic papers to determine potential concentrations of PFAS-containing materials that may be disposed at, or 'input' to SSOM sites and yard waste sites. The PFAS analytical measurements included a summary of PFAS measured in Food Contact Material (FCM), bakery items, eggs, dairy, fruit and vegetables, fish/seafood, meats, and yard materials. The data was compared to a SSOM and Yard Waste sampling report (Wood, 2019) as well as a study of organic fraction of municipal solid waste (OFMSW) (Choi et al, 2019).

Results and conclusions are presented below.

Definition of potential sources and potential PFAS chemicals

Nine different FCM use categories were evaluated as potential sources including aluminum foil bags/wrappers, bakery paper/bags, beverage cups, food paper bags, food paper boxes, food paper wrappers, microwave bags, milk bottles, and paper tableware. PFAS concentrations in microwave bags and paper tableware were generally 1 to 4 orders of magnitude greater than all other categories. Detectable PFAS concentrations across all categories were consistently polyfluoroalkyl substances and more specifically fluorotelomer alcohols and polyfluoroalkyl phosphoric acid esters.

For potentially contaminated food sources, seven different food categories were evaluated as potential PFAS sources including bakery items, dairy, eggs, fish and seafood, fruit, vegetables, and meat. PFAS concentrations were generally higher in eggs, fish and seafood, and vegetables with maximum concentrations 1 to 2 orders of magnitude greater than the other food sources. With the exception of meat, only perfluoroalkyl substances were analyzed. The highest detectable PFAS concentrations in fish and seafood were PFOS and PFOA while shorter-chained PFAS were present in higher concentrations in eggs and vegetables (PFBA, PFBS, PFPeA).

For potential PFAS sources for yard waste sites, trees and shrubs (roots, leaves, needles) and pesticides were considered. Maximum PFAS concentrations for trees and shrubs were generally higher than that of food sources but lower than FCM. Only perfluoroalkyl substances were analyzed and no data was available for polyfluoroalkyl substances in literature reviewed. The highest detectable PFAS concentrations were for PFOA. For pesticides, no analytical data was available.

Definition of potential data gaps

The following data gaps were identified:

- ✓ For FCM, the literature did not adequately evaluate or distinguish among the FCM composition but rather focused on the use categories. Products were not designated by composition such as bamboo, clay-coated paper or paperboard, clear PLA (polylactic acid), paper-lined with PLA, palm leaf, paper with unknown coatings, uncoated paper, and molded fiber products (as previous studies on PFAS have done) but were more generically identified by use categories such as boxes, bags, cups, and wrappers. This made it difficult to evaluate compostable products that would be typically seen at an SSOM site.

- ✓ For FCM, none of the literature defined the materials tested as certified by the Biodegradable Products Institute (BPI), and BPI testing results of products are not publicly available. The efficacy of the certification and product claims of no intentionally added PFAS and a limit of 100 ppm total fluorine as protective of the environment could not be validated.

- ✓ For many food items, dairy (milk), eggs, vegetables, and yard waste, samples were biased high as some were collected in vicinity of fluorochemical manufacturing or firefighting training areas where PFAS were used for 30 or more years. Representative ambient background levels could not be evaluated based on the available data.

- ✓ For baked goods, the concentrations were considered lowest of all material evaluated. There is no understanding of source of PFAS in the baked goods, if they were originally from the FCM (muffin and cupcake liners as an example) or from ingredients used (eggs, butter, etc).

- ✓ For yard waste, there was no literature available that evaluated yard waste specifically. The literature reviewed considered tree leaves, grass, roots, and pine needles as representative of yard waste.

- ✓ For pesticides, there was no available literature illustrating PFAS ingredients were part of the product formulation nor used in pesticide application.

- ✓ For PFAS analytical methodologies, there are a few common applied analytical methods to measure general fluorine content vs targeted speciation of chain length and specific structural details of analytes, including Extractable or Absorbable Organic Fluorine (EOF or AOF) or PIGE Spectroscopy but it becomes difficult to compare results when methodology is not consistent.

Development of a list of products for testing/analysis consideration

The following recommendations should be considered as testing priorities:

- ✓ The first priority is further evaluation of FCM and specifically compostable materials. Since highest PFAS concentrations across all sources evaluated is by far FCMs, evaluate FCM products commonly used in Minnesota, certified by Biodegradable Products Institute (BPI), and disposed of at SSOM sites in Minnesota. A Total Organic Precursor (TOPs) analytical method is recommended to best evaluate potential precursor concentrations and to better profile composition of certified FCMs. A full analytical suite of PFAS is recommended along with branched and linear isomer analysis where fluorine is detected to aid in defining transformation pathways and understanding the terminal products to be expected with transformation. Specific product types recommended for sampling are not identified as it is assumed that the number and types of products are too numerous to be representative.

- ✓ The second priority is to inventory and evaluate incoming loads at SSOM sites to understand composition and variability of input. Once that is determined, establish a sampling plan to analyze PFAS in the incoming loads, active piles, contact water, compost ready for sale, and residuals to determine where, when, and what PFAS are introduced into the process so sources can be controlled and releases mitigated. An understanding of the PFAS profile and resulting contact water and compost would yield a better understanding of source contributions of input materials which in turn lead to better understanding of the potential for transformation and degradation of PFAS once at the site.

- ✓ The third priority is to further evaluate yard waste since literature was not available for yard waste in general. Additional sampling is recommended for various types of yard waste (leaves vs grass clippings as an example) and in various locations (rural vs urban areas). This may yield more informative decision making for best management practices. Pesticide sampling is not warranted at this time as literature review did not indicate PFAS used in product formulations in Minnesota.

- ✓ The last priority is to evaluate potential ambient source contributions in vicinity of SSOM and yard waste sites across the State of Minnesota. Compare and map existing MPCA/MDH ambient background data (soil and surface water at a minimum) in vicinity of SSOM and yard waste sites to develop regional background. Also consider performing a desk-top source evaluation to determine if there are potential primary PFAS sources (including airborne sources) in vicinity of SSOM and yard waste sites that may be contributing to elevated ambient background levels.

1.0 INTRODUCTION

Wood Environment & Infrastructure Solutions, Inc. (Wood) has prepared this report to the Minnesota Pollution Control Agency (MPCA) to document the findings from a per- and polyfluoroalkyl substances (PFAS) organics recycling literature review and data audit. The report summarizes the literature review, data gap evaluation by material type, a comparison to previously collected contact water and surface water samples, and a summary of findings and recommendations.

1.1 PURPOSE

The primary objective of the effort is to:

- ✓ More clearly define potential sources of PFAS at organic recycling sites (Source Separated Organic Materials (SSOM) sites and Yard Waste sites specifically) to allow proactive management and support policy development;
- ✓ More clearly understand potential PFAS chemicals found in contact water and surface water at SSOM and Yard Waste sites to ensure appropriate mitigation measures are considered; and
- ✓ Define potential data gaps based on literature and site data so recommendations may be made for additional research.
- ✓ Develop a list of products for testing/analysis consideration.

The scope of work (SOW) is summarized in section 1.2 and presented in detail in Section 3.0 of this report.

1.2 SCOPE OF WORK

Wood performed a literature review and data audit as described in the following tasks.

1.2.1 Development of Decision Framework

Wood conducted a kick-off meeting with the MPCA Project Team to discuss the project scope, schedule, and budget. The kick-off meeting included a discussion of the preliminary decision-making framework and overall structure for data collection, synthesis and output. A two-tiered approach was considered as presented in Exhibit 1.

Exhibit 1- Two-tiered Approach to Scope of Work

1.2.2 Phase I Input – Acceptable Materials

Wood reviewed existing literature to identify potential sources of PFAS entering SSOM sites and yard waste sites. Questions illustrated in Exhibit II, were considered. Specific elements of the literature review included:

1. Research detailing types and concentrations of PFAS in pesticides or other agricultural chemicals
2. Research detailing types and concentrations of PFAS in food packaging, including but not limited to:
   - o Fiber/paper food packaging
   - o Polylactic acid (PLA) or compostable plastics
   - o Pizza boxes, napkins, paper towels
   - o Food wraps (e.g muffin cups, popcorn bags, fast food wrappers)
3. Research detailing types and concentrations of PFAS in food
4. Research detailing types and concentrations of PFAS in other commonly accepted items at yard waste sites including:
   - o Yard waste bags

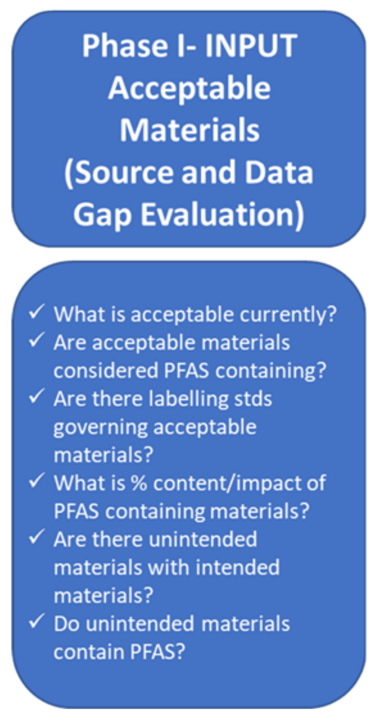


Exhibit 2- Input of Acceptable Materials

- o Yard waste such as leaves, grass clipping and brush

5. Review of acceptable materials lists for compost sites (provided by MPCA) and determination of PFAS sources. Wood reviewed existing literature on product types.

6. Review of existing literature on PFAS limits incorporated into any labeling standards (e.g., Biodegradable Products Institute [BPI] certification) and research pertaining to level of effectiveness of such limits. For example, what does the research suggest about the potential impact of BPI's policy requiring "no intentionally added PFAS and limit of 100 parts per million (ppm) total fluorine" have on surface or contact water.

7. Evaluation of literature data gaps by identifying types of materials for which there is no, or limited information available for which prioritization may be developed for screening/testing for PFAS in materials.

1.2.3 Phase II Output- PFAS Degradation

Wood developed a list of the specific PFAS detected at SSOM sites based on findings from the 2019 report (Wood, 2019). Wood evaluated degradation pathways of the primary PFAS chemicals identified during Phase I (Inputs) to compare to the 2019 report data and evaluated which types of materials may be contributing sources of PFAS. These PFAS were evaluated for degradation pathways, and included considerations for potential deposition and background/ambient concentrations.

Wood compared the analytical data to literature findings. Questions illustrated in Exhibit III, were considered.

Phase 2- OUTPUT PFAS Degradation

- ✓ What are primary chemicals known in acceptable materials?
- ✓ Do primary chemicals leach from materials as-is?
- ✓ Do primary materials result in degradation chemicals that leach or breakdown in environment?
- ✓ What are the PFAS degradation products?
- ✓ Are there other PFAS considerations for deposition?

Exhibit 3- Output PFAS Degradation

2.0 DECISION FRAMEWORK

A risk-based decision-making framework was developed for the project. Wood developed a series of MS Excel database tables to support the execution of the two-tiered approach outlined in Exhibit 1. The framework is as follows:

(1) For Phase I Input:

a. **An overall review data table (Appendix A, Table A-1)** was developed that included:
   - o unique ID,
   - o title,
   - o author,
   - o source,
   - o abstract,
   - o keywords,
   - o objective,
   - o findings,
   - o PFAS evaluated,
   - o other comments,
   - o QA/QC and
   - o Corrections/comments.

As papers were systematically reviewed, a record was generated in the overall review table that corresponded to each paper and included a summary of the information identified above.

b. **An analytical data table (Appendix A, Table A-2)** was developed that included:
   - o unique ID,
   - o media,
   - o material category,
   - o analyte,
   - o result,
   - o units,
   - o converted result,
   - o converted unit (parts per trillion [ppt]),
   - o detection limit,
   - o method,
   - o other notables,
   - o source location city,
   - o source location state,
   - o source location country,

o QA/QC, and corrections/comments.

As each paper was reviewed, a record was generated for each PFAS analyte cited and measured in media of interest. In cases where source data was not provided and only a range or median was provided, the median was selected for the result field and range was documented in the "Other Notables" field.

3.0 PHASE I INPUT – ACCEPTABLE MATERIALS

Wood reviewed existing literature to identify potential sources of PFAS coming into compost sites. Both SSOM sites and yard waste sites were considered.

The MPCA (Mr. Tim Farnan) noted that there are vast differences in approaches to composting across the United States. As an example, it was noted that organizations such as the Northeast Biosolids and Residuals Association (NEBRA) focuses on composting of biosolids specifically, which is quite different than composting practices in Minnesota. As such, any references to Mixed Municipal Solid Waste (MSW) Composting were evaluated carefully to understand the basis and intent of the composting activity. In Minnesota, MPCA has historically used that term to reference composting operations that handle trash/garbage (i.e. is not limited to source separated food scraps, packaging, yard waste). Those were prominent over 20 years ago in Minnesota but have not been part of composting activities in the State for many years. Therefore, Wood did not consider biosolids and mixed municipal solid waste in this evaluation.

The objective of this review focused on composting sites and associated activities currently conducted in Minnesota, which typically fit into two broad categories:

1. SSOM sites - which accept a broad array of materials including food scraps, food packaging/compostable products and yard waste. SSOM sites only take material from residents or businesses that separate their organics from trash.
2. Yard waste sites, which accept only items like brush, leaves and grass clippings.

3.1 REVIEW OF ACCEPTABLE MATERIALS LIST

Wood initiated Phase I by evaluating published acceptable material lists for compost sites (provided by MPCA) to determine if currently accepted materials may be sources of PFAS. Mr. Tim Farnan of the MPCA provided the below sources of information from the City of Minneapolis and Ramsey County as guiding examples of acceptable materials.

For SSOM sites specifically, the following sources were provided:

- Minneapolis' Organics program:

  http://minneapolismn.gov/solid-waste/organics/WCMS1P-139182

  - Detailed yes/no list for what can go in the bin: http://minneapolismn.gov/www/groups/public/@publicworks/documents/webcontent/wcmsp-220296.pdf

- Ramsey County Organics Program:

  https://www.ramseycounty.us/residents/recycling-waste/collection-sites/food-scraps

For Yard Waste sites specifically, the following sources were provided:

- Minneapolis guidelines for yard waste:

  http://minneapolismn.gov/solid-waste/yardwaste/solid-waste_yardwaste-preparation

- Ramsey County's guidance for yard waste: https://www.ramseycounty.us/residents/recycling-waste/collection-sites/yard-waste

The detailed lists of acceptable materials listed above are presented in Appendix B.

3.2 Literature Review

A literature review was performed based on the list of acceptable materials evaluated in Section 3.1. Staff from Wood's Technical Information & Research Center supported the literature search by querying scientific and market data through direct access to online information resources via an Information Services database. EBSCOHost databases were the primary source for access to peer-reviewed journal abstracts. EBSCO databases providing the most relevant search results include: Environment Complete, Agricola, Greenfile, Medline, Science & Technology, Academic Search Complete/Ultimate, Consumer Health Complete, Business Source Complete, and Advanced Placement Source. In addition, Google Scholar, Microsoft Academic, Publish or Perish, and Research Gate were used as additional sources to conduct the literature search and/or provide full-text papers. Where full-text papers were not easily obtained for free, Wood worked with the MPCA librarian to obtain papers at no cost to avoid unnecessary charges. The Boolean search strings for the searches can be found in Appendix C.

The following search terms, based on the acceptable materials list, were used to obtain literature for the SSOM sites:

- PFAS (and associated keywords -PFOS, PFOA, etc.) and
- SSOM
- Food scraps

- o Fruit
- o Vegetables
- o Bread, pasta, baked goods
- o Eggs
- o Dairy items
- o Food-soiled and non-recyclable paper
- o Food contact paper

This abstract query is listed as "Run A" and presented in Appendix C.

The following search terms, based on the acceptable materials list, were used to obtain literature for the yard waste sites:

- o PFAS (and associated keywords -PFOS, PFOA, etc.) and
- o Yard Waste
- o Leaves
- o Vegetation
- o Grass clippings
- o Sod
- o Brush/pruning
- o Pet waste/ animal waste -this is specifically domestic animal waste, prohibited from being discarded with yard waste but may appear as a contaminated material Pesticides/ agricultural chemicals.

This abstract query is listed as "Run B" and is presented in Appendix C.

Based on these search terms, abstract queries were performed and a total of 143 papers were identified initially as result of the queries (Appendix C). Abstracts for each of the papers were closely reviewed and a total of 62 papers were deemed potentially relevant to support the project objectives and each was obtained for review. A total of 27 papers reported measurable analytical data which was input into a MS Excel database (Appendix A, Table A-1 and A-2) for further evaluation. The abstract review summary is presented in Table 1, Summary of Initial Literature Review. The criteria used for relevance was as follows:

- o For abstracts, a paper was deemed relevant if it included the term PFAS, fluorinated, or specific PFAS analytes (e.g. PFOS, PFOA, etc.), as well as any terms that represent the materials on the acceptable materials list in Appendix B or known contaminants (e.g. pesticides, or pet waste).

- For analytical data, a paper was deemed applicable if total fluorine, or specific PFAS analytes were measured and reported in any of the materials that represent the acceptable materials list in Appendix B or known contaminants (e.g. pesticides, or pet waste).

Nineteen papers were identified as “requiring follow-up” meaning they referenced other applicable papers for review, or they referenced supplemental data, source data, or other valuable information that potentially supported the project objectives. Table 1 summarizes this information. The items requiring follow-up were closely evaluated and an additional 25 papers were reviewed and analytical records from 8 additional papers were input into a MS Excel database for further evaluation.

Table 2 summarizes the literature of potential PFAS sources by material type including pesticides/ other chemicals, food, food contact material, compost, yard waste, pet waste, environmental samples and other. The total number of material categories evaluated, total number of literature sources reviewed, total analytical records and unique PFAS analytes measured are also presented. Once all initial papers and follow-up literature was gathered, a total of 86 papers were reviewed, analytical data was noted from 34 papers and 3,320 analytical records were generated and input into Appendix A, Table A-2 Analytical Data. In circumstances where a data gap was identified for an associated material category (i.e., pesticides, and other chemicals), an additional abstract query was completed. All abstract queries and the Boolean search terms are presented in Appendix C.

For those material types with analytes measured, analytes ranged from as little as 10 analytes for fruit to 39 and 40 analytes for FCMs and environmental media. Analytes from the non-polymer class and both the perfluoroalkyl and polyfluoroalkyl substances sub-classes were included. No analytical measurements were identified for analytes from the polymer class. It is important to note that many polyfluoroalkyl substances (such as fluorotelomer-based substances) serve as potential precursors and can degrade to terminal degradation products, such as perfluorocarboxylic acids (PFCAs) and specifically PFOA. This may be the case for many polyfluoroalkyl substances detected in FCMs. This is discussed more in Section 4.2, Summary of Degradation Pathways. Exhibit 4, PFAS Family Tree presents a summary of the PFAS family, the non-polymer and polymer classes, the subclasses, groups, and sub-groups that belong to the family. Precursor groups and associated sub-groups are outlined in blue and orange.

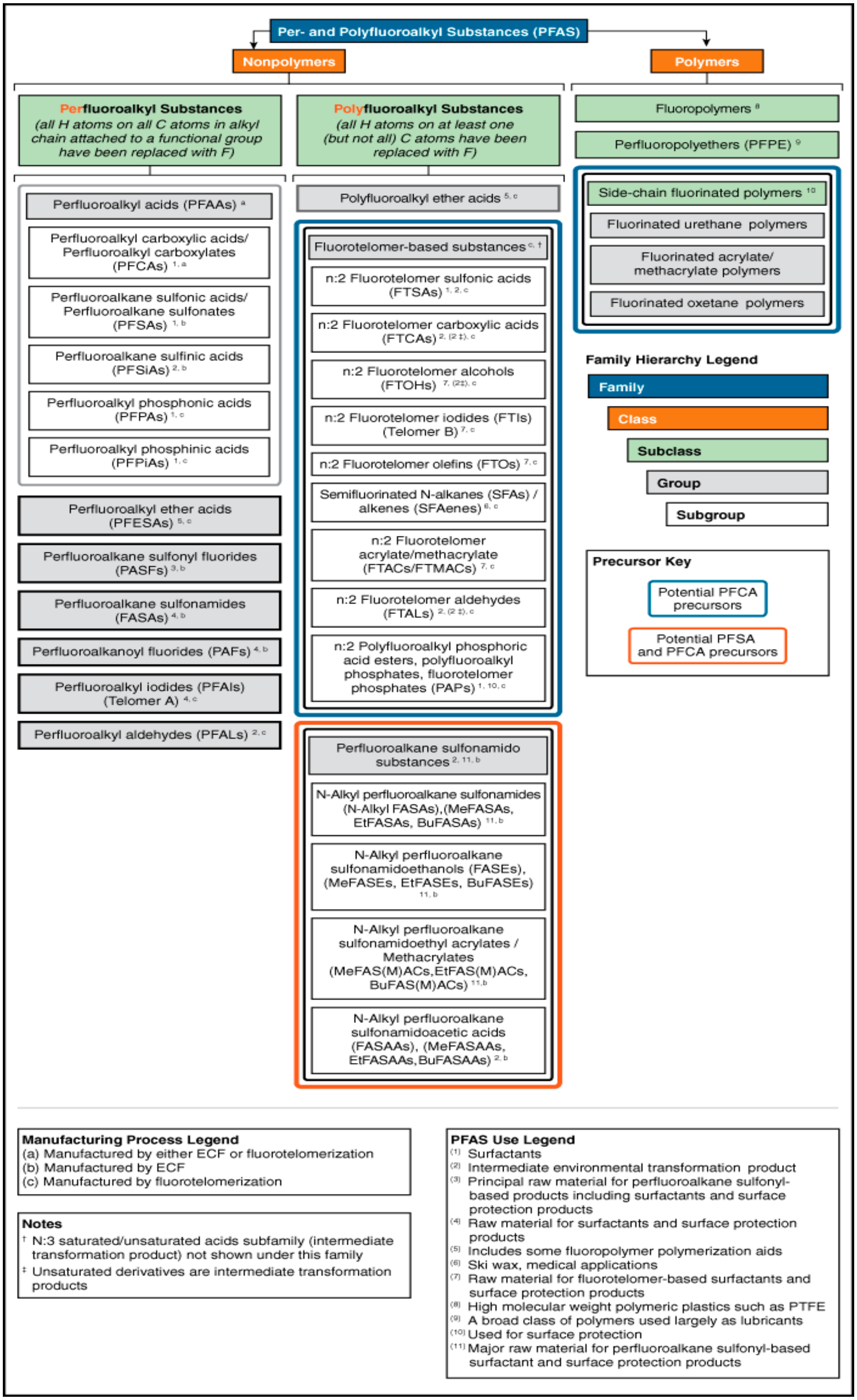


Exhibit 4. PFAS Family Tree (ITRC, 2020)

PFAS are sometimes described as long-chain and short-chain as a shorthand way to categorize sub-categories such as perfluorocarboxylic acids (PFCAs) and perfluorosulfonic acids (PFSAs) that may behave similarly in the environment; however, it is important not to generalize about PFAA behavior based only on chain length. As recent research suggests, other factors besides chain length may affect bioaccumulation potential of PFAS (ITRC, 2020). For information, definitions of long- and short-chains are provided below.

Long-chain refers to:

- ✓ PFCAs with eight or more carbons (seven or more carbons are perfluorinated)
- ✓ PFSAs with six or more carbons (six or more carbons are perfluorinated)

Short-chain refers to:

- ✓ PFCAs with seven or fewer carbons (six or fewer carbons are perfluorinated)
- ✓ PFSAs with five or fewer carbons (five or fewer carbons are perfluorinated)

A summary of analytical findings from each material category are discussed below.

3.2.1 Pesticides or Other Agricultural Chemicals

Pesticides or other organic material containing PFAS potentially cover a broad range of products. One pesticide, sulfluramid (N-ethyl-perfluorooctane sulfonamide), has been documented as containing PFAS; sulfluramid is a synthetic pesticide, used in ant bait for control of household ants. Exemptions have been granted for its continued use in South America (Bejarano, 2019). As stated below, it was confirmed by Minnesota Department of Health (MDH) that sulfluramid has not been used in Minnesota. Based on additional information from the United States Environmental Protection Agency (USEPA) (USEPA, 2008), sulfluramid is a perfluorinated compound, whose major degradate is PFOS. The USEPA negotiated with the technical and end-use registrants a phase-out of products containing sulfluramid, with all registrations expiring by December 31, 2016. Additionally, all affected registrants agreed to discontinue producing any additional sulfluramid manufacturing-use product (MUP) and the acquisition or importation of any additional sulfluramid into the U.S.

Pesticide products contain "active" and "inert" ingredients. The terms "active ingredient" and "inert ingredient" are defined under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). An active ingredient is one that prevents, destroys, repels or mitigates a pest, or is a plant regulator, defoliant, desiccant or nitrogen stabilizer. By law, the active ingredient must be identified by name on the label together with its percentage by weight. The statute defines the term "inert ingredient" merely as an ingredient which is not active. The law does not require individual inert ingredients to be identified by name and percentage on the label, but the total percentage of all inert ingredients must be declared. PFAS may potentially serve as an "inert" ingredient and therefore is not required to be named on any product labelling. Data gaps related to pesticides and other agricultural chemicals as discussed in more detail in Section 3.4, Data Gap Evaluation.

Only one paper of those reviewed pertained to pesticides (Sardina, P et al, 2019). The study evaluated contaminants across land-use gradients and the risk to aquatic systems. The objective of the study was to assess the occurrence, concentration, and distribution of emerging and legacy contaminants (including both pesticides and PFAS among others). A total of 19 pesticides and 18 PFAS were detected in surface water, sediment and soil of residential and industrial sites. The paper is not applicable to the scope of work since the assessment evaluated pesticides but did not evaluate PFAS composition as part of pesticide formulations but rather as their own class of emerging contaminants with unspecified source so the paper was not deemed relevant.

A subsequent literature search, presented in Appendix C as "Run 3", for pesticides and other agricultural chemicals was completed. A total of 41 abstracts were obtained and reviewed. No additional papers were not deemed relevant as none discussed PFAS within a pesticide formulation. Wood discussed the data gap with the MPCA and MPCA subsequently provided a letter from the Minnesota Department of Agriculture (MDA) regarding their evaluation of PFAS as part of pesticides. The letter dated January 2008, from Dan Stoddard, Assistant Director for Environmental Programs at Minnesota Department of Agriculture (MDA) to Mindy Erickson, Environmental Research Scientist at MPCA stated that PFOS and PFOA were never used directly as pesticide active ingredients in Minnesota. Per the letter, pesticides such as sulfluramid never contained PFOS or PFOA however, the active ingredient, N-ethyl-perfluorooctane sulfonamide does degrade to PFOS.

3.2.2 PFAS in Food Packaging

Food contact materials (FCMs) cover a very expansive list of potential products, from industrial food production equipment and machinery, food packaging to kitchen utensils such as non-stick pots and pans (Cousins et. al., 2019). The primary focus of this report as it relates to FCMs is food packaging such as cups, bowls, wrappers, and take-out boxes or bags.

Fluorochemistry was first approved for use in food paper packaging in the 1970s and has been used ever since. The formulations have substantially changed over the years and specifically in the recent past (last 10-15 years) as manufacturers have been forced to move from long-chain perfluoroalkyl substances to short-chain polyfluoroalkyl substances, such as fluorotelomer-based polymeric products like fluorotelomer alcohols (FTOHs). Although chemical manufacturers have moved to short-chain products, there is still concern as to potential human health effects and non-fluorinated alternatives have become available (Cousins et. al., 2019). Composting certification is available and is used as a mechanism to reduce or eliminate PFAS from food packaging. More information regarding certification is provided in Section 3.3.

Several studies have identified that compost sites across the U.S. have detectable concentrations of PFAS. In one of the most recent studies evaluating the organic fraction of municipal solid waste (OFMSW), samples from 10 compost sites in 5 states (WA, OR, CA, MA, and NC) were tested for 17 PFAS (Choi et al, 2019). Results indicated that all site compost had detectable levels of PFAS in the compost however those that accepted food packaging had an order of magnitude higher concentrations of PFAS than those sites without food packaging. Although this paper is used for comparison purposes since minimal directly comparable data exists, it is imperative to note that Source-separated organic material (SSOM) in different from OFMSW:

(1) SSOM sites can be defined as those sites which accept a broad array of materials including food scraps, food packaging/compostable products and yard waste. SSOM sites only take material from residences or businesses that separate their organics from typical household garbage.

(2) Organic Fraction Municipal solid waste (OFMSW) includes separating and composting the organic fraction of municipal solid waste from the inorganic waste. This is done at the municipal solid waste facility rather than at residence or business.

A total of 11 papers of those reviewed pertained to food packaging and FCM. Nine of the papers contain analytical data that was pertinent and were entered into the data tables with 39 different PFAS analytes measured and 26 analytes detected. However, only 7 papers had comparable analyte-specific data. The remaining four papers measured Total Fluorine only, or measured concentrations per surface area. Total fluorine analytical methods are discussed more in Section 6.0, Assumptions and Limitations.

Several items were analyzed for PFAS ranging from food wrappers and beverage cups to pizza and take-out boxes, and popcorn bags. Results ranged from non-detect to a minimum of 20 ppt

(14:2 FTOH in a paper cup) and a maximum of 6,700,000 ppt (10:2 FTOH in a popcorn bag). All analytical results are presented in Table 3-1a, Summary of FCM Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. The highest concentrations tended to be the fluorotelomer alcohols and specifically 10:2 FTOH, 12:2 FTOH, and 8:2 FTOH. This finding is similar to the trend of FTOHs found in FCMs published in Yuan et al, 2016. The polyfluoroalkyl phosphoric acid ester 8:2 diPAP along with 12:2 FTOH and 10:2 FTOH were most frequently detected. Fluorotelomer alcohols have generally replaced PFAAs such as PFOA in FCM in recent years as PFOA was phased out.

In evaluating specific types of FCM, the following was summarized:

- ✓ For FCM bags (from popcorn and roasting bags to other aluminum and foil bags, the lowest concentration was 12:2 FTOH at 110 ppt and the highest concentration was 6,700,000 ppt for 10:2 FTOH.
- ✓ For FCM boxes (including pizza boxes, fast food paper boxes and popcorn boxes), the lowest concentration was 14:2 FTOH at 190 ppt and the highest concentration was 15,400 ppt for 8:2 diPAP.
- ✓ For FCM cups (including beverage cups, coffee cups, ice cream cups, etc), the lowest concentration was 14:2 FTOH at 20 ppt and the highest concentration was 25,560 ppt for PFHxA.
- ✓ For FCM fast food wrappers, the lowest concentration was 8:2 diPAP at 15,000 ppt and the highest concentration was 28,250 ppt for PFDA.
- ✓ For FCM baking paper and paper tableware, the lowest concentration was 6:2 FTOH at 65,000 ppt and the highest concentration was 1,050,000 ppt for 8:2 FTOH.

The Center for Environmental Health evaluated PFAS in food packaging materials (Chiang et al, 2018) using a Total fluorine method to test 130 products (including plates, bowls, clamshells and multi-compartment food trays) representing 39 manufacturers/brands. Products such as bamboo, clay-coated paper or paperboard, clear PLA (polylactic acid), paper-lined with PLA, palm leaf, paper with unknown coatings, and uncoated paper contained no or low fluorine. All molded fiber products such as wheat fiber (wheat straw or wheat stalk), "blend of plant fibers", silver grass (miscanthus), and sugarcane waste (bagasse) including molded recycled paper and PLA-lined molded sugarcane (bagasse) contained fluorine. This study focused largely on the composition of FCM (e.g. bamboo, PLA, molded fiber etc) vs the primary use of the FCM (such as fast food wrapper, microwave popcorn bag, coffee cup, etc) as is the case with all other studies. This makes it very challenging to compare results based on composition.

Comparisons of FCM based on primary use for the other studies are presented below and in Table 3-1b, Summary of Food Contact Materials Review, Maximum PFAS Detections by Material Use Category. Findings by use category for specific analytes are as follows:

- **Aluminum foil bags/wrappers-** No per- or polyfluoroalkyl substances were detected across any samples.
- **Bakery paper/bags-** Although per- and polyfluoroalkyl substances were analyzed, only the polyfluoroalkyl phosphoric acid ester, 8:2 diPAP, was detected at maximum concentration of 16,900 ppt.
- **Beverage cups (coffee cup, drink cups, ice cream cups)-** per- and polyfluoroalkyl substances were analyzed and both were detected. Three fluorotelomer alcohols, 10:2, 12:2, and 14:2 FTOH were detected between 20 and 440 ppt, the polyfluoroalkyl phosphoric acid ester, 8:2 diPAP, was detected at maximum concentration of 13,300 ppt, and the perfluorocarboxylic acid, PFHxA was detected at maximum contraction 25, 560 ppt.
- **Food paper bags (takeaway bag, etc.)-** Although per- and polyfluoroalkyl substances were analyzed, only polyfluoroalkyl substances were detected. Three fluorotelomer alcohols, 8:2, 10:2, and 12:2 FTOH were detected between 110 and 830 ppt.
- **Food paper boxes (pizza box, cinema popcorn box, fast food boxes)-** per- and polyfluoroalkyl substances were analyzed and only polyfluoroalkyl substances were detected. Four fluorotelomer alcohols, 8:2, 10:2, 12:2, and 14:2 FTOH were detected between 190 and 970 ppt, the polyfluoroalkyl phosphoric acid ester, 8:2 diPAP, was detected at maximum concentration of 15,400 ppt, and 6:2 diPAP had maximum detection of 2000 ppt.
- **Food paper wrappers -** per- and polyfluoroalkyl substances were analyzed and both were detected. The polyfluoroalkyl phosphoric acid ester, 8:2 diPAP, was detected at maximum concentration of 15,000 ppt, and 6 perfluorocarboxylic acids were detected ranging from PFDoA to PFBA. Maximum concentrations ranged from 3190 ppt in PFBA to 28,250 ppt in PFDA.
- **Microwave bags (i.e popcorn)-** per- and polyfluoroalkyl substances were analyzed and both were detected. Seven fluorotelomer alcohols, ranging from 18:2 to 6:2 FTOH were detected between 7500 and 6,700,000 ppt, three fluorotelomer carboxylic acids were analyzed and detected, ranging from 24,600 ppt to 161,600 ppt, and the polyfluoroalkyl phosphoric acid ester, 8:2 diPAP was detected at 12,100 ppt. Additionally four perfluorocarboxylic acids, PFHpA, PFHxA, PFPeA, and

PFBA were detected from 5190 ppt to 341,210 ppt.

- **Milk bottles (defined only as "plastic")-** per- and polyfluoroalkyl substances were analyzed and only polyfluoroalkyl substances were detected. The polyfluoroalkyl phosphoric acid ester, 8:2 diPAP, was detected at maximum concentration of 14,300 ppt.
- **Paper tableware (defined as plant fiber based, such as sugar-cane and reed-pulp fiber labelled as degradable, compostable, and eco-friendly)-** Only perfluoroalkyl substances, specifically fluorotelomer alcohols, were analyzed and they were detected. Seven fluorotelomer alcohols, ranging from 18:2 to 6:2 FTOH were detected between 9700 and 1,050,000 ppt.

Perfluorosulfonic acids were analyzed in 6 of the 9 primary use categories but no detectable concentrations were noted. PFAS concentrations were generally two orders of magnitude than all other use categories for both microwave bags and paper tableware. The microwave bag category also had the highest number of analytes detected.

3.2.3 PFAS in Food at SSOM Sites

Since PFAS are ubiquitous as persistent, bioaccumulative and toxic environmental contaminants, they tend to be seen throughout the food chain, with specific concentrations at their highest with increasing trophic levels (D'Hollander et. al., 2010). The European Food Safety Authority published a draft tolerable weekly intake (TWI) of 8 ng/kg bw per week in April 2020. This TWI also protects against other potential adverse effects observed in humans and includes four PFAS, PFOS, PFOA, PFNA, and PFHxS. Additionally, the Food Standards Australia New Zealand (FSANZ) has developed non-regulatory 'trigger points' for livestock products including meat, offal and milk, as well as seafood, fruits and vegetables. The tolerable daily intake is 20 ng/kg bw per day for PFOS + PFHxS and 160 ng/kg bw per day for PFOA. On July 31, 2020, the U.S. Food and Drug Administration (FDA) announced the voluntary phase-out of a certain type of short-chain PFAS, that contain 6:2 FTOH, which may be found in certain food contact substances used as grease-proofing agents on paper and paperboard food packaging. There are 15 Food Contact Notifications held by the four manufacturers that authorize 6:2 FTOH.

Consistently across multiple papers, PFAS was found more frequently and at higher concentrations in fish and other seafood and in meat and meat items and to a lesser extent in other food groups where multiple trophic levels did not exist. A total of 18 papers of those reviewed pertained to PFAS in food. Twelve of those papers contain analytical data that was pertinent and entered in the database. Papers considered PFAS concentrations in several material types including baked goods, dairy items, eggs, fish/seafood, fruit, vegetables, and meat. Analytical results are summarized by material type in Tables 3-2 through 3-8 and discussed below.

Bakery Items

A total of four papers of those reviewed pertained to bakery items. Forty-one analytical records were entered in the data tables with 15 different PFAS analytes measured and nine analytes detected. However, only seven papers had comparable analyte-specific data. The remaining four papers measured total fluorine only, or measured concentrations per surface area. Total fluorine analytical methods are discussed more in Section 6.0, Assumptions and Limitations.

Items analyzed for PFAS ranged from flour to cookies and other bakery items. Results ranged from non-detect to a minimum of 1 ppt (PFDA and PFNA) and a maximum of 1,720 ppt (PFNA in a cookie). All analytical results are presented in Table 3-2, Summary of Bakery Items Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. Highest concentrations tended to be the perfluorocarboxylic acids and specifically PFNA, PFOA, PFHpA. The PFNA and PFOA were most frequently detected.

Dairy

A total of two papers of those reviewed pertained to dairy items. A total of 289 analytical records were entered in the data tables with 18 different PFAS analytes measured and 13 analytes detected.

Items analyzed for PFAS ranged from butter, milk, and yogurt to processed cheese. Results ranged from a minimum of 1 ppt (PFDA and PFOA) and a maximum of 5,680 ppt (PFOS in milk). All analytical results are presented in Table 3-3, Summary of Dairy Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. The highest concentrations tended to be the perfluorocarboxylic acids and specifically PFOA and PFBA, and the perfluorosulfonic acids, specifically PFOS and PFHxS; PFOS, PFOA, and PFHxS were the most frequently detected. These detections and specific analytes reflect the PFAS contamination resulting from aqueous film-forming foam (AFFF) use at a nearby military base.

Eggs

A total of three papers of those reviewed pertained to dairy items. A total of 109 analytical records were entered in the data tables with 14 different PFAS analytes measured and seven analytes detected.

Items analyzed for PFAS ranged from whole eggs, egg whites, to egg yolks. Results ranged from a minimum of 280 ppt (PFHxS in whole egg) and a maximum of 52,000 ppt (PFBA in egg yolk). All analytical results are presented in Table 3-4, Summary of Egg Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. Highest concentrations tended to be the perfluorocarboxylic acids and specifically PFOA and PFBA, and the perfluorosulfonic acids, specifically PFBS. The PFOA, PFBA, and PFBS were most frequently detected. These detections and specific analytes reflect the PFAS contamination resulting from a nearby fluorochemical facility.

Fish/Seafood

A total of five papers of those reviewed pertained to fish/seafood items. A total of 279 analytical records were entered in the data tables with 21 different PFAS analytes measured and 18 analytes detected.

Items analyzed for PFAS ranged from lake trout to rainbow smelt and crustaceans. Results ranged from a minimum of 2 ppt (PFHpA in lean fish) and a maximum of 387,000 ppt (PFOS in an Oyster). All analytical results are presented in Table 3-5, Summary of Fish/Seafood Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. Highest concentrations tended to be the perfluorosulfonic acids, specifically PFOS. The PFOA and PFOS were most frequently detected.

Fruit

A total of four papers of those reviewed pertained to fruit. A total of 33 analytical records were entered in the data tables with 10 different PFAS analytes measured and three analytes detected.

Items analyzed included oranges, bananas, apples, and cherries. Results ranged from a minimum of 14 ppt (PFOS in apple) and a maximum of 13,450 ppt (PFBA in banana). All analytical results are presented in Table 3-6, Summary of Fruit Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. Highest concentrations tended to be the perfluorocarboxylic acids and specifically PFBA. The PFOA and PFBA were most frequently detected. The substantially higher detection (30x) of PFBA coincides with the chain length, illustrating that shorter chain analytes have a higher uptake than longer chain analytes.

Vegetables

A total of 10 papers of those reviewed pertained to vegetables. A total of 934 analytical records were entered in the data tables with 22 different PFAS analytes measured and 12 analytes detected.

Items analyzed for PFAS ranged from potatoes, peppers, tomatoes, fennel and lettuce. Results ranged from a minimum of 0.32 ppt (PFNA) and a maximum of 266,100 ppt (PFBA). All analytical results are presented in Table 3-7, Summary of Vegetables Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. The highest concentrations tended to be the perfluorocarboxylic acids and specifically PFPeA and PFBA, and the perfluorosulfonic acids, specifically PFBS. The PFHxA and PFOA were most frequently detected. The substantially higher detection (20x) of PFBA, PFBS, and PFPeA coincides with the chain length, illustrating that shorter chain analytes have a higher uptake than longer chain analytes.

Meat

A total of five papers of those reviewed pertained to meat and meat items. A total of 119 analytical records were entered in the data tables with 16 different PFAS analytes measured and 8 analytes detected.

Items analyzed for PFAS ranged from beef and pork to chicken. Results ranged from a minimum of 1 ppt (PFNA and PFHpA) and a maximum of 4,500 ppt (PFNA) All analytical results are presented in Table 3-8, Summary of Meat Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte. Highest concentrations tended to be the perfluorocarboxylic acids and specifically PFNA. The PFOA, PFOS were most frequently detected.

3.2.4 PFAS at Yard Waste Sites

A total of three papers of those reviewed pertained to potential yard waste materials (leaves, grass, trees, roots, etc). A total of 119 analytical records were entered into the data tables with 16 different PFAS analytes measured and 11 analytes detected. Results ranged from a minimum of 100 ppt (PFDA) to 700,000 ppt (PFOA in tree leaves near a fluorochemical facility). This indicates that the tree leaves had some amount of uptake of PFAS as result of exposure from nearby facility. All analytical results are presented in Table 3-9, Summary of Yard Waste Review, PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte.

It is expected that yard waste may contain PFAS for two primary reasons: 1) the plants that ultimately make up the yard waste were exposed to soil, air, or water that was contaminated with PFAS and uptake by the plant occurred via roots of the plants (soil and water) or via air (air translocation and deposition on leaves) and 2) although less likely, the yard waste plants were exposed to pesticides that contained PFAS. It has been noted in many studies (Choi et al, 2019) that >65-70% of detectable PFAS in soil are short-chain PFAS and there is a direct correlation between PFAS concentrations in soil and bioaccumulation in plants with short-chains accumulating in the shoots/leaves and long-chains accumulating in the roots.

3.3 LABELLING STANDARDS REVIEW

There are four organizations that verify the product is compostable or evaluate the sustainability of disposable food ware. They are:

1. BPI Compostability Certification (https://bpiworld.org/)
2. Cedar Grove List of Accepted Products (https://cedar-grove.com/about-us)
3. The Cradle to Cradle Products Innovation Institute (https://www.c2ccertified.org/), and
4. Green Seal (https://www.greenseal.org/).

The first two are the most commonly used resources and certify and/or field test based on PFAS (i.e. total fluorine content). The last two have certifications that apply to disposable foodware, but there are few foodware products currently certified to these standards; they each address sustainability more broadly and do not address if a product is compostable. Neither of these (Cradle-to-Cradle Products Innovation Institute and Green seal) are therefore relevant and not discussed further in this report.

Wood reviewed any existing literature on PFAS limits incorporated into any labeling standards and any research pertaining to the level of effectiveness of such limits. No information was available that highlight the significance and effectiveness of the limits at this time. Both BPI and Cedar Grove carefully state that there must be no *intentionally* added (chemical intentionally added in formulation vs added as an unintentional by-product or process contaminant) PFAS as well as a limit of 100 ppm total fluorine. Each certification entity is presented below.

3.3.1 Biodegradable Products Institute

BPI is a nonprofit organization that certifies compostable products and packaging in North America. Their logo on packaging verifies that products and packaging have been independently verified according to scientifically based standards. Beginning January 1, 2020, products claimed as BPI certified must have no intentionally added PFAS and a limit of 100 ppm total fluorine. Based on email correspondence with Rhodes Yepsen, Executive Director of BPI, on June 23, 2020, the policy prohibits the intentional use of fluorinated chemicals in BPI certified products. This is demonstrated with three criteria:

1) The product formula must not have fluorinated chemicals — as evidenced by safety data sheets for all ingredients;

2) Test results from an approved lab showing a maximum of 100ppm total fluorine (unless demonstrated to be from naturally occurring fluorine) and,

3) A statement of no intentionally added fluorinated chemicals signed by the manufacturer.

According to Mr. Yepsen, the 100ppm limit is based on several lines of evidence; first it is listed in the EN13432 compostability standard for Europe (as a way to restrict fluorine, not PFAS), and second, test results from University of Notre Dame on hundreds of foodservice items confirmed that 100ppm was a good threshold for intentional use of PFAS. If companies are non-compliant, their license agreement with BPI is suspended or revoked.

3.3.2 Cedar Grove List of Accepted Products

To accomplish higher food waste diversion and minimize contamination in urban feed stocks, Manufacturing Alliance (CMA) and its affiliated partners provide a program of technical review and field testing of compostable products to determine their true feasibility as food related feed stock when shipped to fully permitted industrial composting sites. Items submitted for CMA field testing include bags, utensils, plates, bowls, clamshells, wraps etc. Effective January 1, 2020, CMA Sites do not accept products for field testing or substrate review that contains > 100 ppm total fluorine. Cedar Grove and members of the CMA work to support these programs while maintaining a high standard of compost quality across 20 composting sites throughout the U.S.

3.4 Data Gap Evaluation

Wood evaluated literature data gaps by identifying types of materials for which there is no, or limited information available. The following data gaps should be carefully considered.

- ✓ For FCM, the literature did not adequately evaluate or distinguish among the use categories of food contact material. Products were not designated as bamboo, clay-coated paper or paperboard, clear PLA (polylactic acid), paper-lined with PLA, palm leaf, paper with unknown coatings, uncoated paper, and molded fiber products. Materials were more generically defined as boxes, bags, cups, and wrappers.

- ✓ For FCM, none of the literature defined the materials tested as certified by the Biodegradable Products Institute (BPI), and BPI testing results of products are not publicly available. The efficacy of the certification and product claims of no intentionally added PFAS and a limit of 100 ppm total fluorine as protective of the environment could not be validated. Although BPI and other certification programs are available and resulting advancement in understanding PFAS content is beneficial, the basis of their definition of "acceptable" may warrant more study. The limit of 100 ppm total fluorine, and a statement of "no intentionally added fluorinated chemicals" does neither entirely address unintentionally added fluorine in the manufacturing process nor specific PFAS analytes in final products. Analyte-specific analysis is useful but cannot adequately quantify all potential PFAS. A combination of organic fluorine testing, such as total fluorine, combustion ion chromatography (CIC), or particle-induced gamma-ray emission (PIGE) to evaluate total fluorine measurements of food packaging samples coupled with analyte-specific targeted analysis, such as liquid chromatography– tandem mass spectrometry, should be able to quantify unidentified organic fluorine not captured by compound-specific analysis (Schultes et al, 2019).

- ✓ For many food items, dairy (milk), eggs, vegetables, and yard waste, samples were biased high as they were collected in the vicinity of fluorochemical manufacturing or fire fighting training areas where PFAS were used for 30 or more years. Adequate ambient background levels could not be evaluated based on the available data.

- ✓ For baked goods, the concentrations were considered lowest of all material evaluated. There is no understanding of source of PFAS in the baked goods, if they were originally from the FCM (muffin and cupcake liners) or from ingredients used (eggs, butter, etc).

- ✓ For yard waste, there was no literature available that evaluated yard waste specifically. The literature reviewed considered tree leaves, grass leaves, roots, and pine needles as representative of yard waste.

- ✓ For pesticides, there was no available literature illustrating PFAS ingredients were part of the product formulation nor used in pesticide/herbicide application. Some of the challenges related to this data gap are the proprietary nature of the product formulation. Manufacturers, when applying for a pre-manufacture notification to obtain authorization to put product into commerce under Toxic Substances Control Act (TSCA), often use the term "confidential business information" (CBI) to describe product ingredients. This has substantially impeded the progress to understanding where and how PFAS may be used in a product as they are not clearly listed on Safety Data sheets. The Organization for Economic Co-operation and Development (OECD) has established a PFAS database and is compiling chemical names for all PFAS used in commerce; this may be a good resource to better understand product formulations and PFAS content. Appendix D provides the OECD database listing more than 4700 Chemical Abstract Services (CAS)-registered polymer and non-polymer substances. Additionally, PFAS may be added to pesticides, as inert rather than active ingredients. The USEPA distinguishes between inert and active ingredients in pesticide products under FIFRA. An inert ingredient is any substance (or group of structurally similar substances if designated by the USEPA), other than an "active" ingredient, which is intentionally included in a pesticide product. It is important to note, the term "inert" does not imply that the chemical is nontoxic. All inert ingredients in pesticide products, including those in an inert mixture, must be approved for use by the USEPA. For more information, go to: https://www.epa.gov/sites/production/files/2015-12/documents/faqs.pdf .

- ✓ Data gaps are apparent with analytical methodologies. There are a few common applied analytical methods to measure general fluorine content vs targeted speciation of chain length and specific structural details of analytes, including Extractable or Absorbable Organic Fluorine (EOF or AOF) or PIGE Spectroscopy. These methods are often used for materials such as food contact papers and packaging. These tests are suitable to obtain an efficient evaluation of total fluorine load but do not allow for the necessary understanding of what specific PFAS analytes are present and at what concentrations which are needed to determine overall toxicity, persistence, and fate.

- ✓ Data gaps in specific analytes and indication of polyfluoroalkyl precursors. Although several PFAS were measured and reported for FCMs, the same was not evident for food or yard waste. Generally, only perfluoroalkyl substances were measured and reported for food and yard waste. Measurement of polyfluoroalkyl substances in food and yard waste may yield valuable information about presence of precursors as well as their transformation pathways and end product PFAS.

- ✓ Data gap in span of analytical data and corresponding detection limits. Analytical data spanning 15 years (2005-2020) was used in the literature review. Analytical methodologies were noted where available as were detection limits. That said, detection limits have improved substantially since 2005 and new PFAS analytes have been added to the targeted analyte list. Previously reported data that may have been identified as non-detect may now be detected as result of improvements in analytical methods or total concentrations may have been underestimated if analyte list was less than what is currently available.

- ✓ Data gaps in availability of supplemental data. In some cases, only summary data was available for review and consideration and supplemental information was either not accessible or available in a timely manner. In these cases, a range from minimum to maximum concentrations were often reported and median concentration used for analysis.

- ✓ Relevant location data. Composting data related to PFAS is relatively limited. To capitalize on all available published literature, Wood utilized publications globally. Analytical data that was referenced, summarized, and used in comparisons were noted with source geographic location. Caution should be used in interpreting the data that has been compiled for comparison. Although it provides a good general sense of contamination, it may not adequately address geographic differences. Variability may be related to proximity of a major source (such as a fluorochemical manufacturing facility or a military base that uses AFFF [which contains PFAS] or variability may be related to country-specific activities related to policy and regulations on PFAS. For example, as a result of the U.S. Food and Drug Administration (FDA) initiatives, manufacturers volunteered to stop distributing products containing PFAS with 8 carbons in chain length (i.e., PFOA and PFOS) in interstate commerce for food-contact purposes as of October 1, 2011. As a result, and illustrated in Yuan et al (2016), use of 10:2 FTOH and longer-chain FTOHs has been effectively reduced in the United States while 10:2 FTOH and longer-chain FTOHs are still used in China and imported to US.

- ✓ Variability in composting operations. In composting operations, the feedstocks vary, the methods of composting vary, and the applications for the compost may vary. In Minnesota as an example, some focus on uniform industrial sources (like Mississippi Topsoils), some take primarily food scraps and yard waste, and some take packaging, food scraps and yard waste.

4.0 PHASE II OUTPUT- PFAS DEGRADATION

Wood reviewed the 2019 report on PFAS in contact water and surface water/stormwater completed by Wood to develop a list of the specific chemical types found. Wood evaluated degradation pathways of the primary PFAS chemicals identified in Phase I to compare to the 2019 report data and evaluate which types of materials may be contributing sources of PFAS. Any research detailing types and concentrations of PFAS in degradation pathways of PFAS identified in Phase I as well as potential deposition and background/ambient concentrations are considered.

4.1 SUMMARY OF REPORT ON CONTACT WATER

An investigation to evaluate contact water was authorized by the MPCA on May 25, 2018. MPCA rules for SSOM compost sites define contact water as water that has been in contact with tipping and mixing areas and compost windrows during their early/active phase. Contact water is required to be collected and treated. Water at yard waste sites and water from SSOM sites that is in contact with curing compost piles and or compost is generally treated as stormwater. Field investigation activities were conducted in accordance with the Sampling and Analysis Plan (SAP) dated November 2018 and updated April 2019. A final report was published September 2019 (Wood, 2019).

The scope of services included the following:

- Collection of water samples from ponds located at five SSOM sites during three separate sampling events;
- Collection of water samples from ponds located at two yard waste sites during three separate sampling events;
- Laboratory analysis of water for PFAS in accordance with Chemicals of Potential Concern (COPCs);
- Data Quality Review (DQR) of the water sample analytical results; and
- Preparation of a site investigation report.

The report included a comparison of PFAS detected in contact water at each of the sites relative to calculated median ambient concentrations of PFAS detected across the State as conducted by the MPCA (MPCA, 2017). The investigation confirmed:

1) The presence of one or more PFAS at concentrations above intervention limits at all SSOM and yard waste sites sampled. Intervention limits are defined as ¼ of the Health Risk Limit (HRL) or Health Based Value (HBV).

2) The detected PFAS at SSOM sites included PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFBS, PFHxS and PFOS.
3) The detected PFAS at yard waste sites included PFBA, PFPeA, PFHxA, PFOA, PFBS, PFHxS, and PFOS.
4) At every composting site in the investigation, at least one sampling event resulted in a PFAS analyte that was over the applicable HRL or HBV.
5) PFAS concentrations measured at the SSOM and yard trimming sites, when compared with published data on ambient background levels, were generally greater than reported ambient concentrations of PFAS in groundwater across Minnesota.
6) PFAS concentrations measured at the SSOM and yard waste sites, when compared to published values of PFAS in leachate from landfills, were lower than the reported data for landfill leachate.

4.2 SUMMARY OF DEGRADATION PATHWAYS

Both SSOM sites and yard waste sites likely contain measurable concentrations of non-polymer per- and polyfluoroalkyl substances (as noted in Exhibit 4). Based on the literature review, SSOM sites contain FCM with contributing sources of polyfluoroalkyl substances, specifically fluorotelomer alcohols , fluorotelomer carboxylic acids, and polyfluoroalkyl phosphoric acid esters in addition to perfluoroalkyl substances also commonly found in food and yard waste (Table 3-1 through Table 3-9).

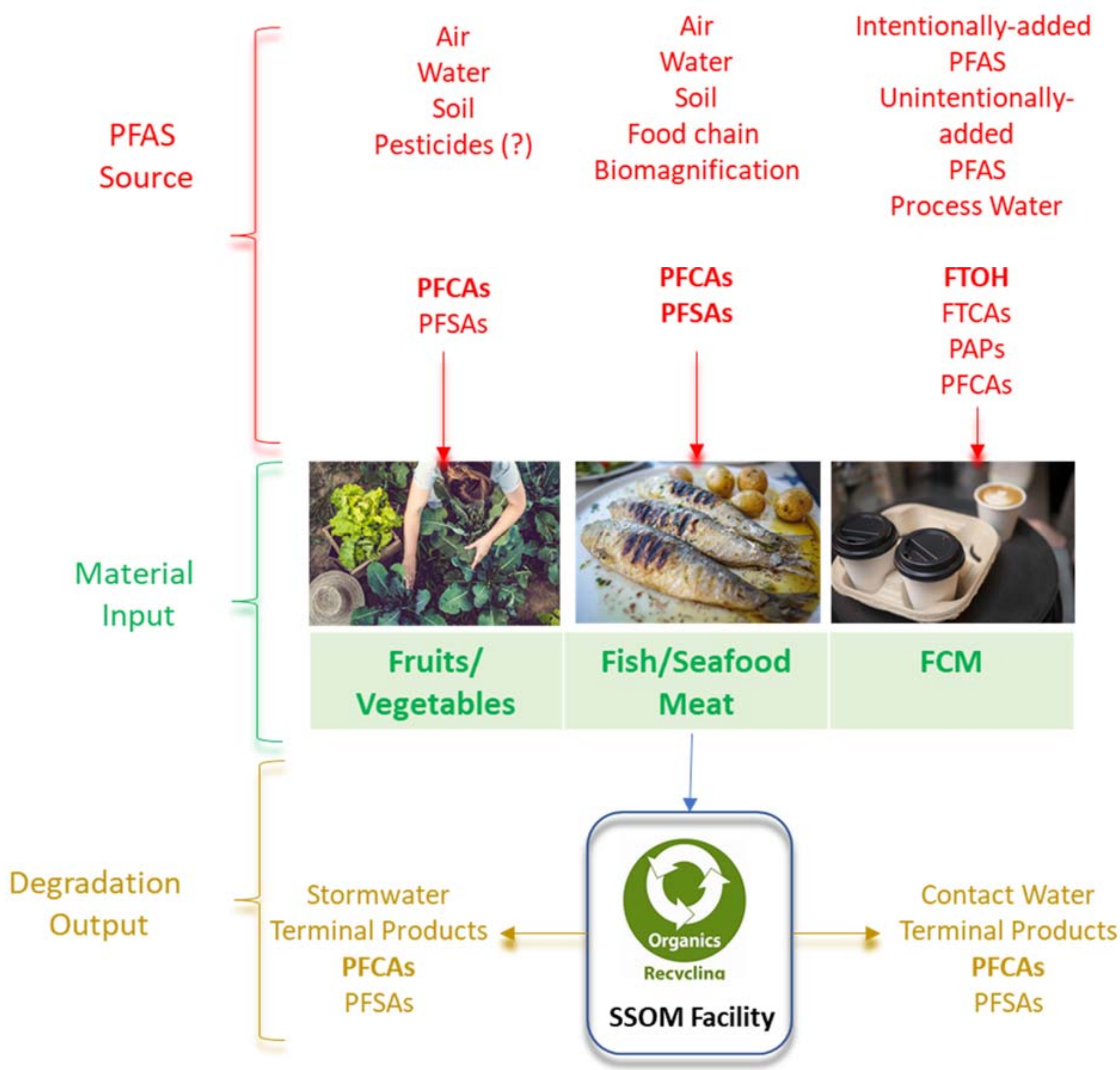
Exhibit 5 illustrates the conceptual site model for SSOM sites. As presented, PFAS sources can be very broad and vary depending on the material type. Food from the first trophic level, or primary producers such as fruits and vegetables may be exposed to PFAS as they grow via contaminated soil, surface or irrigation water, and air. Pesticides containing PFAS may also be a source but more information is needed to evaluate which pesticides contained PFAS and their applicable uses as a probability (see Section 3.2.1 for more information). Based on the relative distribution of the material input, i.e. feedstock, entering the SSOM, the PFAS profile can substantially vary.

Food from the second, third, and fourth trophic levels, or consumers, such as cows, chickens, fish, and crustaceans may also be exposed to PFAS as they grow via contaminated soil, water, and air however, there is a probability that PFAS contamination will be higher as a result of biomagnification for higher trophic-level organisms that are consumed as food (e.g., fish).

PFAS analytical composition in food items will vary depending on the trophic level. It is expected that food from first trophic levels will be higher in PFCAs and shorter-chain analytes and food from higher trophic levels will be contaminated with longer-chain terminal products such as

PFOS and PFOA.

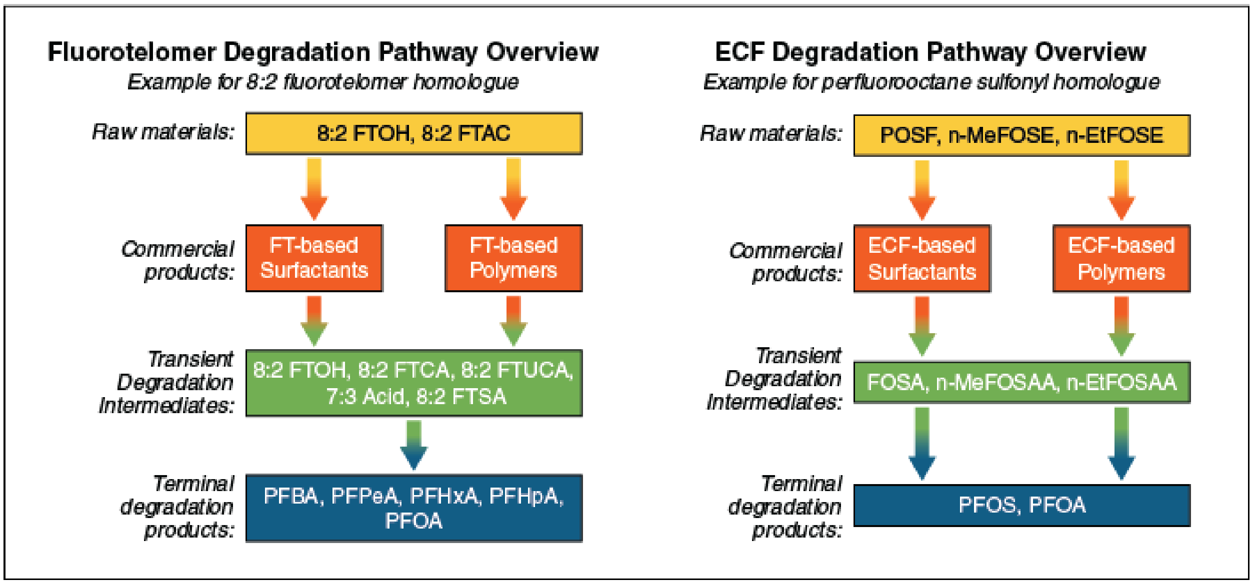
Exhibit 5 General Conceptual Site Model for SSOM sites



A conceptual site model is expected for yard waste sites to include PFAS sources from soil, air, and water in vicinity of trees, brush and grass that is taken up by the material input into the yard waste sites. Pesticides containing PFAS may also be a source, but more information is needed to evaluate which pesticides contained PFAS and their applicable uses as a probability (see Section 3.2.1 for more information).

Exhibit 6 below illustrates example degradation pathways. Most FCMs are now manufactured using a fluorotelomerization process and degradation follows the fluorotelomer degradation pathway presented below. This is evident in Table 3-1 where FCM analytical data includes detectable levels of many transient degradation intermediates. Electrochemical fluorination (ECF) is not relevant for FCMs. Section 4.4 below discusses and compares analytical results from SSOM sites and illustrates the terminal degradation products at SSOM sites (Wood, 2019 and Choi et al, 2019) where analytes such as PFBA and PFHxA are highest.

Exhibit 6- Example Polyfluoroalkyl substance degradation pathways (ITRC, 2020)



4.3 Review of Background/Ambient Concentrations

Ambient levels of PFOS and PFOA have been studied and are useful at both small and larger scales to understand PFAS distribution trends (Vedagiri et al, 2018). Unlike other naturally occurring background, PFAS are synthetic compounds so they are considered anthropogenic and often occur as result of PFAS fate and transport via air deposition, soil, groundwater, and surface water. Table 4-1 illustrates the average PFOS and PFOA concentration ranges in soil, surface water and drinking water. Ambient concentrations may substantially vary depending on geographic location such as proximity to primary sources such as AFFF training areas and fluorochemical manufacturers.

4.4 COMPARISON OF WOOD (2019) REPORT TO LITERATURE REVIEWED

The Wood, 2019 report evaluating select SSOM and Yard Waste sites (Wood, 2019) was compared to a recent study on perfluoroalkyl acid characterization in U.S. municipal organic solid waste composts (Choi et al, 2019) as well as the concentration ranges documented as part of this literature review. Table 4-2, Comparison of Minimum and Maximum PFAS Concentrations Across Wood Study, Compost Literature, and Other Literature presents the information. The Wood 2019 report was described in section 4.1.

The recent study on perfluoroalkyl acid characterization in U.S. municipal organic solid waste composts (Choi et al, 2019) studied the organic fraction of municipal solid waste (OFMSW) and specifically the loads and leachability of 17 PFAAs were analyzed in 9 OFMSW commercial composts and one backyard compost. The following key findings were presented:

1) PFAA concentrations ranged from 28,700 ppt to 75,900 ppt for OFMSW composts that included food packaging and an order of magnitude lower (2,380 ppt to 7,600 ppt) for composts that did not include food packaging.
2) PFOA and PFOS were detected in all composts but OFMSW composts primarily contained short-chain PFAAs (>64%) and PFCAs (>68%)
3) Samples collected at three OFMSW indicated the presence of PFAS precursors including 6:2 fluorotelomer sulfonate and 6:2 dipolyfluoroalkyl phosphate ester.
4) Of the PFAA loads in compost, 25-49% were released to porewater.

Maximum concentrations in the Wood 2019 report were compared to maximum concentrations in the Choi et al study as well as maximum concentrations listed in the general literature review performed as part of this study and the following was noted:

1) Some of the highest PFAS concentrations in SSOM samples collected as part of the Wood 2019 report were also some of the highest for OFMSW in Choi et al study, and in the general literature review. This was specifically the case for PFHxA. However, the relative concentration of PFHxA was 10x higher in general literature (254,500 ppt) and 100x higher in the Wood report (3,440,000 ppt) than in the Choi et al study (49,840 ppt).
2) PFOS was one of the highest concentrations in SSOM samples collected as part of the Wood 2019 report as well as in the general literature review. However, the relative concentration of PFOS was 10x higher in the Wood report (3,070,000 ppt) than in the general literature review (387,000 ppt).).

5.0 CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the literature review, data gap evaluation by material type, a comparison to previously collected contact water and surface water samples, and a summary of findings and recommendations.

For materials being placed in the SSOM facility or at the yard waste sites, currently acceptable materials were defined. Based on review of analytical data, several acceptable materials may be considered as containing PFAS. Although there are label standards governing some acceptable materials (i.e., FCM), the standards apply only to the potential unintended PFAS that may be present which is not specified and only represented as total fluorine.

For PFAS degradation, it can be concluded that both PFAS may be present at a site and based on comparison of the Wood (2019) study to currently available literature and specifically a 2018 Compost study (Choi et al, 2018), the following conclusions may be drawn:

- ✓ Both long-chain and short-chain perfluoroalkyl acids are prominent in the food waste. These analytes will leach as-is and long-chains may degrade or transform to terminal products such as PFOS, PFOA, PFBA, PFPeA, PFHxA, and PFHpA.
- ✓ Polyfluoroalkyl substances continue to be prominent in FCMs and specifically food packaging. These can degrade further to perfluoroalkyl acids, as listed above, in the environment. Eliminating FCM from food packaging will likely reduce but not entirely eliminate PFAS from compost.

Definition of potential sources and potential PFAS chemicals

Nine different FCM use categories were evaluated as potential sources including aluminum foil bags/wrappers, bakery paper/bags, beverage cups, food paper bags, food paper boxes, food paper wrappers, microwave bags, milk bottles, and paper tableware. PFAS concentrations in microwave bags and paper tableware were generally 1 to 4 orders of magnitude greater than all other categories. Detectable PFAS concentrations across all categories were consistently polyfluoroalkyl substances and more specifically fluorotelomer alcohols and polyfluoroalkyl phosphoric acid esters.

For potentially contaminated food sources, seven different food categories were evaluated as potential PFAS sources including bakery items, dairy, eggs, fish and seafood, fruit, vegetables, and meat. PFAS concentrations were generally higher in eggs, fish and seafood, and vegetables with maximum concentrations 1 to 2 orders of magnitude greater than the other food sources. With the exception of meat, only perfluoroalkyl substances were analyzed. The highest detectable PFAS concentrations in fish and seafood were PFOS and PFOA while shorter-chained PFAS were present in higher concentrations in eggs and vegetables (PFBA, PFBS, PFPeA).

For potential PFAS sources for yard waste sites, trees and shrubs (roots, leaves, needles) and pesticides were considered. Maximum PFAS concentrations for trees and shrubs were generally higher than that of food sources but lower than FCM. Only perfluoroalkyl substances were analyzed. The highest detectable PFAS concentrations were for PFOA. For pesticides, no analytical data was available.

Definition of potential data gaps

The following data gaps were identified:

- ✓ For FCM, the literature did not adequately evaluate or distinguish among the FCM composition but rather focused on the use categories. Products were not designated by composition such as bamboo, clay-coated paper or paperboard, clear PLA (polylactic acid), paper-lined with PLA, palm leaf, paper with unknown coatings, uncoated paper, and molded fiber products but were more generically identified by use categories such as boxes, bags, cups, and wrappers. This made it difficult to evaluate compostable products that would be typically seen at an SSOM site.

- ✓ For FCM, none of the literature defined the materials tested as certified by the Biodegradable Products Institute (BPI), and BPI testing results of products are not publicly available. The efficacy of the certification and product claims of no intentionally added PFAS and a limit of 100 ppm total fluorine as protective of the environment could not be validated.

- ✓ For many food items, dairy (milk), eggs, vegetables, and yard waste, samples were biased high as some were collected in vicinity of fluorochemical manufacturing or firefighting training areas where PFAS were used for 30 or more years. Representative ambient background levels could not be evaluated based on the available data.

- ✓ For baked goods, the concentrations were considered lowest of all material evaluated. There is no understanding of source of PFAS in the baked goods, if they were originally from the FCM (muffin and cupcake liners as an example) or from ingredients used (eggs, butter, etc).

- ✓ For yard waste, there was no literature available that evaluated yard waste specifically. The literature reviewed considered tree leaves, grass, roots, and pine needles as representative of yard waste.

- ✓ For pesticides, there was no available literature illustrating PFAS ingredients were part of the product formulation nor used in pesticide/herbicide application.

- ✓ For PFAS analytical methodologies, there are a few common applied analytical methods to measure general fluorine content vs targeted speciation of chain length and specific structural details of analytes, including Extractable or Absorbable Organic Fluorine (EOF or AOF) or PIGE Spectroscopy but it becomes difficult to compare results when methodology is not consistent.

Development of a list of products for testing/analysis consideration

The following recommendations should be considered as testing priorities:

- ✓ The first priority is further evaluation of FCM and specifically compostable materials. Since highest PFAS concentrations across all sources evaluated is by far FCMs, evaluate FCM products commonly used in Minnesota, certified by Biodegradable Products Institute (BPI), and disposed of at SSOM sites in Minnesota. A Total Organic Precursor (TOPs) analytical method is recommended to best measure potential precursor concentrations and to better profile composition of certified FCMs. A full analytical suite of PFAS is recommended along with branched and linear isomer analysis to aid in defining transformation pathways and understanding the terminal products to be expected with transformation. Specific product types recommended for sampling are not identified as it is assumed that the number and types of products are too numerous to be representative.

- ✓ The second priority is to inventory and evaluate incoming loads at SSOM sites to understand composition and variability of input. Once that is determined, establish a sampling plan to analyze PFAS in the incoming loads, active piles, contact water, compost ready for sale, and residuals to determine where, when, and what PFAS are introduced into the process so sources can be controlled and releases mitigated. An understanding of the PFAS profile and resulting contact water and compost would yield a better understanding of source contributions of input materials which in turn lead to better understanding of the potential for transformation and degradation of PFAS once at the site.

- ✓ The third priority is to further evaluate yard waste since literature was not available for yard waste in general. Additional sampling is recommended for various types of yard waste (leaves vs grass clippings as an example) and in various locations (rural vs urban areas). This may yield more informative decision making for best management practices. Herbicide/pesticide sampling is not warranted at this time as literature review did not indicate PFAS used in product formulations in Minnesota.

- ✓ The last priority is to evaluate potential ambient source contributions in vicinity of SSOM and yard waste sites across the State of Minnesota. Compare and map existing MPCA/MDH ambient background data (soil and surface water at a minimum) in vicinity of SSOM and yard waste sites to develop regional background. Also consider performing a desk-top source evaluation to determine if there are potential primary PFAS sources (including airborne sources) in vicinity of SSOM and yard waste sites that may be contributing to elevated ambient background levels.

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APPENDICES

APPENDIX A

ELECTRONIC ONLY
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Overall review (Table A-1)
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APPENDIX B

Acceptable Materials Lists

APPENDIX C

Abstract Queries
Run 1 PFAS and SSOM Sites
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APPENDIX D

ELECTRONIC ONLY

OECD Database

APPENDIX E

ELECTRONIC ONLY

Literature Library

Table 1

Summary of Initial Literature Review

TOTAL Abstracts	TOTAL Papers Reviewed	TOTAL Papers with Analytical Data	TOTAL Requiring Follow-up
143	62	27	19
Detail by general material type			
Food packaging	11	7	
Food	18	12	
Yard waste	6	3	
Not Applicable	15	5	
Applicable but no data	9	--	

Table 2
Material List with Total Number of Analytical Records and Unique PFAS Measured

Material List	Total Literature Sources	Total Records of Analytical	Unique PFAS Analytes Measured
Pesticides/Other chemicals	1	0	0
Fruit	4	33	10
Vegetables	10	934	22
Bread, pasta, baked goods	4	41	15
Eggs	3	109	14
Dairy products	2	289	18
Fish/Seafood	5	279	21
Meat	5	119	16
Food contact material	11	432	39
Compost	1	170	17
Yard Waste	3	119	16
Pet Waste	2	0	0
Environmental (Leachate, gw, etc)	7	461	40
Other	14	334	23

Table 3-1a
Summary of Food Contact Materials Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentrations in Max detected concentration (ppt)	Reference	Mean	Median	Other notables
POLYFLUOROALKYL SUBSTANCES									
Fluorotelomer Alcohols									
18:2 FTOH	18	2	7500	(79)	9700	(79)	8600	8600	Min - paper tableware, Max - popcorn bag (both from Beijing, China & Columbus, Ohio)
16:2 FTOH	16	2	61000	(79)	72000	(79)	66500	66500	Min - paper tableware, Max - popcorn bag (both from Beijing, China & Columbus, Ohio)
14:2 FTOH	14	4	20	(79)	384000	(79)	167803	143595	Min - paper cup, Max - popcorn bag (both from Beijing, China & Columbus, Ohio)
12:2 FTOH	12	6	110	(79)	5650000	(79)	1059350	425	Min -paper bag, Max - popcorn bag (both from Beijing, China & Columbus, Ohio)
10:2 FTOH	10	6	440	(79)	6700000	(79)	1247147	935	Min - paper cup, Max - popcorn bag (both from Beijing, China & Columbus, Ohio)
8:2 FTOH	8	5	630	(79)	4810000	(79)	1172452	830	Min - other, Max - popcorn bag (both from Beijing, China & Columbus, Ohio)
6:2 FTOH	6	2	65000	(79)	80000	(79)	72500	72500	Min - paper tableware, Max - popcorn bag (both from Beijing, China & Columbus, Ohio)
Fluorotelomer Carboxylic Acids									
6:2 FTCA	6	1	161600	(78)	161600	(78)	161600	161600	Microwave popcorn bag
6:2 FTUCA	6	1	114400	(78)	114400	(78)	114400	114400	Microwave popcorn bag
5:3 FTCA	5	1	24600	(78)	24600	(78)	24600	24600	Microwave popcorn bag
Polyfluoroalkyl Phosphoric Acid Esters									
8:2 diPAP	8	9	5300	(78)	120000	(69)	13186	14300	Min - pizza box, Max - FCM (Czech Republic)
8:2PAP	8	2	100000	(69)	230000	(69)	165000	165000	Min & Max - FCM (Czech Republic)
6:2 diPAP	6	3	2000	(78)	55000	(69)	2000	2000	Min Pizza box & Max FCM (Czech Republic)
6:2PAP	6	1	130000	(69)	130000	(69)	130000	130000	FCM (Czech Republic)
Polyfluoroalkane Sulfonamides									
FOSA	8	1	5000	(69)	5000	(69)	5000	5000	FCM (Czech Republic)
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFDoA	12	1	19120	(79)	19120	(79)	19120	19120	Fast food wrappers
PFDA	10	1	28250	(79)	28250	(79)	28250	28250	Fast food wrappers
PFNA	9	1	4970	(79)	4970	(79)	4970	4970	Fast food wrappers
PFOA	8	1	6000	(7)	290000	(7)	148000	148000	Min & Max -popcorn bags
PFHpA	7	3	2000	(79)	10020	(79)	5737	5190	Min - microwave bags, Max - fast food wrappers
PFHxA	6	5	10000	(70)	341210	(79)	130088	25560	Min - FCM (Czech Republic) Max - microwave bags
PFPeA	5	1	20500	(78)	20500	(78)	20500	20500	Microwave popcorn bag
PFBA	4	3	3190	(79)	291000	(78)	190010	275840	Min - fast food wrappers (Spain) Max - microwave popcorn bag

Table 3-1b
Summary of Food Contact Materials Review
Maximum PFAS Detections by Material Use Category

Analyte	Chain Length	aluminum foil bags/wrappers	Bakery paper/bags	Beverage cups	Food paper bag	Food Paper box	Food paper wrapper	Microwave bag	Milk bottle (plastic)	Paper tableware
(ppt)										
POLYFLUOROALKYL SUBSTANCES										
Fluorotelomer Alcohols										
18:2 FTOH	18	NA	ND	ND	ND	ND	NA	7500	NA	9700
16:2 FTOH	16	NA	ND	ND	ND	ND	NA	61000	NA	72000
14:2 FTOH	14	NA	ND	20	ND	190	NA	384000	NA	287000
12:2 FTOH	12	NA	ND	310	110	540	NA	5650000	NA	705000
10:2 FTOH	10	NA	ND	440	570	970	NA	6700000	NA	780000
8:2 FTOH	8	NA	ND	ND	830	800	NA	4810000	NA	1050000
6:2 FTOH	6	NA	NA	ND	ND	ND	NA	80000	NA	65000
Fluorotelomer Carboxylic Acids										
6:2 FTCA	6	NA	ND	ND	NA	ND	ND	161600	ND	NA
6:2 FTUCA	6	NA	ND	ND	NA	ND	ND	114400	ND	NA
5:3 FTCA	5	NA	ND	ND	NA	ND	ND	24600	ND	NA
Polyfluoroalkyl Phosphoric Acid Esters										
8:2 diPAP	8	NA	16900	13300	NA	15400	15000	12100	14300	NA
6:2 diPAP	6	NA	ND	ND	NA	2000	ND	ND	ND	NA
6:2PAP	6	NA	NA	NA	NA	NA	NA	NA	NA	NA
Polyfluoroalkane Sulfonamides										
FOSA	8	NA	NA	NA	NA	NA	NA	NA	NA	NA
PERFLUOROALKYL SUBSTANCES										
Perfluorocarboxylic Acids										
PFTeDA	14	ND	ND	ND	NA	ND	ND	ND	NA	NA
PFTrDA	13	ND	ND	ND	NA	ND	ND	ND	NA	NA
PFDoA	12	ND	ND	ND	NA	ND	19120	ND	NA	NA
PFUnDA	11	ND	ND	ND	NA	ND	ND	ND	NA	NA
PFDA	10	ND	ND	ND	NA	ND	28250	ND	ND	NA
PFNA	9	ND	ND	ND	NA	ND	4970	ND	NA	NA
PFOA	8	ND	ND	ND	NA	ND	ND	ND	ND	NA
PFHpA	7	ND	ND	ND	NA	ND	10020	5190	ND	NA
PFHxA	6	ND	ND	25560	NA	ND	19170	341210	ND	NA
PFPeA	5	ND	ND	ND	NA	ND	ND	20500	ND	NA
PFBA	4	ND	ND	ND	NA	ND	3190	291000	ND	NA
Perfluorosulfonic Acids										
PFDS	10	ND	ND	ND	NA	ND	ND	ND	NA	NA
PFOS	8	ND	ND	ND	NA	ND	ND	ND	NA	NA
PFHxS	6	ND	ND	ND	NA	ND	ND	ND	NA	NA
PFBS	4	ND	ND	ND	NA	ND	ND	ND	NA	NA

Note:
Results indicate maximum concentration detected by analyte per use category
Results not considered where use category not specifically defined (i.e. Only defined as "FCM")
NA= Not Analyzed
ND= Analyzed but not detected

Table 3-2
Summary of Bakery Items Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentration Max detected concentration (ppt)	Reference	Mean	Median	Other notables
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFDoDA	12	1	4	(45)	4	(45)	4	4	Flour (Netherlands)
PFUnDA	11	1	4	(45)	4	(45)	4	4	Flour (Netherlands)
PFDA	10	2	1	(45)	9	(45)	5	5	Min - bakery products (Netherlands) Max- flour (Netherlands)
PFNA	9	3	1	(45)	1720	(46)	579	15	Min - bakery products (Netherlands) Max- cookies (Yukon, Canada)
PFOA	8	3	5	(45)	360	(46)	127	17	Min - bakery products (Netherlands) Max- cookies (Yukon, Canada)
PFHpA	7	2	14	(45)	590	(46)	604	604	Min - Flour (Netherlands) Max - cookies (Yukon, Canada)
PFHxA	6	1	11	(45)	11	(45)	11	11	Flour (Netherlands)
Perfluorosulfonic Acids									
PFOS	8	1	4	(45)	4	(45)	4	4	Bakery products (Netherlands)
PFHxS	6	2	6	(45)	18	(45)	12	12	Min - bakery products (Netherlands) Max- flour (Netherlands)

Table 3-3
Summary of Dairy Items Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentrations Max detected concentration (ppt)	Reference	Mean	Median	Other notables
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFDoDA	12	1	2	(45)	2	(45)	2	2	Butter (Netherlands)
PFDA	10	9	1	(45)	80	(60)	35	30	Min - milk (Netherlands) Max - cottage cheese (Poland)
PFNA	9	11	2	(45)	100	(60)	50	50	Min - milk (Netherlands) Max - natural yogurt (Poland)
PFOA	8	22	1	(45)	1070	(52)	235	175	Min - milk (Netherlands) Max - butter (Dallas, Texas)
PFHpA	7	12	5	(45)	550	(46)	99	40	Min - butter (Netherlands) Max - processed cheese (Yukon, Canada)
PFHxA	6	13	14.9	(67)	108	(67)	51	59	Min and Max - milk (Colvis, New Mexico)
PFPeA	5	7	20	(67)	160	(60)	73	70	Min - milk (Clovis, New Mexico) Max - Kefir (Poland)
PFBA	4	16	43	(45)	2560	(60)	435	200	Min - milk (Netherlands) Max - natural yoghurt (Poland)
Perfluorosulfonic Acids									
PFOS	8	29	10	(45)	5680	(67)	1628	470	Min - milk (Netherlands) Max - milk (Colvis, New Mexico)
PFHpS	7	10	48	(67)	239	(67)	166	188	Min and Max - milk (Colvis, New Mexico)
PFHxS	6	21	10	(60)	1940	(67)	489	50	Min - kefir, milk, naturall yoghurt (Poland) Max - milk (Colvis, New Mexico)
PFPeS	5	2	30.9	(67)	76	(67)	53	53	Min and Max - milk (Colvis, New Mexico)
PFBS	4	4	10	(60)	69	(67)	32	24	Min - butter (Poland) Max - milk (Colvis, New Mexico)

Table 3-4
Summary of Eggs Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentrations Max detected concentration (ppt)	Reference	Mean	Median	Other notables
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFDA	10	6	2100	(3)	6600	(3)	4000	4100	Min - whole egg (China near fluorochemical facility), Max - egg yolk (China near fluorochemical facility)
PFNA	9	7	520	(3)	6000	(45)	1900	1400	Min - whole egg (China near fluorochemical facility), Max - eggs (Netherlands)
PFOA	8	9	1200	(3)	43000	(3)	19000	16000	Min - egg white (China near fluorochemical facility), Max - egg yolk (China near fluorochemical facility)
PFBA	4	9	24000	(3)	52000	(3)	33200	32000	Min - egg white (China near fluorochemical facility), Max - egg yolk (China near fluorochemical facility)
Perfluorosulfonic Acids									
PFOS	8	7	460	(3)	29000	(45)	5200	1100	Min - egg yolk (China near fluorochemical facility), Max - eggs (Netherlands)
PFHxS	6	6	280	(3)	560	(3)	400	500	Min - whole egg (China near fluorochemical facility), Max - egg yolk (China near fluorochemical facility)
PFBS	4	9	16000	(3)	43000	(3)	26600	4000	Min - egg white (China near fluorochemical facility), Max - egg yolk (China near fluorochemical facility)

Table 3-5
Summary of Fish/Seafood Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentrations Max detected concentration (ppt)	Reference	Mean	Median	Other notables
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFTeA	14	3	600	(16)	1300	(16)	1000	1100	Min - rainbow trout (Lake Ontario) Max - lake trout (Lake Ontario)
PFTeDA	14	3	3	(45)	45	(45)	24	24	Min - fatty fish (Netherlands) Max - crustaceans (Netherlands)
PFTrA	13	4	1500	(16)	4600	(16)	3025	3000	Min - alewife (Lake Ontario) Max - lake trout (Lake Ontario)
PFTrDA	13	3	41	(45)	268	(45)	179	229	Min - fatty fish (Netherlands) Max - crustaceans (Netherlands)
PFDoA	12	5	700	(16)	3900	(16)	2280	2100	Min - lake trout (Great Lakes) Max - rainbow smelt & lake trout (Lake Ontario)
PFDoDA	12	3	10	(45)	56	(45)	37	45	Min - fatty fish (Netherlands) Max - lean fish (Netherlands)
PFUDA	11	3	36	(45)	177	(45)	123	157	Min - fatty fish (Netherlands) Max - lean fish (Netherlands)
PFUnA	11	5	1300	(16)	8300	(16)	4400	3500	Min - alewife (Lake Ontario) Max - lake trout (Lake Ontario)
PFDA	10	7	48	(45)	6100	(16)	2518	1790	Min - lean fish (Netherlands) Max - rainbow smelt & lake trout (Lake Ontario)
PFNA	9	15	5	(45)	6800	(16)	1610	1000	Min - fatty fish (Netherlands) Max - rainbow smelt (Lake Ontario)
PFOA	8	36	8	(45)	72500	(16)	3699	330	Min - fatty fish (Netherlands) Max - mussel (Portugal
PFHpA	7	2	2	(45)	5	(45)	4	4	Min - lean fish (Netherlands) Max - crustaceans (Netherlands)
PFPeA	5	1	600	(16)	600	(16)	600	600	Rainbow trout (Great Lakes, Canada)
PFBA	4	1	31	(45)	31	(45)	31	31	Crustaceans (Netherlands)
Perfluorosulfonic Acids									
PFOS	8	66	61	(45)	387000	(16)	45445	4400	Min - fatty fish (Netherlands) Max - oyster (Gulf of Mexico)
PFOSA		9	300	(16)	72000	(16)	11044	1600	Min - lake trout (Lake Superior) Max - rainbow smelt (Lake Ontario)
PFHxS	6	4	9	(45)	70	(52)	37	34	Min - fatty fish (Netherlands) Max - cod (Dallas, Texas
PFBS	4	1	120	(52)	120	(52)	120	120	Cod (Dallas, Texas)

Table 3-6
Summary of Fruit Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentrations Max detected concentration (ppt)	Reference	Mean	Median	Other notables
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFBA	4	5	340	(59)	13450	(59)	3984	450	Min - orange (Poland) Max - banana (Poland)
PFOA	8	8	49	(59)	448	(59)	163	130	Min - apple (Poland) Max - cherry (Poland)
Perfluorosulfonic Acids									
PFOS	8	1	14	(59)	14	(59)	14	14	Apple (Poland)

Table 3-7
Summary of Vegetables Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentrations Max detected concentration (ppt)	Reference	Mean	Median	Other notables
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFDoA	12	1	37.5	(32)	37.5	(32)	38	38	Potato (Italy)
PFUnA	11	2	2.2	(32)	140	(32)	71	71	Min - potatoes (Norway) Max - Vegetalbes (Spain)
PFDA	10	2	2	(45)	1020	(46)	2	2	Min - vegetables/fruit (Netherlands) Max - peppers (Yukon, Canada)
PFNA	9	10	1	(45), '(32)	21.7	(32)	7	7	Min - fruits/vegetables (Netherlands) Max - Chicory (Norway)
PFOA	8	71	210	(3)	770	(46)	79	29	Min - Vegetables (China near fluorochemical facility) Max - peppers (Yukon, Canada)
PFHpA	7	7	4.3	(32)	89.9	(32)	33	31	Min - tomatoe, potato (Italy) Max - fennel (Norway)
PFHxA	6	34	280	(3)	28000	(9)	844	10	Min - Vegetables (China near fluorochemical facility) Max - lettuce (muncipal soil)
PFPeA	5	8	690	(3)	236000	(9)	59350	98	Min - Vegetables (China near fluorochemical facility) Max - lettuce (muncipal soil)
PFBA	4	18	1300	(3)	266100	(9)	16313	56	Min - Vegetables (China near fluorochemical facility) Max - lettuce (industrial impacted soil)
Perfluorosulfonic Acids									
PFOS	8	25	0.17	(32)	101600	(9)	4439	9	Min - Lettuce (Norway) Max - lettuce (muncipal soil)
PFHxS	6	2	0.32	(32)	1.2	(32)	1	1	Min - vegetalbes (Belgium) Max - vegetables (Sweden)
PFBS	4	5	5700	(3)	205200	(9)	41071	11	Min - Vegetables (China near fluorochemical facility) Max - lettuce (industrial impacted soil)

Table 3-8
Summary of Meat Review
PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Analyte	Chain Length	Frequency of detections	Cited PFAS concentrations Min detected concentration (ppt)	Reference	Cited PFAS concentrations Max detected concentration (ppt)	Reference	Mean	Median	Other notables
POLYFLUOROALKYL SUBSTANCES									
Fluorotelomer Carboxylic Acids									
6:2 FTUCA	6	1	1260	(46)	1260	(46)	1260	1260	Cold cuts (Yukon, Canada)
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFUDA	11	1	2	(45)	2	(45)	2	2	Beef (Netherlands)
PFDA	10	2	2	(45)	6	(45)	6	6	Min - pork (Netherlands) Max - beef (Netherlands)
PFNA	9	4	1	(45)	4500	(65)	2064	1877	Min - chicken/poultry (Netherlands) Max - beef steak (Canada)
PFOA	8	7	15	(45)	2600	(65)	519	150	Min - pork (Netherlands) Max -roast beef (Canada)
PFHpA	7	3	1	(45)	480	(46)	162	6	Min - chicken/poultry (Netherlands) Max - beef frozen dinner (Yukon, Canada)
Perfluorosulfonic Acids									
PFOS	8	8	14	(45)	2700	(65)	1210	1085	Min - pork (Netherlands) Max -roast beef (Canada)
PFHxS	6	1	3	(45)	3	(45)	3	3	Chicken/poultry (Netherlands)

Table 3-9

Summary of Yard Waste Review

PFAS Detections, Minimum, Maximum, Mean, and Median by Analyte

Anaylte	Chain Length	Frequency of detections	Cited PFAS concentration Min detected concentration (ppt)	Reference	Cited PFAS concentrations in Max detected concentration (ppt)	Reference	Mean	Median	Other notables
PERFLUOROALKYL SUBSTANCES									
Perfluorocarboxylic Acids									
PFUnDA	11	9	200	(80)	23000	(83)	4883	3200	Min - sephora & cyprus (both Liaoning Province, China) Max - grass root (Little Hocking, Ohio)
PFDA	10	11	100	(80)	11000	(83)	4450	2800	Min - tree leaf & grass leaf, Max - grass root (all Little Hocking, Ohio)
PFNA	9	9	300	(80)	5800	(83)	2580	2000	Min - sephora (Liaoning Province, China) Max - tree leaf (Little Hocking, Ohio)
PFOA	8	12	2800	(80)	700000	(83)	137875	7700	Min - poplar & gingko (Liaoning Province, China) Max - tree leaf (Little Hocking, Ohio)
PFHpA	7	14	1100	(80)	47000	(80)	12071	10000	Min - cyrus, Max - pine needles (both Liaoning Province, China)
PFHxA	6	7	2600	(80)	12000	(80)	7714	6400	Min - willow, Max - gingko & poplar (all Liaoning Province, China)
PFBA	4	7	10000	(80)	49000	(80)	20571	15000	Min - pane Tree, Max - pine needles (both Liaoning Province, China)
Perfluorosulfonic Acids									
PFDeS	10	4	1900	(80)	3800	(80)	2875	2900	Min - willow, Max - gingko & poplar (all Liaoning Province, China)
PFOS	8	5	1600	(80)	19000	(80)	8880	4900	Min - willow, Max - cyprus (both Liaoning Province, China)
PFHxS	6	2	5000	(80)	5000	(80)	5000	5000	Poplar & gingko (both Liaoning Province, China)
PFBS	4	4	2100	(80)	17000	(80)	7800	6050	Min - gingko & poplar, Max - pine needles (all Liaoning Province, China)

Table 4-1
Ambient Concentrations in Soil, Surface Water and Drinking Water

Media		Analyte	Average Concentration Range	Minimum	Maximum	Units
Soil		PFOA	59-1838	1350	31700	ppt
		PFOS	180--1956	<500	2160	ppt
Surface Water	Freshwater	PFOA	650 to 43400	<500	287000	ppt
		PFOS	260 to 132 000	<250	2930000	ppt
	Estuarine	PFOA	3000-3100	2600	3700	ppt
		PFOS	2600-2700	2300	2900	ppt
	Marine	PFOA	NA	15	439	ppt
		PFOS	NA	1.1	73	ppt
Drinking Water		PFOA	NA	<20000	349000	ppt
		PFOS	NA	<40000	1800000	ppt

Table 4-2

Comparison of Minimum and Maximum PFAS Concentrations Across Wood Study, Compost Literature, and Other Literature

Type	PFAS Analyte	Concentration range in Wood, 2019. Evaluation of PFAS at		Concentration range in Choi et al., 2019. PFAA Characterization		Concentration range in literature (ppt)		Other Notables in Literature
		Min detected concentration	Max detected concentration	Min detected concentration	Max detected concentration	Min detected concentration	Max detected concentration	
SSOM	**Perfluorocarboxylic acids**							
	PFBA	30,600	2,060,000 J	2,810	12,040	1.3	13,450	Min- Vegetables (China) and Max- Banana (Poland)
	PFPeA	15,400	780,000	2,660	8,590	0.69	236,000	Min- Vegetables (China) and Max- Lettuce (municipal soil)
	PFHxA	44900 J	3,440,000	10,520	49,840	0.28	254,500	Min- Vegetables (China) and Max- Microwave popcorn bag
	PFHpA	6,150	61,400	2,560	2,560	1	2000	Min- Chicken (Netherlands) and Max- Microwave popcorn bag
	PFOA	6,390	133,000	2,540	10,310	0.21	290,000	Min- Vegetables (China) and Max- Popcorn bag
	PFNA	6,770	13,700	120	1,050	0.52	6,800	Min- Whole Egg (China) and Max- Smelt (Lake Ontario)
	PFDA	8,200	25,800	1,070	4,430	1	28,250	Min-Milk and Bakery (Netherlands) and Max- Food Wrappers (Spain)
	Perfluorosulfonic acids							
	PFBS	6,750	57,300	790	7,630	5.7	205,200	Min- Vegetables (China) and Max- Lettuce (industrial site US)
	PFHxS	6480 J	153,000 J	80	250	0.28	1,940	Min- Whole Egg (China) and Max- Milk (Clovis NM)
	PFOS	6,700	3,070,000 J	350	1,530	0.17	387,000	Min- Lettuce (Norway) and Max- Oyster (Gulf of Mex/ChesapeakeBay)
Yard Waste								
	Perfluorocarboxylic acids							
	PFBA	29,000	574,000	150	640	10,000	49,000	Min- Plane Tree (China) and Max- Pine Needles (China)
	PFPeA	28,700	38,500	410	1,430	NA	NA	
	PFHxA	7,140	31,300	380	1,070	2,600	12,000	Min- Willow (China) and Max - Poplar and Gingko (China)
	PFOA	20,300	64,600	40	1,050	2,800	700,000	Min- Poplar and Gingko (China) and Max - tree Leaf (Little Hocking, OH)
	Perfluorosulfonic acids							
	PFBS	16,900	50,200	ND	ND	2,100	17,000	Min- Poplar and Gingko (China) and Max-Pine Needles (China)
	PFHxS	9,780 J	249,000	70	190	5,000	5,000	Min and Max- Poplar and Gingko (China)
	PFOS	6,580 J	7,790,000	470	1,690	1,600	19,000	Min- Poplar and Gingko (China) and Max-Cyprus (China)

Note: Only those detected concentrations in the Wood 2019 Report are presented here and compared to Literature. Other PFAS were analyzed as part of the Wood 2019 report but were not detected.