PFAS on food contact materials: consequences for compost and the food chain

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Executive Summary

A ban on single-use plastic containers may solve one problem by creating new ones. Single-use plastic food take-out containers will likely be replaced by paper food wrap and cardboard containers coated with toxic, long-lasting chemicals. About half of these food-contact papers and cardboard are coated with per- and polyfluorinated alkyl substances (PFAS) that have the functional value of oil- and water-repellency. However, these potentially toxic, environmentally persistent chemicals bioaccumulate and thus should not be in the food tray. In addition to the serious human health concerns resulting from their transfer to food and subsequent ingestion, the PFAS on these paper products persist when composted, accumulating in the soil, and are taken up by crops grown in that soil. Compost made from these single-use paper products will be hazardous due to high concentration of PFAS. A ban on PFAS in food-contact materials would ensure efforts to eliminate single-use plastic do not create new problems.

Recommendation

To the extent the single-use plastic ban promotes a shift to products that rely on PFAS, this could undermine key objectives of the ban or cause other unexpected health and environmental effects. Aside from wider issues of persistence and potential toxic effects of this large group of C-F chemicals, the negative effect on utility, value, and eventual fate of compost made of food-contact papers containing PFAS is significant. We urge the federal government to consider how substitution of PFAS-laden products for single-use plastics could result in adverse short-, medium-, and long-term health and environmental outcomes. We recommend all food-contact materials sold in Canada require PFAS-free certification.

Halogenated Carbon compounds

Only in the last 80 years have chemists learned how to attach halogens (fluorine [F], chlorine [Cl] and bromine [Br]) to carbon [C] atoms at a commercial scale, doing something that nature very rarely does. Halogen and carbon atom bonding produces new molecules with interesting and sometimes useful properties, but they also have harmful characteristics. Because the bond is so strong (e.g., the C-F bond is the strongest bond in organic chemistry) and because these bonds are almost never found in nature, natural processes of biodegradation (microbial enzymatic attack and normal UV exposure) are very slow to break them. To put it simply: since nature did not put these molecules together, it doesn't know how to take them apart. The halogenated carbon backbone is very stable and persists for an unknown period of time in the environment (Vierke et al., 2012). Those compounds which are lipophilic (an affinity to oil/fat as opposed to water) lead them to bioaccumulate in organisms and the environment. Bioaccumulation, persistence, and toxic effects such as cancer and organ damage (European Commission, 2020; Sunderland et al., 2019) have made chlorinated (Thorton, 2000), bromated and fluorinated carbon compounds the most toxic and polluting group of chemicals on the planet (Richardson et al., 2007). Infamous among this group are DDT, PCBs, chlorofluorocarbons, dioxins, furans, and PFAS.

PFAS chemicals

Compounds known as per- (fully) and poly- (partly) fluorinated alkyl substances (or PFAS), are a group of chemicals made by substituting fluorine atoms for hydrogens on a carbon chain or branched carbon configuration (e.g., C6 denotes a six-carbon chain, but due to branching there may be more than six carbons). This is done using hydrofluoric acid and a carbon compound and high-voltage electricity, creating a bond with very high strength (IARC Publications, 2018). With some modifications, these compounds can be polymerized, producing Teflon coatings (with resistance to heat and almost all solvents) or by attaching a polar end to the carbon chain (e.g., phosphate, sulphate, or carboxylic acid) and creating surfactants with the ability to simultaneously repel oil and water, spread fire-fighting foam evenly, or make carpets stain resistant (Trier et al., 2011). There are many families and sub-families of C-F chemicals, amounting to more than 4,700 different compounds (European Commission, 2020). This paper refers to some (see Table 1), making an important distinction between long-chain carbon compounds ($\geq$ C8) and short-chain compounds ($\leq$ C7). Details of compound usage, production tonnage and chemical structure are considered proprietary (Wang et al., 2015), with few analytical standards commercially available (Trier et al., 2011). These compounds have found uses in cookware, surface treatment of fabrics (carpets, leather, outdoor apparel), metal electroplating, fire-fighting foams and oil-resistant food-contact paper. There are many examples of usage in the fast food industry: burger-wrap papers, bakery contact papers, to-go containers, and pizza box liners. The surfactants are either applied to the surface of food packaging or added

directly to the paper fiber during production. Although their use is not universal in fast-food paper and cardboard packaging, they appear on roughly half of to-go packaging (Schaider et al., 2017), indicating alternatives readily exist. Research has identified coated food papers contribute to the average Canadian's inadvertent ingestion of 250 ng PFAS/day (Tittlemier et al., 2007) out of a total daily exposure of 410 ng PFAS/day/person from all sources.

Table 1 Per- and poly-fluorinated carbon compounds mentioned in this paper, their proper names* and carbon length.

Acronym	Chemical name*	Carbon Chain Length
PFAS	Poly- or per- fluorinated alkyl substances	C2-C20
PFAC	Perfluoroalkyl carboxylic acids	C2-C20
PAA	Perfluoroalkyl acids	C2-C20
PAP	Polyfluoroalkly phosphoric acids	C2-C20
PFBS	Perfluorobenzanoic sulfonate	C4
PFHxA	Perfluorohexanoic acid	C6
PFOA	Perfluorooctanoic acid	C8
PFOS	Perfluorooctyl sulfonate	C8
Gen-X	Recently produced short-chain PFAS	C2-C7

*There are many ways to name the same chemical, offered here is the most common name.

Levels of PFAS found on fast-food packaging

Over the last decade, production of some kinds of PFAS in North America and Europe have been curtailed and effectively banned (notably PFOA and PFOS, both C8), but these have been replaced with shorter chain compounds (C2 to C6, including branched and esterified configurations). Guidelines on PFAS content in paper fibre production allow from 0.2 to 4% of total weight (Schaider et al., 2017 SI; Trier et al., 2011) depending on the chemical. The chemicals are either applied as a surface coating or added directly to the paper pulp.

Disclosure of PFAS mixtures used on packaging is considered proprietary, posing an analysis problem because several similar chemicals can be used interchangeably, whose structures and properties are unknown (Wang et al., 2015). This usually leads to only testing for a specific family of PFAS, but some researchers look at total F as an indication of composite PFAS (Schaider et al., 2017). Researchers report either in millimoles/gram, F weight/area of paper, or F weight/weight of paper. Where possible, these values have been normalized to parts per million (ppm) or parts per billion (ppb) for comparison purposes.

Testing of more than 400 samples of fast food packaging in larger cities in the USA found F in 56% of dessert and bread wrappers, in 38% of burger-contact papers (average of 60 µg/g [60

ppm]) and in 20% of paperboard samples (average of 14 µg/g [14 ppm]) (Schaider et al., 2017). Surface-coating yielded concentrations ranging from 1 to 100 µg/g (1-100 ppm) whereas adding PFAS to pulp yielded 600 to 9000 µg/g (600 to 9000 ppm, or 0.06 to 0.9% of the paper weight (Trier et al., 2011)). This level is consistent with that reported by others, with the sum of tested PAAs (perfluoroalkyl acids) 2250 mg/kg (ppm) and sum of PAPs (polyfluoroalkyl phosphoric acids) 5530 mg/kg (ppm) (Xu et al., 2013). Studies have proven that PFAS does transfer from packaging to the food it contacts, leading to inevitable ingestion. Xu et al. (2013) found 10 to100% transfer over a 10-day test period, depending on the PFAS and the type of food. Often fast food companies are not aware of PFAS in their paper products. Schaider et al. (2017) surveyed all of the companies whose paper goods they tested and none of the respondents knew of its presence and even gave assurances it was not present.

Transfer from PFAS paper products to compost, soil, and plants

A single-use plastic ban would likely result in the food service industry's conversion from plastic (e.g., polystyrene) to paper and paperboard food packaging. This improvement may be perceived as "green" and a sustainable course of action because the paper products can be composted rather than landfilled. However, the addition of PFAS-coated paper to compost contaminates the resulting compost with C-F compounds. As the fibers decompose, all of the PFAS are transferred to the compost and subsequently to the soil it is applied to. Crop amendments such as compost, biosolids, or waste paper fiber (Brändli et al., 2007; D'Eon et al., 2009; Lee et al., 2014) containing PFAS contaminate the soil and subsequently the crops grown on the soil; the livestock that consume the crops; and the milk and meat of the livestock (Kowalczyk et al., 2012). Compost analyzed for families of PFAS (Brändli et al., 2007) has been found to contain 3.4 to 35 ug/kg (compost dry weight) (3.4 to 35 ppb) with a mean of 6.3 ug/kg (6.3 ppb). Compost sourced from urban and rural origin had no difference in PFAS levels. Waste paper biomass, used as an amendment to supply additional carbon fiber to the soil, is a product of paper recycling containing PFAS-coated paper products (Lee et al., 2014). In Ontario, analysis of this amendment has found high levels of PFAS for two large-lot size samples, averaging 790 ng/g (790 ppb) and 2200 ng/g (ppb) for C6-C8 polyfluoroalkyl phosphoric acid diesters (a common surfactant used in coating paper (D'eon et al. 2009 SI)). If a significant portion of compost inputs are fast-food paper products, resulting compost likely have PFAS levels to those found in waste-paper fibre.

Once PFAS contaminates a soil, its long-term fate depends on chain length and polar-end type. Long carbon-chain PFAS compounds (≥ C8) are heavier and more strongly lipophilic, resulting in longer biological half lives and greater bioaccumulation in soil, organisms, and sediment. Esters and short chain PFAS have mobility in water and are more easily taken up by plants and become incorporated into plant tissue (D'Eon et al., 2009; Lee et al., 2014; Sun et al., 2016), making them a source of PFAS ingestion for livestock and humans. PFAS-contaminated

compost was illegally sold to farmers and applied to soil in Germany, resulting in contamination of the ensuing crops and the livestock that consumed the crops (Kowalczyk et al., 2012).

Bioaccumulation:

The translocation of PFAS from soil to plant is known as the Bioaccumulation Factor (Blaine et al., 2013) where:

$$BAF = \frac{PFAS\ in\ plant}{PFAS\ in\ soil}$$

When the BAF is greater than unity (1) this indicates a transfer of the compound from the soil to the plant. Greenhouse and field studies using PFAS-affected soil have measured BAF in normal vegetable crops like lettuce, tomatoes, and pumpkins. Compost, biosolids, or paper biomass were added to soil at levels reflective of several years of cumulative application resulting in total PFAS concentrations of 437 ng/g (437 ppb). Analysis of lettuce, tomatoes, and corn grown in these soils showed plant uptake of PFAS favoured shorter-chain C-Fs with progressively larger BAFs; for example, C8 had a BAF of 1.6, C6 of 4.2, C5 of 20, and C4 of 56 (Blaine et al., 2013). Other studies measuring PAPs (C4 to C12) and PFCAs (perfluoroalkyl carboxylic acids) in similar experiments found the same tendency of increasing accumulation factor with shorter chain length (Lee et al., 2014). However, the concentrations peaked in vegetables after 1.5 months, indicating either a) biotransformation of the compounds into a form that eluded detection or b) elimination into the environment. If the latter, this adds to the body of evidence that short-chain PFAS move much faster through the environment, the food chain, and organisms than long-chain PFAS. This is illustrated by the human half-life of PFOS (C8) of 3.8 years (Nies, 2006), while only 32 days for PFHxA (C6) (Russell et al., 2013). Studies have shown longer-chain C-F compounds tend to bioaccumulate more than smaller chains (Sunderland et al., 2019), due to their stronger lipophilic nature. It is these traits that have triggered the ban on long-chain PFAS (PFOS and PFOA, both C8) and allowed short-chain PFAS as replacement (Vierke et al., 2012; Wang et al., 2015), but their persistence in the environment is likely just as long (European Commission, 2020; Wang et al., 2015) and health effects are presently unknown. A simple version of the chemistry is that ≥ C8 PFAS have a greater affinity to fat and will remain there (bioaccumulate), whereas <C6s have a greater affinity to water, so will be dispersed, but persist in water and plants. Thus, shorter-chain PFAS are more likely to translocate and cycle through the food chain than long chain PFAS, but both remain in the environment for a very long time and are toxic. Short-chain PFAS poses a greater risk in some respects due to the difficulty found in removal from drinking water because standard treatment (activated carbon) is substantially less effective (Sun et al., 2016). This also appears to be true for removal of short-chain PFAS from soil (Ross et al., 2018).

Persistence

Out of all of the carbon-halogen compounds, C-F compounds are the most resistant to breakdown under normal environmental conditions due to their high bond energy. Some PFAS compounds undergo chemical or biologically enabled transformations, but this takes place at the polar end, usually producing a more stable, persistent form (Butt et al., 2014). When considering degradation of the fluorinated carbon chain itself, laboratory experiments have found no significant degradation in soil, sediment, or air in 259 days (Vierke et al., 2012). In water, no degradation took place even in highly oxidative (H_2O_2)/UV experiments (*in* Nies, 2006). No half life has been established under normal environmental conditions (Vierke et al., 2012). For this reason, C-Fs have the popular science nickname of "Forever chemicals" (Gibbens, 2020).

Widespread PFAS contamination of soil and water environmental poses challenges for clean-up, which is a subject of study (Kucharzyk et al., 2017). Use of sorbents for groundwater remediation results in additional highly contaminated materials that must be stored securely or subject to high temperature incineration.

Health effects

Although this submission does not directly pertain to health effects of PFAS compounds, it is necessary to briefly include a summary of the extensive health-related research and recent regulatory directions. A meta-analysis by Sunderland et al. (2019) concluded the most studied PFAS compounds (PFOS and PFOA) cause cancer in acute exposures (i.e., workers in PFAS industries) and chronic exposure levels (drinking water contamination). Other proven possible outcomes from expose are increased susceptibility to thyroid and kidney disease, dyslipidemia, immunological toxicity, and reduced antibody production (IARC Publications, 2018; Sunderland et al., 2019). The replacement of PFOA and PFOS with shorter chain C-F compounds may have a yet-undiscovered health effect (European Commission, 2020). Ongoing work suggests these smaller molecules have a greater chance of interaction with cellular function due to lower steric inhibition (Butt et al., 2014), but comprehensive environmental testing for human and ecosystem harm is in preliminary stages. The precautionary principle has reasonable application here as demonstrated by jurisdictions that have banned all C-F compounds in food contact materials even though specific harm has not yet been proven. The health effects of PFAS did not become known for many decades after their production began. Since the 1990s, environmental monitoring has revealed they are now globally pervasive (Sunderland et al., 2019).

An effective PFAS ban

In recent years, waste management and policy experts have stressed the importance of integrating circular economy principles into the design of products and services to facilitate waste reduction, reuse and recycling (the 3Rs). In December 2019, the Canadian Council of the Ministers of the Environment (CCME) released the Canada-wide Strategy on Zero Plastic Waste (ZPWS). The Zero Plastic Waste Strategy "aims to reduce the harmful environmental impacts of plastic waste through greater prevention, collection and value recovery to achieve a more circular plastics economy" (CCME, 2019). The ZPWS seeks to keep materials and products in use as long as possible by recirculating them back into the economy through recycling, refurbishing or repurposing. This aims to reduce the harmful environmental impacts of plastic waste through greater prevention, collection and value recovery to achieve a more circular plastics economy.

Ultimately, if the Canadian federal and sub-national governments (ie. provincial and territorial) are going to successfully implement circular economy principles, these concepts must be applied to items such as fast-food containers. In theory, the nutrients and fibre from fast-food containers should be circulated back into soil and help to grow future food and plants, through composting. This cycle is fundamentally perverted when persistent toxins are introduced into food packaging that enters this cycle, rendering the finished compost worthless because no farmer wants to contaminate their soil with it. In order to preserve the value of compost to farmers, horticulturalists and gardeners, PFAS – in all of its forms (long and short chain, with ester bonds or phosphorus ends) – need to be banned from paper goods that could potentially be composted. A comprehensive ban on all C-F compounds avoids the need to revisit patchwork legislation as new chemicals are introduced to replace ones specifically identified as harmful (Kwiatkowski et al., 2020). A ban on all C-F compounds is needed on food packaging because continued production of PFAS guarantees their long-term presence in water and the food chain due to their chemical persistence.

The European Union has recognized this legislative gap:

> "The long-term socioeconomic costs of the PFAS emitted to the environment are difficult to assess. Because of their high persistence, PFAS released over the whole lifecycle of a product will remain in the environment for an indefinite time. One of the main concerns is that the contamination in some cases may be irreversible, making fundamental natural resources such as soil and water no longer usable." (European Commission, 2020)

The costs of inaction are difficult to quantify, but in 2019 an extensive analysis by the Nordic Council of Ministers concluded that pervasive PFAS levels are increasing in the environment and the population from many sources (Goldenman et al., 2019). Many non-fluorinated alternatives already exist and the costs for remediating some cases of contamination run to many

millions of Euros. In addition, evidence is mounting of adverse health effects even at current background levels.

Effective alternative coatings for food-contact materials already exist and are readily available. “Compostable” certification of food contact products is an available guarantee of PFAS-free products. Compostability certification carried out by Biodegradable Products Institute (BPI) already verifies no PFAS is used in manufacture of the product as of January 1, 2020. The proposed ban on single-use plastic should be augmented by a requirement for paper products must be certified as compostable and PFAS-free. In addition to BPI’s certification that prohibits the use of PFAS, this could be added to certifications offered by the existing Canadian organizations such as Bureau de Normalization du Quebec (BNQ).

PFAS bans in other places

Presently there is a voluntary production halt on PFOA and PFOS in North America and Europe. Individual countries of Europe and several jurisdictions within the USA have mandated drinking-water thresholds for these two well studied compounds (Seow et al., 2020). Indeed, global background levels of contamination may already be dropping due to the discontinued use of these chemicals but a concurrent rise of substitution chemicals has already been observed (Sun et al., 2016). Of interest here are the jurisdictions that have restricted the use of PFOA and PFOS **replacement** compounds: the host of short-chained C-F compounds, sometimes grouped under the label Gen-X (Table 2). As indicated previously in this paper, these new chemicals are quite possibly as damaging to health as the ones they replace. By every indication, they should be treated as a group because they share the same general qualities and present the same general hazard (Kwiatkowski et al., 2020). They are as persistent, have greater bioaccumulation factors, and are more difficult to remove from drinking water. Governments effecting this legislation are, in the authors’ view, prioritizing the health of their citizens instead of waiting for health problems to emerge and toxicological studies to be completed. This is the precautionary principal in action.

The European Union has decided to study Gen-X compounds for possible restrictions under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals, the regulation governing hazardous chemicals in Europe). Individual countries such as Denmark have determined to their own satisfaction the hazards of PFOS and PFOA replacements and imposed a ban on all PFAS chemicals on food-contact papers beginning July 2020. The Netherlands and other EU member are considering similar legislation (Netherlands et al., 2020) and Germany has proposed reviewing PFHxA and Gen-X compounds under REACH (Germany, 2018). In North America, the city of San Francisco banned single-use plastic containers and PFAS on food-contact papers effective January 2020 (Ordinance Amending the Environment Code to Prohibit

the Sale or Use in the City Made with PFAS, 2018). The state of California is considering a similar ban of short-chain PFAS compounds (Biomonitoring California, 2015).

Table 2 Regulations proposed or enacted in Europe and North America to address the health effects of PFOS, PFOA, and C-F compounds replacing them.

Place	Compound	Restrictions	Effective date
Canada	PFOS, PFOA (C8)	Restricted	2018
USA	PFOS, PFOA (C8)	Voluntary production ban	2011
EU	Gen-X	To be regulated under REACH	2020
	PFBS (C4)	SVHC*	2020
	Entire group of PFAS	Proposed regulation under REACH	2020
Netherlands, Norway, Sweden, Germany, Denmark	Entire group of PFAS	Proposed regulation under REACH	2020
Denmark	Entire group of PFAS	Ban on food contact materials	2020
Germany	PFHxA (C6)	Proposed REACH restrictions	2018
Maine	Entire group of PFAS	Ban on food contact materials	2019
Washington	Entire group of PFAS	Ban on food contact materials	2018
California	Entire group of PFAS	Considering biomonitoring	2015
San Francisco	Entire group of PFAS	Ban on food contact materials	2020

*Substance of Very High Concern

Summary

To the extent the single-use plastic ban promotes a shift to products that rely on PFAS, this could undermine key objectives of the ban or cause other unexpected health and environmental effects. Aside from wider issues of persistence and potential toxic effects of this large group of C-F chemicals, the negative effect on utility, value, and eventual fate of compost made of food-contact materials containing PFAS is significant. We urge the federal government to consider how substitution of PFAS-laden products for single-use plastics could result in adverse short-, medium-, and long-term health and environmental outcomes. We recommend all food-contact materials sold in Canada require PFAS-free certification.

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