PFASs and alternatives in food packaging (paper and paperboard): Report on the commercial availability and current uses

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Executive summary

This report addresses the commercial availability and current uses of alternatives (chemical and non-chemical) to per- and polyfluoroalkyl substances (PFASs) in food packaging(paper and paperboard). The work was conducted within the framework of the OECD/UNEP Global Perfluorinated Chemicals (PFC) Group.

The study is based on reviewed publicly available information from worldwide sources, including from the OECD/UNEP Global PFC Group members and additional stakeholders. The review has been supplemented by in-depth discussions with key players from the value chain for food packaging. The report is based upon a data set which includes information from PFAS producers, non-fluorinated alternative producers and publicly available literature.

The findings of this work are as follows. Short-chain (SC) PFAS and non-fluorinated alternatives to long-chain (LC) PFAS[1] are available on the global market and can be used to produce paper and board for use in food packaging. There are 28 fluorinated substances currently included[2] on the US Federal Drug Administration (FDA) list to confer grease/oil/water resistance to paper and board. These are reported to be used in 19 formulations (DTSC, 2020[1]). The German Bundesinstitut für Risikobewertung (BfR) recommended list contains 12 fluorinated substances that are listed as surface refining and coating agents and which are likely to be used to confer grease and water resistance for food packaging.

On performance alone, both SC PFAS and non-fluorinated alternatives identified in this study can meet the high grease and water repellence specifications required for the common food and pet food packaging uses. For some applications, non-fluorinated alternatives have a performance advantage over SC PFAS.

The current market share of non-fluorinated alternatives appears to be approximately 1% or less. The key reason for the current lack of market share of non-fluorinated alternatives is the higher cost of non-fluorinated alternatives, which results in paper and board for food packaging between 11-32% more expensive[3] than food packaging using SC PFAS.

There are technical challenges to moving from LC PFAS to SC PFAS and from SC PFAS to non-fluorinated alternatives. However, the main obstacle to substitution from SC PFAS to non-fluorinated alternatives is the cost differential. If there are sufficiently strong reasons for the value chain to pay for the premium non-fluorinated alternatives, it will do so.

Based upon this review, a number of policy recommendations are suggested in this report as well as areas that may be considered for further work (see Section Chapter 6.). These have been divided into those aimed at international organisations and those aimed at industry.

Notes

[1] In this report, a distinction is made between LC and SC PFASs using the OECD's definition of PFASs – see section Chapter 1.

[2] Only the substances and formulations listed are permitted to be used in food packaging.

[3] PFAS manufacturers have indicated this may be an underestimate.

List of abbreviations

AKD	Alkyl ketene dimer
ASA	Alkyl succinic anhydride
BfR	German Bundesinstitut für Risikobewertung
CMC	Carboxymethyl cellulose (CMC)
CNCs	Cellulose nanocrystals
CNFs	Cellulose nanofibrils
FCMs	Food contact materials
HEC	Hydroxyethylcellulose
gsm	Grammes per square metre
LC	Long-chain
MFC	Microfibrillar cellulose
NGP	Natural greaseproof paper
PFASs	Per- and polyfluoroalkyl substances
PFC Group	OECD/UNEP Global Perfluorocarbon Group
PFHxA	Perfluorohexanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PTFE	Polytetrafluoroethylene
PVOH	Polyvinylalcohol
SC	Short-chain
SAE	Styrene acrylic emulsion
SVHC	Substance of very high concern
ToR	Terms of reference
UNIDO	United Nations Industrial Development Organization.
US FDA	US Food and Drug Administration
WVM	Water vapour moisture

Chapter 1. Background

1.1. Aim and scope of the study

The OECD/UNEP Global Perfluorinated Chemicals (PFC) Group (OECD, 2020[2]) was set up to facilitate the exchange of information on per- and polyfluorinated chemicals, focusing specifically on per- and polyfluoroalkyl substances (PFASs), and to support a global transition towards safer alternatives. The Group was established in response to the International Conference on Chemicals Management - ICCM Resolution II/5. One of the key work streams of the group is to gather information on alternatives to PFAS to understand what they are, what they are used for, their market penetration, feasibility, effectiveness, and cost. The current study is intended to support this work stream by looking at the commercial availability and current uses of alternatives (chemical and non-chemical) to PFASs in food packaging (paper and paperboard).

PFASs are synthetic substances that are widely used in numerous technologies, industrial processes and everyday applications. Since the discovery of polytetrafluoroethylene (PTFE) in 1938, PFASs, both polymeric and non-polymeric, have been used extensively in various industries world-wide, due to their dielectrical properties, resistance to heat and chemical agents, low surface energy and low friction properties, etc. Due to the large variety of PFAS substances captured in the OECD definition (OECD, 2013) (see text below), the individual PFAS will have different properties, however, in general, the highly stable carbon-fluorine bond and the unique physicochemical properties of PFASs make these substances valuable ingredients for products with high versatility, strength, resilience and durability.

Since the early 2000s, there has been a trend amongst global manufacturers to replace long-chain (LC) PFASs, their salts and their potential precursors with chemicals containing shorter perfluoroalkyl chains or with non-perfluoroalkyl products. This trend is driven by concerns related to the properties of certain LC PFASs with respect to human health and the environment.

In general, the potential human health and environmental implications of PFASs are outside of the scope of this study. These aspects are already covered in detail elsewhere (OECD, 2013[3]; Nordic Council of Ministers, 2018[4]; FluoroCouncil Website, 2020[5]; Nordic Council of Ministers;, 2019[6]). During the preparation of this report several reviewers highlighted the interest in assessing the human health and environmental hazards associated with SC PFAS and non-fluorinated alternatives to LC PFAS. This will be the subject of a separate project of the Global PFC Group, in which the hazard profile of alternatives identified in this report will be examined. It is also noteworthy that there is on-going work in this area, for example work being carried out by SRC Inc. on behalf of Washington State in the US (DTSC, 2020[1]). Such a study could include an account of the reviews carried out by the US Food and Drug Administration (FDA) and the German Bundesinstitut für Risikobewertung (BfR) before including short-chain (SC) PFAS and non-fluorinated alternatives in their lists[1].

In the food packaging sector, certain PFASs are intentionally applied to paper and board packaging where these PFASs confer mainly fat, but also stain and water repellence properties. This repellence function is especially important in the food packaging sector in which oils, greases and water may migrate from food during baking, transport and storage or for use with fast food that is intended to be portable. As such, the packaging is intended to be, or can reasonably expected to be, in contact with the food product (i.e., is a food contact material (FCM[2])). A number of non-fluorinated alternatives available on the market also perform the same function as PFASs. During the preparation of this report it has been suggested to include further information on additional properties of alternatives such as heat and flame resistance. These parameters are indeed useful to be aware of but were considered outside of the scope of this report which is focused on: the commercial availability and current uses of alternatives. However, where this information has been found to be readily available it has been included in the report.

The scope of the study includes both the SC PFASs and non-fluorinated alternatives used in food packaging. Where an alternative is used as a 'drop-in substitute' to a LC PFAS and performs the same chemical function in the packaging, for the purposes of this report it is considered a 'chemical alternative'. This is the usual case for the substitution of a LC PFAS by a SC PFASs. Conversely, where an alternative utilises a 'physical barrier approach' rather than a chemical approach to confer repellence properties, it is referred to as a 'physical alternative'.

For the purposes of this report, distinction is made between LC and SC PFASs using the OECD's definition which is as follows: PFASs consist of a fully (per) or partly (poly) fluorinated carbon chain connected to different functional groups. Based on the length of the fluorinated carbon chain, short and long-chain PFASs can be distinguished. LC refers to:

- Perfluorocarboxylic acids (PFCAs) with carbon chain lengths C8 and higher, including perfluorooctanoic acid (PFOA);
- Perfluoroalkane sulfonic acids (PFSAs) with carbon chain lengths C6 and higher, including perfluorohexane sulfonic acid (PFHxS) and perfluorooctane sulfonate (PFOS); and
- Precursors of these substances that may be produced or present in products.

SC PFAS are PFCAs with carbon chain lengths of < C8 and PFSAs with carbon chain lengths < C6.

The chemical structure of PFAS is described comprehensively elsewhere (OECD, 2013[3]; FluoroCouncil Website, 2020[5]; Buck, 2011[7]).

PFASs are mainly used in conjunction with paper and board substrate, the focus of the study is on alternatives for paper and board food packaging used for fast food wrapping, food storage/shelf-life, food transport and paper and board that needs to have release properties such as from baking moulds i.e., for paper and board in contact with food. Pet food packaging is included in the scope of this report as it requires particularly high-performance grease/water resistant packaging.

Items used for *food consumption* rather than *food packaging* are considered outside the scope of this report. Items used for food consumption, such as kitchenware, plates, utensils and similar items, are not considered food packaging and are outside the scope of this report. Products that use PFASs in materials used for food processing and dispensing equipment (e.g. ice cream dispensers) are also considered outside the scope of this study.

In the preparation of this report it has not been possible to find a definitive list of PFAS used in food packaging/wrapping worldwide. There are numerous references in the literature to fluorinated compounds that have been detected in food packaging following analysis. In this regard, it should be pointed out that the market in the US and the EU has phased out PFOA and the related C8 chemistry to move on to the shorter-chain, typically C6, chemistry. The FluoroCouncil has commented that analytes from studies such as that carried out by Washington State in the US (Washington State, 2020[8]) were substances that are not expected to provide oil and grease repellence and were detected at such low levels that they would not provide functionality (FluoroCouncil, 2019). In addition, what is analysed in such studies are typically extractable PFAS and the ability to quantify and identify specific PFAS with monitoring studies is limited to a small subset of PFAS. Therefore, fluorinated compounds detected in food packaging were not used in this report as a basis for indicating the PFAS which are used in food packaging and intended to confer grease and water repellence. Instead this report utilised those fluorinated substances and mixtures positive-listed or authorised for food packaging use in key regulatory regimes in OECD member countries and regions to prepare an indicative list of intentionally used fluorinated substances and mixtures (see Section 2.3).

It is possible that the presence of fluorinated compounds detected in food packaging may be the result of recycled paper and board that had previously been treated with PFAS. It is also noteworthy that going forward, such impurities may pose a barrier to the recyclability of food packaging in the framework of a circular economy (ECHA, 2016[9]).

Additionally, food packaging that serves a dual use, such as clamshell takeout containers: used for both transport and food consumption, are considered within the scope of this study.

1.2. Methodology

The report is based upon publicly available information supplemented by information from the members of the Global PFC Group, including from national authorities, individual companies, industry associations and research organisations (the list of contributors to the report is available in Annex A). This was further supplemented by the contractor using interviews and targeted information requests to Global PFC Group members as well as key stakeholders identified through the information gathering process. Additional alternative producers were identified by using ChemSec's Marketplace, which is a 'chemical dating site' in which safer alternatives are matched up with demand for a particular performance specification (ChemSec, 2019[10]).

Notes

[1] Only the substances and formulations listed are permitted to be used in food packaging.

[2] In the context of this report the term food contact material is limited to paper and board food packaging.

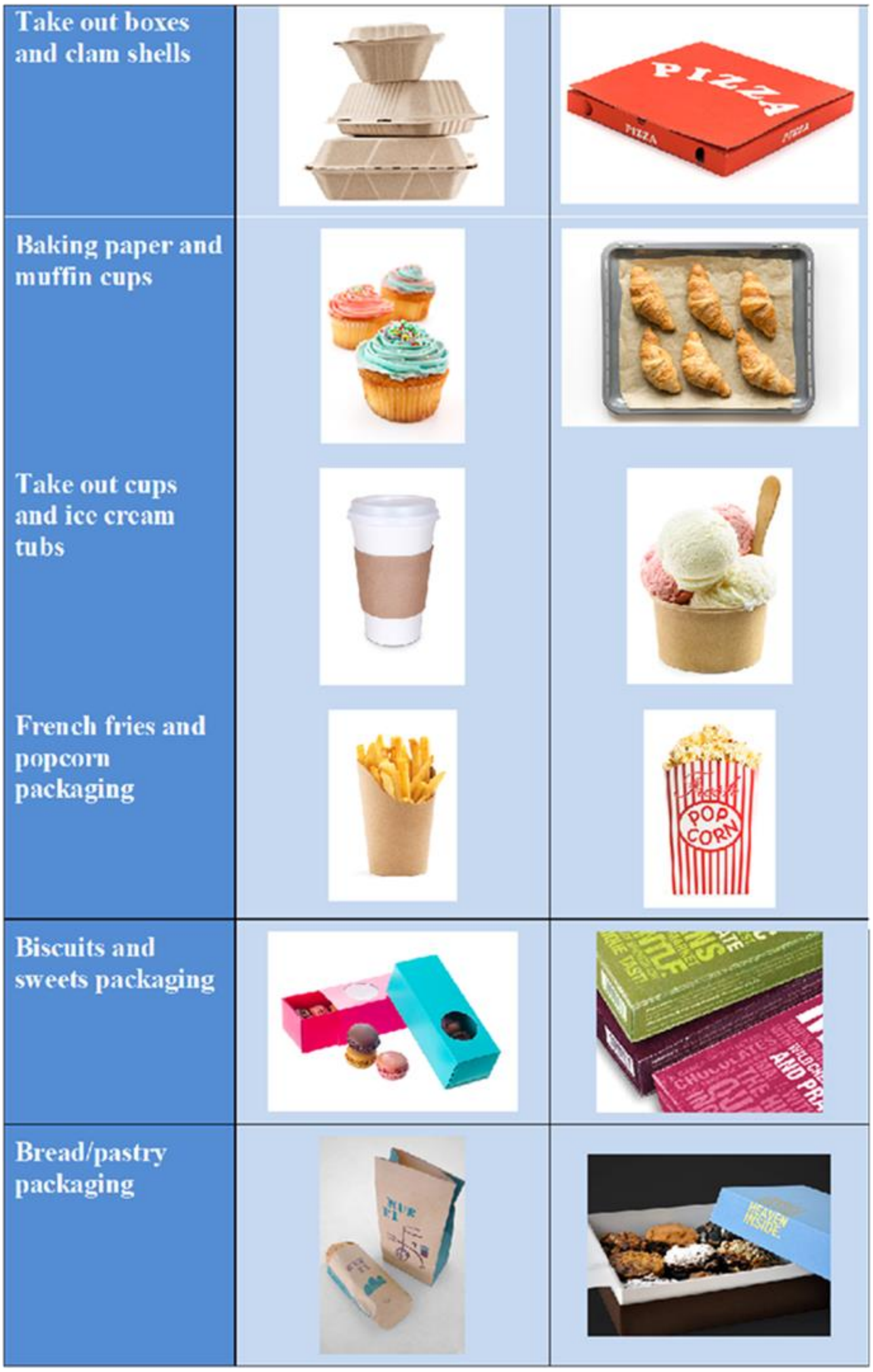
Chapter 2. Commercial availability and market trend

2.1. Overview of the market and trend in the use of PFAS and non-fluorinated alternatives in food packaging/wrapping

PFAS have been used in paper and board food packaging since the 1950s mostly as coatings to prevent the paper material from soaking up fats and water, but also in printing inks and as moisture barriers. The applications particularly target fatty foods, especially those intended to be heated in packaging or stored for an extended period. Examples include fast food paper such as for French fries and hamburgers, microwave popcorn bags, baking paper, baking cups and moulds, sandwich and butter paper, chocolate paper, and paper for dry foods and pet foods. Some common examples of paper and board food packaging where grease and water resistance are required are shown in Figure 1.

Since the 1950s there has been increasing evidence regarding potential human health, environmental, and food chain impacts of specific LC PFAS such as perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) (ITRC, 2017[11]). An important milestone in the evolution of the use of LC PFAS came in 2000 when 3M announced it would no longer manufacture PFOS-based fluorosurfactants using the electrochemical fluorination process which was their standard PFAS manufacturing technology. Since then PFOS, its salts and perfluorooctane sulfonyl fluoride (PFOS-F) have been included in the list of substances restricted by the Stockholm Convention on Persistent Organic Pollutants (Stockholm Convention), which has 184 Parties worldwide. In addition, the fluorochemical industry has put in place several voluntary agreements (e.g. in the US, Canada and the EU) to restrict the use of certain LC PFASs (OECD, 2013[3]).

Figure 1. Common examples of food packaging where grease and water resistance are required



Credits. Biscuits and sweet: 'More - Chocolate packaging' by Luisa Maraffino. Bread and pastry: 'Mie Tierra Nubre Bread' by Ze das Couves; 'Brownerie/Branding/Packaging' by Gila Afya. Biscuits and sweets: 'Ion Επιλογή' by Dylsectic. Pet food: 'Now Fresh by Petcurean' by Matthew Clark; SK Reps Pet food pack by Yuliana Mychko, dashetcky k. All of these images are licensed under Creative Commons CC BY-NC 4.0.

Participants in this study pointed to 3M's announcement as a key milestone for some producers of paper and users in the food packaging industry. Several companies indicated that at this point they proactively took the decision to avoid the use of PFAS entirely for paper and board food packaging and to look for alternatives to PFAS.

Since that time and for a wider range of products than just food packaging uses, concern has been focused upon LC PFASs such as PFOA, its salts and PFOA related-compounds, which were agreed to be listed under the Stockholm Convention by its Parties in May of 2019 (SC, 2019[12]). Similarly, in the EU, PFOA, its salts and precursors have been restricted under EU REACH which is due to come into force in July 2020[1] and there is a proposal to restrict C9-14 PFCAs. As industry has moved away from LC PFASs, certain SC PFASs have also come under scrutiny for the same reasons. For example, under EU REACH, the ammonium salt of hexafluoropropylene oxide dimer acid (HFPO-DA) fluoride (Gen-X) and perfluoro-butanesulfonic acid (PFBS) have now been assigned the status of substances of very high concern (SVHC) and perfluorohexanoic acid (PFHxA), its salts and PFHxA-related compounds has been proposed to be restricted. Also, at the time of writing this report, the European Food Safety Authority (EFSA) is re-evaluating its opinion in relation to the risks posed by PFOA and PFOS in food (EFSA, 2018[13]).

In Canada, several PFAS (PFOS, PFOA, LC-PFCAs their salts and precursors) have been assessed as harmful to the environment. These substances are regulated through the Prohibition of Certain Toxic Substances Regulations (2012) which prohibits the manufacture, use, sale, offer for sale or import of a number of toxic substances, and products containing these substances, with a limited number of exemptions.

In the light of the growing concern and a number of well documented legal actions and influential reports (Berman and Simmons, 2019[14]; WHO, 2017[15]), several US states have put in place (Washington State) or are considering (California, Oregon) implementing legislation to prevent the use of PFASs in FCMs. At the Federal level in the US, in 2016 FDA revoked all regulatory authorizations in Title 21 Code of Federal Regulations (CFR) for LC PFAS used in food packaging, as well as took steps in removing products from effective food contact notifications from the market in 2011. The German BfR followed suit for its listing of LC PFAS in its recommendations for consumer products No. 36: 'Paper and Board for Food Contact' that meet the requirements of § 31.1 of the German Foods, Consumer Articles and Feed Act (RIVM, 2020[16]). Also, a PFAS manufacturer, Chemours, recently announced it will exit the market for the use of PFAS in food paper and board (Chemical Watch, 2019a[17]).

In the EU there is no specific harmonised regulation in place regarding PFASs used in paper and board FCMs, but one EU Member State, Denmark, recently has enacted legislation to remove all PFAS from paper and board packaging (DK, 2019[18]). The Netherlands is also currently investigating the feasibility of similar measures (RIVM, 2020[16]).

With the growing concern over LC PFAS, PFAS manufacturers have switched to SC PFAS such as those based upon C6 technology (PFAS technology based on a six-carbon chain e.g. undecafluorohexanoic acid (PFHxA)). In the absence of LC PFAS, C6 substances are considered to provide an optimal performance/price combination by both PFAS manufacturers and non-fluorinated alternative manufacturers. Nevertheless, a number of non-fluorinated alternatives are now on the market and are considered in more detail in this report.

2.2. The function of PFASs and their alternatives in food packaging

PFASs and their alternatives are primarily used as a barrier or repellent against grease, stains and water to keep the migration of grease and water from the food to acceptable levels during the transport, storage/shelf-life and consumption of the food. These are much sought-after performance characteristics in the current period of high consumption of food-on-the-go.

To perform this function PFASs are mainly used in conjunction with paper and board substrate and can be considered exclusively as chemical barriers or repellents. PFAS typically have a hydrophilic polar head and a hydrophobic moiety. The polar head can be anionic, cationic, non-ionic (at neutral pH) or amphiphilic, which depending on the pH is either ionic or non-ionic. Typical polar heads of PFAS are anionic (e.g. phosphates, sulphonates or carboxylates); cationic (e.g. quaternary ammonium); non-ionic (e.g. polyalkoxylates, polyfluoropoly-ethoxylates and glycols, acrylates); and amphoteric (e.g. betaines, sulfobetaines and amine oxides). PFAS may also be named according to their hydrophobic moiety, which may be a hydrocarbon or a per- or polyfluorinated alkyl chain. PFASs can function as monomers or be attached as a side-chain to a polymer backbone. Polymeric PFASs also include co-polymers, such as perfluoropolyethers (PFPEs), which typically have short perfluorinated chains (C1–4).

Alternatives to PFAS-paper and board are broadly divided into two categories to achieve the same performance: physical or chemical barriers.

For a physical barrier, the paper structure itself serves as an obstacle to penetration. Liquids can soak into paper and board material either if the cellulose fibres are ‘wetted’ or if liquid is drawn into the capillary pores. Traditionally, liquid uptake was prevented by the production of narrow pores, which was achieved by making cellulose fibres very fine (microfibrillated) and cross-bonded, for instance by beating (‘refining’), or by using sulphuric acid to make parchment. Today, it is common to make a physical barrier by laminating an extra layer of plastic or aluminium onto the material. The disadvantage however is that the machines must have laminating facilities, which adds extra costs, and results in food packaging material that is difficult to recycle (see Section 2.4.2). For this reason, plastic and aluminium alternatives are not considered in detail in this report. The alternatives considered in this study act as a physical barrier without these laminated materials such as natural greaseproof paper (NGP), which is made by intensively refining wood pulp.

A chemical barrier can be used to confer repellence/barrier performance against grease, stains and water. This is achieved either by the addition of chemicals to the pulp during paper production (internal sizing) (Peng, 2004[19]) or as a surface treatment to the paper (external sizing).

Sizing is used during paper manufacture to reduce the paper's tendency, when dry, to absorb liquid, with the goal of allowing inks and paints to remain on the surface of the paper and to dry there, rather than be absorbed into the paper. Sizing improves the surface strength, printability, and water resistance of the paper or material to which it is applied. In the sizing solution, optical brightening agents may also be added to improve the opacity and whiteness of the paper or material surface. Sizing chemicals are considered either ‘internal’ or ‘external’ (surface) sizing agents, and PFASs or their non-fluorinated chemical alternatives may be used as either internal or surface sizing agents to repel or act as a barrier to water and grease.

Internal sizing chemicals ('sizing agents') are used in papermaking to make the paper web more hydrophobic. Sizing agents repel water by influencing dewatering and promoting the retention of fillers and fibres in the paper sheet. They are usually added as waxy particles of approximately 1 µm to the pulp. In this way, they will be retained in the paper web without interfering with the crosslinking of the cellulose. During the pressing and drying process of the paper, the wax melts and the sizing agents migrate into the body of the paper and coat the fibres (Roberts, 1996[20]).

Internal sizing agents have the advantage that even if the fibres are exposed to water or fats from food such as chocolates, they will not be wetted. In addition, the paper will maintain a more 'natural' look compared to a shiny plastic or varnish surface, or the glassy look a traditional 'acid sizing' parchment method produces. The downside of internal sizing is that it requires more sizing agent to coat the fibres of paper, say 100 µm thick, than to apply a surface layer of a few microns.

PFASs and the biowax TopScreen™ formulations[2] (see Section 2.5.1) act as internal sizing agents to act as grease and water barriers. Other water barriers include alkyl succinic anhydride (ASA), styrene acrylic emulsion (SAE), alkyl ketene dimer (AKD) and rosin. AKD and SAE can act as a first water resistance barrier, onto which formulations such as TopScreen™ can be applied.

External or 'surface' sizing agents can be added after the production of the paper ('dry-end coating') (Roberts, 1996[20]). This gives greater flexibility in the production (DuPont, 2010[21]). External sizing agents can be applied directly as surface coating films, or be mixed in with varnishes, also called 'lacquers'. Both form a protective surface layer which prevents wetting of the fibres and suction of liquids into the pores of the paper. The majority of surface sizing agents are modified starches. Surface sizing agents are amphiphilic molecules, having both hydrophilic and hydrophobic ends. After reaching the fibre, the sizing agent acts as a surfactant and orients itself perpendicular to the fibre surface, creating a low energy (surface tension) surface (Roberts, 1996[20]). This results in a smooth finish that tends to be water-repellent.

A disadvantage of surface coatings is that the coating can crack, whereby liquid can seep in and blot the paper. This is likely to happen for foods with long storage times which are packaged in thin flexible paper, because the packaging can be easily and repeatedly creased when handled in the supply chain, in the shop, or by the consumer. Another disadvantage is that paper with a thin surface coating used for food packaging intended to be exposed to high temperatures (e.g., for microwavable food) can easily be damaged.

Again, both PFAS and some TopScreen™ formulations act as external sizing agents to confer grease and water repellence to the paper.

2.3. PFAS used in food packaging

In the preparation of this report it has not been possible to find a definitive list of PFAS used in food packaging/wrapping worldwide. A recent literature review indicates that analyses carried out on food packaging has found trace levels of a variety of fluorinated substances[3] (Bokkers B. et al, 2018[22]; BAuA, 2019[23]). The FluoroCouncil has commented that analytes from studies such as that carried out by Washington State in the US (Washington State, 2020[8]) were substances that are not expected to provide oil and grease repellence and were detected at such low levels that they would not provide functionality (FluoroCouncil, 2019).

In order to provide an overview of the PFAS intentionally used in food packaging, a survey was carried out of the key regulatory regimes in OECD member countries for FCMs. For each regulatory regime chemical identity information has been correlated with information on the specified use (when available) of possible PFASs[4] (fluorinated substances) used in food packaging (see Annex B).

Discussions with representatives of industry stakeholders have confirmed that in the absence of specific national legislation, being positive-listed or authorised[5] by two key regulatory regimes is considered globally as a standard of acceptability and is considered safe to use. The two regimes are the US FDA which authorises food contact substances through Title 21 Code of Federal Regulations Part 176 ('FDA 21 Code') and under the Food Contact Notification program (FDA, 2019[24]) and the German BfR recommendations for consumer products that meet the requirements of § 31.1 of the German Foods, Consumer Articles and Feed Act ('BfR Recommendation list') (BfR, 2017[25]). Accordingly, the focus of the regulatory survey has been on these two lists. This has been supplemented by other national/regional regimes where available.

From Annex B and Table 4 it can be seen there are 28 active fluorinated substances currently included on the FDA list to confer grease/oil/water resistance to paper and board. These are reported to be used in 19 formulations (DTSC, 2020[1]). All 28 are listed as used in the manufacture of paper and board intended to come into contact with food. An additional eight substances are included in the FDA list but are noted to have either been withdrawn from the market or are listed as 'introduction into interstate commerce voluntarily ceased by manufacturer'. These are therefore not included in Annex B.

The BfR Recommended list contains 12 fluorinated substances that are listed as surface refining and coating agents. From this description it is likely they are used to confer grease and water resistance for food packaging.

Chemical substance identification is not straightforward on either the FDA or BfR lists for several reasons. The entries are not listed as PFAS, but instead often as reaction mixtures. In addition, CAS numbers or other identifiers are entirely absent in the BfR Recommendation list. For this reason, a search of regulatory lists has been carried out using the term 'fluoro' to identify fluorinated substances that are used in food packaging, rather than PFAS. Despite these obstacles there are a number of observations that can be drawn.

The LC PFASs previously used in food packaging were generally a mixture C8, C10 and C12 chain length PFAS. These have been progressively replaced by short-chain PFAS which are mainly based upon C6 technology as regulatory pressure has grown since 2000 (see section 2.1).

The fluorinated sizing agents that are recommended or approved by the German BfR and the US FDA include polyfluoroalkyl phosphate ester surfactants (PAPs), fluoroacrylates, carboxylic acids, phosphoric acid esters and polyurethane derivatives of PFPEs. Commercial PFASs used for paper typically contain several fluorinated alkyl chains or repeat units. The concentration of the sizing agent is typically allowed to range from 0.2 to 1.5% by weight of the paper and containing up to 45% fluorine.

2.4. Physical alternatives without PFAS

Various alternatives to the use of PFAS for creating physical barrier properties in paper and board exist. Two of the most common types of paper with an intrinsic mechanical barrier against grease are NGPand vegetable parchment. These two materials both have a dense cellulose structure that confers grease resistance. A list of the physical barrier alternatives that have been identified in this study are given in Table 1. To note however, a number of these have not been confirmed as commercially available hence are not the focus of the analysis later in the report.

2.4.1. Cellulose-based physical alternatives

Cellulose based-alternatives for the purposes of this report are divided into NGP, microfibrillar cellulose (MFC), cellulose nanofibrils (CNFs) and cellulose nanocrystals (CNCs).

NGP has both water and grease barrier properties. It is made as a result of intensive refining of wood pulp. In this refining the cellulose fibres are treated so they can take up water. As a result, the fibres will be bonded tightly together by hydrogen bonds, which are formed later during the paper-making process. The resulting paper structure is a compressed and dense network of cellulose fibres where the fibres are physically very close together. The resulting material has very few pores and the pores are small compared to other paper.

The intensive refining makes the fibres flexible and makes it easier for them to come into intimate contact with each other so that they can bond to each other. The greater the refining, the closer the fibres come into contact with each other, resulting in a higher density of the final paper. As a result of the densification of the paper, air permeability and light scattering are reduced.

The structural difference between a non-fluorinated NGP and a fluorocarbon treated paper is illustrated in Figure 2. The greaseproof paper has a dense surface structure created from cellulose, which provides the barrier against grease. The fluorocarbon treated paper has a more open paper structure, but in this case the added chemicals provide a grease repellent surface.

To improve barrier properties and reduce air permeability, greaseproof papers are typically coated with starch, carboxymethyl cellulose (CMC) or polyvinylalcohol (PVOH). Starch closes the surface of the paper and reduces the air permeability and can in this way also improve the water barrier performance (Kjellgren, 2005[26]).

NGP is mainly used as grease and water-resistant paper in food processing and packaging that is intended for contact with fatty foodstuffs such as baking paper, food trays and containers such as muffin cups.

MFC, CNFs and CNCs are produced by refining cellulose using mechanical processes such as high pressure homogenization, grinding, and refining. This is then used as a coating on paper or plastic. MFC cellulose has been discussed by the academic sector since the 1980's, but the interest for this and CNFs has recently been growing significantly. It is beneficial because it can strengthen and lighten fibre materials and it provides excellent oxygen and moisture barriers. Both materials are claimed to have enormous potential to reduce or replace petroleum and fluorochemicals for food and other packaging applications. CNFs have been studied for their excellent oxygen and gas barrier properties, whilst CNCs are less sensitive to moisture due to their highly crystalline nature; however, coatings and films made of CNCs are much more prone to fracture due to their high brittleness. Composites of CNF and CNC are reported to exhibit excellent oil and grease resistance (a Kit value[6] of 11) which is comparable to fluorochemicals (Tyagi P et al, 2019[27]). However, the use of these materials is still in development so are not covered further in this report but should be watched as possible future alternatives to PFAS.

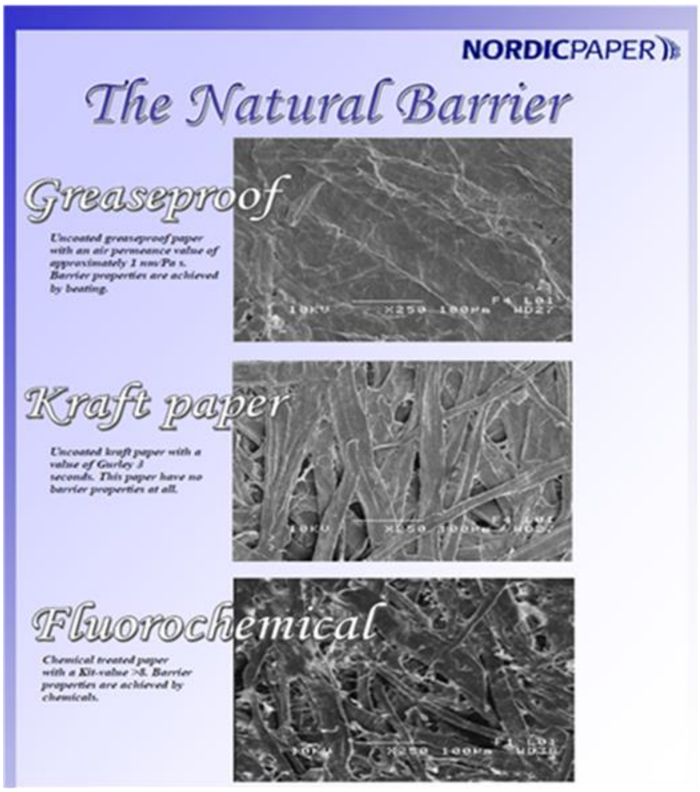
Vegetable parchment initially has a fairly open structure, but when the paper is passed through a bath of concentrated sulphuric acid, the cellulose fibres react with the acid and almost melt together (Twede and Selke, 2005[28]). The reaction between the acid and the cellulose is interrupted by dilution with water and the paper sheet is finally consolidated by a drying process. This treatment results in a paper with high air resistance. The sheet structure is dense with a small number of pores (Giatti, 1996[29]). Vegetable parchment offers a very high barrier to water and fat (Pudumjee, 2020[30]) and is suitable for use as food wrappers and liners.

Table 1. Physical and chemical alternatives to PFAS paper and board used in food packaging based on grease and water barrier performance identified in this study.

Product Category	Physical alternatives	Chemical alternatives
Baking paper	NGP	NGP plus additives*, silicone materials
Food trays/boats	Elephant grass, cellulose pulp	TopScreen™ formulations, clay
Boxes e.g. for French fries	Bamboo**	TopScreen™ formulations, biowax
Wrappers and liners (cold food)	Vegetable parchment	TopScreen™ formulations, biowax
Wrappers and liners (hot food)	None identified	TopScreen™ formulations,
Clamshells & take out containers	None identified	TopScreen™ formulations,
Pet food	NGP	TopScreen™ formulations.
Unattributed FCMs	Clay, wheat straw, MFC, CNCs, CNFs.	Chitosan, copolymer dispersions, aqueous wax dispersions, starch, stone plus resin, HEC, PVOHs, AKD, ASA.

Key:
** Both a physical and chemical alternative;*
*** Some products are marketed as bamboo, but are in fact composite plastic FCMs, since they consist of melamine plastic with a bamboo filler (EWGFCM, 2019[31]). Such composite plastic products are not truly non-plastic alternatives.*

Figure 2. Structural difference between natural greaseproof paper and PFAS-treated paper as shown by scanning electron microscopy.



Source: Nordic Paper 2019

2.4.2. Plastic, aluminium and polylactic acid (PLA)

As referred to in Section 2.2, it is common to make a physical barrier by laminating an extra layer of plastic or aluminium onto the material that will be used in food packaging. The disadvantage of lamination however is that the paper-making plants must have laminating machines adding extra costs. The resulting food packaging material is also difficult to recycle (Nordic Council of Ministers, 2018[4]), although one company is known to be recovering plastic from laminated paper (ECESP, 2020[32]). Because of the barriers to recyclability and the comprehensive coverage of the use of plastics and its drawbacks elsewhere, these alternatives are not considered further in this report.

After further consideration, materials being marked as eco-alternatives to conventional plastics such as PLA, sometimes referred to as 'corn plastics', marketed as ingeo™ by companies such as NatureWorks (Jamshidian M et al, 2010[33]; CPA, 2020[34]) are not covered within the scope of this report. Primarily this is because generally they are used as substitutes for plastics for food consumption, rather than paper; and also, because they face similar criticism as single use plastics concerning recyclability (Smithsonian Magazine, 2006[35]). However, it would be beneficial to conduct a thorough review of PLA as an alternative to plastic materials, including any potential risks to health and the environment throughout their entire life cycle.

Polystyrene and plastic can be used as substitutes for paper and board food packaging for many applications and some plastics may be treated with PFAS. However, there has been a trend in OECD countries to seek to reduce or eliminate the use of these materials for food-on-the-go for reasons of non-sustainability. The result has been a return to the use of paper and board-based food packaging, particularly for cups, food containers, carryout bags and straws. For this reason, these alternatives are not considered in detail in this report.

2.4.3. Other physical alternatives to PFAS

Other physical alternatives to PFAS paper used in food packaging and food consumption include a material either used in conjunction with cellulose-based paper or instead of cellulose-based paper such as elephant grass, palm leaves, bamboo (French fry boxes), clay and wheat straw. A number of producer companies of these alternatives were contacted as part of the study, from which no responses were received.

2.5. Chemical alternatives without PFAS

2.5.1. TopScreen™ barrier products

Solenis produce a number of barrier formulations which are marketed under the trade name TopScreen™. TopScreen™ formulations[7] are used in food packaging and are either water-based synthetic biopolymers or vegetable-oil based bio-waxes[8]. Both the biowax and synthetic polymer products confer grease and water repellence properties, although the synthetic formulation can give better water resistance for the same application volumes. In addition, TopScreen™ formulations confer water vapour moisture (WVM) resistance. This is particularly important for fast food packaging such as hamburgers to prevent water vapour escaping from the hamburger bun, which would result in a dry bun. These are formulated according to customer specifications.

As referred to in Section 2.2, internal sizing agents such as AKD and SAE can be used in conjunction with TopScreen™ products acting as a first water resistant barrier, onto which formulations such as TopScreen™ can be applied.

The biowax formulations can be used for candy twists[9], fast food wrapping, bread bags, meat and cheese wraps, and corrugated board for fruit, vegetables and frozen fish. TopScreen™ grease-proof barriers and TopScreen™ water barriers are suitable for packaging applications that require specific water/moisture barrier properties or grease resistance for polyethylene-free cups, paper and linerboard used for fresh and refrigerated/frozen foods, animal feed/pet food and greasy/oily foods.

2.5.2. Silicone

Silicone is used to an increasing extent in FCMs. Examples are baking moulds, kitchen utensils, teats and surface coating on baking and food paper. In bakeware silicone products can be made flexible and yet still able to retain their shape. Silicone is thermostable and chemically resistant. Paper for food contact can be coated with silicone in order to ensure the paper can be released from the food, for example muffin cases for home baking (NFI, 2017[36]).

The silicone base is usually a silicone polymer that has a skeleton of silicon and oxygen atoms. The individual building blocks (oligomers) are called siloxanes and the polymer is called silicones or polysiloxanes. The terms 'siloxanes' and 'silicones' are often used synonymously. The silicon and oxygen atoms can be arranged in linear or cyclic chains and siloxanes are characterised as being linear or cyclic. At the time of writing certain siloxanes are under regulatory scrutiny in the EU as substances of very high concern (ECHA, 2019[37]).

In silicones there may be a quantity of siloxanes which are residual content after polymerisation or chemical reaction compounds formed during the process. There is also the possibility that siloxanes are formed during the use of silicone products e.g. by repeated used of baking mould at high temperatures.

2.5.3. Other chemical alternatives to PFAS

Other non-fluorinated coatings that are used to improve the grease resistance of paper and board include aqueous dispersions of copolymers (styrene and butadiene), aqueous dispersions of waxes (other than that of TopScreen™), starch, clay, stone (calcium carbonate mixed with a resin), chitosan or water soluble hydroxyethylcellulose (HEC).

Additional sizing agents include non-fluorinated AKD and ASA (Roberts, 1996[20]), styrene–acrylic copolymers (Yeates, 1996[38]), talc-filled water-based polyacrylate (Rissa, 2002[39]), pigment-filled hydrophobic monomer dispersions (Vähä-Nissi, 2006[40]), polyvinyl alcohols and montmorillonite/polyethylene-coatings (Krook, 2005[41]), modified wheat protein, and silicones.

Additional information on these alternatives is limited but included in the report when available. It is also acknowledged that some of these alternatives may contain plastic (e.g., styrene-acrylic copolymers, hydrophobic monomer dispersions, polyvinyl alcohols and polyethylene coatings) and therefore would have the disadvantage described above (see 2.4.2). A list of chemical alternatives identified in this study is provided in Table 1.

Notes

[1] Probably to be deleted from REACH and implemented via an amendment to Regulation (EU) 2019/1021 on persistent organic pollutants.

[2] There are a number of barrier formulations used in food packaging which are marketed under the trade name TopScreen™.

[3] For this reason, the Danish Government introduced legislation to restrict total organic fluorine in paper and board but changed the Danish guideline level of allowable PFAS from that originally proposed of 0.35 µg/dm^2 to 10 µg/dm^2.

[4] A search of regulatory lists has been carried out using the term ‘fluoro’.

[5] Only the substances and formulations listed are permitted to be used in food packaging.

[6] See Section 3.1.1.

[7] A more detailed composition cannot be reported for confidential business information reasons.

[8] Chemical identity is confidential business information.

[9] Packaging for certain sweets.

Chapter 3. Efficacy of alternatives

3.1. The relative performance of identified alternatives

3.1.1. Measurement of performance

The performance specification of grease resistance that is usually required by food packaging companies is referred to as the ‘Kit value or rating’. This is based upon a TAPPI[1] standard procedure (TAPPI, 2012[42]) for testing the degree of repellence and/or the antiwicking characteristics of paper or paperboard treated with fluorochemical (PFAS) sizing agents. The level of grease resistance ranges from a low grease resistance with a Kit value of 1 up to a high resistance of 12. For example, paper which comes into contact with dry foodstuffs for a short period of time will have a lower Kit value than those in contact for a longer time span with a higher grease content. If the application is subjected to oven temperatures, as in the case of tray bakes, then the required Kit rating will be higher. Kit values are supported by TAPPI methods which are industry accepted methods.

The Kit rating test was originally developed to allow papermakers to know when the applied fluorochemical was incorporated into the paper and board sheet and the approximate level of grease resistance imparted. Testing involves placing a series of numbered reagents (varying in surface tension and viscosity or ‘aggressiveness’) onto the surface of the sample. The solutions are numbered from 1 (the least aggressive) to 12 (the most aggressive). The highest numbered solution that does not stain the surface is reported as the ‘Kit rating’.

In this study it was found producers of alternatives to PFAS used as grease/water barriers also need to measure the performance of their products in Kit values to allow food packing manufacturers to compare performance and evaluate whether performance is sufficient for the required food packaging application. It was also found in this study that Kit testing is not fully applicable to non-PFAS alternatives, but nevertheless is the food packaging industry’s required metric.

Water absorptiveness (‘Cobb value’) determines the amount of water absorbed into the surface of paper and paperboard sample in a set period of time, usually 60 or 180 seconds ($Cobb_{60}$ or $Cobb_{180}$). Water absorbency is quoted in g/m^2 (gsm). A $Cobb_{60}$ value of, for example, 30 grams is very low for a board grade indicating good water repellence, but quite high for a thin paper. In flexible packaging (paper grades, not board), $Cobb_{60}$ values typically range from 20 g/m^2 - 30 g/m^2.

Finally, the water vapour moisture (WVM) resistance value is used to measure the resistance of packaging for restricting water vapour through it. This is especially important when considering the need of food packaging to retain moisture e.g. burger wrapping.

3.1.2. Summary of the grease, water and heat/fire performance of alternatives

Table 2 compares the grease and water performance of SC PFAS packaging and non-PFAS alternatives. Across the range of alternatives, both SC PFASs and some non-PFAS alternatives can meet the grease barrier performance that is required across the range of food packaging applications considered in this study.

Non-fluorinated alternatives that met the grease/water repellence performance requirements for the applications considered in this study included physical alternatives such as NGP and chemical alternatives such as TopScreen™ products.

However, manufacturers of paper and board material are not only concerned with the grease/water performance of the material, but also other factors such as the speed and ease with which the material used to make the paper/board can be worked and whether it can be easily glued together and printed upon. For baking papers, the ease of release or separation of the paper from the product is important. For food wrapping used for hot foods, the WVM properties are important.

This study demonstrated that most paper and food packaging producers are still producing paper and board with PFAS for the entire range of food packaging applications. Some commentators referenced the ease of which PFAS paper and board can be machined compared to alternatives, this was particularly apparent when comparing PFAS paper production with intensively refined paper such as NGP. Another advantage of PFAS is that they can be used with paper and board with very uneven fibres such as recycled paper consisting of mixed fibres.

Nevertheless, there are also reported performance benefits of moving away from external sizing PFAS (Nordic Council of Ministers, 2018[4]). For example, gluing and printing become easier, because the fluorinated coating generally makes it difficult for any other chemical to stick to the paper material. Conversely, non-fluorinated microwave popcorn bags have a greater tendency to char or burn, something that is rarer with PFAS paper, possibly because PFAS are generally heat-resistant. Other concerns with non-PFAS alternatives can be that grease resistance reduces over long periods of time, for example in food wrappers.

Concerning the release properties of food packaging from the product, it was found in this study that NGP performs very well as baking paper, e.g., for muffins. It has very low friction surface properties meaning individual cups can be separated (released) easily in fast production processes. For other baking applications NGP is silicone-coated to further enhance these release properties. NGP is not treated to be a flame retardant, but it will not combust in a conventional oven as long as the paper is not in direct contact with the heating element. In tests up to 500 °C, NGP has been found to be resistant to combustion, but in other studies NGP becomes charred after being exposed to 310 °C for 20 minutes. Although not usually a critical parameter for NGP applications, baking paper grades of NGP coated with silicone have been found to have Cobb values of 11 gsm, compared to non-siliconized NGP which could be approximately 35-45 gsm (Nordic Paper, 2020[43]).

MFC is reported to provide excellent oxygen and moister barriers. MFC can be used in the form of film, nanocomposites and paper coatings (Prescouter, 2017[44]).

In general, TopScreen™, a chemical alternative to fluorinated food packaging reviewed in this study, can be formulated to have a WVM performance advantage over PFAS paper as well as excellent grease and water resistance properties. This means on performance alone it is particularly suitable for use in hot food wrapping to ensure the food product does not dry out, prior to consumption. Baking paper formulations of TopScreen™ have also been tested at oven temperatures up to 220 °C without combustion, although the coatings cannot be considered to be flame retardants.

Silicone-based alternatives are known to be water repellent but generally reported not to meet the required grease performance properties for use in a wide range of food packaging (Nordic Council of Ministers, 2018[4]; Wacker Chemical Corp., 2017[45]; Dixit A et al, 2006[46]). Also, whilst silicone alternatives have good release properties, they are often not suitable for industrial-scale baking because they require extensive cleaning to avoid them sticking to the finished food articles. Parchment paper and wax paper have similar disadvantages.

Chitosan has been studied for its potential to provide a grease barrier, and barriers comparable to those obtained with fluorinated resins have been achieved (Ham-Pichavant, 2005). Similarly, paper coated with sodium alginate/sodium carboxymethyl cellulose and sodium alginate/propylene glycol formulations have been demonstrated to have Kit ratings of up to 9 and can provide an effective water barrier as well (Sheng et al;, 2019[47]).

Table 2. Comparison of grease and water performance of commercially available alternatives to long-chain PFAS

Application		Grease/water performance sufficient for food packaging?		
	Kit* value	Short-chain PFAS	Physical alternatives	Chemical alternatives
Burger boxes and clamshells	5-6	Yes	Yes	Yes
Baking paper	4	Yes	Yes	Yes
Takeout cups/ ice cream tubs	5	Yes	Yes	Yes
French fries, hash browns & popcorn wrappers	5 – 8	Yes	Yes	Yes
Packaging for nuts & sweets	3	Yes	Yes	Yes
Packaging for bread & pastry	3	Yes	Yes	Yes
Pet food packaging	12	Yes	Yes	Yes

Note: *Some Kit values are estimated.

3.1.3. Comparison of the costs of the substitute or non-chemical alternative

In the preparation of this report, PFAS and non-fluorinated manufacturers agreed that PFAS-based food packaging is significantly cheaper than non-fluorinated alternatives to achieve a grease and water repellence performance that is acceptable for food packaging use. This price differential appears to be the critical factor in determining the competitiveness of non-fluorinated alternatives. In the value chain the cost difference is passed onto to the users of the manufactured paper and board. This can be an end user if used in the baking sub sector for example or can be a convertor which makes the food wrapping and packaging. The value chain for food packaging is shown in Figure 3.

Figure 3. The value chain for food packaging

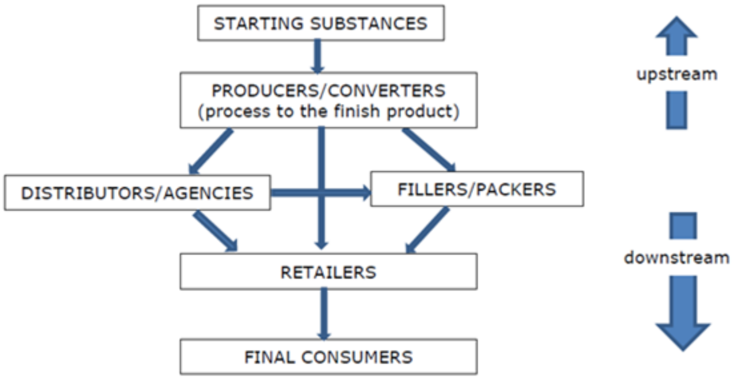


Table 3 below, compares the cost differentials between base paper costs, and the cost of paper either with added SC PFAS, or with a non-fluorinated chemical or physical alternative. The figures indicate the relative costs and do not necessarily reflect actual costs. These indicative figures are based on evidence obtained in this study and are non-attributed to protect the business interests of contributors.

The relative costs in Table 3 show the increased cost of using an alternative chemical to PFAS for food packaging can be an additional 11%. The table also shows the cost differential between a physical alternative such as NGP and a PFAS paper used as a baking paper to be 32%. These are largely costs that would need to be passed down the value chain. A comparison between the base paper cost and the cost of using PFAS from Table 3 also shows a cost differential of €150/tonne, i.e. an increase in 12%, suggesting the use of PFAS alone already implies a significant cost increase from the base paper costs.

Contributions to this project from PFAS manufacturers indicate that the above cost differential may be an underestimate. Instead the cost-in-use of a PFAS-free oil and grease barrier may be up to 2-3 times higher than the cost-in-use of a PFAS-based barrier.

Table 3. Comparison of the costs of alternatives used in paper and board food packaging

Paper/board and treatment	Average* product cost (€/tonne paper)	Average cost differential between base paper and PFAS-treated and non-fluorinated paper (€/tonne paper)	Average difference between base paper and PFAS-treated and non-fluorinated paper (%)	Average difference between PFAS-treated and non-fluorinated paper (%)
Base paper	1 250	0	0	Not applicable
Short-chain PFAS	1 400	Plus 150	Plus 12	Less 11 to 32
Chemical alternative	1 550	Plus 300	Plus 24	Plus 11
Physical alternative	1 850	Plus 600	Plus 48	Plus 32

*Key: * These figures are averages from a range of figures collected and depend upon factors such as the level of refinement of the starting base paper. Also, the figures indicate the relative costs and do not necessarily reflect actual costs. These indicative figures are based on evidence obtained from industry for this study and are non-attributed to protect the business interests of contributors.*

The reasons for the cost differentials were explored in this study. Contributors explained the cost increase between highly refined NGP and PFAS paper is due to increased production costs. This is mainly due to the increased amount of refining, dewatering and drying used to produce NGP compared to PFAS paper which slows the paper-making machines down, presumably increasing energy consumption and therefore increases costs. It is also likely that any physical alternative that relies on a high degree of refinement of a raw material such as cellulose, elephant grass or palm leaves to achieve the required paper performance for use in food packaging would suffer a similar cost differential compared to PFAS paper.

It is also noteworthy that although on a tonnage basis the cost differential between NGP and PFAS paper is significant, the price differential at the consumer (end user) level may be as low as less than 0.5 cents (~14% increase), for a single muffin cup for example.

Contributors explained typically paper for French fries requires a Kit value of about 5, hash brown paper a Kit of 8 and for pet foods the required Kit value is 12. For chemical alternatives to PFAS generally, a higher grammage (g/m^2) of formulation is required to achieve the required Kit value, resulting in increasing costs. Hence for competitiveness it is important to optimise the relationship between grammage and performance by reducing the formulation quantities, whilst still achieving the required Kit value. Typically, wrappers for French fries require a product grammage of 2-3 g/m^2 paper and pet foods 10 g/m^2 on board. Paper with a more closed structure needs less coating, whilst board is more open, and more coating is needed. A PFAS-coating or impregnation adds approximately €100-200/tonne onto the base paper costs, depending upon the Kit value that needs to be achieved. However, an alternative chemical coating/impregnation adds approximately €300/tonne onto the base paper costs.

Paradoxically, PFAS formulations used for food packaging paper are usually significantly more expensive than competitor chemical alternatives on a kilogramme for kilogramme basis. However, after producing the paper for food packaging this cost differential is reversed resulting in the costs/tonne of paper produced described above. This was illustrated in the context of producing heavy weight board such as that used for pet food, clam shell and lunch boxes which is required to have high Kit values. Technically a chemical alternative such as TopScreen™ formulations can achieve the required performance by using a single or double coating, which works by forming a closed film on top of the paper. PFAS-products are mixed with starch and coated on both sides of the base paper to achieve the required performance, and they work by lowering the surface tension at the paper surface. Presumably the use of starch which is relatively cheap and possibly the difference in mode of action results in the overall lower costs of using PFAS formulations relative to the TopScreen™ formulations.

Notes

[1] Technical Association of the Pulp and Paper Industry: https://www.tappi.org/menus/functional-navigation/About-Us/

Chapter 4. Uptake and market penetration of alternatives

4.1. Overview of the market for food contact paper and board materials

Public data have largely not been available to gain a comprehensive overview of the global or regional volume of the market for paper and board food contact materials. The best insight has come from data published by the European Commission's Joint Research Centre (JRC, 2016[48]) which was derived from a variety of sources. This has been used to provide an indicative overview of the market value and volume for paper and board food contact materials below. Some commercially available sources (e.g. Smithers, Freedonia and Technomic) provide such overviews and trend information, but the costs were prohibitive for the purposes of producing this report.

JRC 2016 states the global food contact paper market was valued by Smithers at €47 billion in 2012 but forecast to increase to €70 billion by 2017 (PIRA, 2012[49]). From the same source, the European contribution to the €47 billion was €26.7 billion in 2013, i.e. approximately 57%, assuming annual growth of the overall market had not increased significantly[1]. This was split into €11 billion (41%) for corrugated packaging, €10.2 billion (38%) for carton board and €5.5 billion (21%) for flexible paper packaging.

JRC also noted that The Confederation of European Paper Industries (CEPI)[2]estimated a value of €81 billion for European food paper and board production in 2014, suggesting either the market had significantly grown by 2014 or the Smithers estimate was an underestimate.

In terms of volume, the CEPI value quoted above equated to 13.8 million tonnes of paper and board produced for food contact from three main sectors: folding box board, corrugated boxes and paper sacks. Assuming the European contribution makes up roughly 50% of the total value an indicative value for the total global production of paper and board for food contact materials is 27.6 million tonnes of paper and board.

JRC reports the size of companies in this sector as described by Smithers was fairly evenly split between small (29.7%), medium (34.7%) and large companies (35.6%).

4.2. Market share of alternatives and geographical spread

One contributor to this report producing NGP estimated the global market volume for baking paper at 250 000 – 300 000 tonnes per year of which it has a market share of approximately 25%. Other main producers of NGP are estimated to account for an additional 27% market share. Presumably the remaining 48% is largely composed of baking paper made with SC PFASs, although an unspecified proportion could be made up of other paper such as vegetable parchment or alternative chemical-treated paper.

Placing these volumes of baking paper into the context of the total global volumes of food paper and board estimated in Section 4.1, the baking paper sub sector represents up to approximately 1% of the total global market. Hence baking paper sub sector is a niche market in the overall food packaging paper and board sector.

Producers of chemical alternatives to PFASs used more widely in food paper and board have also provided an estimate of their individual European market share to be <<1%. Although there are several other known producers of alternatives to short-chain PFASs in Europe, on this basis it may be assumed that the large majority of food paper and board in Europe is treated with SC PFAS to confer grease and water resistance.

In the US there is growing pressure to phase out the use of PFASs from food contact materials, and several States are considering or have put in place legislation to this effect (see Section 2.1). Despite this pressure, on the basis of discussions during the preparation of this report it would be a reasonable assumption that chemical alternatives occupy a similarly low market share in the US as in Europe.

In Asia there has not been significant pressure to move away from using PFASs for grease/water resistant food paper and board. The exception to this is Asian companies that supply to the EU market (and presumably the US) where there is a growing pressure to use alternatives. Again, it can be reasonably assumed therefore that alternatives without PFASs occupy a market share in Asia of <<1%.

The above account is broadly consistent with estimates from PFAS manufacturers about their own market share worldwide: for paper and board used in food packaging which is required to have grease and water resistance properties, between 90-95% is treated with PFAS, rather than alternatives. However, the FluoroCouncil has noted that the total volume of paper being treated with PFAS is reducing (FluoroCouncil, 2020[50]). A list of key regulatory requirements for PFAS and alternatives to PFAS in FCMs is provided in Annex B.

4.3. Challenges to substitution and the anticipated time frame for the substitute/ non-chemical alternative to completely eliminate the use of PFASs

4.3.1. PFAS alternatives

The shift from LC to SC PFAS has progressively taken place since 2000. It took a number of years for PFAS manufacturers to develop SC PFAS technology that meets the required specification for use in food packaging. Discussions with PFAS manufacturers have indicated that the replacement of LC with SC PFASs and possibly in the future to non-fluorinated technology is not a linear process. Instead, it requires a stepwise approach to develop the new technology, scale this up to production levels and verify that the technology can be used optimally and cost-effectively by paper and board manufacturers. PFAS manufacturers have commented that a step from PFAS to non-fluorine technology with the same performance would be an order of magnitude change in terms of the challenges it poses.

Following a period of product optimisation, the SC PFAS chemistries provide products with equivalent performance and generally do not require the use of larger quantities. Today’s fluorinated chemistry application rates are typically similar or reduced compared to older, LC chemistries.

As regulatory pressure grows on certain SC PFAS using C6 technology, it could be assumed that shorter chain length PFAS, e.g., C4 technology,[3] may replace C6 technology. However, contributors to this study suggested otherwise, namely that performance may be impacted by progressively shortening the PFAS chain length.

Instead, in the absence of LC PFAS technology, a C6 chain length appears to be an optimal chain length in terms of performance.

4.3.2. Non-fluorinated alternatives

As described in section 3.1, there does not appear to be a performance limitation to using non-fluorinated alternatives. The challenge of using non-fluorinated alternatives is exclusively based upon cost.

In the baking and greaseproof paper market of the food packaging sector, the production of NGP requires intensive refining to produce a product with the required performance characteristics. This production process slows the paper-making machines compared to using PFAS and costs increase by up to more than 30%.

A producer of NGP confirmed that although their products could meet the required performance characteristics of other sub sectors of the market such as pet food packaging, they had chosen not to enter this market because they know they cannot compete on cost. Nevertheless, in the same way that PFAS manufacturers and paper producers are seeking to optimise their processes to minimise cost, producers of NGP are doing the same. Adding certain non-fluorinated chemicals such as starch or carboxymethyl cellulose (CMC) to NGP is one future possibility that could speed up the production of NGP to drive down costs.

For non-fluorinated chemical alternatives, the cost differential, rather than performance is also the critical factor in determining competitiveness and whether paper manufacturers and retailers will purchase the non-fluorinated food packaging. On performance, some chemical alternatives such as TopScreen™ formulations could be used in a wide range of the food packaging market sub sectors considered in this study. Chemical alternative producers are also continually optimising their formulations, working closely with paper producers to seek to drive down the price of the product and to increase its competitiveness compared to PFAS products. Despite this, chemical alternatives remain 11% more costly than their PFAS competitors.

PFAS manufacturers have also commented on the estimated costs and challenges associated with a switch from using a PFAS-based barrier option in food packaging to a PFAS-free one. Before switching, thorough evaluation and testing is necessary. The re-evaluation takes place not only at the paper mill, but also at converting and printing plants and at retailers. For each paper grade, the re-evaluation can cost in the range of €100,000 - 200,000 and can take from 6 months to 1 year to complete.

Producers of PFAS and non-PFAS food packaging agreed that if there is a sufficiently good reason to pay the premium for non-fluorinated paper and board products the value chain will do so. Possible drivers to move to non-fluorinated alternatives are explored in Section 4.4.

4.3.3. Have alternatives received regulatory approval by relevant authorities?

Discussions with producers of alternatives used in food packaging has confirmed that there are two regulatory schemes they aim to be included in if their substances/formulations are to be used in food packaging worldwide. These are both positive lists or lists of substances authorised: 1) Title 21 of the Code of Federal Regulations Part 176 under the US Federal Food, Drug, and Cosmetic Act (the FDA List); and 2) the German BfR recommendations for consumer products that meet the requirements of § 31.1 of the German Foods, Consumer Articles and Feed Act and

Article 3.1 of Regulation (EC) 1935/2004 on Materials and Articles Intended to Come into Contact with Food as to their safety for human health. Where other national or regional schemes exist, alternative producers will comply with these as well in order to place their products on the market in those areas[4].

US Food and Drug Administration (FDA) List

The 1958 Food Additives Amendment to the Federal Food, Drug, and Cosmetic Act, provided the US FDA with authority over all substances used in food packaging that are classified as 'food additives.' Since the 1958 Food Additives Amendment, substances used in all types of food packaging materials that are reasonably expected to migrate into food, e.g., adhesives, coatings, plastic bottles and films, and paper and paperboard, are subject to FDA pre-marketing authorization. Prior to 1997 manufacturers could submit a food additive petition requesting authorization. If accepted and upon review by FDA it was determine that the substance was safe based on the intended use this would result in a listing for the substance in a regulation in Title 21 of the Code of Federal Regulations. In 1997 the Food and Drug Modernization Act provided for a food contact notification program by which the manufacturer could submit a food contact notification (FCN) requesting authorization. If FDA does not object within 120 days, the use of the substance is included in FDA's list of currently effective food contact notifications (FDA, 2019).

FDA's regulation of paper and paperboard can be found at Title 21 Code of Federal Regulations Part 176, entitled Indirect Food Additives: Paper and Paperboard Components. This regulation lists substances that may be used in paper and paperboard in contact with different types of food having various functions in the papermaking process and is divided into two sections. Section 176.170 identifies substances that are regulated for use as components of the uncoated or coated surface of paper and paperboard intended for use in packaging aqueous and fatty foods. Section 176.180 identifies those substances that are regulated for use as components of the uncoated or coated surface of paper and paperboard intended for use in packaging dry foods only. SC PFAS and non-fluorinated alternatives are both listed in the FDA Inventory of Effective Food Contact Notifications and this was searched as a basis for constructing Table 4 below. Only materials specified for use as grease and water repellents are included.

German BfR Recommendations

The BfR list of recommendations on FCMs are to ensure that the materials do not release substances into foods which could cause a health risk for consumers. The recommendations are based on lists of substances which BfR (or its predecessor organisations) has assessed since 1952. When used for the purpose specified in the list, the substances on this list can be considered as non-hazardous for health in accordance with the current state of science and technology, i.e., positive-listed.

Each BfR recommendation refers to a specific material, for instance silicone or paper, and includes polymers used in plastics, silicones, natural and synthetic rubber as well as paper, cartons and cardboards. Furthermore, the BfR makes recommendations which refer to the intended use of the materials, e.g., plastic dispersions for the coating of articles for food contact. Recommendations for paper and board food contact are contained in Recommendation Set XXXVI. Recommendation XXXVI is further divided into Section A raw materials and B Production aids. Section B and was the source for constructing the BfR entries in Table 4.

The BfR Recommendations on FCMs are not legal standards. However, they reflect the current state of science and technology for the conditions under which consumer products of high polymer materials meet the requirements of § 31.1 of the German Food, Consumer Articles and Feed Act (LFGB) and Article 3.1(a) of Regulation (EC) 1935/2004 in terms of their non-hazardousness for human health. Consequently, FCMs and articles must be produced in accordance with good manufacturing practice so that under normal or foreseeable conditions of use no ingredients are released into foods in amounts which could endanger human health.

Table 4 Listing of alternatives in the US FDA and German BfR systems

Alternative	US FDA Inventory	German BfR XXXVI
PFAS/fluorinated substances and mixtures	28 entries	12 entries
Natural greaseproof paper	Certificate of conformity required*	Certificate of conformity required*
TopScreen™ Formulations	Permitted	Permitted
Silicone oils/resins/elastomers	5 entries	Silicone listed as a coating agent

Key: * See (CEPI, 2019[51]). Note: The US FDA and BfR entries are listed in full in Table A B.1.

4.4. Drivers for development of alternatives and increasing their market share

As described in section 2.1 there has been growing concern over the potential implications of LC PFASs for human health and the environment. As a result of these concerns there have been regulatory measures to restrict the use of LC PFASs at the global and regional level (EU and US). There have also been several voluntary agreements not to use LC PFASs. Consequently, some PFAS manufacturers have switched to SC PFASs, although there is now regulatory scrutiny of specific short-chain PFASs as well. Other PFAS manufacturers, such as Chemours, have withdrawn several PFASs from the food packaging market. Alongside these developments, NGOs, the media and some governments are calling for the need to consider banning a wider range of PFASs, or even to ban PFASs as a group, with the exception of essential uses (EU, 2019[52]).

Discussions with both PFAS and non-fluorinated alternative producers have underlined that bridging the total cost of use between PFASs and non-fluorinated alternatives is the key to increasing the market share of non-fluorinated alternatives.

The acceptability of the cost differential is influenced by external pressures on PFAS materials which in turn influences the demand in the food packaging market for PFAS-free alternatives. These external pressures include NGO and/or media campaigns against PFASs. For certain PFAS this pressure is based upon health and/or environmental concerns, whilst for others in the absence of robust data sets, it is based upon the precautionary principle. Certain large retailers with well-known brands are particularly sensitive to these external pressures. Conversely, smaller retailers tend not to respond as quickly to these pressures and purchase according to price. The exception to this is if they are actively promoting fluorine-free food packaging.

One example of a response to market pressure is that of the Coop supermarket in Denmark. It has been pro-active since 2008 working with its suppliers to identify non-fluorinated alternatives for its food packaging and for other products. Since 2014 the Coop has managed to find non-fluorinated alternatives for their own brand paper and board food contact materials, as well as in other consumer goods, such as textiles.

There was agreement amongst non-fluorinated alternative contributors to this study that regulatory pressure would be the most effective tool to bridge the cost differential. For example, a restriction or ban on PFAS used in FCMs would mean that non-fluorinated alternatives such as NGP could become a leading market player in the baking paper, baking cup and potentially fast food & pet food sub sectors. Currently, for a small proportion of customers the increased cost is acceptable for those users that specifically want PFAS-free paper and/or for use in high quality baking paper applications. In the absence of PFAS FCMs, the market would have to shift to alternatives and absorb the costs increases. As mentioned in Section 3.1.3 at the consumer level this increase could be less than 0.5 cents per muffin case. In the absence of regulatory pressure, increased demand from end users or from the value chain for PFAS-free food packaging will be likely to cause a gradual shift in the market.

Other contributors to this study have commented that alternative technical solutions to paper and board grease/water resistant packaging may become more favourable in the future, possibly as a result of regulatory or the external pressures described above. For example, customers may demand that pizza deliveries are made in reusable metal boxes, rather than in oil and water repellent paper-based packaging.

Notes

[1] The US Food Services Industry State of the Industry Report 2019 (FSI, 2019) indicates significant growth in 2018.

[2] Represents 95% of European production.

[3] PFAS technology based upon a four-carbon chain.

[4] To note: as referred to previously (see section 2.1), in the EU, there is no specific harmonised regulation in place for paper and board.

Chapter 5. Status of the shift to alternatives and its sustainability

From the work carried out for this project, two trends are evident in relation to barriers to grease and water used in paper and board food packaging in OECD countries:

1. There has been a shift away from LC PFAS since 3M's announcement in 2000 (see Section 2.1);
2. The shift has predominantly been to SC PFAS, rather than non-PFAS alternatives.

Concerning (1), the shift has mainly been driven by potential health and environmental concerns associated with LC PFAS, several legal cases and pressure from NGOs. The shift away from LC PFAS has chiefly been a result of voluntary agreements by PFAS manufacturers in the US and EU, complemented by measures such as bans/restrictions via the Stockholm Convention on specific LC PFAS. The shift appears to be a total shift, with the exception of certain exempted and temporarily exempted uses. Given this background it is unlikely that this shift will be reversible in OECD countries.

Several contributors to this study have noted that in some regions such as Asia, LC PFAS continue to be used in food packaging and more widely. In such regions there is insufficient pressure to remove LC PFAS from the supply chain, unless packaging is being produced for products being supplied to OECD countries. It is also noteworthy that during discussion at the Stockholm Convention to include PFOA in Annex A, China requested an exemption.

Concerning the sustainability of the shift from LC PFAS to SC PFAS rather than to non-PFAS alternatives, it is unclear whether the current dominant market share of SC PFAS reported in this study is stable or a snapshot of an eventual transition towards non-PFAS alternatives. Manufacturers of both PFAS and non-PFAS alternatives have underlined that if there was sufficient regulatory pressure or customer demand, there would be a shift away from the SC PFAS in favour of non-PFAS alternatives. In these circumstances it is also evident from the discussions the author has had with PFAS manufacturers that they would seek to continue to occupy their dominant market position by developing non-PFAS alternatives.

A further uncertainty is the preferred choice of non-PFAS alternatives, should there be a shift to phase-out PFAS for use in food packaging. Currently, there are several contenders that have the performance capabilities (see Section 3.1) to be used across the entire range of food packaging or at least in specific segments of the market, were it not for the price differential (see Section 3.1.3). It is likely that the high performance non-PFAS alternatives highlighted in this project would enjoy an increased market share, were PFAS no longer available, or if the costs associated with the use of PFAS were increased.

Chapter 6. Policy recommendations and areas for further work

6.1. Recommendations for government authorities and international organisations

- Further disseminate information on the potential health and environmental risks of PFAS and non-PFAS alternatives.
- Consider funding research into non-PFAS alternatives, including an understanding of their functionality, costs and potential health and environmental risks.
- Consider efforts to increase awareness of the use of PFAS and non-PFAS alternatives in paper and board food packaging and the potential risks associated with them (risks include not only risks through use but also during manufacturing, transport, and fate after disposal). This should be carried out in the light of available information and the need for additional research.
- Further evaluate the possibility of a move towards grease and water repellent food packaging that is re-useable, possibly combined with a deposit system.
- Consider developing or funding a pilot programme to implement a chemical leasing approach[1] to the use of PFAS for paper and board food packaging. The present study has highlighted several important factors in the food packaging sector that currently lead to the high use of PFAS to confer grease and water repellence and very low use of non-fluorinated alternatives, including the requirement for a high level of performance and reduced costs. The same factors are also considered critical variables for the chemical leasing model.

6.2. Recommendations for industry associations and specific sectors of industry

- Evaluate options to increase the transparency of the food packaging industry and its use of PFAS/non-PFAS alternatives. This can be achieved by making scientifically robust information available publicly on intentionally used PFAS and non-fluorinated alternatives in food packaging. This can include data and information on their benefits and risks, and can be done using aggregated figures to protect confidential business information.
- Participate in future policy initiatives by international organisations, e.g., a pilot chemical leasing programme.

Notes

1 Chemical leasing represents a change to the business model between chemical supplier and user. In this model the supplier does not sell quantities of chemicals, but instead sells chemical performance and provides a service to optimise the performance of the chemicals companies (UNIDO, 2020).

Chapter 7. Uncertainties and limitations of this report

There are a number of uncertainties and limitations associated with this report. These are mainly related to the lack of publicly available information for SC PFAS and non-fluorinated alternatives. Specifically, the following information is difficult to interpret (because of how it is presented, e.g., formulations on regulatory lists), is infrequently available, or absent:

- Information on the substances and formulations which are used commercially in food packaging and those at the developmental stage
- Performance characteristics in industry standard metrics, e.g., Kit value
- Relative market share and geographical variations
- General market information on food packaging.

These limitations have influenced the methodology for the preparation of this report and the level of confidence that can be attributed to the results. However, the analysis reflects what is available in the public domain and provided by industry collaborators and is considered to reflect the current situation. In terms of representativeness, it is unclear what further information is only within the private domain. Steps were taken to fill these data gaps (see Section 1.2) where possible, and the results presented here are based upon the resulting available data set. It is possible that governments with data-gathering authorities could further collect complementary information, particularly in terms of efficacy and market penetration.

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Annex A. Contributors of Information to this Report

Table A A.1. Contributors of Information to this Report

Contributors
Australia and New Zealand **Food Standards**
Canada **Health Canada & Environment and Climate Change Canada**
Denmark **Veterinary and Food Administration**
Germany **Environment Agency**
Italy **Istituto Superiore di Sanità, Veterinary Public Health and Food Safety**
Japan **Ministry of Health, Labour and Welfare**
The Netherlands **National Institute for Public Health and the Environment (RIVM)**
Norway **Food Safety Authority**
United Kingdom **Food Standards Agency**
United States **Food and Drug Administration** **Washington State** **State of California**
European Commission
FluoroCouncil
Nordic Paper
Solenis Belgium – **Topchim NV**
ChemSec

Annex B. Overview of the regulation of PFAS (fluorinated compounds) and alternatives in paper and board food packaging in the OECD

This table has been compiled from publicly available resources and is not intended to be a comprehensive list of regulatory requirements within the OECD member countries. Instead it is indicative of the regulatory requirements for fluorinated and alternative substances and mixtures that may be used in conjunction with paper and board food packaging. The substances were generally sourced by searching for 'fluoro' in the publicly available regulatory lists. No claim is made that the fluorinated substances and mixtures listed are PFAS or otherwise. The members of the FluoroCouncil were invited to verify whether the listed fluorinated substances and mixtures are PFAS and whether these substances are currently being used to confer grease and water resistance, but this has not been carried out comprehensively. Where the intended or permitted use of the substances and mixtures is described in the regulatory listing this has been reproduced here. This table does not include substances and mixtures outside of the scope of this report (see Chapter 1.) and does not include those substances and mixtures that have been reported to be withdrawn or listed as voluntarily withdrawn from interstate commerce in the US FDA listing. All BfR listings are recommendations. In earlier versions of this Annex several listings were included for Japan. However at the time of finalising this report the Japanese Positive List was in draft form, therefore the listings for Japan have been removed. It has not always been possible to positively identify PFAS, hence the term fluorinated compounds is used instead.

The National Institute for Public Health and the Environment (RIVM), Netherlands provided a reference to their own work (Bokkers B. et al, 2018[22]) that enabled CAS numbers to be included for the BfR listings.

Table A B.1. Overview of the regulation of PFAS (fluorinated compounds) and alternatives in paper and board food packaging in the OECD

Substance	CAS number (if available)	Regulatory system	Specific limitation/use information/listing details (consult references for further details)
		Negative listing (Restrictions and prohibitions)	
Perfluorooctanesulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F)	1763-23-1	Stockholm Convention	Listed under Annex B – Restriction. Production and use to be restricted by Parties except for acceptable purposes and specific exemptions, subject to the provisions of the Annex.
Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds	335-67-1	Stockholm Convention	Listed under Annex A – Elimination. Parties must take measures to eliminate the production, use, import, and export of PFOA, its salts, and PFOA-related compounds, subject to the provisions of the Annex. Time-limited specific exemptions include, for example, invasive medical devices and fire-fighting foams in systems that are already installed.
PFOA and its salts, and related substances	335-67-1	EU REACH [Likely to be regulated by the EU POPs Regulation by 4 July 2020]	Shall not be manufactured or placed on the market as substances on their own from 4 July 2020 in a concentration equal to or above 25 ppb of PFOA including its salts or 1 000 ppb of one or a combination of PFOA-related substances.
Pefluorhexanoic acid (PFHxA)	307-24-4	Proposed EU REACH restriction	Undecafluorohexanoic acid (PFHxA), its salts and related substances shall not be manufactured, used or placed on the market as substances on their own in a concentration equal to or above 25 ppb for the sum of PFHxA and its salts or 1000 ppb for the sum of PFHxA- related substances.

C9-14 PFCAs	**375-95-1, 335-76-2, 2058-94-8 307-55-1 72629-94-8 376-06-7**	**Proposed EU REACH restriction**	**C9 – C14 Perfluoroalkyl carboxylic acids (branched and/or linear), their salts and any related substance (including its salts and polymers). Shall not be manufactured, or placed on the market in a concentration equal to or above 25 ppb for the sum of C9-C14 PFCAs and their salts or 260 ppb for the sum of C9-C14 PFCA related substances.**
PFHxS	355-46-4	Proposed EU REACH restriction	Perfluorohexane sulfonic acid (PFHxS) (linear or branched), its salts and related substances shall not be manufactured or placed on the market in a concentration equal to or above 25 ppb for the sum of PFHxS and its salts or 1000 ppb for the sum of PFHxS related substances.
PFAS (in general)	Not applicable	EU COM Recommendation 2019/794	Coordinated control plan with a view to establishing the prevalence of certain substances migrating from materials and articles intended to come into contact with food. PFOS and PFOA are being investigated.
PFAS (in general)	Not applicable	Australia & New Zealand FSC	No specific PFAS restrictions except those of the Stockholm Convention.
PFAS (in general)	Not applicable	Canada	In Canada, several PFAS (PFOS, PFOA, LC-PFCAs their salts and precursors) have been found to be potentially harmful to the environment. These substances are regulated through the Prohibition of Certain Toxic Substances Regulations (2012).
Ammonium bis (N-ethyl-2-perfluoroalkylsulfonamido ethyl) phosphates, containing not more than 15% ammonium mono (N-ethyl-2-perfluoroalkylsulfonamido ethyl) phosphates, where the alkyl group is more than 95% C8 and the salts have a fluorine content of 50.2% to 52.8% as determined on a solids basis	30381-98-7	US FDA	The FDA removed the authorization for their use as oil and water repellents for paper and paperboard for use in contact with aqueous and fatty foods.
Perfluoroalkyl acrylate copolymer, containing 35 to 40 weight-percent fluorine, produced by the copolymerization of ethanaminium, N,N,N-trimethyl-2-[(2-methyl-1-oxo-2-propenyl)-oxy]-, chloride; 2-propenoic acid, 2-methyl-, oxiranylmethyl ester; 2-propenoic acid, 2-ethoxyethyl ester; and 2-propenoic acid, 2[[(heptadecafluoro-octyl)sulfonyl]methyl amino]ethyl ester	92265-81-1	US FDA	The FDA removed the authorization for their use as oil and water repellents for paper and paperboard for use in contact with aqueous and fatty foods.

Positive listing and lists of substances authorised (Recommendations and approvals)			
Fluorinated substances			
3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, acetate and/or malate	An example of a substance covered by this entry is: 2144-53-8	BfR (Germany) Recommendations	Surface refining and coating agent: max. 1.2 %, based on the dry fibres weight. Copolymer with 2-diethylaminoethylmethacrylate, 2,2'-ethylendioxydiethyldimethacrylate, 2-hydroxyethylmethacrylate
Phosphoric acid ester of Ethoxylated perfluoropoly-etherdiol	200013-65-6		Surface refining and coating agent: max. 1.5 %, based on the dry fibres weight
Perfluoropolyetherdicarbonic acid, ammonium salt	69991-62-4		Surface refining and coating agent: max. 0.5 %, based on the dry fibres weight. The correspondingly treated papers may not come into contact with aqueous and alcoholic foodstuff
2-Propen-1-ol, reaction products with 1,1,1,2,2,3,3,4,4,5,5,6,6- tridecafluoro-6-iodohexane, de-hydroiodinated, reaction products with epichlorohydrin and triethylenetetr-amine with a fluorine content of 54 %	355-43-1		Surface refining and coating agent: max. 0.5 %, based on the dry fibres weight
3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate, or methacrylate acetate or sodium salt	An example of a substance covered by this entry is: 17527-29-6		Surface refining and coating agent: max. 0.4 %, based on the dry fibres weight. Copolymer of 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate, 2-hydroxyethyl acrylate, polyethylene glycol monoacrylate and polyethylene glycol diacrylate with a fluorine content of 35.4 %
			Copolymer with methacrylic acid, 2-hydroxyethylmethacrylate, polyethylene glycol mono-acrylate and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate, sodium salt with a fluorine content of 45.1 %

			Surface refining and coating agent: max. 0.6 %, based on the dry fibres weight. Copolymer with methacrylic acid, 2-diethylaminoethylmethacrylate, acrylic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, acetate with a fluorine content of 45.1 %
			Surface refining and coating agent: max. 0.6 %, based on the dry fibres weight. Copolymer of methacrylic acid, 2-dimethylaminoethyl methacrylate and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, acetate with a fluorine content of 44.8 %
			Surface refining and coating agent: max. 4 mg/dm2. Copolymer of 2-dimethylaminoethyl methacrylate and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, N-oxide, acetate, with a fluorine content of 45 %
			Surface refining and coating agent: max. 24 mg/dm2. Copolymer with 2-hydroxyethylmethacrylate, methacrylic acid, itaconic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, sodium salt
			Surface refining and coating agent: max. 1.0 %, based on the dry fibres weight. Copolymer with 2-hydroxyethylmethacrylate, vinyl pyrrolidone, acrylic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate, sodium salt, with a fluorine content of 41.9 %
Reaction product of hexamethylene-1,6-diisocyanate (homopolymer), converted with 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol with a fluorine content of 48 %	647-42-7		Surface refining and coating agent: max. 0.16 %, based on the dry fibres weight

N-(2-Hydroxyethyl) perfluorooctyl sulphonamide	1691-99-2	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
1-Butanesulfonic acid	29420-49-3	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Acrylic acid, ester with N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7, 8,8,8-heptadecafluoro-N-(2-hydroxyethyl)-1-octane-sulfonamide	423-82-5	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
N-(2-Hydroxyethyl) perfluorooctyl sulphonamide	1691-99-2	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
2-Propenoic acid, 2-[ethyl[(tridecafluorohexyl)sulfonyl]-amino]ethylester	1893-52-3	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
1-Butanaminium, N,N,N-tributyl-, hexafluorophosphate(1-)	3109-63-5	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
1-Octanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7, 8,8,8-heptadecafluoro	4151-50-2	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)

Acrylic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester	17527-29-6	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Ethanaminium, N,N,N-triethyl-, salt with 1,1,2,2,3,3,4,4, 5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonicacid (1:1)	56773-42-3	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
2-Propanoic acid, 2-((ethyl(pentadecafluoroheptyl)-sulfonyl) amino)ethyl ester	59071-10-2	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Fluoropolyethers ammonium phosphate salt	200013-65-6	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Glycine, N-ethyl-N-[(nonafluorobutyl)sulfonyl]-, potassium salt	67584-51-4	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Glycine, N-ethyl-N-[(undecafluoropentyl)sulfonyl]-, potassium salt	67584-52-5	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)

Glycine, N-ethyl-N-[(tridecafluorohexyl)sulfonyl]-, potassium salt	67584-53-6	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Acrylic acid, 2-[methyl[(nonafluorobutyl) sulfonyl] amino] ethylester	67584-55-8	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Glycine, N-ethyl-N-[(heptadecafluorooctyl)sulfonyl]-, potassium Salt	2991-51-7	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
Glycine, N-ethyl-N-[(pentadecafluoroheptyl)sulfonyl]-, potassium salt	67584-62-7	Switzerland FDHA	<10 ppb migration detection limit and not classified as carcinogenic, mutagenic or toxic for reproduction (CMR)
2-propenoic acid, 2-methyl-, 2-hydroxyethyl ester, polymer with 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, sodium salt .	1878204-24-0	US FDA	As an oil, water and grease proofing agent in paper and paperboard, except for use in contact with infant formula and breast milk (see Limitations/Specifications). For use at a maximum level of 1.2 % by weight of the finished paper.

Copolymer of 2-(dimethylamino) ethyl methacrylate with 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, N-oxide, acetate	1440528-04-0	US FDA	As a grease resistant treatment employed either prior to or after the sheet forming operation for paper and paperboard intended to contact food, except for use in contact with infant formula and breast milk.
2-Propenoic acid, 2-methyl-, 2-(dimethylamino)ethyl ester, polymer with 1-ethenyl-2-pyrrolidinone and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate, acetate .	1334473-84-5	US FDA	The FCS will be added at the size press or wet end to impart grease and oil resistance to paper and paperboard, except for use in contact with infant formula and breast milk.
Butanedioic acid, 2-methylene-, polymer with 2-hydroxyethyl, 2-methyl-2-propenoate, 2-methyl-2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, sodium salt .	1345817-52-8	US FDA	As an oil, grease, and water-resistant treatment for paper and paperboard. Not to exceed 1.2 percent by weight of the finished paper.
Hexane, 1,6-diisocyanato-, homopolymer, α-[1-[[[3-[[3 (dimethylamino)propyl]amino]propyl]amino]carbonyl]-1,2,2,2-tetrafluoroethyl]-ω-(1,1,2,2,3,3,3-heptafluoropropoxy)poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]]-blocked.	1279108-20-1	US FDA	As a grease resistant treatment for paper and paperboard employed either prior to or after the sheet forming operation. Not to exceed 0.6 percent by weight (on a polymer basis) of dry paper and paperboard.

2-propenoic acid, 2-methyl-, 2-hydroxyethyl ester polymer with 1-ethyenyl-2-pyrrolidinone, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate sodium salt.	1206450-10-3	US FDA	The FCS will be added at the size press or prior to sheet formation to impart grease and oil resistance to paper and paperboard. Not exceeding 1 percent of the dry fiber.
Diphosphoric acid, polymers with ethoxylated reduced methyl esters of reduced polymerized oxidized tetrafluoroethylene. This substance is also known as phosphate esters of ethoxylated perfluoroether, prepared by reaction of ethoxylated perfluoroether diol with phosphorous pentoxide or pyrophosphoric acid.	200013-65-6 162492-15-1 1314-56-3 2466-09-3	US FDA	As a water and oil repellant in the manufacture of food-contact paper and paperboard. Not to exceed 1.0 percent by weight of finished dry paper or paperboard, in contact with all food types, in microwave susceptor applications. Also for use at levels not to exceed 1.5 percent by weight of finished dry paper or paperboard in contact with all food types.
2-propenoic acid, 2-methyl-, polymer with 2-hydroxyethyl 2-methyl-2-propenoate, α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl) and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate, sodium salt.	1158951-86-0	US FDA	As an oil and grease resistant treatment for paper and paperboard employed at the size press or prior to sheet formation. Not to exceed 0.8 percent by weight of dry paper and paperboard intended for use in contact with all food types.
2-propenoic acid, 2-hydroxyethyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl), α-(1-oxo-2-propen-1-yl)-ω-[(1-oxo-2-propen-1-yl)oxy]poly(oxy-1,2-ethanediyl) and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate.	1012783-70-8	US FDA	As an oil and grease resistant treatment for paper and paperboard employed at the size. Not to exceed 0.4% by weight of dry paper and paperboard intended for use in contact with all food types.

2-propenoic acid, 2-hydroxyethyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl), α-(1-oxo-2-propen-1-yl)-ω-[(1-oxo-2-propen-1-yl)oxy]poly(oxy-1,2-ethanediyl) and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate .	1012783-70-8	US FDA	As an oil and grease resistant treatment for paper and paperboard employed at the size press. Not to exceed 0.4 weight percent of dry paper and paperboard intended for use in contact with all food types under.
2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl).	68228-00-2	US FDA	For use as an oil or grease resistant treatment for paper and paperboard intended for food-contact use not exceeding 0.2 percent of the finished food-contact paper.
2-propen-1-ol, reaction products with 1,l,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-6-iodohexane, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine as manufactured in accordance with the description in the FCN	464178-94-7	US FDA	As an oil/grease resistant sizing agent employed either prior to the sheet forming operation and/or at the size press in the manufacture of paper and paperboard. Not to exceed 0.75 percent by weight of dry paper and paperboard for food-contact (microwave heat-susceptor packaging applications only).
2-propen-1-ol, reaction products with 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-6-iodohexane, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine as manufactured in accordance with the description in the FCN	464178-94-7	US FDA	As an oil/grease resistant sizing agent employed prior to the sheet forming operation and/or at the size press in the manufacture of paper and paperboard. Not to exceed 0.75 percent by weight of dry paper and paperboard intended for use in contact with all foods.

Copolymer of perfluorohexylethyl methacrylate, 2-N,N-diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, acetic acid salt or malic acid salt.	863408-20-2 or malic acid salt 1225273-44-8	US FDA	As an oil, grease, and water resistant treatment for paper and paperboard employed either prior to the sheet forming operation or at the size press. Not to exceed 1.2 percent by weight of dry paper and paperboard intended for use in microwave susceptor applications in contact with all food types.
Copolymer of perfluorohexylethyl methacrylate, 2-N,N-diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, acetic acid salt	863408-20-2 or malic acid salt. 1225273-44-8.	US FDA	As an oil, grease, and water-resistant treatment for paper and paperboard employed either prior to the sheet forming operation or at the size press. Not to exceed 1.2 percent by weight of dry paper and paperboard intended for use in contact with all food types.
2-propen-1-ol, reaction products with 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-6-iodohexane, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine	464178-94-7.	US FDA	As an oil/grease resistant sizing agent employed prior to the sheet forming operation in the manufacture of paper and paperboard. Not to exceed 0.5 percent by weight of dry paper and paperboard intended for use in contact with all food types.
Perfluoropolyether dicarboxylic acid ammonium salt.	69991-62-4	US FDA	As an oil and water repellent employed in the manufacture of food-contact paper and paperboard either prior to the sheet-forming operation or at the size press. Not to exceed 1 percent by weight of the finished dry paper and paperboard to be used in contact with all food types.
2-propen-1-ol, reaction products with pentafluoroiodoethane-tetrafluoroethylene telomer, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine .	464178-90-3	US FDA	As an oil/grease resistant sizing agent at levels up to 0.5 percent by weight employed either prior to the sheet forming operation or at the size press for paper and paperboard intended for use in microwave heat-susceptor packaging and may be used in contact with all food types.

2-propen-1-ol, reaction products with pentafluoroiodoethane-tetrafluoroethylene telomer, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine .	464178-90-3	US FDA	As an oil/grease resistant sizing agent for paper and paperboard employed either prior to the sheet forming operation or at the size press. Not to exceed 0.5 percent by weight of dry paper and paperboard intended for use in contact with all food types.
Diphosphoric acid, polymers with ethoxylated reduced methyl esters of reduced polymerized oxidized tetrafluoroethylene. This substance is also known as phosphate esters of ethoxylated perfluoroether, prepared by reaction of ethoxylated perfluoroether diol with phosphorous pentoxide or pyrophosphoric acid.	200013-65-6 162492-15-1 1314-56-3 2466-09-3.	US FDA	As a water and oil repellent in the manufacture of paper and paperboard. Not to exceed 1.0 percent by weight of finished dry paper or paperboard, in contact with all food types, in microwave susceptor applications.
Perfluoropolyether dicarboxylic acid, ammonium salt.	69991-62-4	US FDA	As an oil and water repellent in the manufacture of food-contact paper and paperboard. Not to exceed 1 percent by weight of the finished dry paper and paperboard.
2-Propen-1-ol, reaction products with pentafluoroiodoethane-tetrafluoroethylene telomer, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine.	464178-90-3	US FDA	As an oil/grease resistant sizing agent employed prior to the sheet-forming operation in the manufacture of paper and paperboard for single use applications. Not to exceed 0.5 percent by weight of the dry paper and paperboard intended for use in contact with all food types.
Diphosphoric acid, polymers with ethoxylated reduced Me esters of reduced polymerized oxidized tetrafluoroethylene. This substance is also known as: phosphate esters of ethoxylated perfluoroether, prepared by reaction of ethoxylated perfluoroether diol.	162492-15-1 with phosphorous pentoxide 1314-56-3 or pyrophosphoric acid 2466-09-3.	US FDA	As a water and oil repellent in the manufacture of paper and paperboard. Not to exceed 1.5 percent by weight of finished dry paper or paperboard in contact with all food types.

Fluorinated polyurethane anionic resin prepared by reacting perfluoropolyether diol, isophorone diisocyanate, 2,2-dimethylolpropionic acid, and triethylamine.	328389-91-9 88645-29-8, 4098-71-9, 4767-03-7, 121-44-8.	US FDA	As a water and oil repellent in the manufacture of paper and paperboard. Not to exceed 1.5 percent by weight of the finished dry paper and paperboard.
Hexane, 1,6-diisocyanato-, homopolymer, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol-blocked.	357624-15-8.	US FDA	As an oil and grease resistant treatment for paper and paperboard employed either prior to the sheet forming operation or at the size press. Not to exceed 0.18 percent by weight of dry paper and paperboard intended for use in contact with all food types under.
2-propenoic acid, 2-methyl-, polymer with 2-(diethylamino)ethyl 2-methyl-2-propenoate, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, acetate	1071022-26-8	US FDA	As an oil and grease resistant treatment for paper and paperboard employed either prior to or after the sheet forming operation. Not to exceed 0,8 percent by weight of dry paper when applied prior to the sheet forming operation, or 0.42 percent by weight of dry paper and paperboard when applied after sheet formation. The finished product is intended for use in contact with all food types (microwave susceptor applications only).
2-propenoic acid, 2-methyl-, polymer with 2-(diethylamino)ethyl 2-methyl-2-propenoate, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, acetate.	1071022-26-8	US FDA	As an oil and grease resistant treatment for paper and paperboard employed either prior to the sheet forming operation or at the size press. Not to exceed 0.42 % by weight of dry paper and paperboard intended for use in contact with all food types under (microwave susceptor applications only).

Non-fluorinated substances			
TopScreen™ formulations	Confidential business information.	Confidential business information.	Confidential business information.
Natural greaseproof paper (NGP)	CAS numbers not applicable	German BfR & US FDA	NGP does not have its own entries in the BfR or US FDA lists but instead producers have obtained certificates of conformity with these regulatory regimes.
Silicone oils with special additives after Section I, No. 3 of Recommendation XV and/or silicone resins or silicone elastomers (silicone rubber)	Not provided	German BfR	Specific silicone-related requirements apply.
Natural and synthetic cellulose fibres bleached or unbleached.	Not applicable.		Raw material.
Wood pulp bleached or unbleached.	Not applicable.		Raw material.
Recycled fibres made from paper or paperboard.	Not applicable.		Raw material. Migration limits for certain specified substances in accordance with the requirements laid down in article 3 of regulation 1935/2004/EC.

Silicone-based food contact substances	Food Contact Notification (FCN) numbers: FCN 41 & 369 (CAS Reg. Nos. 7473-98-5 and 155419-56-0) FCN 76 (CAS Reg. No. 2855-27-8), FCN 826 (CAS Reg. No. 102782-94-5 FCNs 934 & 1006 (CAS Reg. No. 917773-10-5).	US FDA	These silicone-based food contact substances may be employed in coatings on paper and paperboard as release agents. These authorizations are not specifically for grease-proofing paper and paperboard, however these silicone substances may be used as alternatives in some applications currently using PFAS food contact substances.

Key:

Australia & New Zealand FSC: Australia & New Zealand Food Standards Code.

BfR Germany: German Bundesinstitut für Risikobewertung recommendations for consumer products that meet the requirements of § 31.1 of the German Foods, Consumer Articles and Feed Act.

Switzerland FDHA: Annex 10 of Federal Department of Home Affairs on food contact materials.

US FDA: US Food and Drug Administration; Title 21 Code of Federal Regulations Part

This report addresses the commercial availability and current uses of alternatives (chemical and non-chemical) to per- and polyfluoroalkyl substances (PFASs) in food packaging (paper and paperboard).

PFASs are synthetic substances that are widely used in numerous technologies, industrial processes and everyday applications. Since the discovery of polytetrafluoroethylene (PTFE) in 1938, PFASs, both polymeric and non-polymeric, have been used extensively in various industries world-wide, due to their dielectrical properties, resistance to heat and chemical agents, low surface energy and low friction properties, etc. Due to the large variety of PFAS substances captured in the OECD definition, the individual PFAS will have different properties, however, in general, the highly stable carbon-fluorine bond and the unique physicochemical properties of PFASs make these substances valuable ingredients for products with high versatility, strength, resilience and durability.

Based upon this review, a number of policy recommendations are suggested in this report as well as areas that may be considered for further work. These have been divided into those aimed at international organisations and those aimed at industry.

oe.cd/pfass