Report summary food contact materials and packaging

Contents

Introduction

The report investigates the use of PFAS in food contact materials (FCM) and packaging, covering the following applications:

- Food contact packaging in which PFAS are largely used to confer oil and grease resistance. Generic packaging in which PFAS is assumed to be used (plastics mainly) is also described;
- Consumer cookware in which PFAS primarily provide non-stick surfaces;
- Industrial food and feed production equipment in which PFAS are used for non-stick surfaces.

The scope of the work covers the manufacture of goods in each sector and the use of those goods. Production of PFAS and management of materials at end of life (waste stage) are addressed in separate reports.

1. Uses / Applications

Below the main uses for the applications are described whereby three main topics are distinguished: Packaging (and other paper applications), consumer cookware and industrial applications.

1.1 Packaging

- Food packaging
    - Greaseproof paper;
    - Baking papers;
    - Heat resistant packaging;
    - Other food packaging.
- Feed packaging
    - Pet food;
    - Agricultural feed.
- Other (generic) packaging
    - Paper and board (P&B) for non-food/feed applications;
    - Other packaging (plastic, glass, metal) for non-food/feed applications;
    - Folding packaging cartons, carbonless forms, masking papers, tablecloths and wall papers;
    - Coating of beverage cans;
    - Sheets for protecting new cars.

1.2 Consumer cookware

Non-stick coatings for:

- Frying pans;
- Ovenware;
- Sauce pans;
- Cooking plates in electric gadgets such as sandwich toasters, waffle irons.

1.3 Industrial applications

One of the main uses for PFAS in food processing lines is to provide a non-stick coating to conveyor belts, using PTFE or polyvinylidene fluoride (PVDF). Other uses:

- Ovenware (including recoating services)
- Variety of components:
    - Seals, O-rings, gaskets;
    - Tubing and pipes;
    - Expansion joints;
    - Valves and fitments;
    - Conveyor belting, chutes, guiding rails, rollers, funnels and sliding plates;
    - Tanks, funnels, roller (etc.) linings;
    - Blades of knives and scissors;
    - Springs;
    - Filter membranes and sensor covers;
    - Lubricants.

2. Main PFAS substances

2.1 Packaging

The majority of substances are fluorosurfactants, mostly telomeric, either as such or as side-chains of polymers.

- Telomeric sulphonamides e.g. perfluorooctyl sulphonamide;
- Sulphonic acids e.g. perfluorobutane sulphonic acid;
- Fluorotelomer alcohols (phosphate diesters, diPAPs) e.g. (8:2 FTOH) di-phosphate;
- Perfluoroalkyl phosphonic acids (PFPAs);
- Propenoic/butanedioic/heptanoic acid esters and as side-chains on a polymer;
- Polyacrylates with perfluorinated side-chains;
- Fluorosilicone/siloxanes.

2.2 Consumer cookware

- Gen-X - emulsifier, polymer processing aid (PPA)
- Fluoropolymers/Monomers:
    - Ethylene or tetrafluoroethylene (TFE)-based:
        - PTFE;
        - Ethylene TFE (ETFE);
        - Ethylene chlorotrifluoroethylene (ECTFE).
    - Propylene-based
        - FEP (perfluoroethylene propylene);
        - Hexafluoropropylene variations.
    - Polyvinylidene fluoride (PVDF) – based
        - Perfluoroalkyl vinyl ethers e.g. PFMVE;
        - Copolymers of hexafluoropropylene;
        - PTFE copolymers.
    - PFA (perfluoroalkoxy ethanes).
        - Fluorosilicones/siloxanes.
        - Perfluoroelastomers (terpolymers) (liquid processing systems).

2.3 Industrial applications

The PFAS substances most often used now in industrial processing include PTFE (known as Teflon), FEP, PFA and ethylene tetrafluoroethylene (ETFE) (co-polymers of ethylene and tetrafluoroethylene known as Tefzel).

- Gen-X - emulsifier polymer processing aid (PPA)
- Fluoropolymers /Monomers:
  - Ethylene or tetrafluoroethylene (TFE)-based:
    - PTFE;
    - Ethylene TFE (ETFE);
    - Ethylene chlorotrifluoroethylene (ECTFE).
  - Propylene-based
    - FEP (perfluoroethylene propylene);
    - Hexafluoropropylene variations.
  - Polyvinylidene fluoride (PVDF) – based
    - Perfluoroalkyl vinyl ethers e.g. PFMVE;
    - Copolymers of hexafluoropropylene;
    - PTFE copolymers.
  - PFA (perfluoroalkoxy ethanes);
  - Fluorosilicones/siloxanes;
  - Perfluoroelastomers (terpolymers) (liquid processing systems).

Below in table 1 some (indicative) substances used in food contact material are mentioned. .

Table 1: Substances (indicative list with some examples) used in food contact material.

Substance Name	Abbreviation	CAS Number	Chemical Formula	Use	Function / Regulatory Listing
2,3,3,3-tetrafluoro-2-heptafluoropropoxy)-propinoic acid; *or* perfluoro[2-(n-propoxy)propanoic acid]	GenX, HFPO-DA, FRD-903	13252-13-6	$C_6HF_{11}O_3$	Consumer and industrial cookware	PPA in Reg. 10/2011. Substitute for PFOA
Polytetrafluoroethylene; *a polymer of*: tetrafluoroethylene	PTFE (Teflon)	9002-84-0 116-14-3	$(C_2F_4)_n$ C_2F_4	Cooking and baking equipment	Monomer listed in Reg 10/2011 Polymer for coating cookware, such as coatings on frying pans and articles for oven baking, and moulded articles for industrial use.
Silicone Rubber, fluorinated	No data	64706-30-65	No data	Liquid processing equipment	No data
Perfluoroalkyl(C6-C16) phosphates of bis(2-hydroxyethyl)amine or Diethanolamine salts of mono- and bis(1H,1H,2H,2H-perfluoroalkyl(C8-C18) phosphates [mono- and di-PAP, FT]	No data	65530-64-5	NH2+(CH2CH2 OH) (O)P(O-) (OCH2CH2 CnF2n+1)2	Food, nonfood & feed packaging	Additive

3. Manufacturing & market price + market development

Food and drink is the largest manufacturing sector in the European Union (EU) in terms of turnover, value added, and employment, making a 2.1% contribution to EU gross value added (Food Drink Europe, 2019). It was estimated that the food and beverage sector accounted for 15% of turnover and some 13% added value of the EU manufacturing industry in 2012. The sector involves 291,000 companies, employing some 4.82 million people and generating a turnover of €1.2tr as of 2017 (Food Drink Europe, 2020). Exports outside the EU account for 10% of the turnover of the food and drink sector (€120 billion out of a total turnover of €1.2 trillion/year) (Food Drink Europe, 2019).

Import & Export:

No import data was available. Exports outside the EU account for 10% of the turnover of the food and drink sector (€120 billion out of a total turnover of €1.2 trillion/year) (Food Drink Europe, 2019). No differentiation for the three topics could be made.

3.1 Packaging

Paper and board packaging use in packaging has been relatively steady in the EU since 2015 (CEPI, 2020). In 2015, 38.95 million tonnes of paper were consumed in the EU for packaging, whilst in 2019 this figure had risen to 41.35 million tonnes, representing a compound annual growth rate of 1.5% per year.

Market size was $3.7 billion in 2020 growing 3%, $4.9 billion by 2025. Overall, some factors suggest the market for PFAS in packaging could grow whilst others suggest the market could shrink.

Paper and board packaging tonnages were based on CEPI information. See table 2.

Table 2: Paper and Board Consumption for Food and Feed & Generic Packaging in Europe in 2019 (CEPI, 2020)

	Quantity (Million tonnes)
Case materials	28.4
Carton board	6.2
Wrappings	2.6
Other paper and board for packaging	4.2
Total	**41.4**

It is observed that increased recycling of goods contaminated with PFAS will lead to spread of PFAS throughout all of the paper and board market.

For plastic packaging tonnages, tonnages information is widely available (in contrast to possible PFAS content information). According to Geyer, Jambeck & Law (Geyer, Jambeck, & Law, 2017) there is a strong upward trend in global plastic production, including packaging material. See figure 1 below.

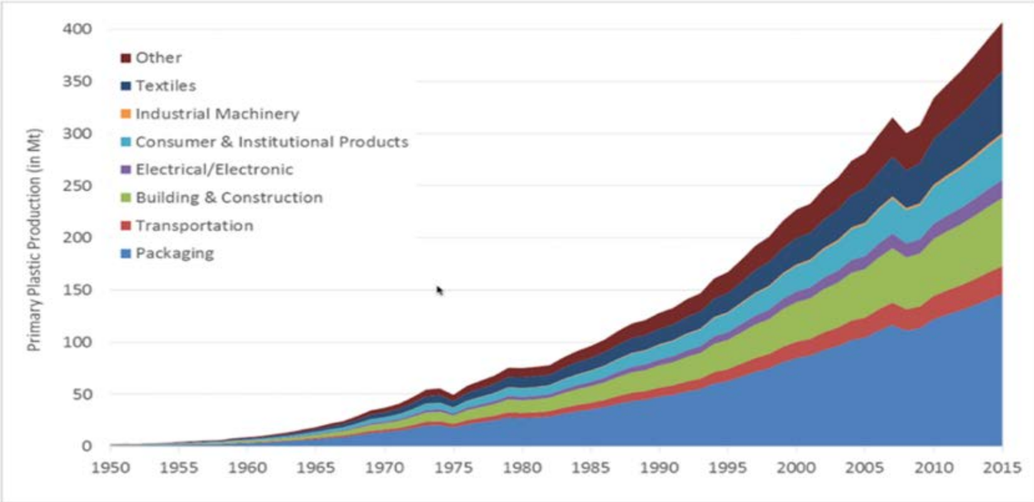

Figure 1: Global Trend in Plastic Demand 1950 – 2015. Source: (Geyer, Jambeck, & Law, 2017)

Regarding the packaging part of plastics the information from ING, 2019 has been used. See figure 2.

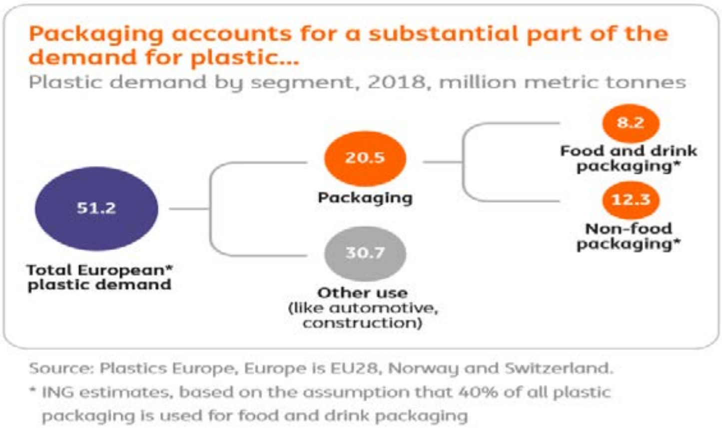

Figure 2: Plastic Packaging as a Proportion of total Plastic Demand in Europe. Source (ING, 2019)

Increased demand for plastics and paper and board for packaging appears from industry surveys. It has to be mentioned that The Single Use Plastic Directive could lead to more moulded fibre food packaging nearly all of them containing PFAS.

Market price & autonomous market development:

No detailed information on market prices. There is information on price-differences to alternatives (see the Alternatives chapter). The autonomous market development see also the tables in the Annex.

No. of production sites:

No specific information available.

3.2 Consumer cookware

It has been estimated, based on Plastics Europe information, that 3,500 tonnes of fluoropolymers (FPs) were sold into the cookware market of the EU28 in 2015, representing sales of €60 million to the FLUOROPOLYMER industry and with associated goods generating a production value of €2 billion (AFW, 2017). The figure of €60 million represented just under 8% of the FLUOROPOLYMER market in the EU for 2015 (AFW, 2017)

The global non-stick cookware market is estimated to be growing strongly at rates around 5% to 7% per year and it is estimated that it will be worth $12.5 billion by 2025 (Grand View Research, 2019; IndustryARC, 2020). Within this, the market for 'ceramic' products that do not use PFAS is anticipated by the same source to be growing around 6.9% per year (Grand View Research, 2019)

It is concluded that the likely trend in the EU consumer cookware market for the next decade in the absence of a restriction will be for use of Fluoropolymers to be maintained at existing levels, around 3,500 tonnes annually (AFW, 2017).

For EU the best baseline is for constant demand in this sector in the coming years, broadly in line with stakeholder opinion. There is growth in demand for alternative non-sticks (particularly ceramics) which could fill growth in demand for non-sticks within Europe.

Market price & autonomous market development:

No detailed information on market prices. There is information on price-differences to alternatives (see chapter on Alternatives). For autonomous market development see also the tables in the Annex.

No. of production sites:

No specific information available.

3.3 Industrial applications

There is potential for some growth in the market for PFAS particularly on the component side (rather than coatings) given stricter legislation on food quality and the use of more severe conditions for cleaning and sterilisation of food processing equipment. Estimated growth ranges in the order of 10-20% by 2025 relative to 2015. A future estimate of growth of 1-2% seems appropriate. Applied to the 3,000 tonnes per year usage for the EU28 in 2015 (AFW, 2017), demand would increase to between 3,300 and 3,700 tonnes per year (noting that this range covers both food and pharmaceutical operations, and that it has not been possible to disaggregate the quantities for each application).

Market price & autonomous market development:

No detailed information on market prices. There is information on price-differences to alternatives (see the Alternatives chapter). For autonomous market development see also the tables in the Annex.

No. of production sites:

No specific information available.

4. Tonnage

4.1 Packaging

<u>Paper and board (P&B) packaging</u>

EEA-wide tonnage figures of PFAS used in paper and board food packaging in this project have not been identified in the literature or from stakeholders. Instead, the PFAS tonnages utilised as a basis for deriving emission estimates have been calculated from available data with a number of assumptions applied. The sources of data for estimating PFAS tonnages in Paper & Board (P&B) packaging are as follows and the data used are tabulated in the below table 3.

Table 3: Summary of Data Used for Estimating PFAS (Surfactants) Tonnage in Paper and Board Food Packaging

	Geographical Coverage	**Data**		**Source**
			Tonnes	
Total P&B Packaging Consumption (That may be used in food & feed contact i.e. closest disaggregated categories to food packaging)	EU-27 & United Kingdom (UK) & Norway (NO)	Carton Board	6,169,000	(CEPI, 2020) Data from 2019
		Wrapping	2,647,000	
		Sum of above	**8,816,000**	
		Case materials	28,369,000	
		Other P&B packaging	4,166,000	
		Total	**41,351,000****	
Total organic fluorine content of supermarket food packaging e.g. popcorn bags, cookie bags, pizza boxes, greaseproof paper.	UK	95% of the packaging had fluorine content	Range of fluorine content (mg/kg or g/tonne): Average = 537 Maximum = 1200	(Fidra, 2020)
Paper and paperboard food wrappers from fast food restaurants	US	46% food contact papers and 20% paperboard samples have detectable fluorine		(Schaider et al, 2017)
Permitted concentrations of PFAS in paper and board food packaging	EU and US	EU(BfR): 0.5 – 1.2% US FDA typically 0.5% Call for evidence 0.4 – 1.0%	Range is: 0.4 – 1.2% (dry weight)	(BfR, 2020b) (U.S. Food and Drug Administration, 2021)
Estimate of the proportion of total* paper packaging that contains PFAS	Not specified (assumed EU)	Up to 1% (assume 0.5 – 1.0%)		(RIVM, 2020a)

Notes: *Presumed to be packaging that may come into contact with food, rather than generic (packaging for non-food items) packaging; **Assumed to include feed and food contact P&B

In the table below, based on Paper & Board packaging tonnages and average PFAS content (see table 3), PFAS quantity is calculated

Table 4: Estimates of Intentionally Added PFAS in Total P&B Packaging for Different Assumptions According to in EU-27 & UK & NO 2019

Proportion of Total P&B with PFAS (%)	**Quantity of P&B*** (tonnes)	**Permitted Level PFAS** (%)	**Quantity of PFAS** (tonnes)
0.5	206,755**	0.4	827
	206,755	1.2	2,481
1.0	413,510**	0.4	1,654
	413,510	1.2	4,962

*: Based on total Paper and Board (P&B) Packaging consumption = 41.351,000 tonnes.
**: See also calculation below
Range of P&B packaging containing PFAS:
If 0.5% of the total P&B packaging consumed
contains PFAS (RIVM, 2020a) = 0.5/100 x 41,351,000
= 206,755 tonnes of P&B packaging
If 1.0% of the total P&B packaging consumed
contains PFAS (RIVM, 2020a)
= 1.0/100 x 41,351,000
= 413,510 tonnes of P&B packaging
i.e. the quantity of P&B packaging containing PFAS in 2019 was 206,755 – 413,510 tonnes

For comparison purposes, the quantities of PFAS in P&B food packaging were estimated in addition using a different starting assumption i.e. the fluorine content of the P&B packaging. From (Fidra, 2020), the quantity of fluorine that is present in P&B packaging is a *maximum* of 1200 mg/kg (equivalent to g/tonne) or an *average* of 537 g/tonne. These two figures have been used to derive a range of the total quantity of PFAS in wrapping and board packaging. To estimate the PFAS content of P&B packaging an approximation of the PFAS content has been derived assuming the fluorine content is 50% of the total molecular weight. This is based upon an estimated average value assuming the PFAS present can be molecules such as perfluorohexanoic acid (PFHxA) (fluorine content 66%), or side-chain polyacrylates e.g. polymethacrylate (fluorine content is 12.8% (Wenqiang, 2014)) that was also utilised in the proposed restriction for PFHxA (ECHA, 2020b). See table 5 for the results.

Table 5: Estimates of PFAS in Carton Board and Paper Wrapping Packaging for Different Assumptions Based on Detected Fluorine Levels in EU-27 & UK & NO 2019

Proportion of Wrapping and Carton board with PFAS (%)	**Quantity of carton and wrapping*** (tonnes)	**Quantity with PFAS**** (tonnes)	**Detected fluorine concentration**† (g/tonne)	**Quantity fluorine in paper or board**$ (tonnes)	**Quantity of PFAS**†† (tonnes)
46 (paper)	2,647,000	1,217,620	537	654	1,308
	2,647,000	1,217,620	1200	1,461	2,922
95 (paper)	2,647,000	2,514,650	537	1,350	2,700
	2,647,000	2,514,650	1200	3,018	6,036
20 (board)	6,169,000	1,233,800	537	663	1,326
	6,169,000	1,233,800	1200	1,481	2,962

Notes:

- * from Table 3
- **(column 1 /100) x column 2
- † maximum and average concentration of fluorine detected in supermarket and fast food restaurant P&B packaging (Fidra, 2020)
- ††Quantity of PFAS is calculated from the fluorine content assuming fluorine comprises 50% of the molecular weight

Without further information to enable a more accurate analysis, the upper and lower bound of each of the ranges of tonnages from table 4 and 5 have been utilised to estimate emissions during the service-life of paper and board packaging.

Generic plastic packaging

Publicly available data on the quantities of plastic packaging that contains PFAS have not been identified. Expert judgement estimates of the quantity of plastic packaging that contains PFAS (residues) is approximately maximum 0.1% (RIVM, 2020a). Applying this expert judgement and assuming the use of PFAS would be mainly in plastics with food contact:

4.2 Consumer cookware

Pharmaceutical applications are outside of the scope of this report and because the data for this segment are not broken down further in (AFW, 2017)[1], the quantity of 3,000 tonnes is an over-estimate of the total amount of Fluoropolymers used in the food industry. These data cover EU-28 (i.e. including the UK) and include imported Fluoropolymers as well as those manufactured in the EEA.

Table 6 Tonnage data (2015) Used for the Emission Estimates from Fluoropolymers (AFW, 2017)

Market Segment	**Quantity of Fluoropolymers Sold** (tonnes)
Consumer Cook and Bakeware	3,500
Industrial Food Production and Pharmaceuticals	3,000

From the description in (AFW, 2017) this data does not include any polymer processing aids (PPAs) that have been used in the production of Fluoropolymers, except it can be assumed any present as an impurity in the final Fluoropolymer.

4.3 Industrial applications

Tonnages of Fluoropolymers are disaggregated to some degree in (AFW, 2017). For the industrial use category ‘food and pharmaceuticals’, 3,000 tonnes of Fluoropolymers were sold in the EU-28 in 2015. Unfortunately, this figure has not been able to be further disaggregated to provide a split between the food and pharmaceutical sectors. Given the uncertainties, the tonnage and emission estimates described should be regarded as indicative only.

The yearly European Economic Area (EEA) PFAS tonnages used are summarised for the three applications. Emissions to the environment are also mentioned in the scheme below.

Sub uses	**Tonnages/y**
Packaging	827 - 4.962
Consumer cookware	3.500
Industrial applications	3.000

[1] Plastics Europe has not been able to provide any further disaggregated data.

5. **Emissions product manufacturing and product use**

5.1 Packaging, consumer cookware and industrial applications

Because PFAS emission data are not generally available, one method that has been employed in the current report is to derive emission estimates using the so-called 'standard REACH methodology', which is set out in ECHA's R.16 Guidance (ECHA, 2016). Estimates presented here are derived using the first level (tier 1) methodology. This relies upon having tonnage data for the substance(s) of interest at the relevant point in the life cycle of that substance. In table 7 the emissions during manufacturing of Paper & Board are presented. In table 8 the emissions during service life of Paper & Board are presented.

Table 7: Summary of Estimated PFAS Emissions from the Manufacture of Paper and Board Packaging (2019), Consumer and Industrial Cookware

Material	**Method Used**	**Addition/Detection**	**PFAS Emissions from Use at an Industrial site** (tonnes/year)			**Total Emissions*** (tonnes/year)
			Air	Water	Soil	
Paper and Board Food Packaging in EU-27 & UK & NO(2019) (Surfactants)	Quantitative REACH Methodology (ECHA, 2016) Calculated using Environmental Release Category (ERC) 5	Intentionally** added lower	471.5	471.5	9.4	943.0
		Detected† higher	3440.5	3440.5	68.8	6,881.0
	Quantitative Emissions from P&B manufacturing (FDA, 2010)	Intentionally** added	No data	11.3 – 82.6	101.8 – 743.1	113.1 – 825.7
Consumer and Industrial Cookware (EEA) (Fluoropolymers excluding polymer processing aids)	Qualitative	Intentionally added	No quantitative data	No quantitative data	No quantitative data	Very Low

Notes:
*Sum of emissions to individual environmental compartments
**i.e. added during the papermaking process during this revolution of the papermaking-recycling loop, †Detected by measuring total fluorine concentration in food packaging, so includes PFAS from current and possibly previous revolutions of the papermaking-recycling loop. Shaded data used in in tonnage flow diagrams (Figure 3).

Table 8: Summary of Estimated PFAS Emissions from Articles During their Service-life (Indoors and Outdoors)

Material	Use*	Addition/ Detection	Total PFAS Emissions from widespread use ERC 10a (Outdoor) (kg/year)			Total Outdoor Emissions$ (tonnes/year)	Total PFAS emissions from widespread use ERC 11a (Indoor) (kg/year)			Total Indoor Emissions$ (tonnes/year)
			Air	Water	Soil		Air	Water	Soil	
Paper and Board Food Packaging in EU-27 & UK & NO (2019) (Surfactants)	Total paper and board food packaging	Intentionally added lower**	21 – 41	1,323 – 2,646	1,323 – 2,646	2.7 – 5.3	21 - 41	21 - 41	Not applicable	0.0 – 0.1
		Intentionally added higher†	62 – 124	3,970 – 7,939	3,970 – 7,939	8.0 – 16.0	62 – 124	62 – 124	Not applicable	0.1 – 0.3
	Consumer Food Wrappings	Detected lower	33 – 73	2,093 – 4,675	2,093 – 4,675	4.2 – 9.4	33 – 73	33 – 73	Not applicable	0.1 – 0.2
		Detected higher	68 – 151	4,320 – 9,658	4,320 – 9,658	8.7 – 19.5	68 – 151	68 – 151	Not applicable	0.1 – 0.3
	Consumer Food Carton Board Packaging	Detected lower	33	2,122	2,122	4.3	33	33	Not applicable	0.1
		Detected higher	74	4,739	4,739	9.6	74	74	Not applicable	0.2
Fluoropolymers Sold in EU-28 (2015) (Fluoropolymers excluding polymer processing aids)	Consumer Cook and Bakeware	Not applicable	88	5,600	5,600	11.3	88	88	Not applicable	0.2
	Food and Pharma Industry Use††	Not applicable	75	4,800	4,800	9.7	75	75	Not applicable	0.2

Notes: PFAS used in paper and board packaging are surfactants (telomers and polymers with telomeric side-chains; PFAS used in consumer and industrial cookware are fluoropolymers. Data from polymer processing aids has not been included, except for impurities. The emission estimates of PFAS from Fluoropolymers in this table are based upon EU-28 consumption data that excludes exports but included imports.

*For each of the uses different estimates are derived based on different assumptions i.e. all the emission estimates are not intended to be summed up, however the results of the comparable estimations have been used to derive ranges. **derived from the lower end of a range of figures, † derived from the higher end of a range of figures, ††The source data includes Fluoropolymer use in the pharmaceutical industry that is not in the scope of the report but cannot be separated out. Therefore, the resulting emissions can be over-estimates. Shaded data used in tonnage flow diagrams (Figure 4).$ Emissions from outdoor and indoor uses should not be summed together; instead, they represent possible emissions if the total tonnage is used either outdoors or indoors.

Re-coating emissions not mentioned here but plotted in figure 4 and explained in table 9

Below a tonnage and emission flow chart for paper and board packaging (the main packaging use where PFAS is applied) is plotted

Estimates either from total P&B consumption (right branch) or from data for carton board and wrapping packing (left branch) result in reasonably similar estimates of the total PFAS tonnage flows from manufacturing to recycling or waste disposal.

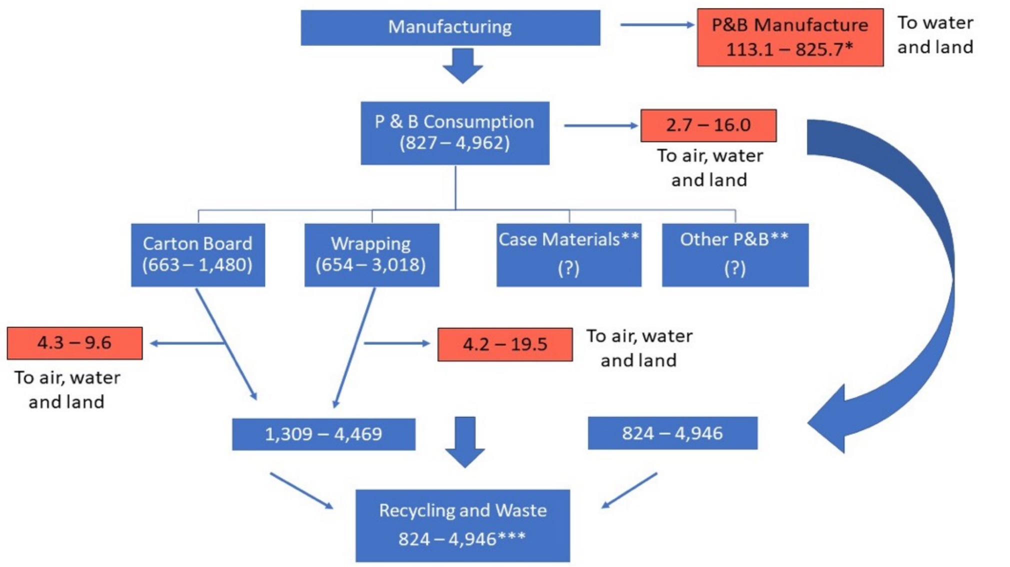

Figure 3: Indicative PFAS (surfactant) tonnage flows (tonnes/year) for <u>paper & board packaging</u> in 2019 (EU-27 & NO & UK)

<u>Notes for Figure:</u>
Values in red boxes are emissions of PFAS/year. Emissions of PFAS from the service-life of packaging are based solely on outdoor use and represent a worst-case scenario. Outdoor emissions could be considered to include emissions from litter
Values in blue boxes are tonnage flows of PFAS from manufacturing through the service-life of products to waste/recycling.

- *Emissions from paper and board (P&B) manufacturing represent a reasonable worst-case scenario.
- ** It has not been possible to clarify the quantities of PFAS in vase materials and other P&B.
- ***The quantities of PFAS going to waste/recycling is either 1,309 – 4,469 tonnes or 824 – 4,926 tonnes, depending upon the starting point for the estimate - either right or left branch.

For indicative purposes, the widest range of tonnages is indicated. (CEPI, 2020) notes 72% of P&B packaging is recycled in EU-27 & NO & UK. There may be PFAS in case materials and other P&B packaging, but no data has been identified to support this. Polymer processing aid emission are not included, except for impurities.

The data on PFAS in generic packaging are scarce and during the extensive stakeholder consultation to prepare the report, data returns on this issue have been very low. Nevertheless, on the basis of available data, emissions of PFAS from generic packaging has been addressed in a qualitative manner.

PFAS emissions from the manufacturing of P&B food and feed contact materials have been estimated using:

- The REACH methodology (ERC's) and
- Data that is available from PFAS entries in the US Inventory of Effective Food Contact Substance (FCS) Notifications (U.S. Food and Drug Administration, 2021) for large US P&B manufacturing plants. The US FDA data is based upon information from the P&B industry and is therefore expected to be more representative of real life than the generic approach of the REACH methodology.

Below a tonnage and emission flow chart for consumer cookware and industrial cookware is plotted.

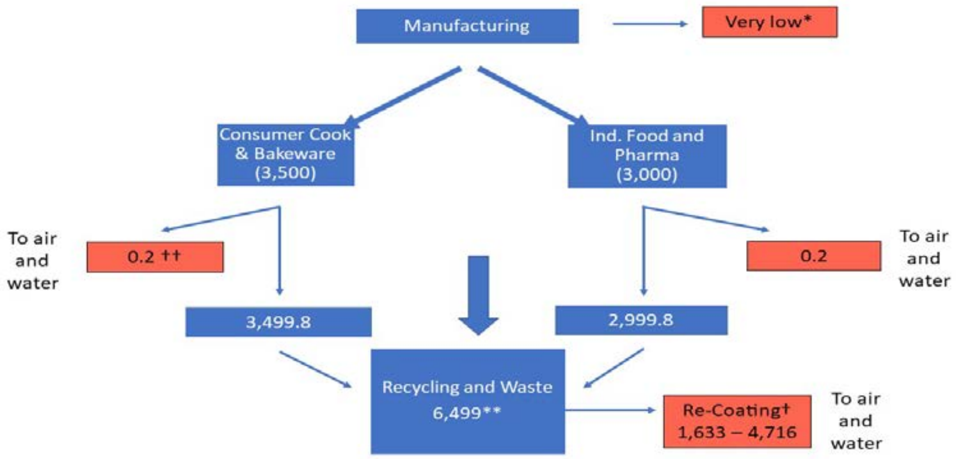

Figure 4: Indicative PFAS (Fluoropolymers) Tonnage Flows (Tonnes/year) For <u>Consumer Cookware and Industrial Food Products</u> in 2015 (EU-28)

<u>Notes for Figure:</u>
Values in red boxes are emissions of PFAS (fluoropolymer)/year. Emissions of PFAS during their service-life when used in the food industry are based solely on indoor use and represent a reasonable worst-case scenario. Values in blue boxes are tonnage flows of PFAS from manufacturing through the service-life of products to waste/recycling. Emissions from the service-life of consumer cookware and industrial products is a very small proportion of the overall quantity of PFAS flow. PFAS removed from re-coating appears to be a much larger proportion. The remaining quantities have been expressed with a decimal point to indicate the prior emissions and do not reflect their accuracy.

- * Emissions from manufacturing are estimated on a qualitative basis and are for normal operating conditions.
- ** The total quantities of PFAS going to the waste/recycling phase of the life cycle are summed for indicative purposes (note this is an over-estimate). PFAS-coated metal cookware is generally recycled at the end of its life to reclaim the valuable metal (STO, 2020-21).
- † Emissions from re-coating industrial cookware are a worst-case scenario estimate.
- †† Qualitative evidence suggests losses from consumer cookware could be 10% or more. Polymer processing aid emissions are not included, except for impurities.

No publications have been identified that indicate the quantity of Fluoropolymer lost during cookware use by consumers. However, numerous examples have been found online on consumer websites of pans that have clearly lost a significant part (10%* or more) of the Fluoropolymer-coating during use, revealing the bare metal.

*: 10% of 6,500 = 650, with an average life span of approximately 5 years, leads to 130 tonnes/y. This is emitted to the environment.

During the preparation of the report, re-coating has been seen as a potential emission source. Comprehensive data on the quantities of Fluoropolymers removed from industrial cookware for recycling purposes (which is then re-coated) have not been identified. However, in Sweden, information was available and has been extrapolated. Given the uncertainties with the tonnage and emission estimates, the values should be regarded as indicative only.

Table 9: Data Used to Calculate the Quantities of PTFE in Industrial Cookware

Parameter	Quantity	Source
Pans re-coated in Sweden each year**	20,000*	(RIVM, 2020b)
Total surface area of the Swedish pans	500,000 sq. metres	(RIVM, 2020b)
Population of Sweden	10.38 million	(Statista, 2020)
Population of EEA (without UK)	453,500,612	(Eurostat, 2020a)
Density of PTFE	2.16 g/cubic cm	(WSH, 2021)
Average coating thickness	35 – 100 µm	(PTFE Coatings, 2021)

Notes: *Assumed to be number of units stripped and re-coated per year; **Assumed to be in all of Sweden, i.e. not one operators' data.

i.e. in Sweden each year between 37.8 – 108 tonnes of PTFE are removed from industrial bakeware.

In the table below, the PFAS emissions for packaging, consumer cookware and industrial cookware are presented.

Table 10: Key Findings from the Exposure Assessment – Emissions of PFAS & methods used

Life-Cycle Phase and Activity	PFAS Emission Estimate (tonnes/year)	PFAS Type ***	Coverage	Estimation Scenario	Methodology	Other Details
Service-life of P&B FCM Packaging	2.7 – 19.5	Telomers and polymers with side-chain telomers	EU-27 & UK & NO	Worst-case	REACH*	Based on outdoor emissions
Service-life of Consumer Cookware	0.2**	Fluoropolymers	EU-28	Reasonable worst-case	REACH	Based on indoor emissions
Service-life of products used in the food industry	0.2†	Fluoropolymers	EU-28	Worst-case	REACH	Based on indoor emissions
Manufacturing of P&B FCM Packaging	113.1 – 825.7	Telomers and polymers with side-chain telomers	EU-27 & UK & NO	Reasonable worst-case	Calculation from stakeholder data	Based on data for large installations in the US
Manufacturing Consumer Cookware and Products used in	Very low	Fluoropolymers and PPAs	EEA	Normal operating conditions	Estimation from stakeholder data	Qualitative assessment
Re-coating Industrial Cookware	1,633 to 4,716	Fluoropolymers and PPAs	EEA	Worst-case	Calculation from stakeholder data	Calculation is for PTFE only

PFAS used in paper and board packaging are surfactants (telomers and polymers with telomeric side-chains; PFAS used in consumer and industrial cookware are fluoropolymers. Emission data based on polymer processing aids (PPAs) has not been included, except for impurities.

- * Standard REACH methodology (ECHA, 2016).
- ** May be an under-estimate.
- *** Type of PFAS from which emissions originate using expert judgement. † May be an over-estimate.

It is envisaged that use and emissions of PFAS in these sectors will continue at a similar rate to the estimates today. There is evidence of some trends in parts of the market, but these suggest a mix of increasing and decreasing demand.

6. **Exposure**

Others than emissions to environment this is not described.

7. **General discussion on emissions and exposure**

The extent to which the data collected for the food industry is applicable to the animal feed industry is unclear. The relevant EU trade associations and a leading company have all highlighted that there is an absence of data on this issue. Given the high-performance grease and water repellence properties needed for some animal feed packaging (STO, 2020-21) it is likely that PFAS are used for this function in the same way as in food packaging. This is supported by other recent work (OECD, 2020). For the purposes of this report and based on this evidence, it is assumed that the FCMs used in food packaging and Fluoropolymers used for human food process applications are similar to those used in animal feed applications. No calculations have been made for feed applications however.

Emissions during the production and use of articles are, in general, small, apart from the production of PFAS treated paper and board and recoating operations for industrial bakeware. Understanding of waste management systems and the fate of PFAS sent to waste management is therefore extremely important for understanding the potential for human exposure from these sources.

8. **Alternatives**

8.1 Packaging

A wide range of alternatives for packaging is available including:

- Natural greaseproof paper
- Clay coatings
- Silicone
- Biopolymers
- Synthetic plastics
- Waxes

The assessment found several options that met the necessary criteria made from uncoated paper, or paper treated with waxes and clay. Several other options met at least some criteria whilst on others it was concluded that there was insufficient data available to pass judgment. A study for the Nordic Council has come to similar conclusions that alternatives to the use of fluorinated materials are available and functional for almost all uses of paper and board FCMs intended for various foods, and close to cost-neutral for retailers, and hence likely also for manufacturers (Trier, Taxvig, Rosenmai, & Pedersen, 2017).

The OECD (OECD, 2020) reported that the key reason for the current lack of market share of non-fluorinated alternatives is their higher cost. The study indicated that PFAS-free paper and board for food packaging is 11-32% more expensive than food packaging using short chain PFAS (OECD, 2020).

Table 11: Comparison of the Costs of Alternatives Used in Paper and Board Food Packaging.

Paper/board product	**Average* cost and treatment (€/tonne paper)**	**Average cost difference 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	Not applicable	Not applicable	Not applicable
Short-chain PFAS	1,400	+150	+12	+11 to +32%
Chemical alternative	1,550	+300	+24%	+11%
Physical alternative	1,850	+600	+48%	+32%

*: Source: (OECD, 2020)

The analysis suggests that costs of switching away from the PBT substance to alternatives in the food packaging market is proportionate to the reduction in risk, based on comparison with the indicative benchmarks that have been used previously in REACH.

8.2 Consumer cookware

- Ceramic, silicone coatings
- Stainless steel
- Silicone bakeware (not just coated)
- Anodised aluminium

Other options (e.g. copper) have little penetration into the market or are not yet widely available/tested (e.g. superhydrophobic coatings).

There are several alternatives to the use of Fluoropolymer-coated cookware that are already available on the consumer market, and in some cases have significant market share. Currently, there is little evidence for systematic differences in price between these options. There is good evidence that good quality Fluoropolymer-coated options will outlast ceramic coatings, which in turn will be outlasted by, for example stainless steel pans. To further complicate the situation, consumer surveys indicate that a good quality ceramic coating can be expected to outlast a low-quality Fluoropolymer coating (Which?, 2021).

8.3 Industrial applications

- Ceramic, silicone coatings (e.g. industrial cookware)
- Stainless steel (e.g. industrial cookware, production line components)
- Silicone bakeware (e.g. industrial cookware, lubricants, seals)
- Synthetic rubbers (e.g. seals, gaskets, pipes, tubes for liquid processing)

These options applied for different uses, e.g. ceramic or silicone coatings to bakeware, synthetic rubbers for components such as gaskets and tubing.

The use of Fluoropolymers in the industrial food and feed sectors is complicated by a wide variety of applications from baking tin coatings to pipes, pipe coatings and various types of seal, with differing potential for PFAS release and population exposure. The ease of substituting alternatives will be similarly variable.

Some parts of the market (e.g. some industrial bakeries) are already using alternatives to Fluoropolymer coatings in bakeware. Analysis has been presented by one company demonstrating that whilst the coatings do not last as long as Fluoropolymer coatings, and hence need more frequent re-coating, the overall cost of re-coating operations is significantly cheaper. Another company providing a similar service, however, claims that the use of Fluoropolymer coatings is essential.

Estimates of the quantity of PFAS released as a result of Fluoropolymer use by the sector are dependent to a large extent on the waste management phase.

9. Economic impacts in case of a full PFAS ban

9.1 Packaging

The Washington State Department of Ecology (Washington State DOE, 2021) has carried out an extensive analysis for an assessment of alternatives to the use of PFAS in food packaging. Limited information has been obtained on the difference in price between packaging options. Results from the Washington State study did not show systematic differences in price between PFAS- and non-PFAS options, for several specific types of article (Washington State DOE, 2021)

Results indicated a range for the substitution cost of €37.5 to €112.5 per kg for a PFAS content of the paper of 0.4%, and €12.5 to €37.5 per kg for a PFAS content of the paper of 1.2%. All estimates are well below the lower indicative benchmark of €1,000 per kilogram PBT substance observed by (Oosterhuis, 2017).

9.2 Consumer cookware

There are several alternatives to the use of Fluoropolymer-coated cookware that are already available on the consumer market, and in some cases have significant market share. Currently, there is little evidence for systematic differences in price between these options.

Information from observed prices on the market indicate that there is no systematic difference in the price of frying pans manufactured using Fluoropolymer or other coatings. On this basis, even a small reduction in emissions associated with a switch to alternatives is proportional for goods with a similar product lifetime. The longer service lifetimes for some Fluoropolymer coated goods compared to some alternatives (particularly ceramic coatings) can, however, affect this conclusion. Nevertheless, some uncoated kitchenware (e.g. stainless steel saucepans) can far outlast Fluoropolymer-coated pans, so for that part of the market the reverse situation applies.

9.3 Industrial applications

There are numerous elements to economic impacts of a ban on the use of Fluoropolymers in the food and feed production and transport sectors, including: Non-Fluoropolymer options are clearly available on the market to perform the same general functions.

Some elements of cost are described drawing on information from the stakeholder consultation. It should be noted that respondents were mainly from companies providing or using Fluoropolymers, rather than producers and users of alternatives:

- The cost of components made of different materials. Data collected (AFW, 2017) indicate a cost for PTFE in the region of €17,000 to €20,000 / tonne and of Fluoropolymer more generally averaging around €15,000/t, leading to a factor 3 increase in the costs of some components (specifically, pipes and tubing were identified).

- The costs of R&D to develop new solutions has to be taken into account
- Increased downtime and shorter service life has to be taken into account

The diversity of the food and drink sector, the range of applications of Fluoropolymers within the sector and the lack of data on many of those applications prevents calculation of the economic impacts of a restriction to a reasonable level of confidence.

10. **Methods used & uncertainties**

Comprehensive data on the quantities of PFAS placed on the EEA market for the uses in the scope of this report are not publicly available.

PFAS used in packaging have been estimated by several methods taking as a starting point the P&B market data such as tonnage consumed that is publicly available from the Confederation of European Paper Industries (CEPI, 2020). The geographical scope of this includes the European Union (EU)-27, the United Kingdom (UK) and Norway.

The quantities of Fluoropolymers consumed in EU-28 primarily have been drawn from a Plastics Europe source – A Socio-economic Analysis of the European Fluoropolymer Industry (AFW, 2017). This contains data for the Fluoropolymer market in 2015 and is disaggregated into various market segments. From discussions with stakeholders (STO, 2020-21) it is understood these data are the most accurate and comprehensive that are publicly available, are widely used by industry, and have been constructed partially from data obtained from Fluoropolymer manufacturers, but also from EUROSTAT data averaged over a five-year period to reduce the effects of annual fluctuations (AFW, 2017). These data are also currently in the process of being updated (STO, 2020-21). In the absence of other comparable data, these data have been used as the principal source of Fluoropolymer consumption data.

On the basis of the above sources and emission estimates from the Exposure Assessment module, indicative tonnage flows have been constructed from product manufacturing through to end-of-life/recycling.

Assuming the estimates of usage from (AFW, 2017) are broadly correct (acknowledging that they cover both the food and pharmaceutical industries rather than food specifically), the major uncertainty affecting the analysis concerns the fraction of PFAS emitted as a result of use by the sector.

10.1 Packaging

Important uncertainties are present in the estimation of the quantities of PFAS used in the packaging sector and resulting emissions. In the absence of a comprehensive list of PFAS currently used in FCMs in the European Economic Area (EEA), EEA manufacturers and suppliers refer to three legislative regulatory positive lists (‘regulatory lists’)

The three main regulatory lists are:

1) Recommendations for consumer products that meet the requirements of § 31.1 of the German Foods, Consumer Articles and Feed Act and of Article 3 (1a) of Regulation (EC) No. 1935/2004 on materials and articles intended to come into contact with food (‘BfR Recommendation list’) published by the German Federal Institute for Risk Assessment (BfR) (BfR, 2019c);

2) PFAS entries in the US Inventory of Effective Food Contact Substance (FCS) Notifications to the US Food and Drug Administration (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) (U.S. Food and Drug Administration, 2021); and

3) Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food[2] ('EU 10/2011'). Annex I of this Regulation is a positive list of authorised monomers, other starting substances, macromolecules obtained from microbial fermentation, additives and polymer production aids (PPAs) that may come into contact with food and limit values are established for some individual substances.

To supplement these sources, other principal sources of data for PFAS used/were used included: 1) the stakeholder consultation (STO, 2020-21) and 2) literatures sources (Glüge et al, 2020; Trier, Taxvig, Rosenmai, & Pedersen, 2017; Bokkers B. , 2018), and to a limited degree several individual European Food Safety Agency (EFSA) opinion substance reports and a report 'Product – Chemical Profile for Food Packaging Containing Perfluoroalkyl or Polyfluoroalkyl Substances' (California Environmental Protection Agency, 2020).

Chemical substance identification is not straightforward from these regulatory lists for several reasons. The entries are often not listed as a substance but instead as components of reaction mixtures

10.2 Consumer cookware

During the preparation of the report insufficient information has been obtained to allow a quantitative estimation of the emissions during the manufacture of domestic and industrial cookware. Because of the absence of such information, even a default calculation by the REACH methodology has not been possible.

10.3 Industrial applications

In case of recoating the removed coating can be released in gaseous emissions or to water, depending upon whether the coating is removed by 'burning off' at 450 C for 4-5hrs to break down the coating followed by grit blasting (RIVM, 2020b); water blasting at 1500 bar (RIVM, 2020b); or by abrasive stripping (Guerrero-Vaca et al, 2020). Burning off has the potential to release PFAS breakdown substance such as trifluoracetic acid (TFA) (Nature, 2001) to air, subsequent grit blasting or abrasive removal has the potential to create solid waste and water blasting emissions to the aquatic compartment.

From the data available here, it has not been possible to allocate the emissions to the different environmental compartments, or to estimate the quantity of the total PTFE removed that actually ends up in the environment, because it is assumed that a significant fraction is removed by risk management measures at re-coating installations in the EU before being released to the environment. Stakeholders contributing to this report have explained PFAS-coated metal cookware is generally recycled at the end of its life (STO, 2020-21). This is particularly the case for cookware from industrial sources. (And to a lesser degree from consumer sources). However, the current primary aim of this recycling is to reclaim the valuable metal, rather than remove the PFAS.

Another uncertainty is in relation to the quantities of PFAS in comparison with the total quantity of PFAS consumed by the food industry of 3,000 tonnes, a figure recognised to be an over-estimate because it also includes PFAS used in the pharmaceutical industry.

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R0010&from=EN

11. ANNEX

Tonnage & emissions

<table>
<tr><th>Sub-use</th><th>Tonnage
(tonnes/y in EEA)
PFAS solely polymers in table</th><th>Expected trend
(--/-/0/+/++)*</th><th>PFAS emissions (tonnes/y) in EEA
Ex. waste stage emissions</th></tr>
<tr><td>Packaging</td><td>Product: 41,351,000 (paper and board)
Product: 20,500,000 (plastic packaging)
PFAS: 827 – 4,962 ton (in paper and board)
PFAS: No data (for plastic packaging)</td><td>+ (3%)</td><td>124 – 871</td></tr>
<tr><td>Cookware</td><td>Product: No data
PFAS: 3,500 ton (Plastic Europe, AFW, 2017)</td><td>+ (5%)</td><td rowspan="2">1,633 – 4,716
(mainly recoating emissions)</td></tr>
<tr><td>Industrial applications</td><td>Product: No data
PFAS: 3,000* ton (Plastic Europe, AFW, 2017)
*: including pharmaceuticals (could not be disaggregated)</td><td>++ (10-20%)</td></tr>
</table>

*-- = strong decrease, - = decrease, + = increase, ++ = strong increase, 0 = neutral

Alternatives

Sub-use	Non-PFAS alternatives
Packaging	Natural greaseproof paper
	Vegetable parchment
	Clay coatings
	Silicone
	Biopolymers (e.g. chitosan, starch, cellulose, polyvinyl alcohol, bioplastics such as polylactic acid (PLA), biowaxes)
	Synthetic plastics (e.g. low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high density polyethylene (HDPE), polypropylene (PE), ethylene vinyl alcohol (EVOH), polyvinyl alcohol (PVOH), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET))
	Microfibrillar cellulose (MFC), cellulose nanofibrils (CNFs), cellulose nanocrystals (CNCs)
	Aqueous dispersions of co-polymers (e.g. styrene acrylic emulsion (SAE))
	Aqueous dispersions of waxes (e.g. TopScreen)
	Water soluble hydroxyethylcellulose (HEC)
	Alkyl succinic anhydride (ASA), alkyl ketene dimer (AKD)
	Aluminium foil
	Lamination using impermeable barriers
	Other plant fibres (miscanthus, etc.)
	Bitumen coating
	Re-usable materials

Sub-use	Non-PFAS alternatives
Consumer Cookware	‘Ceramic’ coatings (sol-gel) *Replacement of coating material*
	Silicone coatings *Replacement of coating material*
	Silicone cookware (not coated metal) *Alternative base material, uncoated*
	Superhydrophobic coatings *Hydrophobic coatings, replacement of coating material* *Nanoscopic layer which is able to resist water. They are made from different materials like zinc oxide polystyrene, precipitated calcium carbonate, carbon nano-tube substances, manganese oxide polystyrene.*
	Enamelled cast iron / seasoned cast iron *Alternative base material and non-stick coating*
	Full ceramic cookware (not just coated) *Alternative base material*
	Carbon steel *Alternative base material, uncoated*
	Anodized aluminium coating *Alternative base material, may be coated*
	Stainless steel *Alternative base material, uncoated*
	Copper *Alternative base material, uncoated*
Industrial applications	Stainless steel
	Ceramic coatings
	Silicone and silicone coatings
	Synthetic rubbers and similar compounds (nitrile rubber, ethylene propylene rubber, neoprene, PES (polyethersulfone))

12. References

AFW. (2017). *Socio-economic Analysis of the European Fluoropolymer Industry.* Amec Foster Wheeler, for Plastics Europe.

BfR. (2019c). *Paper and board for food contact .* Retrieved from https://bfr.ble.de/kse/faces/resources/pdf/360-english.pdf

BfR. (2020b, 10 26). *Database BfR Recommendations on Food Contact Materials*. Retrieved from BfR Web site: https://bfr.ble.de/kse/faces/DBEmpfehlung_en.jsp

California Environmental Protection Agency. (2020). *Product – Chemical Profile for Food Packaging Containing Perfluoroalkyl or Polyfluoroalkyl Substances.* ttps://dtsc.ca.gov/wp-content/uploads/sites/31/2020/07/Draft-Profile_PFASs-in-Food-Packaging_FINAL_ADA.pdf.

CEPI. (2020). *KEY STATISTICS 2019 European pulp & paper industry.* Confederation of European Paper Industries.

ECHA. (2016). *Guidance on information requirements and chemical safety assessment. Chapter R.16: Environmental exposure assessment.*

ECHA. (2020b). *RoI Entry for PFHxA*. Retrieved from ECHA Registry of Intentions Restrictions: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d

Fidra. (2020). *Forever chemicals in the food aisle; PFAS content of UK supermarket and takeaway food packaging.* PFAS-Free Org. Retrieved from https://www.pfasfree.org.uk/wp-content/uploads/Forever-Chemicals-in-the-Food-Aisle-Fidra-2020-.pdf

Food Drink Europe. (2019). *Data and Trends: EU Food and Drink Industry 2019.* hthttp://fooddrink.bg/assets/upload_files/125/oJXFEcgow1WFuYrHsIobmdwBRqtZVIrsOuDRzoZ6.pdf.

Geyer, R., Jambeck, J., & Law, K. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*, DOI: 10.1126/sciadv.1700782.

Glüge et al. (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). *Environmental Science: Process and impacts., 22*, 2345-2373.

Grand View Research. (2019). *Nonstick Cookware Market Worth $12.5 Billion By 2025 | CAGR: 4.9%*. Retrieved from Grand View Research: https://www.grandviewresearch.com/press-release/global-nonstick-cookware-market

Guerrero-Vaca et al. (2020). Experimental Study for the Stripping of PTFE. Coatings on Al-Mg Substrates Using Dry Abrasive Materials. *Materials*, 13, 799.

ING. (2019). *Plastic packaging in the food sector Six ways to tackle the plastic puzzle.* https://think.ing.com/uploads/reports/ING_-_The_plastic_puzzle_-_December_2019_%28003%29.pdf.

Nature. (2001). Out of the frying-pan, into the air. *Nature*, doi:10.1038/news010719-19.

OECD. (2020). *PFAS and alternatives in food packaging (Paper and paperboard) Report on the commercial availability and current uses.* https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/PFASs-and-alternatives-in-food-packaging-paper-and-paperboard.pdf: OECD Series on Risk Management No.58.

Oosterhuis, F. e. (2017). Towards a proportionality assessment of risk reduction measures aimed at restricting the use of persistent and bioaccumulative substances. *Environmental Policy and Regulation*.

RIVM. (2020a). Personal communication & Wageningen University and Research centre.

Schaider et al, L. A. (2017). Fluorinated Compounds in U.S. Fast Food Packaging. *Environmental Science and Technology Letters*