Annex to the

ANNEX XV RESTRICTION REPORT

PROPOSAL FOR A RESTRICTION

SUBSTANCE NAME(S): Per- and polyfluoroalkyl substances (PFASs)

IUPAC NAME(S): n.a.

EC NUMBER(S): n.a.

CAS NUMBER(S): n.a.

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1	Original version for pre-publication	February 2023
2	A.2.1.6. – Update of table A.3 and A.4	March 2023
	A.3.10.1.11. – addition of a reference	

TABLE OF CONTENTS

TABLES

FIGURES

Annex A Manufacture and uses

Annex A contains an introduction to this Annex (A.1), information on PFAS manufacture, import and export (A.2), and information on main uses/use sectors (A.3). For 15 sectors, data on uses, volumes, and main PFASs applied is summarized in sections A.3.3 to A.3.17. Finally, the waste stage of the PFAS life cycle is described in section A.3.18. In the Appendix to Annex A, background information to uses, volumes and PFASs applied, is included.

A.1. Introduction

Many different PFASs are used in a wide range of applications. As actions taken so far have not sufficiently addressed the concerns related to the use of PFASs, the goal is to minimise environmental and human exposure to PFASs, at all stages of their life cycle. An illustrative picture of the life cycle of PFASs, including manufacturing and use as well as waste management, is depicted in Figure A.1.

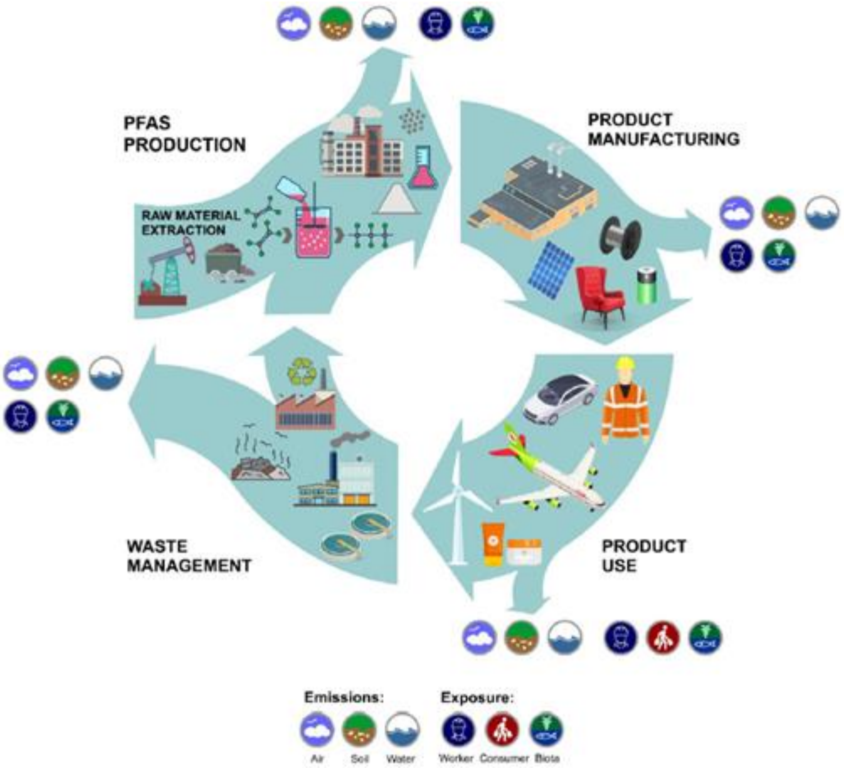


Figure A.1. The lifecycle of PFASs (EC, 2020).

PFASs have typical properties like chemical inertness, radiation resistance, temperature resistance, weathering resistance, oil-, water- and stain repellence, electrical inertness, corrosion protection, low coefficient of friction and non-flammability. These (combined) properties, partly the result from the very strong carbon-fluorine bond (C–F), make PFASs useful in a very broad range of processes and products (Glüge et al., 2020; ITRC, 2022). In particular fluoropolymers and side-chain fluorinated polymers are used in a broad range of applications.

In their key paper on PFAS applications, Glüge et al. (2020) provide a more detailed overview of many use categories where PFASs have been employed and for which function. The article also specifies which PFASs have been used and discusses the magnitude of the uses. Despite being non-exhaustive, the study clearly demonstrates that PFASs are used in almost all industry branches and many consumer products. In total, more than 200 use categories and subcategories are identified for more than 1 400 individual PFASs. In addition to well-known categories such as textile impregnation, fire-fighting foams, and electroplating, the identified use categories also include many categories not described in the scientific literature, including PFASs in ammunition, climbing ropes, guitar strings, artificial turf, and soil remediation.

For this dossier, the major uses of PFASs have been identified from literature and stakeholder consultations. Data on uses, volumes and PFASs applied was collected by approaching stakeholders through a call for evidence (CfE) from May to July 2020. Data for different sectors was compiled and verified by consultants and was complimented with data from public sources. Subsequently, data was again verified by a second stakeholder consultation round from July to October 2021. For each sector a separate report was drafted. Summarised details on manufacture and uses, including volumes, are included in Annex A. PFAS volumes/ tonnages could, in most cases, not be disaggregated to tonnages at substance level, although many PFAS are mentioned in the Appendix of this Annex. A more detailed description of the data collection process is provided in Annex G.

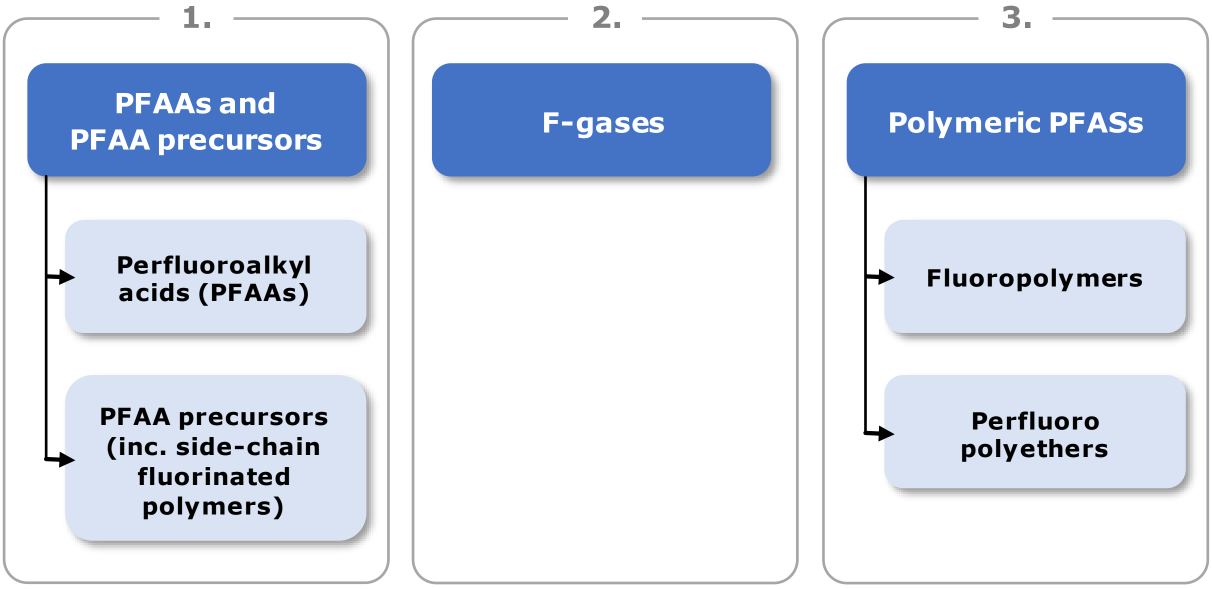
No information is available on the participation rate of stakeholders. It is likely that not all stakeholders provided information and that therefore the volumes presented in Annex A are an underestimation of the actual volumes used in the sectors. Stakeholders provided in general more data on polymeric PFASs and fluorinated gases than on non-polymeric PFASs. Where possible data from literature was added. Sometimes assumptions regarding volumes had to be made (see the sections on uses). A more detailed description of assumptions, uncertainties and sensitivities is provided in Annex F.

For most sectors, a summary table is provided in which the volumes of PFASs used are presented. The summary tables include data collected from stakeholders and from public sources unless otherwise indicated, at the highest level of detail possible.

As described in detail in the main report and in Annex B.1, PFAS grouping in the restriction proposal is based on the OECD 2021 PFAS report (OECD, 2021). It should however be noted that in Annex A PFAS grouping is slightly different, the difference concerning the side-chain fluorinated polymers (SCFPs). SCFPs are chemically speaking polymers and in that sense belong to the polymeric PFAS group (as done by OECD), but for impact assessment purposes they are grouped under PFAA precursors. Hence, the following three main PFAS groups were chosen for the impact assessments, see also Figure A.2:

1. PFAAs and PFAA precursors (including side-chain fluorinated polymers)
2. Fluorinated gases
3. Polymeric PFASs

Per use sector, the impact assessment is performed for total PFAS and additionally for the three main groups mentioned above. Of note, total PFAS does not only include PFASs in the three main groups, but also PFASs that cannot *à priori* be allocated to the main groups. These non-allocated PFASs are included in the 'Other PFASs' group in Figure A.2.



PFAAs and PFAA precursors
Contains the perfluoroalkyl acids (PFAAs), and precursors of PFAAs, including side-chain fluorinated polymers (and perfluoroalkyl ether side-chain fluorinated polymers); excludes F-gases.
F-gases
Contains the gases that fulfil the PFAS definition. Not restricted to the substances mentioned by the F-gas regulation.
Polymeric PFASs
Contains fluoropolymers as PTFE, PVDF and perfluoropolyethers; excludes side chain fluorinated polymers.
Other PFASs
Contains all PFAS substances which are not covered by the three main categories.

Other PFASs

- CF_3 on active substances
- Side-chain fluorinated aromatics
- Perfluoroalkanes (non-gaseous)
- Perfluoroalkyl-*tert*-amines
- Perfluoroalkylethers
- Others

Figure A.2. Overview of PFASs groups used for impact assessment (Annex E).

Figure A.3 presents the structure of the PFASs supply chain. The top tier consists of the suppliers of raw materials like fluorite (also called fluorspar, calcium fluoride, CaF_2). Raw materials are used by manufacturers of PFASs as well as manufacturers of PFAS containing materials (e.g. PFAAs (including PFAA precursors), side-chain fluorinated polymers and fluorinated gases). Raw materials and production aids can either be manufactured in the EEA or imported from third countries, either directly from manufacturers based outside the EEA or through EEA based distributors or importers. PFASs can either be used to formulate other PFAS containing products or be directly used by downstream users. PFASs can be placed on the EEA market either directly by EEA based manufacturers/processors or via imports from third countries.

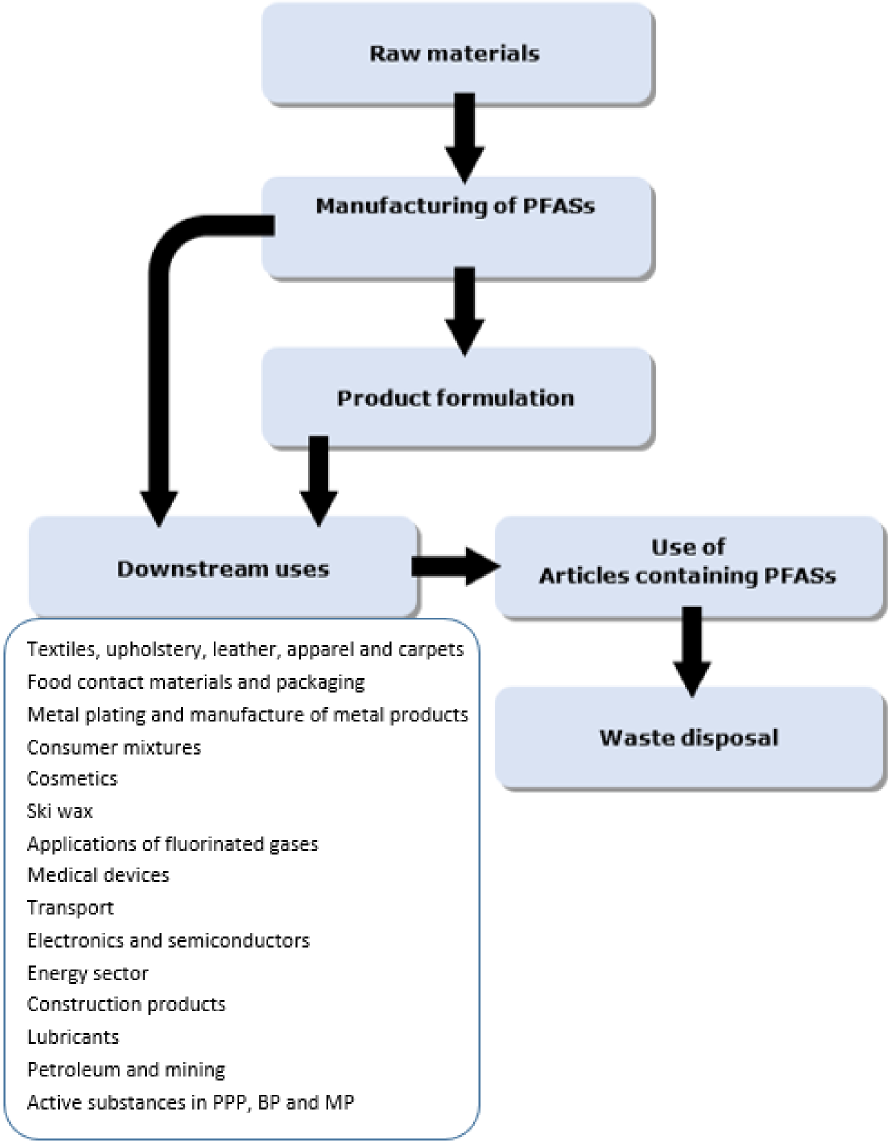


Figure A.3. Schematic simplified presentation of PFASs supply chain, including main uses.

With the 15 major use sectors, the Dossier Submitters believe to have covered rather exhaustively the PFAS uses. It is recognized though that it is impossible to be complete, given the large number of PFASs and the broad range of processes and products they are useful for. From literature and stakeholder consultations indeed some additional uses/applications were identified. For these however no detailed assessment was performed, e.g. because they concerned niche applications or because the applications are currently of little relevance in the EU. Important to note is that although not every single application has been assessed in detail, *all* applications are covered by the restriction proposal as the PFASs used eventually end up in the environment due to releases during manufacture, use or in the waste stage. Table A.1 presents an overview of all the more and less researched PFAS applications (including PFAS manufacturing and waste stage).

Table A.1. Overview of PFAS applications and the level at which they were researched.

PFAS applications			
PFAS manufacture	Textile, upholstery, leather, apparel and carpets (TULAC)	Food contact materials and packaging	Metal plating and manufacture of metal products
Consumer mixtures	Cosmetics	Ski wax	Applications of fluorinated gases
Medical devices	Transport	Electronics and semiconductors	Energy sector
Construction products	Lubricants	Petroleum and mining	Waste stage PFAS applications
Laboratory equipment & filtration	Plant protection products and biocides	Chemical industry	Firefighting foam
Medicinal products	Plastics (other than packaging) and rubber/elastomer production (including flame retardants)	Pyrotechnics	Personal care products other than cosmetics
Fracking (currently hardly applicable in EEA)	Immersion cooling (currently hardly applicable in EEA)	Defence industry	Printing inks
Cement industry	Professional cleaning and polishing	Other niche applications	Uses (yet) unknown

- Green uses are researched in detail
- Blue uses are researched in general
- Orange uses not researched in detail
- Purple use: Separate restriction proposal

A.2. Manufacture, import and export

A.2.1. PFASs manufacture

A.2.1.1. Introduction

In this section, PFASs manufacturing and related processes are discussed, from the mining of raw materials to the synthesis of specific PFASs.

All organic fluorine compounds in the supply chain are synthetically manufactured. All fluorine used in the manufacturing of these organic fluorine compounds are made from mined fluorite (CaF_2), also called fluorspar (Harsanyi and Sandford, 2015). About 11% of fluorite consumed in Europe is used to produce fluoropolymers (Wahlström et al., 2021).

About half of all fluorite produced is used in iron and steel production, while the second half is used for production of anhydrous hydrogen fluoride (HF). Almost 70% of the HF is used for fluorinated organic substances. The link between HF and PFASs is presented in Figure A.4. With current global reserves of 500 million tonnes fluorite, there is less than 100 years left at the current mining level (Harsanyi and Sandford, 2015).

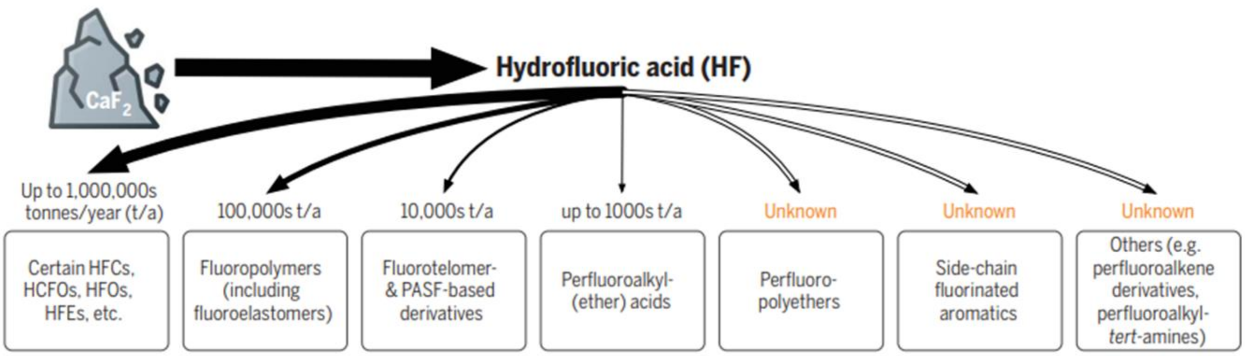


Figure A.4. Hydrofluoric acid (HF) use (Evich et al., 2022).

A.2.1.2. PFAA and PFAA precursors

Perfluoroalkyl acids (PFAAs) are fully fluorinated alkyl acids. Substances which can react to form PFAA are called PFAA precursors, and include for example perfluoroalkyl iodides, perfluoroalkane sulfonyl fluorides and perfluoroalkenes.

There are two main manufacturing methods to produce compounds containing perfluoroalkyl chains, described in detail in Buck et al. (2011). Below are short summaries of the two methods:

A.2.1.2.1. Electrochemical fluorination (ECF)

In the ECF method, an organic raw material (e.g. octane sulfonyl fluoride, $C_8H_{17}SO_2F$) undergoes electrolysis in anhydrous HF, leading to the replacement of all the H atoms by F atoms. In this process, carbon-chain rearrangement and breakage may occur, resulting in a mixture of linear and branched perfluoroalkyl isomers and homologues of the raw material. When octane sulfonyl fluoride is used as a substrate in the ECF process, perfluorooctanesulfonyl fluoride is formed. This is the major raw material used to manufacture PFOS and its salts.

A.2.1.2.2. Telomerisation

In this process, a perfluoroalkyl iodide, most commonly perfluoroethyl iodide (C_2F_5I), is reacted with tetrafluoroethylene (CF_2=CF_2) to yield perfluoroalkyl iodides with extended perfluoroalkyl chains. The perfluoroalkyl iodide mixture is often further reacted with ethylene to introduce a non-fluorinated tail to the molecule. The iodide may be substituted with for example an alcohol group for the formation of fluorotelomer alcohols (FTOH). Telomerisation is applied at least at one site in Europe in Gendorf. Here, C6 fluorotelomers are being produced.

A.2.1.3. Side-chain fluorinated polymers

Side-chain fluorinated polymers are polymeric PFASs consisting of variable compositions of non-fluorinated carbon backbones with per- or polyfluoroalkyl side-chains, as well as side-chains that partly have no fluorinated carbons.

Some examples of side-chain fluorinated polymers are fluorinated acrylate, urethane and oxetane polymers. During the lifetime, the side-chains can be released mostly as telomeric PFASs, (e.g. fluorotelomer alcohols) that can degrade further into perfluoroalkylcarboxylic acids (PFCA) which is why side-chain fluorinated polymers are considered to be PFAA precursors.

Side-chain fluorinated polymers are made by polymerisation e.g. a fluorinated acrylate or methacrylate monomer. These fluorinated acrylate monomers are copolymerized with one or more non-fluorinated acrylate monomers, and possibly other monomers, to give the final side-chain fluorinated acrylate polymers. These polymers are made using fluorotelomers and perfluoroalkane sulfonamido (meth)acrylates, but also include side-chain fluorinated siloxane derivatives. Fluorinated urethane polymers may also be based on urethane polymers formed by reacting fluorotelomer alcohols, or perfluoroalkane sulfonamidoethanols, with polyisocyanate homopolymers, followed by a cross-linking step.

To provide a rough estimate of the volume range of PFAA and PFAA precursors currently produced in the EEA, REACH registered substance datasheets were reviewed for all relevant PFASs. These are summarised in the appendix Table A.71 and Table A.72. Estimation of the total volume might not be accurate, due to the lack of information submitted by manufacturers and producers of PFASs. Volumes are low (400 – 4 500, rounded) compared to fluorinated gases and polymeric PFASs.

A.2.1.4. Fluorinated gases

Not all F-gases included in the F-gas regulation, are PFASs according to the definition used for the restriction proposal (see section 1.1.1 of main document, e.g. HFC-22 and SF_6). On the other hand, there are PFASs which are volatile and reside in the gaseous state which are not in the F-gas regulation but are within the definition used for the restriction proposal. These include for example fluorotelomer alcohols or perfluorinated trialkylamines (which are gases in the atmosphere but liquids under normal conditions). In Annex A, unless specifically explained, fluorinated gases are those gases that are within the definition used for the restriction proposal (see Figure A.5). Fluorinated gases are mainly used as starting materials in the production of fluoropolymers and as heat transfer agent in refrigeration and air conditioning.

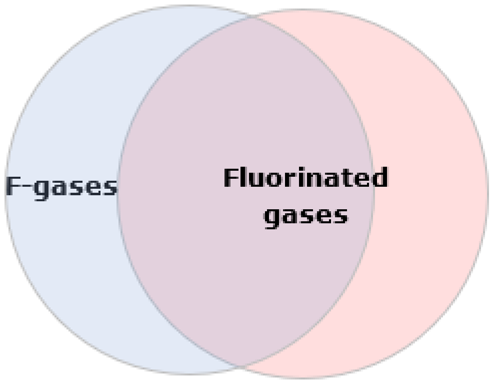


Figure A.5. Distinction between F-gases (blue) and fluorinated gases in scope (orange).

A.2.1.4.1. Fluorinated gases as starting materials in the production of polymeric PFASs

According to stakeholders, about 45% of fluorinated gases are used as monomers in the production of polymeric PFASs. This means that these gases are starting materials for fluoropolymer production and are consumed in the process. There are about 20 manufacturers of PFASs (Table A.4). Like mentioned before, some of the fluorinated gases contain fluorine but are not PFASs. Examples are HCFC-22, used for PTFE manufacturing, and HCFC-142b, used for PVDF manufacturing.

A.2.1.4.2. Fluorinated gases used as refrigerants

The change in fluorinated gases use in refrigerants over time, from Chlorofluorocarbon (CFC) through Hydrofluorocarbon (HCFC) and Hydrofluorocarbon (HFC) to Hydrofluoroolefins (HFO) is explained in Figure A.6. There is a current transition to using HFO, due to lower global warming and ozone depletion potential. However, many HFO can degrade to PFASs such as TFA.

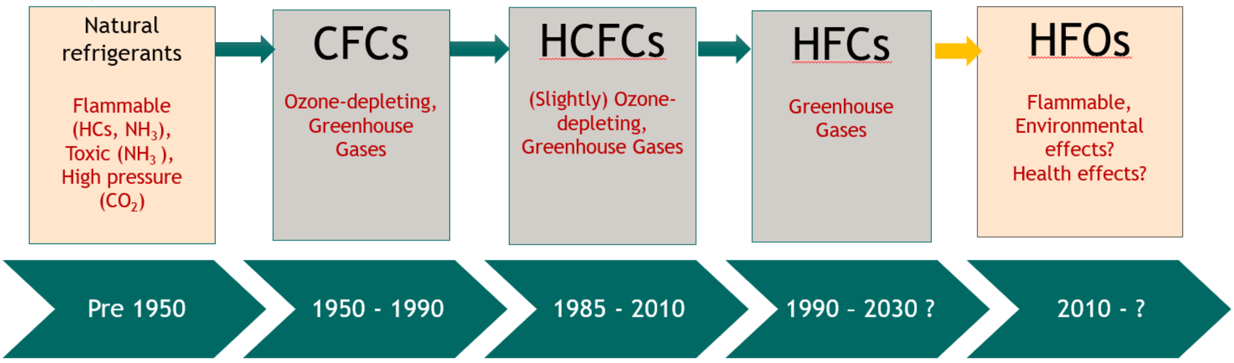


Figure A.6. Schematic presentation of timeline synthetic refrigerants.

Industry introduced CFCs as synthetic refrigerants for use in these applications in the 1930s, leading to widespread use by the 1950s of freons, such as CFC-11, CFC-12 and CFC-13. However, CFCs were identified as the causal agent in damage to the stratospheric ozone layer that protects the earth from the harmful effects of ultraviolet radiation from the sun during the 1970s, which led to their being banned under the 1987 Montreal Protocol. Subsequent amendments increased the scope of the protocol, for example leading to the banning of HCFCs that replaced CFCs because of lower (but not negligible) ozone depletion potential. These measures have contributed to the phase-out of CFC use around the world, as well as the phase-out of HCFC use to be achieved by 2030. In Europe HCFCs have been phased out already, in accordance with the EU regulation on ozone depleting substances.

Industry developed hydrofluorocarbons (HFCs) as in-kind replacements for CFCs and HCFCs. HFCs did not damage the ozone layer. Refrigerant examples include HFC-134a and blends of HFCs such as R-407C. However, many HFCs have a high global warming potential (GWP) contributing to the greenhouse effect. HFC use was addressed by the 1997 Kyoto Protocol, an international treaty that extended the 1992 United Nations Framework Convention on Climate Change (UNFCCC) to reduce greenhouse gas emissions. However, some HFCs are still in use today in Europe, for certain applications and where the GWP is below a specified level as defined in the EU F-gas regulation. This regulation has contributed considerably to the reduction in impact of HFCs on the climate.

Hydrofluoroolefins (HFOs) are the latest generation of drop-in fluorinated refrigerants. HFOs do not impact the ozone layer and have low GWP. However, these substances degrade in various quantities in the environment to persistent substances such as trifluoroacetic acid (TFA).

The production of HFC requires many starting materials. By-products are formed as well. See table Table A.2 for illustration.

Table A.2. Fluorinated gas production in Europe (UBA, 2021).

Gas produced	**Production in t/y and EU productions sites (2018)**	**Starting materials, intermediates, by-products and potential minor components**
PFC-218	≥10 to <100, Italy (1 plant)	
HFC-227ea	>1 000, Germany (1 plant)	HCC-20 (trichloromethane, chloroform) Hexafluoropropene (HFO-1216) Tetrafluoroethene (HFO-1114) HCFC-124 HCFC-22 HFC-23
HFC-134a	<10 000, Germany (1 plant), France (1 plant)	HCC-1120 (trichloroethene) HCFC-131a HCFC-132b HCFC-133a u-HCFO-1122
HFC-143a	<1 000, France (1 plant)	Unknown
HFC-365mfc	<10 0000, France (1 plant)	Pentachlorobutane 2-chloropropene
HFO-1234yf	10 000 – 100 000, France (1 plant) + import	Unknown if this plant produces HFO-1234yf due to legal disputes (ARKEMA, 2020)

Production of fluorinated gases is dominated by HFC, which accounts for more than 90% of the total, with HFC-134a and HFC-365mfc accounting for the largest parts. HFC-134a (in scope) is by far the most relevant regarding EEA production volume. It is REACH registered in the tonnage band 10 000 – 100 000 t/y. HFC-365mfc (in scope) is registered as confidential, so no tonnage band is available. HFC-365mfc is being produced in one plant in Europe. HFC-134a is currently being replaced with HFO-1234yf (in scope) especially in mobile air conditioning (for passenger cars). On a global scale Europe is not a large producer of HFC and HCFC (Booten et al., 2020).

The trend to use the "low global warming potential" refrigerant in cooling systems is stimulated by the F-gas regulation. HFO are key in this transition as they have low global warming potential due to short atmospheric lifetimes. See also Figure A.7 below, which is based on data from Table A.97 in the appendix.

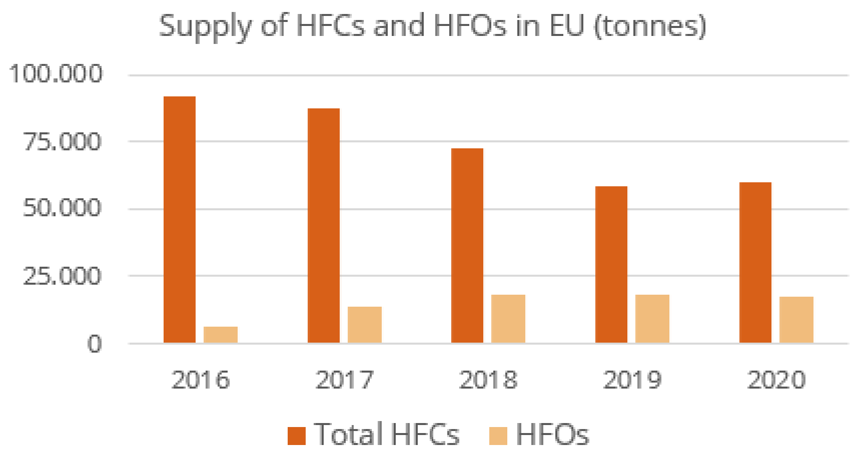


Figure A.7. Supply of HFC and HFO in EU (see Table A.97), taken from EEA (2021).

One key HFO substance is HFO-1234yf. It is REACH registered in the tonnage band 10 000 – 100 000 t/y. Another key HFO substance is HFO-1234ze(E), which has been mainly used as a foam blowing agent in polyurethane foam and as refrigerant. It is registered in the tonnage band 1 000 – 10 000 t/y. Other important HFOs now are HFO-1336mzz(Z) (100 – 1 000 t/y) HFO-1336mzz(E) (10 – 100 t/y).

A.2.1.5. Polymeric PFASs

Polymeric PFASs is a main group of PFASs, according to Figure A.2. It includes fluoropolymers, perfluoropolyethers and side-chain fluorinated polymers. The latter group left out for impact assessment purposes.

Fluoropolymers have various material properties (mechanical strength, inert, thermal stability, resistance to degradation, etc) and are used in very diverse applications.

Fluoropolymers are made by (co)polymerisation of monomers, at least one of which contains fluorine bound to one or both of the olefinic carbon atoms, to form a carbon-only polymer backbone with fluorine atoms directly attached to it. Typical monomers used include tetrafluoroethylene (TFE), hexafluoropropylene (HFP), vinylidene fluoride (VDF), chlorotrifluoroethylene (CTFE), vinyl fluoride (VF), trifluoroethylene (TrFE) and perfluoroalkyl vinyl ethers (PAVE). Figure A.8 presents an overview of widely used homo- and co-fluoropolymers.

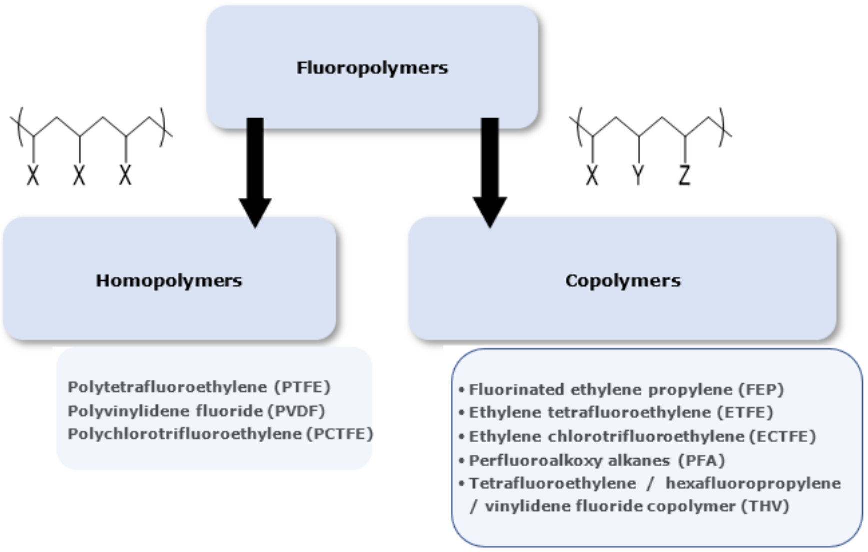


Figure A.8. Landscape of main fluoropolymers taken from Zeus (2019).

Fluoropolymer production often requires not only fluorine containing monomers but also fluorinated production aids. Production of fluoropolymers is performed at different levels:

- The polymerisation: Molecules that start the reaction (initiators) and catalysts may be required, depending on the type of polymerisation.
- The medium: polymerisation is carried out in a dispersion (suspension or emulsion), this creates a microbubble (solid or liquid) in which the polymers are formed. Surfactants or emulsifiers are called polymerisation aids.
- Polymer processing: after the reaction is finished, the polymers are shaped into their desired form, for example by extrusion, for which polymer processing aids are used.

Fluoropolymers are generally produced by one of two processes: emulsion polymerisation or suspension polymerization (Lohmann et al., 2020).

A.2.1.5.1. Polymerisation aid

Polymerisation aid is the term used to describe a surfactant or emulsifier, fluorinated or non-fluorinated. According to a stakeholder, about 50-60% of fluoropolymers are manufactured without fluorinated polymerization aids. Examples of PFAS polymerisation aids are: PFOA, PFNA, PFHxA, 6:2 FTSA, the ammonium salt of hexafluoropropylene oxide dimer acid (HFPO-DA) and dodecafluoro-3H-4,8-dioxanonanoate.

Currently, industry seems to be in transition to use polymerisation aids without PFASs. Some manufacturers, e.g. Gujarat, recently announced they can produce fluoropolymers PTFE and PVDF without polymerisation aids containing PFASs (Chemical Watch, 2022). Four companies have recently reported replacement of fluorinated polymerisation aids with nonfluorinated polymerisation aids[1].

A.2.1.5.2. Polymer processing aid

Polymer processing aids are used in the extrusion of various thermoplastic polymers. Polymer processing aids behave as lubricants and improve the extrusion quality, homogenisation of pigments and fillers and output of thermoplastic polymers. Polymer processing aids are fluoropolymer-based additives which perform at low concentrations as extrusion aids. They are for instance used in blown film extrusion of linear low-density polyethylene (LLDPE). Other applications include pipe extrusion of high-density polyethylene (HDPE). Typical processes include blown and cast film, pipe, sheet, cable, extrusion blow moulding, monofilament, tapes and fibres. Substances used as polymer processing aids are e.g. low molecular weight PTFE, FEP, perfluoroalkoxy alkanes (PFA), etc. (Lohmann et al., 2020).

A.2.1.5.3. Perfluoropolyethers (PFPE)

PFPE are polymers from perfluorether monomers. One structural trait is that they have moieties of –CnF2n-O-CmF2m- in the polymer backbone. For an overview, see the Nordic Working Paper (Wang et al., 2020), chapter 4.

PFPEs are used as lubricants in specific industrial sectors, as well as certain consumer applications related to surface protection.

A.2.1.6. Manufacturing sites

Globally, there are eight manufacturers, making up 60% of the worldwide PFASs market. (Table A.3). According to a stakeholder, China's market share is larger than indicated in Table A.3, the stakeholder estimates a market share for all Chinese producers of >65%. S&P Global's (2022) mentions a Chinese market share of about 40%. Chinese manufacturers include Fuxin Ltd., Dongyue Group, Juhua Group Corp., Changshu 3F Zhonghau and Zhejiang Yonghe Refrigerant Co., Ltd. In Table A.3, the main manufacturers of fluoropolymers are included (AGC Chemicals Europe, 2020).

Table A.3. Main global manufacturers of fluoropolymers.

Manufacturers of PFASs	Location	Approximate Global Market share (%)
AGC Inc.	Japan / USA	4
Arkema	France / China / USA	7
Chemours	USA / Netherlands / China	12
Daikin	Japan / USA / China	11
3M / Dyneon	US / Japan	5
Solvay	Belgium / China / USA	8
Shandong Donyue Group	China	13
Archroma	Germany	unknown
Others	Global	40

The main global manufacturers of fluorinated gases are situated in China (9 sites), Japan (4 sites), India (1 site), USA (1 site) (Seidel and Andersen, 2015).

[1] https://chemicalwatch.com/439992/indian-company-plans-to-substitute-pfass-in-ptfe-production-via-emulsion, https://www.chemours.com/en/news-media-center/all-news/press-releases/2022/chemours-announces-process-innovation-with-new-viton-fluoroelastomers-advanced-polymer-architecture, https://kynar500.arkema.com/en/product-information/fluorosurfactant-free/, https://www.solvay.com/en/article/eliminating-pfas, date of access for all: 2022-12-16.

An overview of the most important European manufacturers /producers of PFASs is presented in Table A.4.

Table A.4. Non-exhaustive overview of European (including UK) PFASs manufacturers (stakeholder information).

Location	Company	Manufactured PFASs (currently and or in past)
Italy		
Collebeato BS	Daikin (Heroflon S.p.A.)	PTFE compounds and micropowders
Spinetta-Marengo	Solvay Solexis SPA	FKM, FC-218 and PTFE
France		
Pierre-Bénite Cedex	Arkema	HFC-134a, PVDF
Salindres	Solvay	Trifluoromethanesulfonic acid (TFMS), Trifluoromethanesulfonic anhydride , Trifluoroacetic acid (TFA), Potassium trifluoromethanesulphinate
Pierre-Benite Cedex	Daikin Chemical France S.A.S	high-performance fluoroelastomers (source: Daikin 2020 Public comment PFHxA #3066.pdf)
Tavaux	Solvay Solexis	HFC-365mfc, PVDF, PTFE, PFBA, HFA
Villers St. Paul	Chemours	No specific data
Germany		
Gendorf	Archroma	C6 fluorotelomers, Textile Chemicals, Paper Specialties and Emulsions on basis of C6 fluorotelomers
Bad Wimpfen	Solvay	HFC-365mfc, Solkane; 4-Ethoxy-1,1,1-trifluoro-3-buten-2-one (ETFBO), Trifluoroacetyl chloride (TFAC), Trifluoroacetic acid (TFA), Trifluoroacetic acid anhydride (TFAH), Trifluoroacetic acid ethyl ester (TFAEt), Trifluoroacetic acid methyl ester (TFAMe), Trifluoroacetic acid isopropyl ester (TFAiP), 1,1,1-Trifluoroacetone (TFK)
Industriepark Höchst,Frankfurt am Main	Daikin Refrigerants Frankfurt GmbH	refrigerant gas and pharma propellants: HFC-227 pharma and HFC-134a pharma
Leverkusen	Lanxess	No specific data
Germany = Burgkirchen	Dyneon	fluoropolymers, PTFE, PFA, FEP, ETFE
Belgium		
Zwijndrecht	Dyneon LLC (Division of 3M)	compounding of fluoro-elastomers, HFP, 1,1,1,2,2,4,5,5,5-Nonafluoro-4-(trifluormethyl)-3-pentanone
Mechelen	Chemours	Teflon coatings
The Netherlands		
Dordrecht	DuPont Performance Elastomers LLC	PTFE, FEP, Chlorotrifluoroethylenevinylidene

Location	Company	Manufactured PFASs (currently and or in past)
		fluoride (FPM/FKM) Viton™
Oss	Daikin Chemical Netherlands B.V.	Pre compounded base-polymers
Poland		
Tarnow	Zaklady Azotowe, Poland	PTFE (Tarflen)
United Kingdom (not EEA anymore)		
Preston	F2 Chemicals Ltd	perfluorinated fluids
Runcorn, Cheshire	Mexichem/Koura	HCFC, HFC; Hydrofluorocarbon (HFC) refrigerants HFC-125
Thornton-Cleveley, Lancashire	AGC	PTFE, ETFE, PFA

Identifying EU PFAS producers appeared complex and some production sites might have been overlooked. The Forever Pollution project, (The Forever Pollution Project – Journalists tracking PFAS across Europe) also identified EU PFAS producers. See: Methodology___The_Map_of_Forever_Pollution_2023.02.23.pdf (lemonde.fr).

A.2.1.7. Volumes

A.2.1.7.1. PFAAs and PFAA precursors

Based on responses from stakeholders, the volume of PFAA and PFAA precursors manufactured, is between 10 000 and >100 000 t.

A stakeholder estimated the volumes of side-chain fluorinated polymers manufactured and imported in the EEA between 10 000 and 100 000 t.

Fluorinated gases

Fluorinated gases are manufactured in the EU/EEA at 92 000 t (midpoint) annually: see Table A.5. Fluorinated gases for the European market are mainly manufactured outside of the EU/EEA and imported, see text below Table A.3 and Table A.8. Fluorinated gases are mainly produced for use in HVACR applications.

Annual fluorinated gas manufacturing volumes were derived from EEA reports, REACH registrations and stakeholder information. As mentioned before, HFC and HCFC production in Europe is low compared to China and USA: See HFO production in Europe appears to be hardly existing. Fluorinated gases for the European market are mainly manufactured outside of the EU/EEA and imported, see Table A.8.

The volume of HFC-134a supplied to the EEA market is around 26 000 t/y (EEA, 2020). In the ECHA registration database, volumes of between 10 000 and 100 000 t are included. A stakeholder confirmed this volume range.

HFC-125 and HFC-134a are used as component in refrigerant blends. In the ECHA registration database, volumes of between 10 000 and 100 000 t of fluorinated gases that are used as components in refrigerant blends are included. This number also includes gases that are not PFASs. The EEA is the only region that produces HFC-365mfc, with 15 000 t produced per year (Stemmler et al., 2007).

According to stakeholders, there is no known production of HFC-152a in EEA and according to the European Environmental Agency, the total supply to the EEA was 3 100 t in 2019 (EEA, 2020).

In Table A.5, EEA production volumes of fluorinated gases are included. As a starting point, the volumes of F-gases on the 2018 OECD list, that are registered under REACH in the EU, were calculated and fluorinated gases in scope were marked. Addition of the midpoint volumes led to a total of a production + import tonnage of fluorinated gases of 131 530 t/y.

Several fluorinated gases that are registered, to a total of 127 000 t, are not included in the OECD list and midpoint volumes were added to the total volume. A volume of 1 285 t/y of additional fluorinated gases, mentioned by a stakeholder, was added to the total volume as well.

It should be noted that ECHA registrations also include imported volumes that cannot be disaggregated from manufactured volumes. Based on EEA (2021) data this amounts to 83 267 t/y for 2019. This volume is subtracted from the total fluorinated gases manufactured and imported in Table A.5. Very likely, the volume of 83 267 t/y is an under estimation. This can be illustrated by an example: octafluorocyclobutane, is registered in the tonnage band ≥10 000 to <100 000 t and none of the registrants seem to be producers, so likely it is imported to EEA. The tonnage band for octafluorocyclobutane (likely used a.o. as refrigerant) therefore alone already covers the total reported import tonnage by EEA of 83 267 t/y. Additional information is provided in Table A.70 in the Appendix.

The total amount of fluorinated gases manufactured, based on midpoint registrations of volumes, is estimated to be 175 000 t/y (rounded). The EEA F-gas reporting (2021) indicates a lower number of 15 000 t/y for 2019. The number of EEA is likely an underestimation as it is based on (mandatory) reporting, but not all companies report. This is i.e., reflected in the highly variable numbers of reporting companies. In the EEA these numbers are not considered as this is not required in the F-gas reporting framework. The tonnages the Dossier Submitters are looking for therefore could be higher. Also REACH registrations suggest far higher tonnages.

A broad manufacturing tonnage range, between 15 000 and 176 000 t/y, the latter based on REACH midpoint registration, is most likely. Stakeholder information on manufactured PFAS tonnage in EEA suggested a range between 14 000 and 53 000 t/y.

Table A.5. Annual volumes of fluorinated gases in PFAS scope manufactured in the EEA.

PFAS group	**Volume (t/y)[a]**
Subtotal fluorinated gases REACH registered substances (midpoint) from OECD database: Manufacturing and import	131 530
Subtotal fluorinated gases REACH registered substances (midpoint) non-OECD: Manufacturing and import	127 000
Subtotal fluorinated gases mentioned by a stakeholder: Manufacturing and import	>1 285
TOTAL fluorinated gases manufactured and imported	259 815
Import EEA (2021) reporting 2020	83 267[b]
Total fluorinated gases manufactured based on REACH registrations (corrected with EEA import figure)	**176 548**
Total fluorinated gases manufactured based on EEA (2021) reporting 2019	**15 000**

[a] REACH midpoint registration numbers were used.
[b] From (EEA, 2021).

A.2.1.7.2. Polymeric PFASs

EEA fluoropolymers volumes

Wood (2022) estimated that in 2020, around 49 000 t of fluoropolymers per year were produced in the EEA, where processing aids were not included. For processing aids production volumes are unaccounted for (Glüge et al., 2020). Stakeholders indicated volumes between 49 458 and 101 763 t.

ACG Chemicals estimated the EEA volumes of PTFE at 34 000 t, whereas one stakeholder mentioned a volume of 3 500 t for PTFE as a micro-powder (AGC Chemicals Europe, 2020). In a study in 2019, production volumes of 15 000 – 20 000 t of PVDF were estimated. During the stakeholder consultation it was indicated that 8 300 t fluoroelastomers were manufactured in 2018.

Worldwide fluoropolymer volumes

According to AGC Chemicals Europe, in 2018, the global fluoropolymer production capacity of the six largest producers was 468 000 t (AGC Chemicals Europe, 2020).

The main polymers produced are PTFE and PVDF. According to industry PTFE, PVDF, and FEP, represent approximately 80% of the total global fluoropolymer production.

K-profi, Sympatex, and AGC Chemicals estimated worldwide volumes of PTFE to be between 150 000 and 170 000 t for different years (2016, 2017, 2018) (AGC Chemicals Europe, 2020; K-Profi, 2016; Sympatex Technologies GmbH, 2021) (Table A.6).

Estimates indicate that current PVDF production capacity in Europe is mainly available at Solvay and Arkema. Current global PVDF production capacity is estimated to be around 80 000 t[2] but increasing mainly due to electric vehicles[3].

Global and EEA production volumes for fluoropolymers with separate information for PTFE and PVDF are provided in Table A.6.

Table A.6. Global and EEA fluoropolymer production volume, including PTFE and PVDF.

Fluoropolymer	**EEA volumes (t/y)**	**Source (Publication year in brackets)**	**Global volumes (t/y)**	**Source (Publication year in brackets)**
Total	49 000 (2020)	Drohmann et al. (2021)	405 000 (2020)	https://www.globalbiotechinsights.com/articles/22323/2020-fluoropolymer-technology-highlights-by-idtechex
PTFE Micropowder	34 000 3 500	AGC Chemicals Europe (2020) Stakeholder consultation	150 000 – 170 000 (2016, 2017, 2018)	K-Profi (2016), Sympatex Technologies GmbH (2021), AGC Chemicals Europe (2020)
PVDF	15 000 – 20 000 (2019)	Drohmann et al. (2021)	80 000 estimation (2022)	Drohmann et al. (2021)

[2] https://www.plasteurope.com/news/SOLVAY_t249594/, date of access: 2022-12-02.
[3] https://www.icis.com/explore/resources/news/2022/06/13/10774387/belgium-s-solvay-more-than-doubles-china-pvdf-capacity/, date of access: 2022-12-02.

Worldwide perfluoropolyether volumes

Eight of the polymeric substances that are currently in the market are PFPEs (Buck et al., 2021).

EEA PFASs manufacturing volumes

Table A.7 includes a summary of PFASs manufacturing volumes.

Table A.7. PFASs manufacturing volumes in EEA (in 2020)[a].

PFAS group	Low volume (t/y)	Midpoint (t/y)	High volume (t/y)
PFAA and PFAA precursors	53 902	85 977	118 051
Fluorinated gases	15 000	95 774	176 548
Polymeric PFASs	49 000	75 381	101 763

Light blue cells denote PFAS volumes that have been used for impact assessment.

[a] The lower and upper estimates reflect the responses to the survey, or other industry data. Some companies reported exact figures, while others reported ranges. In some cases, companies reported volume data as "greater than x", with no upper bound included (e.g. ">1 000 t"). Therefore, the "upper estimate" is not a true maximum value.

A.2.2. Import

Stakeholders provided information on volumes of PFASs imported into the EEA (excluding PFASs in articles). Data on imports of specific PFASs into the EU were also retrieved from the Eurostat International Trade in Goods database[4] and from literature. An overview is provided in Table A.8. More details are provided in Table A.73 in the appendix.

The annual import volume of fluorinated gases was estimated to be 84 250 t (EEA, 2020). The European Fluorocarbons Technical Committee (EFCTC), a sector group of Cefic) estimated that illegal import could be as high as 33% of the legal EU HFC market[5]. EFCTC, highlights those Chinese exports to the EU could be 27% larger than what the EU reports as imports from China (EFCTC, 2020).

Table A.8. PFASs imported into the EEA from third countries (t/y) based on consultations. In brackets the reference year. Eurostat data and literature review.

PFAS group	Minimum volume (t/y) (stakeholders)	Maximum volume (t/y) (stakeholders)	Eurostat (t/y) (2019)[a]	Literature (t/y)
PFAAs and PFAA precursors	4 053	6 120	103 586	no data
Fluorinated gases	11 500	51 800	19 198	84 284 (EEA, 2020)
Polymeric PFASs	10 419	21 500 (2015) (Wood, 2022) 37 900 (2018) Stakeholder Fluoroelastomer: 6 400 (2018) Stakeholder, 15 000 (2020) (Wood, 2022)	36 148	15 000 (Wood, 2022)
TOTAL	**25 972**	**95 820**	**158 932**	**99 284**

[a] Eurostat data might underestimate volumes because GN/HS codes are selective. On the other hand, presented volumes might include formulated products where PFASs are a percentage of the formulation.
[b] Includes bulk fluorinated gases import (73 478 t) as well as import of fluorinated gases within products and equipment (10 806 t) based on EEA (2020).

It should be noted that these numbers do not include all PFASs and should be interpreted with caution. EU is a net importer of fluoropolymers, with an import volume of 15 000 t in 2020 according to Plastics Europe (Wood, 2022).

[4] https://ec.europa.eu/eurostat/databrowser/view/DS-045409/legacyMultiFreq/table?lang=en, date of access: 2022-12-15.
[5] https://www.fluorocarbons.org/news/illegal-trade-round-up-february-2021/, date of access: 2022-12-15.

A.2.3. Export

The annual export volume of fluorinated gases was estimated to be 24 033 t, excluding SF_6 as it is not a PFAS (EEA, 2020). Drohmann et al. (2021) estimates export volumes for fluoropolymers at 24 000 t (2020) and stakeholders estimate the volumes at 40 500 t (2018). Stakeholders also mention 6 900 t (2018) for fluoroelastomer export. A summary of the volumes of PFASs exports, retrieved from Eurostat is presented in Table A.9. A detailed overview is presented in Table A.74 of the appendix.

Table A.9. PFASs exported from the EEA (in t/y) based on consultations, Eurostat data and literature review.

PFAS group	Minimum volume (t/y) (consultation)	Maximum volume (t/y) (consultation)	Eurostat (t/y) (2019)	Estimates from literature (t/y)
PFAAs and PFAA precursors	No data	No data	131 866	No data
Fluorinated gases	No data	No data	10 371	24 033 based on EEA (2020)
Polymeric PFASs	24 000 (2020)	40 500 (2018) 6 900 (2018) fluoroelastomer	28 718	No data
TOTAL			**170 955**	

A.3. Uses

A.3.1. Summary

PFASs are used in numerous applications. All these applications sooner or later reach an end-of-life stage: The waste stage. Because of high waste tonnages and main PFAS application in articles, the waste treatment is of higher relevance for some PFAS applications: TULAC, food contact material & packaging, electronics and end-of-life-vehicles (ELV) are examples of such applications.

In waste treatment landfilling and incineration are the most important final waste treatment methods. Recycling can extend the lifetime but eventually for almost all substances, mixtures or articles only landfilling and incineration apply. In recycling, PFASs currently cannot be removed. It therefore can be present in recycled articles like paper or plastics.

There is no direct link between PFAS tonnage put on the market in a certain year and the PFAS waste tonnage for that application. Applications with longer lifetimes i.e., passenger cars or construction material, might have highly deviating waste quantities compared to production volumes in the same year (because of lower sales volume in the past and/or lower PFAS content in the past). As PFAS use has increased over the last decades the waste stage will remain an important source of PFAS emissions for many years to come, even in case of a full PFAS ban.

The PFAS tonnages of all checked uses are summarised in Table A.10 below, based on the grouping used for impact assessment and presented in Figure A.2.

Table A.10. Estimated tonnages for PFAS manufacture and major PFAS use sectors for 2020. Tonnages are for new products on the market, unless stated otherwise.

Application	**PFAAs and PFAA precursors (t/y)**			**Fluorinated gases (t/y)**			**Polymeric PFASs (t/y)**			**Total PFASs (t/y)**		
	low	**mid**	**high**	**low**	**mid**	**high**	**low**	**mid**	**high**	**low**	**mid**	**high**
Manufacture	53 902	85 977	118 051	15 000	95 774	176 548	49 000	75 381	101 763	**117 902**	**257 132**	**396 362**
TULAC[b]	8 092	20 620	33 148				33 091	71 318	109 544	**41 183**	**91 938**	**142 692**
Food contact materials and packaging	3 267	6 305	9 342				15 330	17 880	20 430	**18 597**	**24 185**	**29 772**
Metal plating and manufacture of metal products	2	30	57				960	960	960	**962**	**990**	**1 017**
Consumer mixtures										**21**	**26**	**30**
Cosmetics										**0.028**	**32.1**	**64.2**
Ski wax										**1.6**	**1.6**	**1.6**
Applications of fluorinated gases[c,d]				*493 173* 30 671	*493 173* 30 671	*493 173* 30 671				***493 173*** **30 671**	***493 173*** **30 671**	***493 173*** **30 671**
Medical devices	1 279	2 387	3 495	20 160	33 080	46 000	3 233	7 633	12 032	**24 672**	**43 100**	**61 527**
Transport[c]							*97 216* 6 410	*159 712* 10 532	*222 208* 14 653	***97 216*** **6 410**	***159 712*** **10 532**	***222 208*** **14 653**
Electronics and semiconductors	841	1 195	1 549	140	140	140	1 560	3 088	4 615	**2 541**	**4 423**	**6 304**
Energy sector	293	294	294				2 592	2 756	2 920	**2 885**	**3 050**	**3 214**
Construction products	987	1 696	2 405				4 254	7 287	10 320	**5 241**	**8 983**	**12 725**
Lubricants	1	6	10	70	110	150	1 100	1 550	2 000	**1 171**	**1 666**	**2 160**
Petroleum and mining	4.4	7	9.5				3 500	5 500	7 500	**3 504**	**5 507**	**7 510**
TOTAL (excl. manufacture)[e]	**14 766**	**32 540**	**50 310**	**513 543**	**526 503**	**539 463**	**162 836**	**277 684**	**392 529**	**691 168**	**836 787**	**982 398**
Total[f]	14 766	32 540	50 310	51 041	64 001	76 961	72 030	128 504	184 974	137 860	225 105	312 341

a: In some cases a basis for providing a range is lacking. There the available estimate is applied throughout; b: TULAC = Textile, upholstery, leather, apparel and carpets; c: For these sectors the tonnages relate to "technical stock volume" (presented in italics), representing an estimated 2020 PFAS volume in use in the sector as a whole. For reference only, the tonnages brought new to market in 2020 are also given; d: Includes tonnages for fluorinated gases in transport sector; e: Total based on best available data (stock if available, new to market if stock is not available); f: For reference only, also the total new manufactured tonnage put on market in 2020 is presented.

A summary of PFAS volumes per use category distinguished is given in the main dossier. In Table A.11 the PFAS volume are sorted based on volume ranges.

Table A.11. Uses sorted on volume range.

Application	Tonnage range
Applications of fluorinated gases	5
TULAC	5
Medical devices	5
Manufacture	5
Food contact materials and packaging	5
Transport	5
Construction products	4
Electronics and semiconductors	4
Lubricants	4
Petroleum and mining	4
Energy sector	4
Metal plating and manufacture of metal products	3
Cosmetics	2
Consumer mixtures	2
Ski wax	1

Table legend

Tonnage range (t/y)	
1	0 – 10
2	10 – 100
3	100 – 1 000
4	1 000 – 10 000
5	>10 000

A.3.2. Introduction

Many different PFASs are used in a wide range of applications, and there is no comprehensive source of information on the many individual substances and their functions in different applications. PFAS are used in almost all industry branches and many consumer products. Glüge et al. (2020) presented a comprehensive overview of the applications of PFASs, and they identified more than 200 use categories and subcategories for more than 4 700 different PFASs.

In A.3 the use of PFASs in 15 sectors is discussed. In this section (A.3.2), a brief overview of European use of PFASs is provided. In sections A.3.3 to A.3.17 detailed data on uses and volumes in various sectors is presented. In A.3.18, the waste stage is discussed.

A.3.2.1. Use of PFASs

For polymeric PFASs (of which fluoropolymers and perfluoropolyethers are main subgroups for impact assessment purposes), substantial information is available.

A.3.2.1.1. Fluoropolymers

According to Glüge et al. (2020), fluoropolymers are mostly used in the production of plastic and rubber, coatings, paints, lubricants, greases, and in the chemical industry. Many fluoropolymers are used in articles that are (partly) imported. This applies to textiles, electronics, cars, etc.

The group of fluoropolymers is dominated by PTFE, combined with fluorinated ethylene propylene (FEP), perfluoroalkoxy alkanes (PFA), ethylene tetrafluoroethylene (ETFE), and other tetrafluoroethylene-copolymers; they account for around 75% of the fluoropolymer market. Other important fluoropolymers include polyvinylidene fluoride (PVDF) and fluoroelastomers.

Fluoropolymers are used in a variety of sectors requiring properties such as:

- chemical resistance and inertness
- thermal stability
- cryogenic properties
- low coefficient of friction
- low surface energy
- low dielectric constant
- Resistant to UV degradation
- Resistant to degradation by hydrolysis
- High levels of bio-resistance (resistant to biological contaminants)

For an extensive overview on fluoropolymers, see Table A.75 and Table A.76.

Table A.12 below illustrates a selection of sectors where fluoropolymers are used and for which applications certain fluoropolymers have proven suitable due to their specific properties.

Table A.12. Examples of sectors, properties, and applications of fluoropolymers[6].

Sectors	Properties	Applications
Automotive	Mechanical property, thermal property, chemical property,	O-rings, gaskets, valve stem seals, shaft seals, linings for

[6] https://www.sciencedirect.com/topics/materials-science/fluoropolymer, date of access: 2022-12-15.

Sectors	Properties	Applications
	and friction property	fuel hoses, power steering, transmission, lubricants, and coatings
Chemical industry	Chemical resistance, mechanical property, thermal property, and weather stability	Coatings for heat exchangers, pumps, diaphragms, impellers, tanks, reaction vessels, autoclaves, containers, flue duct expansion joints, heavy-wall solid pipe and fittings
Electrical/electronic	Dielectric constant, flame resistance, and thermal stability	Electrical insulation, flexible printed circuits, ultrapure components for semiconductor manufacture
Architectural and domestic	Weatherability, flame retardancy, friction property, thermal stability	Water-repellent fabric, architectural fabric, non-stick coatings for cookware, and fiberglass composite for constructions
Engineering	Mechanical property, thermal stability, chemical stability, weatherability, and surface energy	Seats and plugs, bearings, non-stick surfaces, coatings for pipes, fittings, valve and pump parts, and gears
Medical	Surface energy, biological stability, mechanical property, chemical resistance	Cardiovascular grafts, ligament replacement, and heart patches

A.3.2.1.2. Fluoroelastomers

Fluoroelastomers have high heat and flame resistance, and good resistance to ageing, ozone, oxidizers, oils and many chemicals. They also have low gas permeability and low compression set. However, they usually have only limited low temperature capabilities, although some special lower temperature grades are available. They have limited resistance to steam, hot water, and polar fluids such as strong organic acids (e.g. formic acid), methanol, ammonia and some amines and are swollen by ketones and ethers, whereas new peroxide cured grades have somewhat improved chemical resistance. They can also become glassy at temperatures not far below room temperature. Principal applications are as temperature-resistant O-rings, seals and gaskets as illustrated in table Table A.13 of non-exhausted specific uses and applications overview in various industrial sectors.

Table A.13. Fluoroelastomers - non-exhaustive overview over specific uses and applications in various industrial sectors[7].

Automotive	Aerospace	Industrial
Shaft seals	O-ring seals in fuel, lubrication, and hydraulic systems	Hydraulic O-ring seals
Valve stem and valve seals	Manifold gaskets	Check valve balls
Fuel injector O-rings	Fuel tank bladders	Military flare binders
Fuel hoses and fuel hose liner	Firewall seals	Diaphragms
In-tank and quick connect fuel system seals	Engine lube siphon hose	Electrical connectors

[7] https://www.sciencedirect.com/topics/engineering/fluoroelastomers, date of access: 2022-12-15.

Gaskets (valve and manifold)	Clips for jet engines	Flue duct expansion joints
Balls for check valves	Electrical connectors	Valve liners
Heat-sealable tubing for wire insulation	Shaft seals	US FDA approved seals in food handling processes
Bellows for turbocharger lubricating systems	Traps for hot engine lubricants	Industrial roll covers (100% FKM or laminates with other elastomers)
Lathe cut gaskets	Tire valve stem seals	Safety clothing and gloves
Engine head gaskets	Heat-sealable tubing for wire and cable insulation	V-ring packers

USA based Interstate Technology and Regulation Council (IPRCO) provided an overview of PFAS uses with a specific section for fluoropolymers (ITRC, 2022).

According to AGC chemicals, a total of 50 900 t of fluoropolymers were used in 2018 in western Europe[8]. AGC Chemicals estimated the European consumption of PTFE to be 34 000 t.

According to PlasticsEurope (Wood, 2022), 40 000 t of fluoropolymers is used in 2020 in the EEA. With yearly 49 000 t production and 15 000 t import and 24 000 t export.

The automotive industry is the main user of FKM, a fluoroelastomer (64%), followed by chemicals/plastics (11%), aerospace (9%)and other (16%).

Worldwide fluoroelastomer consumption was estimated to be 13 800 t in 2019 (Ebnesajjad, 2021).

For fluorinated gases, a volume of 69 000 t/y (2018) was found, see Table A.14 (rounded numbers)(UBA, 2021). This number excludes HFO use in Europe (which is on the rise) (Nystedt, 2022).

Table A.14. Volumes of fluorinated gas used in the EU in 2018 (rounded numbers).

Substance name	**EU 2018 fluorinated gas use (t/y)**
HFC-125	13 000
HFC-134a	33 000
HFC-143a	confidential
HFC-227ea	1 400
Other HFC	4 100
HFO-1234yf	11 000
Other HFO and HCFO	6 300
TOTAL	**68 800**

For the use of PFAA and PFAA precursors in the EEA, no information was available.

[8] https://www.agcce.com/fluoroplastics/, date of access: 2022-12-15.

A.3.3. Textiles, upholstery, leather, apparel and carpets

A.3.3.1. Uses

PFASs have commonly been used across multiple Textiles, Upholstery, Leather, Apparel and Carpets (TULAC) products, as well as in mixtures for re-impregnation of different TULAC products. The key function that PFASs provide in these applications are water and oil repellence. Based on a review of a paper by Glüge et al. (2020), as well as further literature and industry input (through the CfE and second stakeholder consultation round), a number of specific application categories within the TULAC sectors have been identified. Table A.15 demonstrates the major use categories that are within the scope of this Annex XV dossier along with key sub uses and the functionality that PFAS provides for these products.

Note that medical devices can also include textiles in some cases. Medical devices are covered by a separate part of the Annex XV dossier (see paragraph A.3.10). To maintain clarity, medical textiles used in this section refers to any use of textiles in a medical setting, excluding use within or on the patient (e.g. implantable textiles like gauzes or exterior bandages). This definition includes articles such as mattress protectors upon hospital beds, curtains and drapes around the bed, and gowns and personal protective equipment (PPE) used by medical professionals.

In addition, textiles for use in the transport sector (such as automotive and aerospace industry) are described in section A.3.11 and thus not included in this section.

The major use categories can be distinguished as shown below in Table A.15.

Table A.15. Overview of different TULAC categories.

Major use category	Subcategory-uses with examples included	Technical function of PFASs claimed by stakeholders
Home textiles	Carpets and rugs	Water repellence, oil repellence
	Curtains and blinds	Water repellence, oil repellence
	Textile based coverings (e.g. fabrics for soft-furnishings, tablecloths, bedding)	Water repellence, oil repellence
Consumer apparel and accessories	Indoor and outdoor wear	Water repellence
	Sportswear	Water repellence, oil repellence
	Footwear	Water repellence, oil repellence
	Accessories (e.g. umbrellas, bags, wallets)	Water repellence
Professional apparel	Professional sportswear and footwear	Water repellence, oil repellence
	PPE for industrial and professional use (other than sportswear)	Water repellence, oil repellence, stain-resistance, soil protection
Technical textiles[a]	Outdoor technical textiles (e.g. canvas, awnings, tarps, tents, sails, rope)	Water repellence, oil repellence, stain-resistance, soil protection
	Medical applications (e.g. surgical drapes, gowns, curtains)	Water repellence, oil repellence, stain-resistance
	High performance membranes	Water repellence, oil

Major use category	Subcategory-uses with examples included	Technical function of PFASs claimed by stakeholders
	(e.g. automotive and medical)	repellence, stain-resistance, thermal stability
Leather applications	Leather based goods (e.g. leather bags, wallets, belts)	Water repellence, oil repellence
	Indoor and outdoor wear	Water repellence, oil repellence
	Footwear	Water repellence, oil repellence
	Professional sportswear and footwear	Water repellence, oil repellence
Other	E.g. home fabric treatments (sprays) for leather/textiles	Water repellence, oil repellence, stain-resistance, soil protection

[a] Textile product manufactured for non-aesthetic purposes, where function is the primary criterion.

The analysis presented in this report will be limited to the applications listed above. In addition to the function listed above, PTFE is used across multiple TULAC sectors and is reported to have specific functions in TULAC with regard to chemical inertness (protective clothing), hydrophobicity[9] (protective and outdoor clothing) and water vapour permeability.

The function and purpose of using PFASs in TULAC was elaborated further by respondents from the CfE, stating that TULAC materials made with these substances exhibit the following benefits and properties:

- Waterproof properties (lower water permeability and wettability).
- Chemical resistance and inertness.
- Protection against exposure to liquid such as blood and other body fluids, but also chemicals and electrical discharge.
- Extremely robust mechanical properties (e.g. resistance to abrasion) and provides low friction.
- Weatherability including UV protection and resistance to corrosion from salt water:
- Resistant to high temperatures (thermally stable), but at the same time flexible.

Fluorochemicals are not necessarily specified within TULAC product standards within the EEA but the function of PFASs is important to the fulfilment of some technical standards[10].

A.3.3.1.1. Use of PFASs in filtration and separation media

Filtration and separation media[11] covers various professional uses. One example is nonwoven filters coated with side-chain fluorinated polymers for oil and water separation in e.g. gas turbines, hydraulic applications, nuclear industry, respiratory applications and air pollution control and dust collection.

Filtration and separation media also include high performance membranes as a subgroup with special properties, such as ePTFE membranes and filters. An ePTFE membrane is created when PTFE, a linear polymer consisting of fluorine and carbon molecules, is expanded, creating a microporous structure with highly desirable characteristics, including a high strength-to-weight ratio, biocompatibility, high thermal resistance and many others. The filters function by physically trapping and removing unwanted molecules and particles, either by adsorption or chemical reactions, while the membranes use a thin, permeable layer or sheet of material, e.g. expanded porous layers such as ePTFE, where the medium passes

[9] A hydrophobic surface is a water repelling, low surface energy surface that resists wetting of water.
[10] Table A.78 contains a list of standards that apply to TULAC products.
[11] A subset of technical textiles is shown in Table A.16.

through to remove unwanted molecules and particles. Membranes of ePTFE are used in various high-tech applications such as medical devices implanted in the human body and electronic cables transmitting signals from outer space.

Use of C6 side-chain fluorinated polymers in filtration and separation media

Filtration and separation media treated with C6 side-chain fluorinated polymers consist primarily of non-woven material or paper composed of manmade fibres, natural fibres (or a combination of both), with resins that contribute to the structural or physical properties of the media. Filtration and separation media manufactured with C6 side-chain fluorinated polymers play a critical role in the following applications, among others: medical devices, PPE, HVACR (including EPA/HEPA/ULPA), Air Pollution Controls (APC), dust collectors, hydraulic systems, coalescers, gas turbines, and fuel systems. There are alternatives to C6 available for these applications since only water-repellence is needed.

The restriction proposal for PFHxA includes a derogation for filtration and separation media used in high performance air and liquid applications that require a combination of water- and oil-repellence. SEAC concluded in its opinion that:

> *During the consultation on the Annex XV report, several stakeholders requested a complete derogation for the use of PFHxA in filters and membranes. The Dossier Submitter proposes a derogation for filtration and separation media used in high performance air and liquid applications that require a combination of water- and oil repellence properties, even though it is well-noted in the Background Document and by SEAC that such a broad derogation leads to a certain degree of uncertainty as it might be possible that alternatives are already available or will become so in near future for some applications. Cost estimates for the uses affected are scarce, only some information was provided by stakeholders during the consultations. This information mainly indicates that specifically costs related to substitution, e.g. loss of effectiveness of products due to no alternatives being available currently, could be potentially very high. Stakeholders reported that appropriate filtration reduces maintenance needs, extends service life and prevents failures of equipment; they also expect energy consumption and related greenhouse gas emissions to increase in the absence of C6-treated filtration media. During the consultations on the Annex XV report and the SEAC draft opinion, it was stated that the absence of a derogation will put manufacturing facilities located in the EU at risk and result in a supply interruption of filtration and separation media for several purposes until adequate alternative candidates are identified and requalified. SEAC agrees to the Dossier Submitter's conclusion that more information on the different applications and specifically a more detailed discussion on substitution possibilities as well as on any potential related costs would be needed in order to draw a robust conclusion on the socio-economic impacts.*

The Dossier Submitter has not received any information that affects this conclusion.

Use of ePTFE-based filter applications

Over the decades, PTFE as a woven fabric and as a needlefelt material has been used in various filtration applications, particularly those involving aggressive chemical environments. The PTFE filters can be used in liquid applications as well as dry dust applications[12].

Expanded PTFE is used as a film or membrane on a growing number of filters across every industry including food and packaging, pharmaceutical, minerals, power generation, metals, chemicals, engineering, automotive, and aerospace. The membrane is laminated to a wide variety of substrates such as polyester needle felts and woven glass fibre to be made into

[12] https://www.sciencedirect.com/topics/engineering/expanded-polytetrafluoroethylene, date of access: 2022-12-15.

filter bags, and pleatable materials such as polyester and cellulose for filter cartridges and elements. The substrate acts as a stable supporting base for the membrane. The type of substrate is determined based on the specific application requirements to which the filters will be subjected[13].

One of the key advantages of ePTFE membrane filters is the filtration efficacy of sub-micron sized particles, assisting in meeting the terms with the increasingly rigorous norms and regulations pertaining to health and the atmosphere in working areas. The shape of the dust, rather than its size, is an important factor when considering the abrasive potential of the dust. Angular particles like those present in cement have a far more abrasive potential despite them being very small in size. The velocity of airflow carrying the dust, the filter unit and ductwork design are other important aspects that demand attention to make sure that the service durability of the filters is not significantly reduced due to degradation (Reports And Data, 2020).

A.3.3.1.2. Use of PFAS in Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE) can include items such as safety helmets, gloves, eye protection, hazmat suits, high-visibility clothing, safety footwear, safety harnesses, ear plugs, ear defenders and respiratory protective equipment. This section focuses on protective clothing used for professional and industrial uses, however, not for medical applications[14].

PPE requires CE marking, by which the manufacturer indicates that PPE is in conformity with the applicable requirements set out in EU legislation. This means that a set of European (EN) standards must be met for PPE placed on the EEA market. Table E.13. in Annex E.2.2.2.1. contains a summary of performance and test standards for types of PPE where PFAS is commonly used.

Annex I of the PPE regulation (EU 2016/425) defines three risk categories; where Category I includes a list of minimal risks, Category III covers a list of risks that may cause very serious consequences such as death or irreversible damage to health, and Category II includes risks other than those listed in I and III.

Requirements, including specific technical standards, for PPE are mentioned in Table A.78.

A.3.3.1.3. Reported concentrations of PFASs in TULAC

Limited information is available on the concentrations of PFASs in a range of textile products. With respect to the concentration of PFASs that are present in the finished TULAC products, there are varying concentrations reported. One stakeholder suggested that overall, the PFASs concentration across TULAC products can be summarised as in the range of <0.1 - 7%[15]. Further detailed information was received during the CfE for specific TULAC products. Working concentrations of PFASs in a range of textile products noted by respondents are listed in Table A.16 below.

Table A.16. Applied concentrations of PFASs in a range of textile products.

Textile product	% in the final textile product
High performance upholstery	<0.1 C6 SCFP in final textile product
Outdoor textiles	2 of FEP/PFAA in final product

[13] https://www.filtsep.com/content/features/membranes-expanded-ptfe-finds-new-markets, date of access: 2022-12-15.

[14] Regulation (EU) 2016/425 (PPE) does not apply to PPE: (a) specifically designed for use by the armed forces or in the maintenance of law and order; (b) designed to be used for self-defence, except for PPE intended for sporting activities; (c) designed for private use to protect against: (i) atmospheric conditions that are not of an extreme nature, (ii) damp and water during dishwashing.

[15] Euratex Submission to stakeholder consultation.

Textile product	% in the final textile product
Chemical protective suits	PTFE (max 1), THV (max 1) or FKM or Fluorosilicone (50-90)
Protective and technical textiles where PTFE is used as a membrane material	100 of membrane is PTFE
PPE - (non-medical)	1.5 - 3
Medical gowns, drapes and PPE	C6 concentration average for all products <0.5
Within some face masks	1.9 of ePTFE in final products (by weight).
Leather straps	200 µg/m^2
Architectural polyester/PVC fabrics as fluoropolymers	<1 as a protection of polyester PVC fabrics.
Non-Launderable Textiles	≤0.1 total fluorine on weight of fabric
Membrane	C6 PFAS represent approximately less than 1 of total weight of the membrane

As a comparison, the reported concentration ranges for PFOS presented in UNEP (2018b) for the TULAC categories were textiles and upholstery: 2 - 3%; synthetic carpets: 0.03%; and leather: 0.025 - 0.05%. These concentrations are broadly in line with those reported during the CfE, except for PTFE where concentrations vary widely. However, very little information was provided for the home textiles sector.

A variety of PFASs are in use for TULAC applications. The identified substances have been disaggregated into PFAAs and PFAA precursors (including side-chain fluorinated polymers) and polymeric PFASs before developing the following groupings:

- PFAA and PFAA precursors
- All C2-C3 PFAS substances
- All C4 PFAS substances
- All C5 PFAS substances
- All C6 PFAS substances
- All C9 – C14 PFAS substances
- Other non-polymer PFAS substances
- All side-chain fluorinated polymer groupings

Non-polymeric PFASs are used in the production of side-chain fluorinated polymers and are not in themselves present in the TULAC final product (other than as impurities).

For the "other" non-polymer PFAS, this broadly covers longer chain PFASs (≥C15), and a range of aromatic substances. Note that a wide range of substances are described as 'reaction products', some of which are oligomeric/polymeric, and some of these are non-polymers.

<u>PFAAs PFAA precursors</u>

The side-chain fluorinated polymer group was a smaller sub-set overall (in terms of tonnage, see Table A.20) and in many cases the respondents from CfE simply replied with terms like 'perfluorinated C4 and C6 side-chain polymer', rather than naming specific substances. However, based on the concerns raised in the academic literature this group was identified a potentially important, so has been separated from the fluoropolymers group.

Side-chain fluorinated polymers with various perfluorinated chain lengths from C2 to C14, that occur in TULAC applications either intentionally or as contaminants, are described in Table A.17 (Knepper and Lange, 2012).

Table A.17. Side-chain fluorinated polymers used for TULAC applications.

Category	Subcategory Hydrophilic group	Applications
Side-chain fluorinated polymers	Alcohols, silanes, alkoxylates, fatty acid esters, adipates, urethanes, polyesters, acrylates	Soil/water repellence for carpet, fabric/upholstery, apparel, leather, metal/glass
	Phosphate esters	Soil/water repellence for carpet, fabric/upholstery, apparel, leather, metal/glass. Oil/water repellence for plates, food containers, bags, wraps, folding cartons, containers, carbonless forms, masking papers

Whether side-chain fluorinated polymers bestow water- or oil-repellent functions to TULAC is determined by the chemical linkages within the polymer backbone and the fluorinated side-chain. These can be esters (using acrylate or methacrylate monomers) urethane, or ethers (using oxetane monomers).

Fluorinated gases

Stakeholders mention fluorinated gases to be used in significant quantities for manufacturing of polyurethane foam in the seating of furniture. However, the gases mentioned are not PFASs. It cannot be excluded that fluorinated gases that are PFASs are used as well.

Polymeric PFASs

- PTFE
- PVDF
- FEP
- PFPEs (as a family)
- PFA (as a family)
- Other fluoropolymers

The approach taken for polymers was to create separate entries for the substances with the highest tonnages of use. The "other" category in this case covers two general groups, remaining unique polymer substances (e.g. THV, FKM, FFKM) which are used in much lower quantities, and a range of reaction products, which are either oligomeric or polymeric. Note that in many cases this includes aromatic structures.

Based on the data gathered from the CfE, stakeholder engagement, and market research, around 120 unique PFAS (82 of which had CAS numbers, the rest contained many polymers without a CAS number) are identified in the TULAC sector which are used intentionally or are the product of degradation or an impurity. The majority of substances reportedly used in TULAC sector in the EEA are fluoropolymers (particularly PTFE) and to some extent side-chain fluorinated polymers. Notably, all the substances reported to be used in professional textiles were PTFE or fluoropolymers of >20 carbon chain length, whereas in all the other use categories a broader array of chain length PFASs are currently reported to be used. The list of PFASs used in this sector is not provided here due to Confidential Business Information.

A.3.3.2. Volumes

In 2017, the EU-28 produced 7.4 kg of textile products per person while consuming nearly

26 kg (Table A.10) (EEA, 2019). This indicates that around 12 million tonnes of textile products were consumed in the EEA based on the current population. A large proportion of textiles within the EEA are imported (mainly finished products from Asia). Exports mainly comprise intermediate textile products, such as technical fibres and high-quality fabrics in which the European industry specialises. Indicative estimates of quantities sold, as well as import and export data, per sub-category of TULAC are presented in Tables 25 and 26 in Annex E.2.2.4.2.

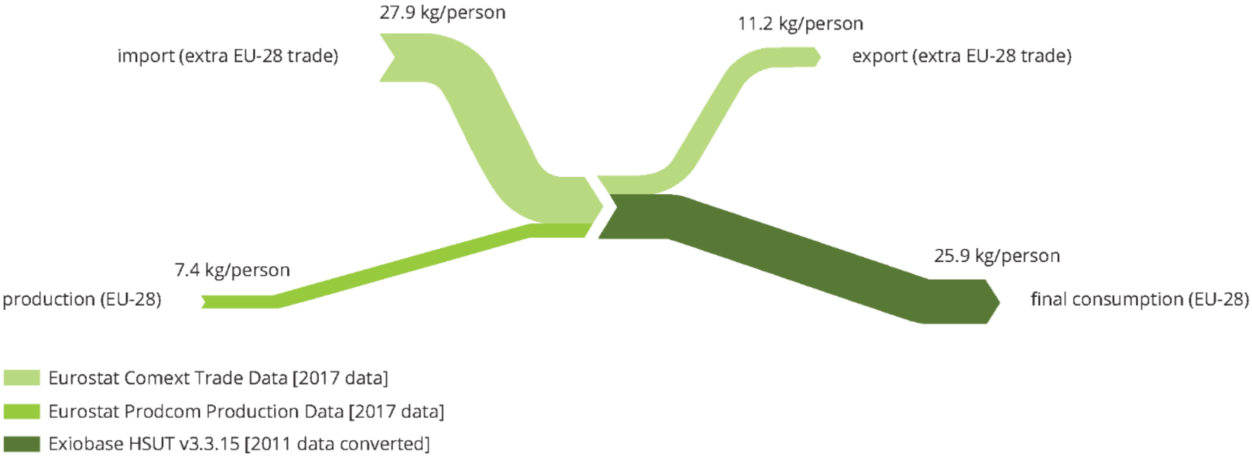


Figure A.9. Annual import, export, production, and consumption flows of textile products in the EEA-28, 2017. Source: EEA (2019).

In the EU-27 in 2021, there were around 143 000 companies operating in the textile and clothing industry (EURATEX, 2022). The number of companies dealing with articles containing PFAS has not been identified.

The textile industry is quoted to be one of the most extensive users of PFAS. For example, the Annex XV Restriction Dossier for PFHxA (ECHA, 2019) estimates that ~78% of the PFHxA used in the EEA is for clothing, while ~4% is used in firefighting foams, and ~3% for other uses (e.g. chrome plating, paper, inks, paints etc). Overall, textile applications account for an estimated 35% of the demand for fluorotelomers globally (Goldenman et al., 2019).

Tonnage estimates below are based on the information gathered in the CfE. It is estimated that between 41 000 (low estimate) and 143 000 t (high estimate) of PFAS are used within TULAC products in the EEA annually. These estimates might include some degree of double counting of "functional PFAS", precursors and intermediates. The reason for this is that, based on the information from the CfE, it has been difficult to distinguish between these groups and there is therefore a risk that precursors have been calculated separately and added with the "functional PFASs" formed by these precursors, resulting in a doubled or higher quantity estimate (see Appendix VI for a more detailed description).

The report by Wood (2020) concludes that TULAC is approximately 45 000 - 80 000 t/y. Based on this, the "low estimate" (41 000 t) appears more credible than the "high estimate".

There is however some uncertainty regarding how well quantities of PFAS in imported TULAC articles are covered by these estimates. No data has been provided or found on the proportion of imported textiles that contain PFAS. One question in the consultation was if the calculations (based on data from the CfE) also covered imported TULAC sufficiently. Approximately 30% replied "yes", 20% answered "no", and the remaining 50% did not have an opinion or information.

The estimated tonnages of PFAS in different applications are reported in Table A.18. According to the information received in the CfE, around 80% of the estimated total tonnage is fluoropolymers. The CfE also indicates that the key dominant TULAC sectors using PFAS are consumer apparel, followed by home textiles and technical textiles. This information on the use of PFAS per subcategory of TULAC is uncertain since tonnages reported for several sub-categories in the CfE have been split equally across the subcategories when there is no other information. The report by Wood (2020) estimates that PFAS use is substantially larger in the subcategories home textiles and consumer apparel than in professional apparel and technical textiles. No responses on PFAS in leather applications were received during the CfE.

According to CfE input from the Filtration and Separation Coalition, the volume of C6 PFAS used for the filtration and separation media placed on the EU market is approximately 67 t/y. This volume covers professional and industrial uses. C6-treated filters for consumer use (e.g. vacuum cleaners, air purifiers) constitute a marginal fraction.

As indicated in Table A.18, the estimated tonnage of PFAS used in 'Professional apparel' is 5 220 - 20 044 t total PFAS and 101 - 1 100 t total non-polymeric PFAS. Some part of this is used in PPEs, but a more exact quantification has not been possible to derive.

During stakeholder consultations following the second stakeholder consultation (see Annex G) three companies[16] in the PPE sector indicated that around 20 percent of the PFAS used in the PPEs they put on the EEA market were used in PPEs protecting against Category III risks. The remaining 80 percent were used in PPEs protecting against Category I or II risks.

Several stakeholders indicate that there may be a risk of overuse of PFAS, with a higher level of protection than necessary, as the customer's way of using PPE is not always clear. This could, for example, be because PPE customer's want their entire work force at a facility to have uniform clothing and, consequently, that the tasks that require the highest level of protection sets the standard for the PPE used by all workers.

There is no publicly available quantity data of PFAS for maintenance and reimpregnation of PPE in the EEA. An approximative calculation provided by the European Textile Services Association (ETSA) indicates that around 20 t of pure PFAS are used in the European market to reimpregnate PPE[17].

The reported concentration ranges for PFAS for the TULAC categories are listed in Appendix . However, limited information is available on the concentrations of PFAS in a range of textile products.

[16] These companies make up a limited share of the market. Their total annual quantity of PFAS use in PPE articles for the EEA market is approximately 3 t. Therefore, it is unclear if these estimates can be extrapolated to the entire EEA PPE market.

[17] Written communication with Home European Textile Services Association (ETSA) November 2021.

Table A.18. Tonnages of PFAS used in TULAC industry in EEA (2020).

Sub use	C2- C3 PFAS substances (t/y)		PFAA ≥C4 (t/y)		Side-chain fluorinated polymers (t/y)		Total PFAAs and PFAA precursors (t/y)		Fluoro polymers (t/y)		PFPE (t/y)		Total polymeric PFASs (t/y)		Total PFAS (t/y)	
	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high
Home textiles	717	3 433	363	770	230	559	1 310	4 761	4 658	22 049	262	558	4 920	22 607	6 230	27 368
Consumer apparel	717	3 433	363	770	1 019	10 034	2 099	14 237	5 801	32 353	261	557	6 062	32 910	8 161	47 148
Professional apparel	0	0	1	101	100	1 000	101	1 101	5 119	18 943	0	0	5 119	18 943	5 220	20 044
Technical textiles	717	3 433	364	869	14	22	1 095	4 324	4 845	21 659	262	558	5 107	22 217	6 201	26 541
Medical textiles	0	0	0	0	0	0	0	0	331	1 096	0	0	331	1 096	331	1 095
Leather textiles	-	-			-	-	-	-			-	-	-	-	-	-
Other	0	0	2 422	6 103	1 067	2 621	3 489	8 724	11 551	11 762	1	10	11 552	11 772	15 041	20 496
Total (TULAC)	2 150	10 300	3 512	8 612	2 430	14 236	8 092	33 148	32 305	107 861	786	1 683	33 091	109 544	**41 183**	**142 692**

Table A.19. Tonnages of PFASs used in the TULAC industry in EEA in year 2020, as taken for impact assessment (mid points from low and high estimates as presented in table above).

Sub use	C2- C3 PFAS substances (t/y)	PFAA ≥C4 (t/y)	Side-chain fluorinated polymers (t/y)	Total PFAAs and PFAA precursors (t/y)	Fluoro polymers (t/y)	PFPE (t/y)	Total polymeric PFASs (t/y)	Total PFAS (t/y)
Home textiles	2 075	566	395	3 036	13 354	410	13 764	16 799
Consumer apparel	2 075	566	5 527	8 168	19 077	409	19 486	27 655
Professiona l apparel	0	51	550	601	12 031	0	12 031	12 632
Technical textiles	2 075	617	18	2 710	13 252	410	13 662	16 371
Medical textiles	0	0	0	0	714	0	714	714
Leather textiles	-	-	-	-	-	-	-	-
Other	0	4 278	1 844	6 107	11 657	6	11 662	17 769
Total (TULAC)	6 225	6 062	8 333	20 620	70 083	1 235	71 318	**91 938**

Total estimated PFAS use per substance type over all TULAC uses is presented in Table A.20.

Table A.20: Total tonnages of subgroups of PFAS used per year for TULAC in the EEA in 2020 (low and high estimate).

PFAS substance	**Low estimate (t/y)**	**High estimate (t/y)**
PFAAs and PFAA precursors		
All C2- C3 PFAS substances	2 150	10 300
All C4 PFAS substances	17	46
All C5 PFAS substances	1	1
All C6 PFAS substances	3 399	8 435
All C9-C14 PFAS substances	2	2
Other non-polymeric PFAS	93	129
Side-chain fluorinated polymers	2 430	14 236
Polymeric PFASs		
PTFE	15 202	68 465
PVDF	1 058	5 082
PFPE	786	1 683
FEP	55	189
PFA	7	21
Other and unspecified fluoropolymers	15 984	34 104
PFAAs and PFAA precursors TOTAL	8 092	33 148
Polymeric PFASs TOTAL	33 091	109 544
Total tonnage used per year (all PFAS)	**41 183**	**142 692**

A.3.3.3. Summary

Because of the vast range of properties, PFASs are widely used in the textiles, upholstery, leather, apparel and carpets (TULAC) industry. The main properties PFASs provide in this industry are, water repellence, oil repellence, protection against stain-resistance and thermal stability. Stakeholders report an estimated annual use of between 41 000 and 143 000 t (rounded numbers). Over 75% of the PFASs used are fluoropolymers, almost half of which is PTFE. Other fluoropolymers used include PVDF, PFPE, FEP, PFA, and others. C2-C3 and C6 PFAS, as well as side-chain fluorinated polymers, are the most abundant PFAAs and PFAA precursor that are being applied in the TULAC sector. TULAC thereby is a large PFAS use sector. A large proportion of textiles within the EEA are imported (mainly finished products from Asia).

A.3.4. Food contact materials and packaging

A.3.4.1. Uses

PFASs in food contact material (FCM) and packaging are largely used to confer oil and grease resistance in the following main applications:

- Packaging (including non-FCM packaging);
- Consumer cookware;
- Industrial food and feed production equipment.

Fluoropolymers are mainly used for non-stick properties of material coatings for consumer cookware and industrial applications.

Oil and grease resistant food contact *paper packaging* products are often based on the surface application of side-chain fluorinated polymers (SCFP). For production of thin film (PP and PE) *plastic packaging*, PFASs are mainly used as polymer processing aids. Often fluoroelastomers are used as polymer processing aids in the extrusion of PP, PE and polyolefin films.

Numerous PFAS are used in food contact materials and packaging, see Table A.80, Table A.81 and Table A.82.

A.3.4.1.1. Packaging

Packaging is a very broad sub-use. PFASs are used where oil and grease resistance are important. In food and feed packaging PFASs are intentionally applied to paper and board packaging to confer primarily fat, but also repel stain and water (included water vapour). 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. Some pet food and feed packaging applications require particularly high-performance grease/water resistant for example to maintain quality of dried food (OECD, 2020).

A major use for PFASs is application to paper and board substrate for fast food wrapping. Not only is food packaging of relevance, but also feed packaging and generic packaging. The following sub-uses were seen in packaging:

Food packaging

- Greaseproof paper;
- Baking paper;
- Heat resistant packaging;
- Other food packaging (e.g. milk containers, stretch and shrink films, pouches, frozen food packaging);
- Coating of (food and beverage) cans (Often PTFE wax and micropowder PTFE are used).

PFAS coatings may also be applied to disposable packaging items used for food consumption such as paper plates, bowls and ice cream tubs.

Feed packaging

- Pet food;
- Agricultural feed.

Generic packaging

- Paper and board for non-food/feed applications;
- Folding packaging cartons, carbonless forms/pressure sensitive paper, masking papers, tablecloths, and wall papers;
- Coated drums: fluorination of plastic (food or non-food) containers;
- Coated chemical containment bottles used for non-food packaging;
- Other packaging (coated plastic, glass, metal) for non-food/feed applications;
- Plastic films for health and hygiene;

Processing and polymerisation aids application in especially PP and PE thin film production

PFASs are also used as processing aids in the manufacture of plastic materials including thermoplastic packaging, to improve the flow properties of the plastic for example in the production of plastic sheets. The use of the processing aid may enhance the throughput of material and permits production of thinner films[18].

Currently there are three main types of PFASs used in packaging:

a) Short chain fluorotelomer side-chain (C6) polymeric PFASs, with high molecular weight acrylic polymers that contain fluorotelomer functionality to provide repellent performance.

b) Perfluoropolyether (PFPE) based oil and grease repellent products.

c) Fluoroplastics: FEP, PFA (perfluoroalkoxy ethanes), and FKM (fluorocarbon-based fluoroelastomer materials);

- Largely unknown PFASs (by-product of fluorine gas treatment of plastic containers such as HDPE containers);
- Fluorinated HDPE containers used for substances in various applications.

Consumer cookware

Fluoropolymers such as PTFE are used as non-stick coatings in consumer cookware. Non-stick properties prevent food from sticking, facilitate cleaning, provide durability, prevent corrosion and reduce the need for oil in cooking. Fluoropolymer coatings also tend to withstand high temperatures, such that they can be used in cooking. They are also insulators and do not conduct electricity[19].

These coatings may be found in pans, in baking tins and on the surface of electrical cooking appliances such as toastie makers and grills. They may also be used in dishwashers (Plastics Europe, 2017).

Temperature resistant coatings are dispersions or solutions of artificial organic resins in water or organic solvents for producing non-stick coating for utensils and other food contact articles. Usually, the coatings consist of combinations of fine-grain homo- or copolymers of tetrafluoroethylene with solutions or dispersions of film-forming artificial organic resins[20].

PTFE non-stick coatings normally consist of up to three coats and have an operating temperature of up to 260 °C[21]. They are selected due to low friction properties, good

[18] http://www.plastemart.com/plastic-technical-articles/polymeric-processing-aid-performs-better-than-conventional-waxes/1592#, date of access: 2022-12-16.
[19] https://coatingsystems.com/fep-coating-beneficial-kitchen/, date of access: 2022-12-16.
[20] https://www.bfr.bund.de/de/bfr_empfehlungen_zu_materialien_fuer_den_lebensmittelkontakt-447.html, date of access: 2022-12-16.
[21] http://www.ptfecoatings.com/ptfe-coatings/non-stick.php, date of access: 2022-12-16.

abrasion resistance and good chemical resistance, which make them easier to clean without damage. Fluorinated ethylene propylene (FEP) non-stick coatings melt and flow during baking to provide non-porous films, they have good chemical resistance and are low friction. The maximum recommended use temperature for FEP coatings is 200 °C. Perfluoroalkoxy (PFA) coatings also melt and flow during baking to create non-porous films but have a higher continuous use temperature of 260 °C. PFA coatings are harder than those of PTFE or FEP. Ethylene tetrafluoroethylene (ETFE) coatings have good chemical resistance but a lower continuous operating temperature of 150 °C; conversely, they are very durable.

Consumer cookware can be divided in the following sub-uses. Non-stick coatings for:

- Frying pans;
- Baking trays and bake pans;
- Sauce pans;
- Cooking plates in electric appliances such as sandwich toasters, waffle irons;
- Consumer bakeware including cake tins, bread-loaf tins, etc.;
- Seals, O-rings, gaskets, tubing and pipes in consumer electrical equipment such as coffee machines (mentioned and described under industrial applications);
- Filters to capture contaminants from for example steam filtration in food processing.

Key PFASs found to be used in consumer cookware are:

- Fluoropolymers:
    - PTFE
    - ETFE
    - ECTFE
    - FEP
    - hexafluoropropylene;
  - PFA (perfluoroalkoxy ethanes)
  - Perfluoroelastomers and FKMs
  - (PTFE) coated elastomers

A.3.4.1.2. Industrial applications

Industrial applications cover the equipment to produce food and feed, as well as their packaging materials at an industrial scale. See for instance a website for PFTE coatings[22].

PFAS are used in food processing equipment primarily for their non-stick properties combined with non-reactivity with chemicals, thermal resilience during cooking and wear resistance providing durability. The majority of PFASs used in this market segment are fluoropolymers. One of the main uses for PFASs in industrial applications is in food and feed processing lines where PFAS (polymers) provides a non-stick coating to conveyor belts, using PTFE or PVDF. Fluoropolymer dispersions are, for example, formulated into coatings for conveyor belts for commercial food and feed products. PVDF is used in fabrication of industrial cookware equipment mainly for its mechanical properties and chemical resistance. Fluoropolymers are widely used in industrial bakeware moulds and trays because they provide long-lasting oil and fat-free mould release. Fluorothermoplastics and PTFE are also processed into valves and fittings for commercial food and feed products. PTFE impregnated glass cloth is commonly used in food contact applications as a release agent.

[22] http://www.ptfecoatings.com/industries/packaging.php, date of access: 2022-12-15.

Other applications:

- Piping and tubing for drinking water applications;
- Filters to capture contaminants from, for example, steam filtration in food processing;
- Seals, O-rings, gaskets, tubing and pipes, expansion joints;
- Valves and fitments, conveyor belting, chutes, guiding rails, rollers, funnels and sliding plates, tanks, funnels, rollers, linings, blades of knives and scissors, springs, filter membranes and sensor covers, lubricants;
- Re-coating of industrial bakeware.

In industrial applications, PFASs are often used to enhance productivity, to prevent clotting, to enable hygienic conditions etc. PFASs most often used in industrial processing are PTFE, FEP, PFA and ETFE.

Key PFASs used:

- Fluoropolymers:
    - PTFE
    - ETFE
    - ECTFE
    - FEP
    - Hexafluoropropylene variations
    - PVDF–based
- PFA (perfluoroalkoxy ethanes);
- Perfluoroelastomers (liquid processing systems)
- PTFE coated elastomers are often used as seasling in pressure bearing equipment
- Others
    - PFMVE
    - PTFE copolymers

Figure A.10. Automatic Chappati making (left) and hydraulic seal kit (right). Source: Creative Commons BY-SA 2.0.

According to a stakeholder, transport rollers, baking trays, extruders and tanks often have a thickness of 20 - 100 µm, consisting of about 50% by weight of the fluoropolymers PTFE, FEP and PFA. Dry lube coatings for guide rails, O-rings (Figure A.10), bearings, and valve seats often have a thickness of 5 - 20 µm, consisting of about 50% by weight of PTFE. Anti-corrosion coatings for tanks and pipelines often have a thickness of 500 – 1 500 µm, consisting of about 95% by weight of the fluoropolymers PFA, FEP, ETFE, and ECTFE. In the appendix, Table A.80, the main substances used in FCM and packaging are mentioned.

A.3.4.2. Volumes

A.3.4.2.1. Packaging

Paper and board packaging

Paper and board packaging volumes were based on information from CEPI, the European association representing the paper industry (Table A.21).

Table A.21. Paper and board packaging consumption for food and feed and generic packaging in Europe in 2019and beverage can EEA production (Cepi, 2020).

	Quantity (million t/y)
Case materials	28.4
Carton board	6.2
Wrappings	2.6
Other paper and board for packaging	4.2
Total	**41.4**

EEA-wide volume figures of PFASs used in paper and board food packaging have not been identified in literature or from stakeholders. Instead, the PFAS volumes utilised as a basis for deriving emission estimates have been calculated from available data with a few assumptions applied. Data sources are shown in the Appendix in Table A.79.

In Table A.22, based on paper and board packaging volumes and average intentionally added PFAS content (values from German and Dutch regulation) from Table A.79 (see Appendix) PFAS quantity is calculated.

Table A.22. Estimates of intentionally added PFASs in total paper and board food packaging for different assumptions according to in EU-27, UK and NO 2019.

Proportion of total paper and board with PFAS (%)	**Quantity of paper and board[a] (t)**	**Permitted Level PFAS (%)**	**Quantity of PFAS (t)**
0.5	206 755[b]	0.4	827
	206 755	1.2	2 481
1.0	413 510[b]	0.4	1 654
	413 510	1.2	4 962

[a] Based on total paper and board Packaging consumption = 41 351 000 t. See table Table A.21.

[b] Based on the calculation in the text below.

Range of paper and board packaging containing PFAS:
If 0.5% of the total paper and board packaging consumed contains PFAS
= 0.5/100 x 41 351 000
= 206 755 t of paper and board packaging

If 1.0% of the total paper and board packaging consumed contains PFAS
= 1.0/100 x 41 351 000
= 413 510 t of paper and board packaging
i.e., the quantity of paper and board packaging containing PFAS in 2019 was 206 755 – 413 510 t.

For comparison purposes, the quantities of PFASs in paper and board food packaging were estimated in addition using a different starting assumption i.e., the fluorine content of the paper and board packaging. From Dinsmore (2020), the quantity of fluorine that is present in paper and board packaging is a *maximum* of 1 200 mg/kg (equivalent to g/t) or an *average* of 537 g/t.

These two figures, shown in Table A.22 and Table A.23, have been used to derive a range of the total quantity of PFASs in paper wrapping and carton board packaging. To estimate the PFAS content of paper wrapping and carton board packaging an approximation of the PFAS content has been derived assuming an estimated average fluoride content of the total molecular weight. This is assuming that the PFASs present can be like perfluorohexanoic acid (PFHxA) (fluorine content 66%), or side-chain fluorinated polyacrylates e.g. polymethacrylates (fluorine content is 12.8% Yao et al. (2014)) that was also utilised in the proposed restriction for PFHxA (ECHA, 2019). See Table A.23 for the results.

Table A.23. Estimates of PFAS in carton board and paper wrapping packaging for different assumptions based on detected fluorine levels in EU-27, UK and NO (2019).

Proportion of Wrapping and Carton board with PFASs (%)	Quantity of carton and wrapping[a] (t)	Quantity with PFASs (t/y)	Detected fluorine concentration[b] (g/t)	Quantity fluorine in paper or board (t)	Quantity of PFASs[c] (t/y)
46 (paper)	2 647 000	1 217 620	537	654	1 308
	2 647 000	1 217 620	1 200	1 461	2 922
95 (paper)	2 647 000	2 514 650	537	1 350	2 700
	2 647 000	2 514 650	1 200	3 018	6 036
20 (board)	6 169 000	1 233 800	537	663	1 326
	6 169 000	1 233 800	1 200	1 481	2 962

Notes:

[a] From Table A.79 in the appendix.

[b] Maximum and average concentration of fluorine detected in supermarket and fast-food restaurant paper and board packaging (Dinsmore, 2020). These numbers are in line with the ChemTrust total organic fluorine content of throwaway packaging

[c] Quantity of PFAS is calculated from the fluorine content assuming fluorine comprises 50% of the molecular weight

The PFAS loads in Table A.22 and Table A.23 are in the same range. However, Table A.23 focused on all PFASs (intentionally added and unintentionally present) and Table A.22 solely focuses on intentionally added PFASs. Without further information to enable a more accurate analysis, the upper and lower bounds of each volume range, from Table A.22 and Table A.23, have been utilised to estimate emissions during the service-life of paper and board packaging.

PFAS in lacquers and ink (for paper-based and aluminium-based packaging)

About 70% of the PFAS residues in paper and aluminium based packaging products are present in lacquers and inks according to a stakeholder. Mainly PTFE wax/micro powder PTFE is used in printing ink. According to stakeholders about 500 t/y of PFASs in the EEA are used in lacquers and inks. As lacquers and ink are also used for non-packaging the total PFAS use could be far higher.

Generic plastic (food) packaging PFAS polymer processing aid use

Generic (plastic) packaging tonnages can be better derived via waste statistics than via production statistics as waste databases are more centralised and accessible. In the year 2019 packaging waste generated was 177 kg per inhabitant in the EU. Paper and cardboard (41%), plastic (19%), glass (19%), wood (16%) and metal (5%) are the most common packaging types.

PFAS polymer processing aids are used in the manufacturing of generic plastic packaging and plastic food packaging. It is likely also used in the production of rubber and non-plastic packaging uses especially in cases where thermoplastics are used (Glüge et al., 2020). Polymer processing aids enable polymers such as PP, PE, and polyolefins to be processed (e.g. extruded) at higher rates and can also reduce energy consumption. Polymer processing aids are based on fluoropolymers (fluoroelastomers or fluorothermoplastics) and not on low molecular weight PFASs or side-chain fluorinated polymers according to a stakeholder. Elastomer-based polymer processing aids are manufactured without the use of a fluorinated emulsifier. Polymer processing aids are frequently formulated with inorganics and non-fluorinated aliphatic polyethers or polyesters as synergists. Some polymer processing aids require fluorinated emulsifiers in their manufacturing process.

According to information from an industry association PFAS processing aids are only needed for thin film production. Other stakeholders mention that for all plastic extrusion, PFAS processing aids are needed.

According to stakeholders PFAS polymer processing aid concentrations normally range between 500 – 1 000 ppm. This quantity is carried over from production and has no function in the finished plastic. No information was available on the fate of the PFASs that is not carried over to the product in the packaging production facility. For new production batches and according to stakeholders, new PFASs are added on a regular basis but details on volumes and emissions are lacking.

Combining volume data: 20 000 000 t plastic packaging demand in EEA market/y. 16% of plastic (packaging) material are being produced in EEA, so not imported = 32 000 000 t plastic packaging material produced in EEA (Plastics Europe, 2020).

PFAS polymer processing aid concentrations of 500 – 1 000 ppm result in a yearly estimated 1 640 – 3 280 t of PFAS processing aids being used for plastic packaging production in EEA.

The presence of PFASs in common non-food plastics packaging (and possibly even all plastics) also raises questions about recyclability claims as these types of plastic packaging are commonly recycled.

<u>Plastic food packaging PFAS residues</u>

As PFASs are used as processing aids for PE and PP flexible packaging production, PFAS residues might be present in the final article. According to a stakeholder the yearly EEA market for flexible food packaging is around 300 000 t and the concentration of PFASs in the finished packaging articles is around 0.1% (stakeholder information) representing a carry-over of material from production. This leads to a volume of 0.1 * 300 000 = 300 t PFASs residues in EEA per year in food packaging only. This is excluding other flexible, non-food, packaging.

Assuming that the total packaging volume could be twice as high as the food packaging volume, providing the following range for PFAS in flexible food packaging production: 300 – 600 t PFASs residues in flexible food packaging production in EEA/y.

<u>Fluorine surface treatment of plastic containers</u>

Fluorine gas treatment of plastic containers is used to introduce desired surface properties for storage of certain products such as (bulk) chemicals but also food. A barrier on the plastic surface is created by leading fluorine over polymer containers like HDPE type containers. This treatment of the HDPE like containers degrades to PFCAs which is found in the content in the container (by leaching from surface of the container to the content), according to a study conducted in the USA by Environmental Defense Fund (EDF). The USA EPA has a webpage regarding this topic[23]. PFAS leaching from HDPE containers increases with time[24].

It is estimated that hundreds of millions of polyethylene and polypropylene containers are treated this way each year. EPA indicated that this might be a very significant use (see also Rand and Mabury (2011)). Details on volumes are not yet available in USA or in EEA since this use was recently identified in USA.

Wrapping of cars

Different materials are used (PE, PVC, polyester, PET, polyurethane, and Teflon polymers). When 1 kg wrapping is used per car and if every brand and model use wrapping, assuming 25% market share of Teflon polymers (see PR Newswire (2018)) the calculation below could be a indication of tonnage:

"In 2019 15 769 041 passenger vehicles were manufactured in the EU (ACEA, 2020). For trucks and busses the number of newly registered vehicles had to be used as proxy for newly manufactured vehicles. Comparing the numbers for newly manufactured and newly registered passenger cars (15 769 041 to 15 340 188 (ACEA, 2020)) the assumption can be made that these numbers, order of magnitude, correspond. In 2019 2 503 992 new trucks (sum of light and heavy commercial vehicles) and 42 838 new buses were registered in the EU (ACEA, 2020)."

750 000*1 kg = 10 000 t wrapping sheet*25% fluoropolymer (PTFE) = 3 950 t/y. The fluoropolymer wrap share and market volumes for wrapping cars already on the market are unclear.

Coating of cans

Cans and especially beverage cans are often coated with PTFE wax or micropowder PTFE to reduce friction and facilitate easy sliding of cans on production lines. It can be used to protect cans from rusting and to protect the can liner from acid in the food or drink inside the can.

PTFE coated beverage cans are not considered FCM when the outside of the can is coated and food is not in direct contact with the coating (note: sometimes the inside of the can is coated as well).

The production volume of aluminium cans (2019) in Europe for food and beverage is around 488 kt (Wielenga, 2021). There is no data on the import of food and beverage cans. 488 kt is therefore an underestimation of food and beverage can use in the EEA; 0.1% PTFE wax * 488 000 t = 4 880 t PTFE use in EEA/y.

This is a minimum tonnage since import of food and beverage cans is not considered and coating of other cans other than food and beverage is not considered in this calculation. According to Food Packaging Forum approximately one third of can coatings were used in non-food packaging (Geueke, 2016).

[23] https://www.epa.gov/pesticides/pfas-packaging, date of access: 2022-12-15.

[24] https://www.epa.gov/pesticides/epa-releases-data-leaching-pfas-fluorinated-packaging, date of access: 2022-12-15.

No detailed information on market prices of PFASs used in packaging production has been identified. There is information on price-differences to alternatives (see the Alternatives chapter). The autonomous market development is also presented in the tables in the Annex.

A.3.4.2.2. Consumer cookware

There are 195 million households in the EU according to FEC (Federation of European manufactures of cookware and cutlery). FEC assumes that there are at least 3 pieces of coated cookware in each household resulting in 600 million pieces of coated cookware in EU households. Assuming a replacement of every 4 years this results in 150 million pieces of coated cookware being sold in Europe per year.

For consumer cook and bakeware, data from Plastics Europe 2017 was used and is reported as 3 500 t/y as presented in Table A.24. It should be noted that stakeholders in the second consultation in summer 2021 mentioned 5 600 t of fluoropolymer use for consumer cookware (GlobalInfoResearch, 2022).

From the description in Plastics Europe (2017) this data does not include any polymer PPAs that have been used in the production of fluoropolymers, except it can be assumed that any PPA still present is an impurity in the final fluoropolymer.

No detailed information on market prices of PFASs applied in consumer cookware has been identified. There is information on price-differences to alternatives (see Annex E.2.3.). For autonomous market development see also Annex E.

<u>Industrial applications</u>

These data cover EU-28 (including the UK) and include imported fluoropolymers as well as those manufactured in the EEA.

Stakeholders indicated that drinking water and beverage production uses approx. 3 000 t/y of fluoropolymers as gasketing and membrane materials (e.g. water purification and processing). Stakeholders in 2021 consultation mentioned 1 800 t/y in EEA of PTFE being used for the maintenance of free bearings and sliding elements using PTFE compounds. For a small niche application 61 t was mentioned. German stakeholders mentioned that in 2020 at least 140 t was applied in Germany for bakeware coating and this use continues to increase. Therefore, in 2015 3 000 t for industrial applications seems a reasonable estimate, noting that a further 3 000 t/y for drinking water and beverage production might have to be added.

In Table A.24 the fluoropolymer volume data for cookware and industrial applications is summarized.

Table A.24. Volume data (2015) used for the emission estimates from fluoropolymers taken from Plastics Europe (2017).

Market segment	Quantity of Fluoropolymers sold (t/y)
Consumer Cook and Bakeware	3 500 Stakeholder feedback second consultation 2021 mentioned 5 600 for cookware and food processing (GlobalInfoResearch, 2022)
Industrial Food Production and Pharmaceuticals Drinking water and beverage production	>3 000 (1 800 already for maintenance) - 6 000

Given the uncertainties, the volume and emission estimates described here should be regarded as indicative only.

According to a stakeholder, it was estimated (in the summer 2021 second stakeholder consultation) that 2.8 million tonnes of rubber goods were produced in Europe annually. A figure that has been stable over the last years (part of this volume includes rubber uses for which PFAS is applied, often as processing aid like in thermoplastics production). It is estimated that the use of fluoropolymers in the rubber sector is in the range of 4 500 – 18 000 t/y. Approximately 4-5% are products for the food contact and drinking water sector. That leads to 180 – 900 t fluoropolymer coated rubber for the sector. Because it is not clear if this tonnage is included in other numbers presented below, it was not used for tonnage calculations.

The yearly EEA PFAS volumes used are summarised for the three main applications in Table A.25 and in the generic table format distinguishing between the three main PFAS groups in Table A.26.

Table A.25. PFAS EEA volume per year per sub-use.

Sub-use*	**Specific use**	**PFAS (t/y)**	**Main PFAS type**	**Source**
Packaging	Paper and board packaging	827 – 4 962	Polymeric PFAS	Estimate, in EU-27 & UK & NO (2019)
	PPAs used in (thermoplastic) packaging production and rubber production	1 640 – 3 280	Non-polymeric PFASs	Estimate based on CEPI and literature data and stakeholder data on rubber manufacturing
	Flexible (thermoplastic) packaging PPAs residues	300 - 600	Non-polymeric PFASs	Estimate, based on stakeholder data
	Lacquers and ink residue	>>500	Polymeric PFASs, mainly PTFE wax	Estimate, based on stakeholder data
	Car wrapping	3 950	Polymeric PFAS	Estimate
Consumer cookware	Consumer cookware coating	3 500 – 5 600	Polymeric PFAS	Plastics Europe data (2015)
Industrial application	Beverage can coating	4 880 (minimum as import of food and beverage cans is not considered nor coating of non-beverage cans).	Polymeric PFAS (e.g. PTFE wax)	Estimate, based on stakeholder input and market volume
	Industrial applications coating	3 000 - 6 000	Polymeric PFAS	Plastics Europe (2015) and stakeholder input
	Drinking and beverage production	>3 000 Of which 180 – 900 coated rubber	Polymeric PFAS	Stakeholder input

* PFAS from gas treatment of fluorinated HDPE containers not clear and not mentioned in table.

Table A.26. Volumes of PFAS estimated to be used in food, feed and packaging industry in the EEA per year.

	Total PFAAs and PFAA precursors (t/y)			**Total polymeric PFASs (t/y)**			**Total PFAS (t/y)**		
	low	midpoint	high	low	midpoint	high	low	midpoint	high
(Surfactants) in Paper and Board Food Packaging	827	2 895	4 962				827		4 962
Generic Plastic packaging & rubber (processing aids)	1 640	2 460	3 280				1 640	2 460	3 280
Consumer Cook and Bakeware				3 500	4 550	5 600	3 500	4 550	5 600
Industrial Food Production and Pharmaceuticals				3 000	4 500	6 000	3 000	4 500	6 000
PFAS residues in packaging	300	450	600				300	450	600
Lacquers and ink	>>500	>>500	>>500				500	500	500
Car wrapping				3 950	3 950	3 950	3 950	3 950	3 950
Beverage can coating				4 880	4 880	4 880	4 880	4 880	4 880
Total	3 267	6 305	9 342	15 330	17 880	20 430	**18 597**	**24 185**	**29 772**

A.3.4.3. Summary

PFASs in food contact material (FCM) and packaging are primarily used for their grease repellent properties and can be found in the following main applications: packaging, consumer cookware, and industrial food and feed production equipment. Plastic packaging is excluded here.

Packaging covers a broad spectrum of uses including food, feed, generic packaging in paper and processing aids to produce thin films plastics. The three main types of PFAS used in packaging cover PFPEs, side-chain (C6) fluorinated polymers and fluoropolymers. In the extrusion of thermoplastic packaging or the polymerization, fluoropolymers are often used as processing aids.

For consumer cookware (polymer) PFASs (i.e TFE, PTF, PFA, PTFE, FKMs are mainly used to achieve non-stick coatings for goods such as frying pans, plates, baking wear, and electrical equipment.

Finally, PFAS polymers including PTFE, FEP, PFA and ETFE are commonly found in the equipment of food and feed at an industrial scale and are used for instance in non-stick coatings for conveyer belt, the fabrication of cookware, and in valves and fitting for commercial food and feed products. PFASs used in industrial application are often used to enhance productivity, such as by preventing clotting or enabling hygienic conditions. Total volume of PFASs in FCM and packaging are estimated to be 18 600 - 30 000 t/y in the EEA, with fluoropolymers as major contribution to the volume.

A.3.5. Metal plating and manufacture of metal products

A.3.5.1. Uses

PFASs are used in metal plating processes and in the manufacture of metal products. In metal plating, PFASs are used to lower the surface tension of the plating solution and to decrease aerosol emissions (wetting agent, mist suppressing agent) (UBA, 2017; UBA, 2022; UNEP, 2018a). In the manufacture of metal products PFASs are used to e.g. lower the surface tension, to promote the flow of metal coatings or to inhibit the formation of acid mist, to inhibit corrosion on steel and to improve the life of baths. The uses and applications of PFASs are described in Figure A.11 and Table A.27.

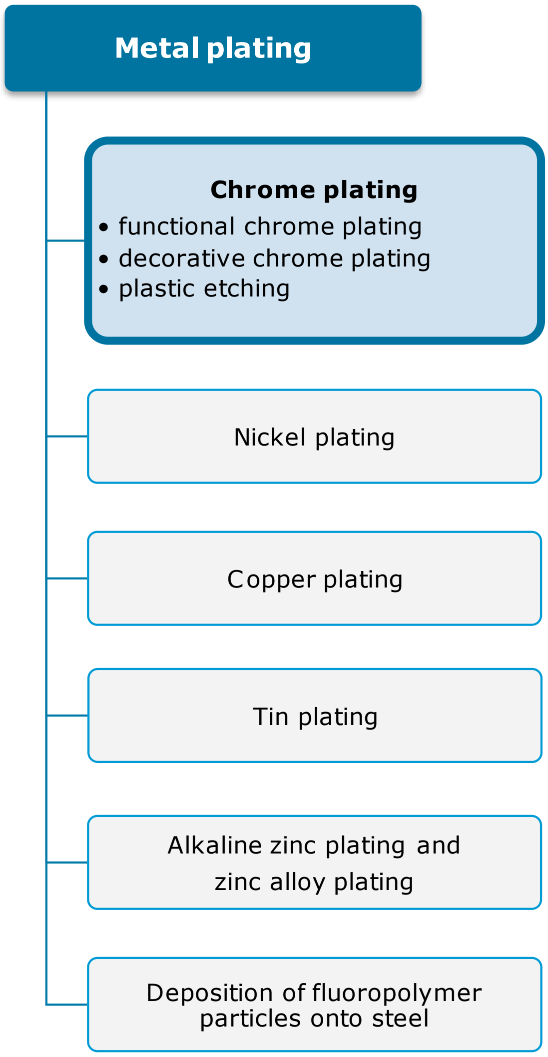


Figure A.11. Overview of metal plating types.

Table A.27. Uses of PFASs in metal plating processes and manufacture of metal products.

Process	Examples
Metal plating	Mist suppressant
	Lowering surface tension of plating solution (Glüge et al., 2020; UBA, 2022)
	Pretreatment (etching) of plastic followed by electroplating (e.g. chrome coating) (Glüge et al., 2022)
	Nickel-plating: non-foaming surfactant - increasing the strength of the nickel electroplate by eliminating pinholes, cracks, and peeling (EC, 2005; Kissa, 2001); sliding characteristics to prevent seizure of parts
	Copper plating: preventing haze by regulating foam and improving stability while improving brightness and adhesion (EC, 2005; EPA-DK, 2005)
	Tin plating: produce a plate of uniform thickness (EC, 2005; Kissa, 2001)
	Supporting the deposition of fluoropolymers onto steels for surface protection (EC, 2005).
Manufacture of metal products	Inhibit the formation of acid mist or spray over metal electrowinning tanks (Glüge et al., 2020)
	Treatment of coatings of metal surfaces (Glüge et al., 2020), lowering the surface tension and thus promoting the flow of metal coatings and the prevention of cracks in the coating during drying.
	Use as corrosion inhibitor on steel (Kissa, 2001). For this purpose, cationic and amphoteric fluorinated surfactants are used to impart a positive charge to fluoropolymer particles which facilitates the electroplating of the fluoropolymer (Kissa, 2001).
	Coatings on metal (Glüge et al., 2020)
	Used for processing of aluminum e.g. during etching of aluminum to improve the efficient life of alkali baths or in the phosphating process of aluminum to dissolve the oxide layer of the aluminum (Glüge et al., 2020; Kissa, 2001).
	Cleaning of metal surfaces (Glüge et al., 2020; Kissa, 2001). The fluorinated surfactants disperse scum in molten-salt baths, speed runoffs of acid when metal is removed from the bath and increase the bath life.
	Solvent displacement drying (e.g. for water removal prior to plating, coating, and other surface treatments) (Glüge et al., 2020)
	Electrical insulation of bearing houses
	Seals, valves, bearing coating, hose products, tank liners, gaskets and packing in food processing, medical and pharmaceutical industries, chemical and oil industries, aerospace and automotive industries, industrial equipment for sensor technology; Fluoropolymers are used due to high chemical and temperature resistance, high durability (reduction of friction and wear), good sliding properties, pressure resistance
	Anti-stick coating and anti-stick parts in silicone moulding processes (e.g. automobile industry); coating of processing tools or moulds (function as mould release aid)

Information on the use of fluorinated substances in tin, copper and nickel-plating processes is limited. Some information on chrome plating is available indicating that mainly C6 fluorinated substances are used. With the identification of PFOS as a persistent organic pollutant (POP) and inclusion in Annex B of the POP regulation (EU 2019/1021) only the use of PFOS as a mist suppressant for non-decorative hard chromium (VI) plating in closed loop systems is allowed. The ban of PFOS led to the substitution with 6:2 fluorotelomer sulfonate (6:2 FTS also known as H4-PFOS) in chrome plating processes (UNEP, 2018a). A survey conducted by the German Environment Agency (UBA, 2022) showed that in functional[25] chrome plating and plastic electroplating only 6:2 FTS-containing wetting agents were used (30 facilities participated in the survey). In decorative[26] chrome plating 6:2 FTS-containing (60%) as well as fluorine-free (40%) wetting agents were used. The use of fluorinated substances other than 6:2 FTS was not noted. PFAS used in metal plating processes and in the manufacture of metal products are described in the Appendix, Table A.83.

A.3.5.2. Volumes

Information on the concentration of PFASs, the annual production volume or annual import and export volumes of these PFASs relating to the specific use in chrome/metal plating processes and processes for manufacture of metal products, is only scarcely available. Information on the concentration of PFASs per use, annual production volumes volumes/ import volumes of all used PFASs for metal plating/manufacture of metal products, information on annual emissions/release and future emissions and information on costs is not available.

A.3.5.2.1. Metal plating

Based on the PFHxA restriction dossier an annual use volume of 30 t/y (central estimate, range 2 - 57 t/y) for 6:2 FTS in the EU (incl. UK) was estimated.

A.3.5.2.2. Manufacture of metal products

During manufacture of metal products mainly fluoropolymers and C6 fluorinated substances are used (see Appendix Table A.83). Glüge et al. (2020) estimated that around 900 t PFASs (fluoropolymers) were used in the manufacture of metal products in Sweden, Finland, Norway and Denmark between 2000 and 2017. With the assumption that the four countries account for about 5.2% of the EEA population the Dossier Submitters estimated that on average around 960 t of PFASs are used in the manufacture of metal products in the EEA per year.

In Table A.28, an overview of volumes is presented for both metal plating and manufacture of metal products.

Table A.28. PFAS volumes in metal plating processes and manufacture of metal products estimated for EEA (t/y).

	Total PFAAs and PFAA precursors (t/y)			**Total polymeric PFASs (t/y)**			**Total PFAS (t/y)**		
	low	midpoint	high	low	midpoint	high	low	midpoint	high
Metal plating	2	30	57				2	30	57
Manufacture of metal products				960	960	960	960	960	960
Total	2	30	57	960	960	960	**962**	**990**	**1 017**

[25] Functional chrome plating (also known as hard chrome plating): aim of functional chrome plating (layer thickness mostly 10 – 100 µm) is to provide e.g. hardness, corrosion and wear resistance, lubricity and high resistance against chemicals.

[26] Decorative chrome plating: used for decorative surface finish. The thin layer of metal (layer thickness 0.05 - 0.5 µm) provides properties like aesthetically pleasing appearance or non-tarnishing.

A.3.5.3. Summary

Because of the vast range of properties PFASs are widely used in metal plating processes and in the manufacture of metal products. In metal plating processes PFASs are used to lower the surface tension of the plating solution and to decrease aerosol emissions. In the manufacture of metal products PFASs are used e.g. to lower the surface tension, as corrosion inhibitor on steel and to improve the life of baths. Stakeholders report an estimate annual use of 1 017 t (rounded numbers). Approximately 960 t of PFASs are used in the manufacture of metal products in the EEA per year and approximately 57 t of PFASs are used in metal plating in the EEA per year.

A.3.6. Consumer mixtures

A.3.6.1. Uses

PFASs are found in a high number of diverse applications that are used by consumers, including textiles, cosmetics and food contact materials, which are described in other parts of this dossier. This chapter focuses on PFAS used in mixtures intended for consumer use and analyses PFAS use in the following applications:

PFASs are utilised in:

- Cleaners for glass, metal, ceramic, carpet and upholstery
- Waxes and polishes for e.g. furniture, floors and cars
- Floor polish removers
- Drycleaning products
- Dishwashing products as rinse aid
- Windscreen treatments for automobiles and windscreen wiper fluids
- Car care products
- Rain-repellent fluids in the aviation industry
- Anti-fog agents
- PTFE spray for lubrication of doors, locks, bike chains, motorcycles etc.
- Musical instruments:
    - Lubricants for music instruments
    - Guitar strings
    - In piano keys

More details on PFASs used and CAS numbers are mentioned in the Appendix, Table A.84 to Table A.90. A variety of PFAS including fluorotelomer alcohols and ethoxylates, perfluoroalkylcarboxylic acids, perfluoroalkylethers, perfluoroalkanesulfonamide acetates and polymers such as PTFE are used in consumer mixtures for various technical functions such as for achieving water and stain repellence and as wetting agents. More detail on specific PFASs used in the different applications is given in the Appendix based on Glüge et al. (2020).

Information on concentrations of PFAS in cleaning compositions, polishes, and waxes is sparse and comes with a wide range of uncertainty. Three different sources of information were used for the purpose of this dossier:

1. Information given by industry on websites and in brochures
2. Information found in safety data sheets or submitted by companies during the CfE and consultation
3. Information from literature (mainly measurements)

Information on specific PFAS concentrations is rather sparse; however, end-use concentrations of PFAS in cleaning compositions, polishes and waxes generally are reported to be in the range of 10 - 1 000 ppm, concentrations of 200 ppm or less are typical (Chemours, 2017; ICT). Regarding specific PFAS concentrations in musical instruments, no information was found. Available data on concentrations of PFAS in consumer mixtures (polishes, waxes, cleaning agents and anti-fog agents) can be found in Table A.85 until Table A.91 in the appendix to this section.

For concentrations significantly below 10 ppm, an intended functional role seems doubtful. More information was obtained via an explorative research of product labels and information gained from the CfE. Rather large concentrations were found in one car polish product (12% PTFE (waxyclean, 2020)) and a rain-repellent fluid used in the aviation industry. Due to the limited number of products for which information is available, it is unclear whether these concentrations are typical for such products.

A.3.6.2. Volumes

There is limited information available to the Dossier Submitters regarding the volume of PFAS manufactured for cleaning agents, polishes, and waxes. In detail, for the Scandinavian countries Norway, Denmark, Sweden, Finland it was estimated (using the SPIN database) that in a period of 17 years (2000 – 2017), 21 t PFAS was used in *cleaning agents* (Glüge et al., 2022). Extrapolation from this figure to an annual tonnage for the entire population of the European Economic Area (EEA) results in an estimation of 20 t/y (assuming a population of 27 million of the a forementioned Scandinavian countries and 453 million for the EEA). This estimate is uncertain, given that consumer behaviour and prevalence of PFAS in cleaning products within the EEA varies. Moreover, the estimate for the Scandinavian countries comes with uncertainties. For example, PFAS concentrations of only a small number of substances are known, which may not constitute all the PFAS present in cleaning products. Therefore, there is the possibility that for cleaning agents, the total volume is substantially higher than the estimate given above. On the other hand, this volume also includes industrial cleaning, thus possibly overestimating the volume for non-industrial cleaning agents.

Only incomplete information is available to the Dossier Submitters regarding the market for PFAS in musical instruments. Based on stakeholder information it is assumed that 1 – 10 t/y of PFAS are used for musical instruments. There is, however, a relatively large uncertainty with respect to the total volume used in the EU because no information on products by other companies was available to the respondent.

There is (incomplete) information on the PFAS total tonnage in the consumer mixtures sector. The Dossier Submitters, however, cannot disaggregate PFAS volumes in more detail than presented here, despite knowing (main) PFAS used in consumer mixtures. See Table A.84 in the Appendix.

A.3.6.3. Summary

Because of the vast range of properties, PFASs are used in the consumer mixtures industry. PFASs are used in cleaning products, products that bestow water repellent properties, and musical instruments. Stakeholders report a large uncertainty regarding the use volumes, the best estimate is an annual use of **21 – 30 t**.

A.3.7. Cosmetics

A.3.7.1. Uses

PFASs are used intentionally in various categories of cosmetics as, for instance, emulsifiers, antistatics, stabilizers, surfactants, film formers, viscosity regulators and solvents (Pütz et al., 2022). Out of these, the most frequently occurring properties for these PFASs are the functions skin conditioning, film forming, solvent and surfactant. Table A.29 and Figure A.23 (Appendix) illustrates the identified properties of the most frequently used PFASs in cosmetics.

Table A.29. Main PFAS and identified properties in cosmetics.

PFAS	PFAS category	Identified properties according to CosIng
PTFE	Polymeric PFASs	Bulking
C9-15 fluoroalcohol phosphate[a]	PFAA and PFAA precursors	Skin conditioning
Perfluorodecalin	PFAA and PFAA precursors	Detangling Skin conditioning Solvent
Perfluorooctyl triethoxysilane[b]	PFAA and PFAA precursors	Binding
Perfluorononyl dimethicone[a]	PFAA and PFAA precursors	Skin conditioning
Polyperfluoromethylisopropyl ether	Polymeric PFASs	Skin conditioning
Octafluoropentyl methacrylate	PFAA and PFAA precursors	Binding
Acetyl trifluoromethylphenyl valylglycine	PFAA and PFAA precursors	Skin conditioning
Methyl perfluorobutyl ether	PFAA and PFAA precursors	Solvent Viscosity controlling

[a] Covered by the PFOA restriction in POPs and the C9-C14 PFCAs restriction in REACH.
[b] Covered by the (3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl) silanetriol and TDFAs restriction in REACH.

The estimates of use are split according to the following product groups listed below and are based on databases (CosmEthics, Kemiluppen, ToxFox) of cosmetic products identifying which PFASs are used, their functions and how commonly found they are in different product groups:

- Skin care
- Toiletries
- Hair care
- Perfumes and fragrances
- Decorative cosmetics

A.3.7.2. Volumes

Based on the most reliable cosmetic databases, Kemiluppen and CosmEthics, the total number of cosmetic products and market share of PFAS-containing products were estimated. The market share of PFAS-containing cosmetic products (based on units sold) ranged from 1.1 to 1.4%. An even more similar range was obtained after removing discontinued products listed in the Kemiluppen database (1.3 compared to 1.4%).

An analysis of the market share of PFAS-containing products revealed that most occurred in the product category decorative cosmetics (3.7%), followed by skin care, hair care and toiletries (0.78, 0.65 and 0.27% respectively). The occurrence of PFASs in perfumes and fragrances was negligible with 0.03% (Based on cosmEthics).

Table A.30 illustrates the share of cosmetic products and product versions that contain PFASs (%) sorted according to the Cosmetics Europe categories for the emission calculations. Data is based on the total number of products and product versions containing and not containing PFAS according to the CosmEthics database (entire database information included, i.e., product and product versions, EU/EEA and non-EU/EEA). Note that the CosmEthics product sub-categories were rearranged into Cosmetics Europe product categories and ambiguous product sub-categories such as "other" were removed.

Table A.30. Share of cosmetic products and product versions containing PFAS*.

Product category (**Cosmetics Europe**)	**Total number of products and product versions**	**Total number of cosmetic products and product versions containing PFAS**	**Share of cosmetic products and product versions containing PFAS (%)**
Decorative cosmetics	29 118	1 068	3.67
Hair care	21 938	142	0.65
Perfumes and fragrances	3 637	1	0.03
Skin care	40 103	314	0.78
Toiletries	17 844	49	0.27
Total	112 639	1 574	1.40

* The numbers are slightly overestimated as they also include Hydrofluorocarbon 152a which is not a PFAS.

The different databases were consulted to get an overview of the identity and frequency of occurrence of PFAS (i.e., compounds with at least one -CF2) in cosmetic products. Around 170 unique PFAS ingredients potentially in cosmetic products were identified within the cosmetic ingredient database (CosIng). Forty-two of these were present in products within three European cosmetic databases, among which polytetrafluoroethylene (PTFE; a PFAS polymer) and C9-15 fluoroalcohol phosphate were most frequent. Analysis of the data shows that three out of the top ten listed PFAS among all considered cosmetic databases are under current or pending restriction. In total about 1/5 to 1/3 (KEMI, 2021) of the cosmetic products listed in the cosmetic product databases consulted contain PFASs that are or are about to be restricted. Table A.92 in the Appendix shows more details on PFAS INCI names found in cosmetic products in the different databases.

Due to limited information, the yearly tonnage of cosmetic products per category was indirectly derived from data on market value per product category and assumptions on price per kg of product (see KEMI (2021) for more details).

Based on data on market value per product category and assumptions on price per kg of product (see KEMI (2021) for more details) the annual volume per cosmetic product category was estimated (Table A.31). These estimates were used together with data on share of products per category that contain PFAS and PFAS concentrations based on analytical data to estimate annual PFAS volumes (Table A.32). Although there is information on the PFAS total tonnage is cosmetics and PFAS in cosmetics, the Dossier Submitters cannot disaggregate tonnages despite knowing (most) PFAS used. Table A.92 in the Appendix demonstrates identified PFAS used.

The concentration of PFASs in the products was derived by measuring total fluorine (TF), the extractable organic fluorine (EOF) and individual PFASs (targeted analysis) in purchased cosmetic products with at least one PFAS on the ingredient list (see KEMI (2021) for more details). Please note that total PFAS volume for Perfumes and Fragrances are not provided in Table A.32 as only one out of 3 637 products (CosmEthics database) within Perfumes and Fragrances listed a PFAS as an intended ingredient. As a result, this category's product concentration was assumed to be equal to zero.

Table A.31. Calculated total amount of cosmetic products sold per year in the EEA in 2019; data based on assumptions and Retail Sales Price, as well as market share from Cosmetics Europe as well as assumptions and data from the CosmEthics database (metric tonnes).

Product category	**Total amount of products (t/y in 2019)**
Skin Care	273 000
Toiletries	1 110 000
Hair Care	838 000
Perfumes and Fragrances	77 600
Decorative Cosmetics	18 800
Total EEA market[a]	2 320 000

[a] *EU-27 and Norway (i.e., EEA without Lichtenstein and Iceland)*

Table A.32. Total annual PFAS volume per main cosmetics category in EEA.

	Total PFASs (t/y)		
	low	midpoint	high
Skin care	0.014	25	49.9
Toiletries	0.002	1.25	2.5
Hair care	0.003	2.30	4.6
Decorative cosmetics	0.010	3.55	7.1
Total	**0.028**	**32.11**	**64.2**

A.3.7.3. Summary

PFASs have a myriad of uses in various cosmetic products, for instance as emulsifiers, antistatic properties, stabilizers, skin conditioning, binding, and viscosity regulators. The most frequently identified properties of PFASs in cosmetics included conditioning, film forming, solvents and surfactants. Based on the analysis of three European databases (CosIng, Kemiluppen, and CosmEthics) C9-15 fluoroalcohol phosphate and PTFE were reported most often found in cosmetic products. A large share of cosmetic products (in total about 1/5 up to 1/3) listed in the cosmetic product databases consulted for this study contained PFASs that are or are about to be restricted. According to this report, the total PFAS volumes are estimated to be between 0.028 to 64.2 t/y. Based on market share, 1.1 to 1.4% of products contain PFASs. Within that they are found most in decorative cosmetics (3.7%), followed by skin care, hair care and toiletries (0.78, 0.65, and 0.27%, respectively).

A.3.8. Ski wax

A.3.8.1. Uses

PFASs have commonly been used in the production of gliders and other ski wax products used for preparation of skis (including both cross country and downhill/alpine skis, freestyle skis), snowboards, as well as in mixtures for cleaning and impregnation. The key property that PFASs provide in this application is a high-water repellence (hydrophobicity) thus allowing a suitably low surface tension for the skis on snow. Waxes are an important means of lubrication in skiing, to reduce friction between the base of the skis and snow, allowing the skis to glide more freely. It has been shown that the use of high fluorinated waxes can result, on average, in a 4% increase in performance of the skis (Breitschädel et al., 2014). There are three main types of friction that require specific lubrication in skiing:

- Dry friction – when dry snow granules come in contact with the ski base.
- Wet friction – when a high moisture content snow creates suction between the ski base and snow.
- Electrostatic friction – when a ski base runs on snow creating an electrostatic attraction between the ski and snow.

PFASs, including fluoropolymers (e.g. PTFE), are also sometimes used in in the sole of skis as well as in shoes and different equipment for skiing. However, the present assessment covers the treatment of skis with PFAS-containing mixtures.

Fluorinated waxes tend to be used primarily during competitions. However, professionals are known to use fluorine-free waxes during training. Similarly, amateur skiers mostly use fluorine-free alternatives. However, in some countries it is still common to use fluorinated waxes, also among amateur skiers. Ski wax can come in a variety of different types, each designed for specific conditions, compositions, or a certain performance level. The most common forms of wax are listed in Table A.33.

Table A.33. Overview of different ski wax types (both grip and glide wax)[27].

Type	Market insights	Method of application	Use
Block wax	Most common wax form	Block wax needs to be melted on the ski base once it is heated up with an iron, then ironed into the pores of the bases evenly to allow faster gliding.	Waxes in block form last the longest on skis.
Liquid wax	Found at high and low end of the cost spectrum	Supposed to be applied onto a cloth or it comes with an applicator then rubbed on the bases of the skis. Often used in conjunction with other forms of wax including fluorocarbon waxes.	Short-term solution to allow for faster gliding properties for up to 24hrs.
Paste wax	Very economical and easy to apply	Small fabric applicator to apply and buff in. The longer you buff it into the base the longer it lasts on your skis. Can be used as an overlay.	Typically available in a universal temperature range.
Powder wax	Typically have high costs due to the high	Designed to be used after a few layers of block wax are applied.	Often used sparingly for important races

[27] https://www.skis.com/Buying-Guide-for-Ski-Wax/buying-guide-5-3-2013,default,pg.html, date of access: 2022-12-15.

Type	Market insights	Method of application	Use
	number of fluorocarbons they contain	Used to increase gliding properties.	only.
Spray wax	Typically used on top of several layers of high-end block wax to offer the best gliding properties	Once it is sprayed on, allow it to absorb and dry for 5 minutes, then use a cork to further buff it in.	Most found in high-end finishing racing wax as an overlay.

Lists of examples of PFAS-based and fluorine free ski waxes is provided in Table A.93 and Table A.94 in Appendix A.3.8.

A.3.8.1.1. Skin skis

Skin skis differ from traditional skis in that they are designed to allow skis to slide forward but not backward. Initially, animal fur or mohair, a natural material from the hair of goats, was used for skin skis. It was then substituted by nylon skin material treated with Teflon or by a mix of the two.

Real mohair treated with Teflon is used on high-performance models[28]. Nowadays, mainly synthetic skins are used for both cross country and alpine skiing when going uphill. The skins grip the snow, thus providing a forward kick. The skins are then easily removed for skiing downhill[3], while they may be permanently attached under the ski on cross country skis. Given that the skin mimics the functions provided by the grip wax, it is not necessary to use grip wax on the skis. However, it can be necessary to apply anti-icing products to the skins to eliminate icing, as it is done for grip wax-treated skis. In addition, the skin should be cleaned periodically[28]. The glide zone of the skis (i.e., in front of and behind the kick) needs to be re-waxed every 100 km travelled, similar to classic skis[29] and in most cases, it is possible to use the same wax for both skin and traditional skis.

A.3.8.1.2. Main PFAS

The main PFAS used in ski waxes are perfluoroalkanes and semi-fluorinated alkanes. The semi-fluorinated alkanes used are di-block and tri-block semi-fluorinated n-alkanes (SFAs) and are typically mixed with normal paraffins in the formulations of ski waxes. Perfluoroalkyl carboxylic acids (PFCAs) of varying carbon chain lengths (6–22 carbons) are often found as residual impurities from the manufacture in commercially available fluorinated ski waxes, see the studies by Nilsson et al. (2010) and Fang et al. (2020). PFCAs are not thought to have a technical function in the ski waxes given their relative low levels compared to the perfluoroalkanes and SFAs. Perfluoroalkane sulfonic acids (PFSAs) have also been measured in ski wax, but often at even lower levels than the PFCAs.

Fluoropolymers are also used in some waxes.

Based on the complex interplay of PFAS, regarding some PFASs being a precursor and/or impurity to each other, it is in some cases difficult to state if individual substances are used intentionally or are the product of degradation or an impurity. In each case, the specific composition of the wax varies depending on the different snow conditions, humidity levels and weather conditions for which they are designed. Commonly the

[28] https://www.webcyclery.com/about/skin-skis-101-pg259.htm, date of access: 2022-12-15.
[29] https://www.crosscountrysports.com/care-for-your-skin-skis/, date of access: 2022-12-15.

composition of waxes is divided into the following categories (Table A.34).

Table A.34. Overview of different ski wax composition.

Wax composition	Price	Properties	Labelling
Pure Fluorocarbon	Expensive products as they have a high fluorocarbon content.	Comes in liquid, powder or block form. Liquid form is the most popular. High resistance to dirt and oils to provide a long lasting, fast gliding ski.	Typically have FC or Cera in the title of the wax.
High Fluorocarbon	Typically, more expensive ski waxes. The higher the fluorocarbon content the more expensive.	Provide the highest number of gliding properties in areas with high humidity, man-made snow, dirty snow or places with very cold temperatures. Made for every temperature range.	Typically has HF in the title of the wax.
Low Fluorocarbon	Best value wax when you compare price and performance.	Available in every temperature range. Can be used by themselves or to prepare the base.	Typically has LF in the title of the wax.
Hydrocarbon	Contain no fluorocarbons and are very economical.	Very durable and repel dirty snow conditions very well. Can be used by themselves (best in colder conditions), or they can be used to help prepare bases for use with higher-end waxes.	Typically has CH in the title of the wax.
Eco-friendly/plant-based wax	More expensive than typical hydrocarbon wax.	Often made from a mix of naturally occurring waxes. Tend to be biodegradable.	Often labelled 'eco'.

A.3.8.2. Volumes

Information obtained from stakeholders suggests that the total ski wax market is split approximately 50/50 between consumer and professional sales, and the racing market accounts for ~10% of the market sales. (EEA as well as world market) is split approximately 50/50 between *consumer and professional sales, and the racing market accounts for ~10% of the market sales (ECHA, 2016).* No information was available on the sales of specific alternative products, nor the volumes associated with the various wax types (block, liquid, powder etc). PFASs in ski wax seems to have been introduced in the late 1980s (Masia, 2010). Historical trends in use of ski wax indicate that:

- The highest use year for non-PFAS based ski wax globally was 1978, where 300 t of glide waxes were used.
- Some companies no longer manufacture ski waxes containing PFASs and are currently selling off their remaining stock. Companies have been working on the development of non-fluorinated alternatives since 2013.
- Since 2017 the PFAS-based ski wax market has shrunk for various reasons, because of the higher prices of some PFAS-based waxes, due to global policy developments related to the use of PFOS and PFOA, and also due to decreasing number of professional athletes.

Production of PFASs based waxes is expected to decrease in the following years. Due to increasing concern and publicity regarding the potential human health and environmental effects caused by the use of PFASs in ski wax treatments, there is a concerted move within this sector towards phasing out the use of PFASs and moving towards safer alternatives. In particular, in 2019 the International Ski Federation (FIS) set to introduce a full ban on all PFASs in waxes in all competitive ski disciplines from their 2020-2021 season, a move that follows national-level bans imposed, for example by the Norwegian Ski Association in 2017. However, enforcement of the FIS ban has been postponed until after the season 2021-22 (FIS, 2021). This delay was because they are still developing a Fluorine Tracker, an instrument that would instantly detect the presence of PFASs on the ski, thus making the competitions fair. At the same time FIS has prohibited any products containing C8 fluorocarbons/PFOA at all FIS events from season 2021 and 2022 onwards to mirror the PFOA regulations in the chemical legislation.

Based on stakeholder information it is estimated that the total global production of ski wax is 120 t (in 2020). Of these, the EU produces 60%, which equals 72 t. Ca. 30% of the 72 t of ski wax produced in the EU annually is PFAS-based, i.e., 21 t. An average PFAS concentration of 7.6% w/w. is assumed in fluorine-based wax (which includes both fluoropolymers and non-polymeric PFAS), which amounts to **1.6 t** (or 1 640 kg) of PFASs used annually in the EEA for ski-wax formulations. The Dossier Submitters, however, cannot disaggregate PFAS volumes in more detail, despite knowing the (main) PFASs used.

Since the EU is a major manufacturer of ski-waxes according to stakeholders, 60% of global production, it is assumed that no imported ski-wax will be needed and that all ski-wax manufactured will service the EU's needs, hence that net export/import is zero. It is possible that the EU is a net-exporter of ski-wax but data on exports was not identified.

Regarding manufacturing in the text above already information has been given. In Figure A.12 a high-level market overview in EEA is given.

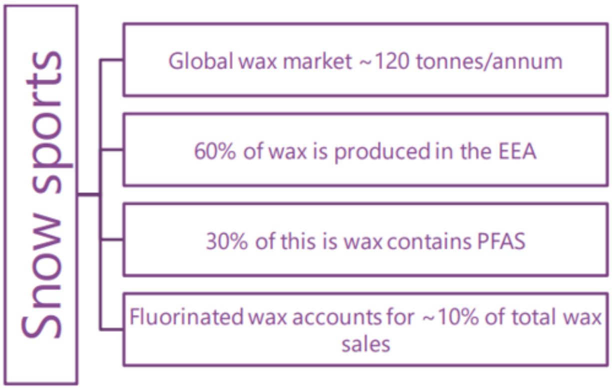


Figure A.12. High level market overview of ski waxes in the EEA (information obtained from stakeholder consultation).

In Table A.35, an historic overview of production volumes is listed. Information from stakeholders indicate that the peak year for production and consumption of ski-wax globally (all formulations, including both PFAS and fluorine free) was 1978, where 300 t of wax was used. However, it is important to note that the use of PFAS based substances only came into circulation later, with the first patents lodged in 1990. Based on feedback from EU's largest manufacturer, market data for the latest year suggests total global production for ski-wax in 2020 (again, all formulations) was 120 t. This suggests that overall global consumption of ski-wax has declined since the peak years of the late 1970s.

Further information about assumptions behind the volumes in Table 29 can be found in the report by the Norwegian Environment Agency (NEA, 2021b).

Table A.35. Assumed production rates, based on stakeholder information and consultant assessment, for PFAS-based wax used to calculate the backward-looking time-series.

Year	**Global production (t/y)**	**EEA fraction of production (%)**	**Total EEA ski-wax production (all formulation) (t/y)**	**Proportion of EEA production covering fluorinated waxes (%)**	**PFAS-based ski-waxes produced in the EEA (t/y)**
1978	300	60	180	0	0
1990	250	60	150	10	15
1995	225	60	135	30	40.5
2000	200	60	120	50	60
2005	175	60	105	50	52.5
2010	150	60	90	50	45
2015	135	60	81	40	32.4
2020	120	60	72	30	**21**

Mobile air conditioning is an application where HFOs have replaced HFCs to a considerable extent, and use volumes are underestimated if only volumes of HFCs and PFCs, as reported in the GHG Inventory Data, are taken into account, which is the case in Table A.35. In section A.3.11 on PFAS applications within transportation, the overall volumes of fluorinated gases used in mobile airconditioning was estimated at 12 222 t/y with basis in the number of new vehicles manufactured and registered in the EU and typical refrigerant loading in each type of vehicle.

A.3.8.3. Summary

PFASs used in ski wax allow for easy gliding and skiing due to their specific properties of high-water repellence and low surface tension. The most used PFASs in fluorinated waxes are perfluoroalkanes and semi-fluorinated alkanes. Other PFASs include PFSAs, PFCAs of varying carbon chain lengths (6–22 carbons) which are often found as residual impurities, and fluoropolymers. The EU is currently a major manufacturer of ski wax, producing 60% of global production, which equals to 72 t according to stakeholder data from 2020. Assuming an average PFAS concentration of 7.6% w/w, it is estimated that **1.6** t of PFASs are used annually in the EEA for ski-wax formulations. There is a concerted move within this sector towards phasing out the use of PFASs and moving towards safer alternatives.

A.3.9. Applications of fluorinated gases

A.3.9.1. Uses

A short summary of the applications of fluorinated gases for various uses in the EU/EEA was prepared by Exponent and published by the Norwegian Environment Agency (Exponent International Ltd., 2021).

As the definition of PFAS, used by the Dossier Submiter (as well as OECD) include substances with only one fully fluorinated carbon atom, several small fluorinated molecules that are often gases are covered. Some of these substances, in this dossier called fluorinated gases, are well-known heat transfer agents familiar from freezers, heat pumps, air-conditioning and other applications. Some of the fluorinated gases are common with the set of gases addressed in the F-gas regulation, but there are also differences in the scope of the F-gas regulation and the PFAS restriction proposal.

This definition covers most F-gases as defined by the European F-gas regulation and the Montreal Protocol. Fluorinated gases are a family of man-made gases used in a range of industrial and consumer applications. There are however, fluorinated gases which are grouped as F-gas according to the European F-gas regulation and the Montreal Protocol but are not a PFASs. This is for instance the case for SF_6, HFC-23 and HFC-152a. On the other hand, there are volatile PFASs which partition considerably to air while they are not among the F-gases in the F-gas regulation. For example, fluorotelomer alcohols or perfluorinated trialkylamines (gases in the atmosphere but liquids under normal conditions). The current assessment covers substances that are both F-gases and fall within the PFAS-definition. See also Figure A.5. These substances are used primarily in the applications which are covered by the F-gas regulation and the Montreal Protocol, including heating, ventilation, air-conditioning and refrigeration (HVACR), and as foam blowing agents, propellants, solvents, cover gases in magnesium industry and as clean fire suppressing agents.

These uses are presented in Figure A.15. In this figure, it can be seen that the main uses are air conditioning (41%) and refrigeration (34%). Fluorinated gases may be used either alone or in blends. They are sometimes used in combination with gases outside of the scope of Annex A or with non-fluorinated gases.

Not assessed in this section:

- A considerable fraction of fluorinated gases produced is used as starting materials or monomers in the manufacture of other fluorochemicals and polymers. In principle, these gases are consumed in such manufacturing processes, and therefore they are not considered in this section which covers end uses of fluorinated gases. Chemical manufacture with fluorinated gases as building blocks is often claimed to be handled in closed systems with incineration of off-gas. However, emissions may occur from the manufacturing plants. In the case of fluoropolymer manufacture, releases of fluorinated gases are sometimes underestimated. One example is the release of perfluorocyclobutane (PFC-318) in the manufacture of PTFE from HCFC-22 ($CHClF_2$) as reported by (Muhle et al., 2022). According to atmospheric measurements, PFC-318 has increased sharply since the early 2000s.
- Fluorinated gases used in medical applications, mainly metered dose inhalers (MDI), are mentioned in section A.3.10 (Medical devices).
- Some of the fluorinated gas substances in the proposed restriction scope can sometimes also be used as a fluid. There is not a clear border between gas and liquid for these (and many other) compounds. Sometimes they are used as a refrigerant gas, but in other cases the same substance can be used as a solvent for cleaning in its liquid form – although it may evaporate fast after use. Some of the

applications of fluorinated solvents are in closed systems or in applications in which users can manage and minimize emissions. In many applications, the fluids are filtered in situ and can be recycled and reused. This liquid application of fluorinated gases/liquids in PFAS scope is not described in detail here (nor in another section of the dossier).

Fluorinated gases used for the different applications are mentioned in this section. Chapter 1 includes hydrofluorocarbons (HFC), perfluorocarbons (PFC), hydrochlorofluorocarbons (HCFC), unsaturated hydro(chloro)fluorocarbons (HFO and HCFO), hydrofluoroethers (HFE), fluoroketones (FK) and other fluorinated compounds. Fluorinated gases may be used either alone or in blends.

It is common to use specific codes for the different fluorinated gases in the sector. For example, HFC-134a represents a specific hydrofluorocarbon, while HFO-1234yf refers to a certain hydrofluoroolefin compound. Sometimes the "HFO"/"HFC" is replaced by a common "R" which means the same, but without specifying the subclass, e.g. R-134a and R-1234yf. The identity of all fluorinated gases mentioned in this report can be found in Table A.96.

Use of fluorinated gases for the manufacture of PFAS is covered in more detail in Section A.2.1. Key related regulations are the F-gas regulation and the Mobile Air-conditioning (MAC) directive (Directive 2006/40/EC). The current F-gas Regulation (Regulation (EU) No 517/2014), which applies since 1 January 2015, replaces the original F-gas Regulation adopted in 2006. The F-gas regulation has the following ambitions: Limiting the use of some important F-gases that can be produced and imported into the EU; Banning the use of F-gases in many new types of equipment where less harmful alternatives are widely available; Preventing emissions of F-gases from existing equipment. However, the basis for the F-gas regulation is the GWP of the substances in scope and their contribution to global warming (and not their volumes per se), while other concerns are not taken into account, e.g. atmospheric degradation to TFA which precipitates and causes exposure to the humans and the environment. The Mobile Air-Conditioning (MAC Directive prohibits the use of F-gases with a GWP of more than 150 in new types of cars and vans introduced from 2011, and in all new cars and vans produced from 2017. One consequence of the MAC directive is the transition to low-GWP HFO in large volumes which are a considerable source of TFA in the environment. As the current dossier focuses on different environmental concerns as the F-gas regulation and MAC directive, an evaluation of substances and applications independent from these regulations is performed.

A list of the specific fluorinated gas substances identified in different uses and sub-uses on the market is found in Table A.95, and a condensed list of the fluorinated gases together with their chemical identity is found in Table A.96. Data on trend in the supply in EU-28 of fluorinated gases 2007 – 2019 is found in Table A.96.

An overview of the annual volumes for the different applications follows after their introduction, in Table A.36. In total 43 different substances have been identified as relevant in this assessment. Five of them are not within scope of this restriction proposal as they do not carry a fully fluorinated C-atom. However, they are of interest for the understanding of the relevant applications as they are used in blends together with other fluorinated gases that are within the scope.

Altogether 14 HFCs/HCFCs have been identified as being in use, as well as 12 HFOs/HCFOs, several of which are isomers. Two fluoroketones, six hydrofluoroethers (HFE), 16 HFC and HFC/non-PFAS blends and 20 HFC/HFO blends have been found to be relevant. In addition, nine substances grouped as 'others' are in use, including perfluoroalkyl amines and a nitrile.

The substances HFC-23 (CHF_3), HFC-32 (CH_2F_2), HFC-152a (CHF_2-CH_3), HCFC-141b (CCl_2F-CH_3) and HFO-1132a (CH_2=CF_2) are not covered by the scope definition of the present restriction proposal due to their chemical structures. However, they are used in blends with other fluorinated gases that are within scope. Besides, the full overall volume of the different applications (including both PFAS and non-PFAS gases) is of relevance as a shift to a different specific gas could affect the whole application volume.

Fluorinated gases are a group of industrial chemicals used as heat-transfer medium in heating, ventilation, air conditioning and refrigeration (HVACR), and as foam blowing agents, propellants, solvents, cover gases in magnesium industry and as fire suppressants. These major sectors may be further divided into sub-applications. There are also several niche applications (e.g. for gas leak detection) that are not specifically addressed in the current assessment. In the present assessment primarily applications with use volumes and emissions reported to the UN Framework Convention on Climate Change (UNFCCC) are covered as the methodology to collect relevant data would be the same for these applications and based on reporting under the convention. It should also be recognized that there is a gradual transition from the traditional applications of fluorinated gases to the uses of fluorinated liquids that may be of the same or similar chemical structures to the gases, often called functional or engineered fluids. Information has been included in this section when this has been submitted by stakeholders as comments to this sector, see 'Minor uses' at the end of this section.

Reclaim and recycling or destruction of fluorinated gases plays an increasing role in the sector and promotes a circular economy and further reduces emissions. Several companies offer collection and regeneration service for used refrigerants. However, emissions are still large from the sector.

Below the main uses of fluorinated gases are introduced. A list of all specific substances identified together with their respective uses and sub-uses is found in Table A.95.

A.3.9.1.1. Refrigeration, air conditioning and heat pumps

Main sub-use categories assessed:

- Domestic refrigeration
- Commercial refrigeration
- Industrial refrigeration
- Transport refrigeration
- Mobile air conditioning (MAC)
- Stationary air conditioning and heat pumps
- Domestic air conditioning and domestic heat pumps for space heating
- Commercial air conditioning and heat pumps
- Domestic heat pumps (clothes dryers)

Refrigerants are commonly used in refrigerators, freezers, chillers and air conditioning units at home, in stores and in cars. An emerging market concerns the use of heat pumps for space and water heating, and domestic hot water production, as well as in some consumer products such as 'tumble dryers' for clothes. Refrigeration and heat pumps are also widely used commercially and in industry, for example, supermarket refrigerators and freezers, drinks chillers in bars and restaurants, manufacturing and transporting chilled and frozen goods, and in specialised applications such as for cooling large data centres, for servers, electronics and for industrial processes. There are also refrigeration systems found in commercial aircrafts. In many cases the refrigerant, or heat transfer liquid, is a fluorinated gas. There are a range of different gases available for such purposes, with different properties that are suitable for different specific applications. However, often fluorine-free alternatives are available, like the natural refrigerants carbon dioxide (CO_2), hydrocarbons and ammonia. Isobutane (R-600a) is the major refrigerant used in domestic refrigeration in Europe and around 50% of light commercial systems are using propane (R-290) and its use is growing. In larger commercial systems CO_2 is technically feasible and a frequently used option.

The technical function of refrigerators or heat pumps relies on a refrigerant substance or mixture that acts as working fluids to maintain low temperatures in an enclosed environment. The most common refrigeration and air conditioning cycle used in these settings is the vapour-compression cycle, in which the circulating refrigerant absorbs and removes heat from the space to be cooled and expels the heat elsewhere. Heat pumps work on the same principle, but in reverse. Reversible air-to-air heat pumps are increasingly used not only to cool, but also to provide heating to buildings in an energy efficient manner. Large scale industrial heat pumps for district heating (more than 3 MW, use of turbo compressors) often rely on fluorinated gases as working fluid.

Fluorinated gases are also sometimes used in refrigeration air dryers, although this is a minor application.

Mobile air conditioning is used to cool the interiors of cars, trucks, buses, trains, ships and construction machinery etc. Previously, HFC-134a was extensively used for this purpose, while HFO-1234yf now replaces the former in new vehicles in order to reduce the climate impact. The refrigerant circuits for electric vehicles are more complex and larger, as the battery must also be cooled. Therefore, more refrigerant must be used per vehicle with increasing electrification of the vehicle fleet. One stakeholder has pointed out that future cars and vehicles will be electrically driven and that combined air-conditioning and heat pump systems will be the standard solution due to energy efficiency constraints.

Secondary loop MACs (SL-MAC), also called indirect systems, are vapor compression refrigerant systems where the evaporator is replaced with a chiller with a coolant flow loop to provide cooling for passenger comfort, window defogging, and thermal control of batteries and other components (Chen et al., 2020). Such systems are designed so that only a secondary fluid (antifreeze coolant, water/glycol, etc.), not the refrigerant, enters the passenger cabin, while the refrigerant sub-system stays in the engine compartment. This increases refrigerant choice, since refrigerants that may be flammable but have more desirable thermo-physical characteristics can be used more safely. SL-MAC systems have also proven to have higher energy efficiencies compared to direct expansion systems. HFC-152a (not a PFAS) has been shown to be an affordable and efficient refrigerant in SL-MAC.

Refrigeration is used widely in chemical, pharmaceutical and food processing industry, throughout the supply chain, including manufacturing, storage and transportation. Fluorinated gases are often used in refrigeration equipment where extreme controlled temperatures are required (below -40 °C), more specifically in vaccines and biopharmaceuticals manufacturing. Blood banks, medical examination and tissue and cell diagnostics may also rely on the use of fluorinated gas refrigerants. Fluorinated gases are frequently used in ultra-low temperature freezers or cryogenic storage. Furthermore, such gases are used in refrigerated laboratory equipment that require precise temperature control over a large temperature range, e.g. test and measurement equipment and refrigerated centrifuges. However, this equipment is usually designed with hermetically sealed systems to avoid leakage, and at end of life, the fluorinated gas is normally collected under controlled circumstances to avoid releases. Low temperature refrigeration also has applications within commercial refrigeration.

HFOs may be used in organic rankine cycle (ORC) technology to generate electricity by recovering waste heat from industrial processes such as glass/ceramics factory and using geothermal energy and biomass. The same technology is also used for cooling purposes in data centres to minimize energy consumption by half compared to the current system and thus enhance energy efficiency.

Variable refrigerant flow (VRF) and direct expansion appliances show enhanced energy efficiency compared to hydronic heating system. For those appliances, fluorinated gases will stay relevant in the future according to stakeholder input.

Nuclear energy plants also use fluorinated gas refrigerants for certain purposes.

Fluorinated gases are often used as refrigerants in military aircrafts, naval ships and submarines, and land vehicles for the common refrigerant applications, as well as for cooling of weapon systems and storage of sensitive material like ammunition, pharmaceuticals and fuels.

A.3.9.1.2. Fluorinated gases used as Foam-Blowing Agents

Main sub-use categories assessed:

- Foam-blowing agent (closed cell)
- Foam-blowing agent (open cell)

Foams are widely used in household, commercial and industrial settings often to provide thermal insulation, for example to retain heat within a building or boiler, to keep heat out of refrigerated areas, or to prevent pipes from freezing and cracking in cold weather conditions. Foam is also used to fill gaps in buildings to prevent excessive air movement and can be used as a protective and cushioning cover, such as for seat covers or vehicle steering wheels. Key factors in selection of foam blowing agents relate to the cost of substances, flammability and efficiency of insulation. Additional factors apply in some applications for specific foams, for example relating to compression and flexural strength and resistance to water. See Figure A.13 for an example of insulation foam application.

Foam-blowing agents are present in the mixtures created for foam production, ensuring that foam expands after release and prior to solidifying. Foams may be open-cell or closed-cell depending on application. For open-cell foams, emissions of blowing agents occur during manufacture and use or shortly after. Most emissions from closed-cell foams occur during the service-life of the foams or at disposal of the product into which the foam has been added. From a business perspective, the use of fluorinated gases in open cell foam is not wise since the (expensive) blowing agent gets out of the product.

Polyurethane (PU) foams used in refrigeration are closed-cell foams, and applications include domestic refrigerators and freezers, commercial refrigerators, freezers, cold rooms and vending equipment and also refrigerated trucks and reefers, as well as domestic hot water tanks. PU boardstock is a closed-cell foam which may be flexible or rigid and includes polyisocyanurate boardstock (PIR board) and continuous boardstock with a flexible facer. It is used in residential and commercial construction for applications such as easy to install insulation boards for loft conversions or for pitched roofs in between rafters. PU Spray foam may be open-celled or closed-celled. Closed-cell spray foam retains the blowing agent in the foam cells and has better insulating properties than open-cell foams. It is used for insulating structures that would be hard to get to, such as around windows and doors, gaps around pipes, as a filler insulate with solid preformed foams, an example being an insulated road tanker.

Figure A.13. Prefabricated XPS foundation insulation being installed at a building site (left) and direct application of insulating foams (right). Both images used royalty-free from CC BY 2.0, photographers akhouseproject and dunktanktechnician.

In building materials, the olefinic fluorinated gas FA-188 is used as a foam insulation additive due to its effectiveness in reducing the foam cell size and thus the thermal conductivity of polyurethane and other rigid foam formulations.

Rigid Polyurethane pipe-in-pipe and block foam is closed-cell and may be used as pipe insulation particularly for larger scale applications such as district water pipes, to prevent pipes from freezing and cracking. This type of insulation foam may also be used in central heating, manufacturing and in the mining industry.

Polyurethane integral skin foams are open-cell foam used in cushions, mattresses, furniture, toys and sporting equipment. Extruded polystyrene foam (XPS) boards are used for building insulation, including under floor insulation and often competes with PU board stock. This type of foam has also been used for its high strength insulating properties in the construction of roads, railway tracks and airport runways. XPS board foam may also be used for marine and leisure buoyancy products such as surf and body boards. Phenolic foams are closed cell foams and include phenolic board stock and block foams which are used primarily for industrial heating and ventilation applications for the insulation of pipe work, for insulation in roofing, cavity walls and flooring.

In the home appliance sector, foam insulation is sometimes used in constrained spaces in white goods, and in order to reach a sufficient level of insulation, fluorinated gases are used as blowing agents.

New techniques and innovative pathways are developed for the recycling PU/PIR products and collection of blowing agent. However, some of the infrastructure applications using foam blown with fluorinated gases have a long lifetime, up to 40 years.

A.3.9.1.3. Solvents

According to stakeholder input the main applications of fluorinated gases used as solvents (sometimes referred to as functional fluids or fluorinated liquids) are industrial metal cleaning to remove oil and grease, electronics cleaning for the removal of flux, and precision cleaning to remove particulates or dust, and cleaning in relation to various lubrication processes. Such techniques may be in use for example during the manufacture and maintenance of electronics, fibre optics and equipment for aerospace, medical devices and defence. In some applications components must be absolutely reliable throughout their designed lifetime and must meet the strictest cleaning and safety standards. Particularly relevant are fluorinated solvents used for cleaning of parts and component in oxygen-enriched environments.

An industrial use of fluorinated solvents is the use as carrier fluids to deposit lubricants, silicones, coatings, adhesives and other materials in smooth coatings, as well as for the formulation of dissolved polymeric PFAS oils and greases. Furthermore, fluorinated gases/solvents may be used as heat transfer media, thermal testing fluids and in electrical/electronics testing.

Fluorinated solvents (e.g. hexafluoroisopropanol, HFIP) are used in additive (3D) printing as a debinding agent prior to sintering for 3D printing of metals. They are also used as a smoothing agent for some polymer 3D printing applications, including for respiratory medical articles, Covid-19 diagnostic items, automotive and aerospace components, electronics and consumer items.

Key factors in selection of solvents relate to the cost of substances, non-flammability, thermal and chemical stability, dielectric properties (poor electrical conductance meaning that they can be used safely in contact with electronics), compatibility with dissolved materials, low surface tension and viscosity, high liquid density, and low toxicity. Although there are many alternatives for this use, PFAS-substances, such as HFCs, HFEs and HFOs, are still claimed to be required for some applications, especially precision cleaning.

A.3.9.1.4. Propellants

Propellants are used to expel the contents of an aerosol from a canister through a nozzle, in products such as deodorants and hair sprays. Technical propellants are used for industrial uses for items such as lubricant sprays, dusters, cleaners, safety horns, degreasers, cold sprays, and paints. Propellants used in medical applications like MDI (Metered Dose Inhalers) are covered in section A.3.10.

Liquified compressed gases are widely used as propellants, as they maintain a relatively constant pressure as the contents are dispensed, maintaining consistent droplet size and spray rate which may be required for technical aerosols. In contrast, compressed gases, such as carbon dioxide, cannot produce a consistent particle size and spray rate, thereby limiting their applicability, with performance falling as the contents of a can are used up and pressure within the can falls. Where a non-flammable propellant is required, HFOs are often used, alone or in a propellant blend.

A.3.9.1.5. Cover gases

Main sub-use categories assessed:

- Die casting
- Sand casting

A cover gas (or shielding gas) is used to prevent rapid oxidation of a molten metal surface for example in magnesium casting and recycling industries. The function of the cover gas is to provide a protective film above the molten metal, preventing oxidation. Fluorinated gases have suitable properties for this application.

A.3.9.1.6. Fire suppressants

Main sub-use categories assessed:

- Total flooding systems
- Local streaming agents

Fire-fighting foams are not part of this assessment. They are covered in a separate restriction proposal. In the present assessment only clean fire suppressing agents, which are not foams, are included.

Fluorinated gases (e.g. HFC-125 and HFC-227ea) are used for fire protection purposes where their main advantage is that they are 'clean', non-conductive to electricity (i.e., have good dielectric properties) and are considered safe for humans to breathe at the concentrations used. In this context, 'clean' refers to the ability of the fire suppressant to not leave non-volatile residues after discharge, i.e., avoid the potential damage caused by conventional extinguishing agents. This means that fluorinated gas fire suppressants occupy a niche market, when there is a need to protect items that otherwise would be damaged by a fire extinguishing agent, and in enclosed spaces where some other fire suppressants would pose a risk to human health. Fire suppressants may be divided into total flooding agents and local streaming agents. Areas of use include portable and fixed aircraft fire protection systems (e.g. engine, auxiliary power units and cargo compartments), as well as specific risk situations (e.g. clean-room protection, electronic-, IT- and control room installations mainly at critical infrastructures) including the defence sector.

2-BTP ($CH_2{=}CBrCF_3$) is a frequently applied substance for fire suppression. The substance is a halogenated clean agent (HCA) used as halon replacement agent in handheld extinguishers onboard aircraft. Some fluoroketones, (e.g. FK-5-1-12 ($CF_3CF(CF_3)C(=O)CF_2CF_3$), are also introduced as a third-generation fire suppressant. Clean fluorinated gas fire suppressants may also be used in archives and museums with paper archives, historical documents, priceless works of art and antiquities where other fire protection fluids cannot be used.

Fluorinated gas fire suppressants are specifically used for several military applications, e.g. in engine- and crew compartment systems on army ground vehicles (e.g. HFC-236fa) and in fixed systems protecting flight simulators and command centres. In combat the soldiers have very limited possibilities to leave the vehicle and are therefore exposed to the extinguishing media.

A.3.9.1.7. Minor uses

Insulation gas in electrical equipment

Historically, SF_6 has been used as an insulation gas in high-voltage power generation and distribution equipment, including gas insulated switchgear and gas insulated lines. Recently, research and development has led to the replacement of SF_6 (very high GWP) with low-GWP fluorinated gas alternatives that would reduce the contribution to climate effects considerably. Specifically, the nitrile C4-FN and the ketone C5-FK are used for this purpose, including in medium- and high-voltage gas insulated power generation and distribution equipment such as switchgear and lines. This application is considered in detail in section A.3.12 on electric/electronic equipment.

Electronics and semiconductors manufacture

In the electronics and semiconductor industry fluorinated gases are used in etching and chamber cleaning processes to form nano-level fine semiconductor integrated circuits etc. CHF_3, CF_4, perfluoroethane, perfluorinated alkanes and cycloalkanes are examples of fluorinated gases used for these purposes. In most cases the substances are used as a solvent. Although the amount used is small, today's electronics products require extremely complicated and delicate processing to realize various functions such as high performance, multi-function, and low power consumption. To achieve this, various gases/liquids are combined to perform processing with advanced and delicate control. Fluorinated gases are also used in Carnot cooling cycles in electronics and switchgear, as well as in industrial process refrigeration in the manufacturing plant, while hydrofluoroethers and perfluoropolyethers are used within as high-performance heat transfer fluids. Further details may be found in section A.3.12 on electronics and semiconductors electric/electronic equipment.

IT hardware immersion cooling

Immersion cooling is a method for cooling data centre IT hardware, including 5G network components, by directly immersing the hardware in a non-conductive fluorochemical liquid. The heat generated by the electronic components is directly and efficiently transferred to the fluid. This reduces the need for interface materials, heat sinks, fans, shrouds, sheet metal and other components that are common in traditional cooling methods. This application is considered in detail in section A.3.12 on electric/electronic equipment.

Preservation of cultural paper-based materials

Fluorinated –gases/liquids are used in a procedure for preservation of paper-based cultural heritage materials. The procedure includes suspending MgO in a fluorinated solvent for treatment of paper materials to stop acid corrosion and preserve the objects. Fluorinated solvents can deliver the alkaline buffer without degrading ink, binding materials, glue or discolour the paper.

Plasma coating

Some fluorinated gases are used in plasma coating of recycled HDPE plastic containers to limit the migration from recycled plastic to filling goods. The gases react with the plastic under the conditions with formation of a fluorinated protective layer.

Calibration and reference materials

Fluorinated gases and liquids are used as analytical reference materials and for the calibration of measurement instruments.

A.3.9.2. Volumes

In Table A.36 an overview of PFAS volumes is presented. The main use groups are distinguished. A description of the methodology used in the estimation of volumes for the different applications is found below the table.

Table A.36. Yearly total volume of HFCs and PFCs in EEA per main use category.

		Total fluorinated gases (t/y)
Commercial refrigeration	Manufactured products	7 915
	Stocks	90 992
	Decommissioning	5 717
Domestic refrigeration	Manufactured products	122
	Stocks	4 496
	Decommissioning	671
Industrial refrigeration	Manufactured products	2 360
	Stocks	34 358
	Decommissioning	1 219
Transport refrigeration	Manufactured products	1 010
	Stocks	9 915
	Decommissioning	226

		Total fluorinated gases (t/y)
Mobile air conditioning	Manufactured products	5 221
	Stocks	115 763
	Decommissioning	4 647
Stationary air conditioning	Manufactured products	7 465
	Stocks	148 791
	Decommissioning	6 865
Foam blowing agent (closed cell)	Manufactured products	4 940
	Stocks	57 635
	Decommissioning	170
Foam blowing agent (open cell)	Manufactured products	271
	Stocks	9 848
	Decommissioning	No data
Fire protection	Manufactured products	863
	Stocks	20 201
	Decommissioning	208
Aerosols (non-MDI)	Manufactured products	504
	Stocks	907
	Decommissioning	No data
Solvents	Manufactured products	No data
	Stocks	0
	Decommissioning	No data
Other	Manufactured products	No data
	Stocks	267
	Decommissioning	No data
Total HVACR	Manufactured products	**30 671**
	Stocks	**493 173**
	Decommissioning	**19 724**

There are two main data sources that have been used extensively for market data (volumes) on fluorinated gases and their different applications, each with different strengths and limitations:

- Greenhouse Gas Inventory: EU/EEA Governments annually report to the United Nations Framework Convention on Climate Change, UNFCCC (EEA, 2022) – the so-called Greenhouse Gas (GHG) Inventory data. This is compiled according to the standard methodology and guidance set out by the Intergovernmental Panel on Climate Change (IPCC). Data from the GHG Inventory for 2018 (published in 2020) have been used in this assessment. The data used were mainly the data for fluorinated gases that are included in the GHG Inventory which is titled the 'Sectoral background data for industrial processes and product use'. These data are included in Table 2(II). B-H of the inventory and have been used.

The reporting includes emission data in addition to market volumes. The GHG Inventory includes fluorinated gases of the type HFCs and PFCs, which are the most important subclasses, but it does not include for example the HFOs which are growing in use. The geographical scope of the GHG Inventory data for 2018 is EU-28 plus Iceland (IS). Norway (NO) reports separately to the UNFCCC process, so for the purposes of this project the Norwegian data has been added to the EU GHG Inventory data to provide a geographical coverage of EU-28 & IS & NO. No data were available for Liechtenstein.

- F-gas report: The European Environment Agency annually collects and publishes F-gas data reported by industry according to the obligations under Regulation (EC) No 517/2014 (the 'F-Gas Regulation'). The report used in this project was published in 2020 as the 'F-Gas Report' (EEA, 2020) and provides EU data up to and including 2019 and covers F-gas activity (production, reclamation, imports, exports, destruction and feedstock use), supply of F-gases (trends in supply) and progress of phasing down the use of hydrofluorocarbons (HFCs). The F-gas report does not include data for Iceland and Norway. The reporting threshold is 1 metric tonne, or 100 t CO_2 equivalents of F-gas produced or imported/exported in bulk, and 500 t CO_2-equivalents for F-gases in products[30]. The F-gas report is limited to volumes of F-gases placed on the market and does not cover emissions. However, it includes market volumes for the emerging HFOs (in principle also HFEs, but data are generally confidential for these).

Market data on fluorinated gases filled into new products and in stocks each year have primarily been derived from data collated by the EU/EEA for the GHG Inventory and summarized for EU-27 & IS & NO & UK. Data for HFOs, which are not reported in the GHG Inventory, have been extracted from the F-gas report.

Volumes of fluorinated gases from manufacturing to decommissioning is available at the sub-application level and is indicated in the material flow diagram in Figure A.14. The data are disaggregated as follows: 1) Filled into new manufactured products; 2) In operating systems (annual stocks); 3) Remaining in products at decommissioning, while data are not disaggregated at the substance-in-each-sub-application level.

In 2018 in total, 30 671 t/y fluorinated gases were filled into new products for the first time during their manufacturing process, while 493 173 t/y were found in operating systems (Annual stocks in operating systems refers to products that already contain fluorinated gases and are in operation) used in EU-27 & the United Kingdom (UK) & Iceland (IS) & Norway (NO) (EEA, 2022). Remaining in products at decommissioning is 19 724 t/y gases. From the GHG Inventory data for 2018, refrigeration and air conditioning account for 78% (24 093 t/y) of the total amount of these fluorinated gases filled into new manufactured products and 82% (404 315 t/y) of the gases in operating systems (technical stocks).

[30] An implication of the high reporting threshold for products (in CO2e) is that HFOs often are underreported due to their low GWP. For example, HFO-1234yf with a GWP of 4 is replacing HFC-134a with GWP 1430 for use in AC in passenger cars. With a specific charge of approximately 0.5 kg per passenger car, the 500 t CO_2e reporting threshold corresponds to 250 000 passenger cars with HFO-1234yf refrigerant.

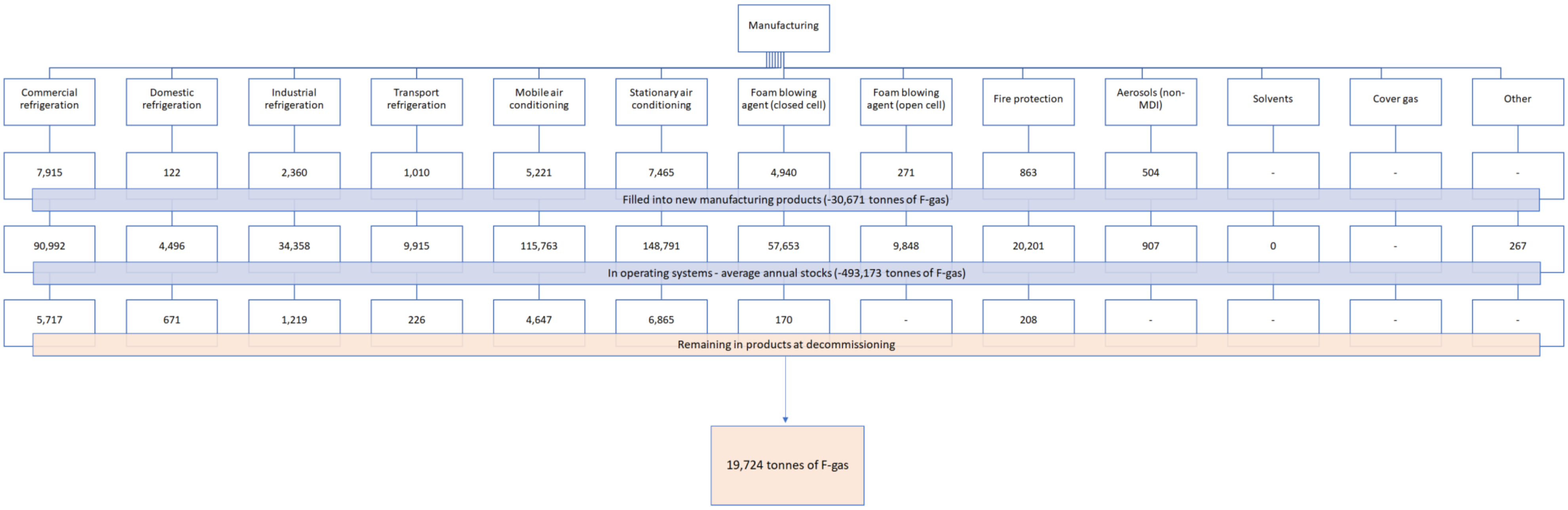


Figure A.14. Material Flow diagram – fluorinated gases from product manufacturing until decommissioning, 2018.

Looking at the fluorinated gases filled into new manufacturing products in Figure A.14 and comparing the volumes of the different applications, the distribution shown in Figure A.15 below can be obtained. The total amount of fluorinated gases filled into new products equals 30 671 t/y.

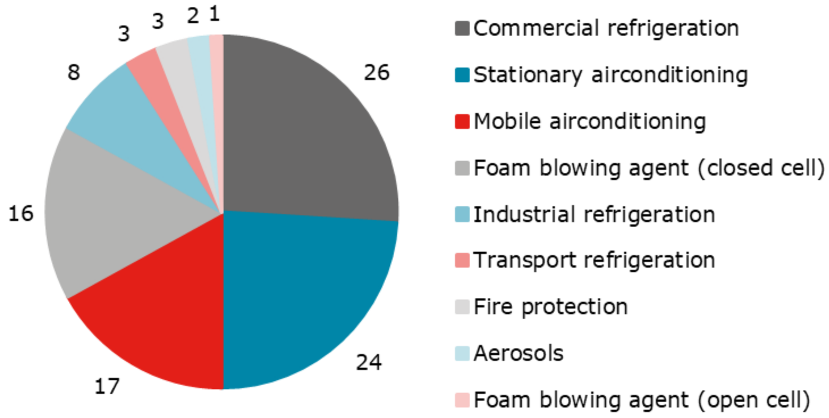


Figure A.15. Fluorinated gases filled into new manufactured products in 2018 (EU-27 & IS & NO & UK). Figure adapted from GHG Inventory (EEA, 2020).

According to stakeholder input, the market volumes of closed cell insulation foams can be split between polyurethane spray foams, extruded polystyrene and phenolic foams, with phenolic foams potentially accounting for around 50%.

In the GHG Inventory the reporting on applications of solvents is very limited. This may be due to the volume threshold for reporting to the GHG Inventory is high and not suitable for these applications. However, it is evident that the volumes of fluorinated solvents used are low compared to other applications. According to stakeholder information, an amount of 140 t of fluorinated solvents is used annually within electronics and semiconductors, mostly for cleaning, see section A.3.12. Furthermore, an estimated 35 – 75 t/y of fluorinated solvents is used for cleaning in relation to lubrication processes, see section A.3.15.

In addition to the above-mentioned fluorinated gas market data from the GHG Inventory, HFOs are being increasingly used. These are not reported in the GHG Inventory, but data may be found in the F-gas report. The F-gas report investigates trends in the supply of fluorinated gases in the EU, and Figure A.16 below, copied from the report (EEA, 2020), shows the estimated trends in different intended applications since 2007.

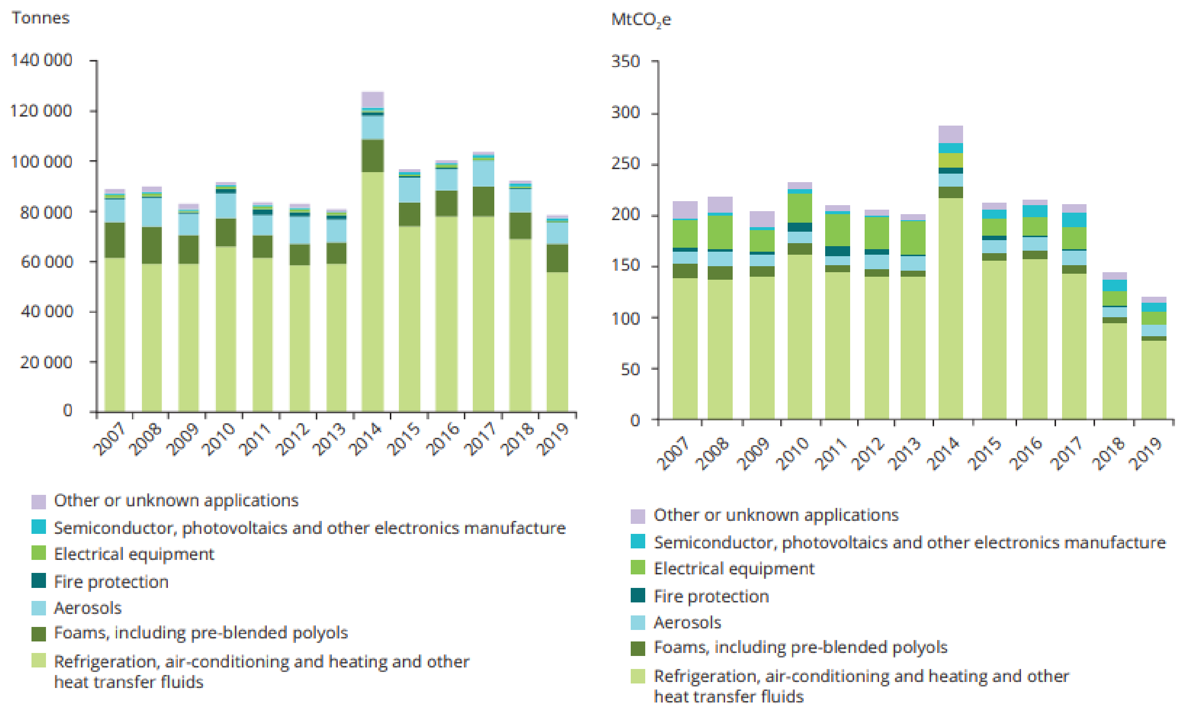


Figure A.16. Intended applications of EU total supply of fluorinated gases, 2007-2019. Reproduced from F-gas Report, Figure 4.7 and 4.8 (EEA, 2020).

Data collected from the F-gas report on the use volumes of HFOs and HCFOs and compared with other fluorinated gases can be found in Table A.97 in the Appendix. The majority of HFOs currently being used commercially as a single substance (rather than a blend) are in mobile air conditioning (MAC) systems for passenger cars and in light goods vehicles, commercial air conditioning, heat pumps and process cooling. In commercial and transport refrigeration HFOs are mainly used in HFC/HFO blends such as R-448A, R-449A, R-450A, R-452A and R-513A. The overall volumes of HFOs/HCFOs for all applications increased from 6 305 t in 2016 to 18 350 t in 2019, while the relative proportion of HFOs/HCFOs compared to other fluorinated gases in the same period increased from 6 to 24% (Table A.97).

According to the GHG Inventory data 5 221 t/y of HFCs were supplied to the EU market in 2018 for mobile air conditioning, Figure A.14. The F-gas report lists 1 206 t/y imported fluorinated for MAC in 2018, while EU total imports of HFOs/HCFOs in 2018 was 19 235 t/y. With basis in the number of newly produced/registered road vehicles and the volumes of gases used in different types of vehicles, it was estimated that 12 222 t of fluorinated gases were used in HVACR-systems for passenger comfort in new vehicles in the EU in 2019, see section A.3.11.

Figure A.17 shows the imports of fluorinated gases into the EU-28, including both bulk imports and imports contained in products and equipment (EEA, 2020). The overall import volume of fluorinated gases decreased by 14% from 2018 to 2019 (EEA, 2020). Imports of HFCs fell by 19%, while imports of HFOs/HCFOs increased by 6%. The share of HFCs in total imports was 79% in 2018 and 74% in 2019.

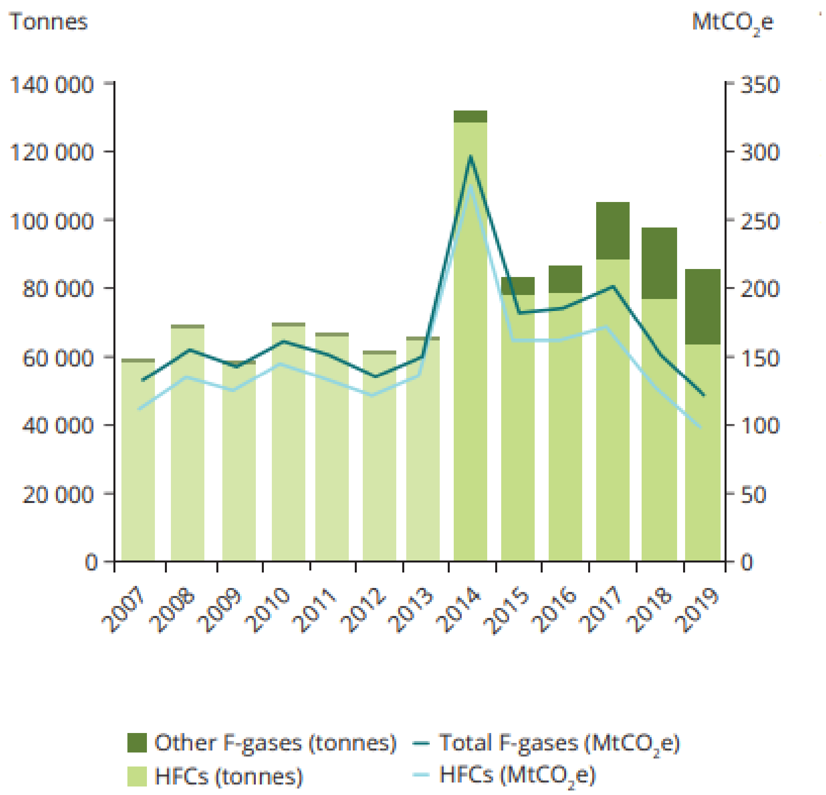
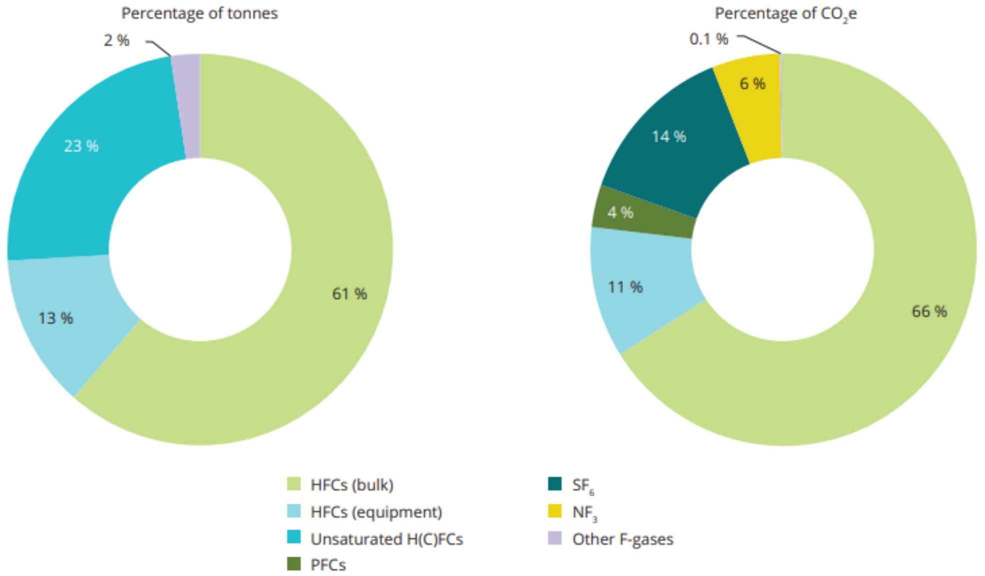


Figure A.17. EU imports of fluorinated gases, both bulk imports and imports contained in products. Copied from the F-gas Report, Figure 3.3 in EEA (2020).

Figure A.18 provides an overview of the supply of fluorinated gases in 2019 in more detail: the largest proportion is HFCs delivered in bulk (61% of total EU supply), while about 13% is HFCs delivered in products and equipment. Unsaturated HFCs (= HFOs) have risen to a share of 23%. PFCs, SF_6 and other gases are supplied almost exclusively in bulk. The picture looks quite different when looking at the total supply measured in CO_2-equivalents.



Note: The geographical scope of presented data is the EU-28.
Source: EEA (2020b).

Note: The geographical scope of presented data is the EU-28.
Source: EEA (2020b).

Figure A.18. 2019 total supply by types and groups of fluorinated gases. Reproduced from F-gas Report, Figure 4.3 and 4.4 in EEA (2020).

To get an impression of the relative importance of the different fluorinated gases that are not within the chemical scope of the present restriction proposal, one can look at the total supply of fluorinated gases (in tonnes) reported at the substance level in the F-gas Report (EEA, 2020), Table A5.17. An extract for the substances HFC-23 (CHF3), HFC-32 (CH_2F_2) and HFC-152a (CHF_2-CH_3) is presented in Figure A.19 below. Data were not available for HCFC-141b and HFO-1132a, but their uses are expected to be limited. The use of HFC-32 is evidently increasing, and in 2019 constituted 18.5% of total supply of the fluorinated gases on volume basis. The total EU supply of HFC-32 in 2019 was 14 483 t. HFC-152a is fairly stable around 4%, while HFC-23 is negligible in comparison to the overall supply.

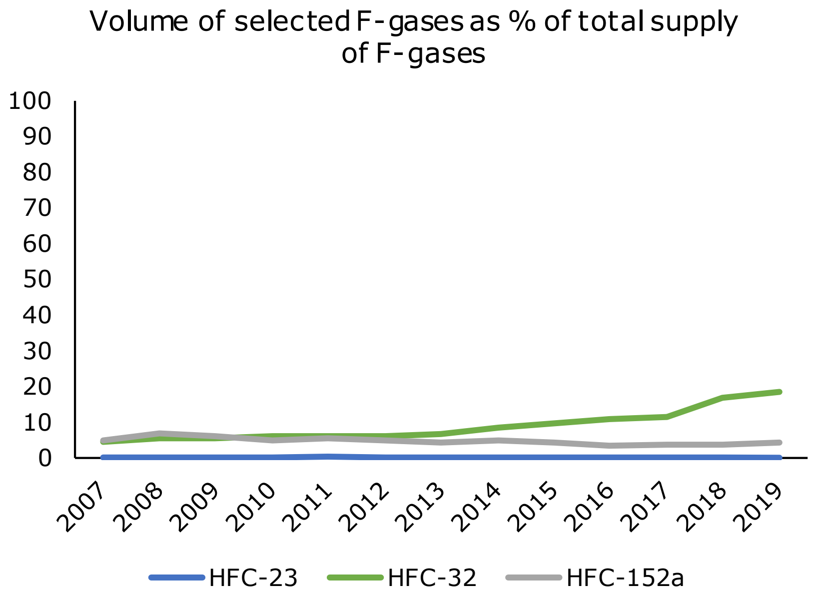


Figure A.19. Supply of gases outside the scope of the PFAS restriction proposal in the EU as percentage of total supply of fluorinated gases based on tonnes supplied.

Although some fluorinated gases used in various applications and in considerable overall volumes are outside of the chemical scope of the PFAS restriction proposal (e.g. HFC-32), the overall volumes of gases (both PFASs and non-PFASs) for the different applications is of interest as trends and shifts may affect the whole sector use volume as a response to technical or regulatory development. Furthermore, the gases outside of the chemical scope are often used in blends with fluorinated gases within scope.

Illegal use and trade of HFCs is a considerable problem in the EU/EEA. The illegal trade undermines regulations, results in more HFC emissions that fuel global warming and significantly reduces government income and the profits of legitimate businesses. It is very difficult to provide an accurate estimate of the extent of these illegal activities. However, one estimate was provided by the Environmental Investigation Agency which estimated that 16.3 million tonnes CO_2 equivalents of bulk HFCs were illegally placed on the EU market in 2018 (EIA, 2019). This represents more than 16% of the 2018 quota. The number represents the amount of HFCs imported through normal customs channels outside of the quota system, and traditional smuggling comes in addition to this and is much more difficult to quantify. There is a large variation in the fraction that the illegal import of HFCs constitutes between the European countries.

A.3.9.3. Summary

Fluorinated gases are widely used in certain specific areas, e.g. refrigeration, foam blowing agents and as clean fire suppressing agents. The main uses of such gases are in air-conditioning (stationary and mobile) (41%) and refrigeration (commercial, industrial and transport) (34%). The total annual use volume of fluorinated gases for HVACR for manufactured products is 30 671 t, for stocks 493 173 t, and for decommissioning 19 724 t.

A.3.10. Medical devices

A.3.10.1. Uses

Medical devices are regulated under EU Regulation 2017/745. Various items can be considered medical devices, see text below as defined in the currently abovementioned regulation (EC, 2017a).

'medical device' means any instrument, apparatus, appliance, software, implant, reagent, material or other article intended by the manufacturer to be used, alone or in combination, for human beings for one or more of the following specific medical purposes:

—diagnosis, prevention, monitoring, prediction, prognosis, treatment or alleviation of disease,

—diagnosis, monitoring, treatment, alleviation of, or compensation for, an injury or disability,

—investigation, replacement or modification of the anatomy or of a physiological or pathological process or state,

—providing information by means of in vitro examination of specimens derived from the human body, including organ, blood and tissue donations

In vitro diagnostic medical devices, on which the restriction proposal is also applicable, are regulated under EU Regulation 2017/746. Various items can be considered in vitro diagnostic medical devices, see text below as defined in the currently abovementioned regulation (EC, 2017b).

'in vitro diagnostic medical device' means any medical device which is a reagent, reagent product, calibrator, control material, kit, instrument, apparatus, piece of equipment, software or system, whether used alone or in combination, intended by the manufacturer to be used in vitro for the examination of specimens, including blood and tissue donations, derived from the human body, solely or principally for the purpose of providing information on one or more of the following:

(a) concerning a physiological or pathological process or state;

(b) concerning congenital physical or mental impairments;

(c) concerning the predisposition to a medical condition or a disease;

(d) to determine the safety and compatibility with potential recipients;

(e) to predict treatment response or reactions;

(f) to define or monitoring therapeutic measures.

Specimen receptacles shall also be deemed to be in vitro diagnostic medical devices;

Medicinal products (including active pharmaceutical ingredients), anaesthetics and contrast media are considered not in scope of medical devices. Furthermore, personal protective equipment (clothing, drapes), medical electronics and constructive applications in hospitals are also not included, since these are part of TULAC (A.3.3), electronics (A.3.12) and construction (A.3.14), respectively.

The EU Medical Device Regulation has classified medical devices into three classes with increasing risk: Class I, II and III. Each device class requires a different level of regulation and compliance.

- Class I are devices like tongue depressors, bandages, gloves, bedpans, and simple surgical devices
- Class II devices include wheelchairs, X-ray machines, MRI machines, surgical needles, catheter and diagnostic equipment
- Class III devices are used inside the body, for example heart valves, stents, implanted pacemakers, silicone implants and hip and bone transplants

In future these devices will be registered in the European database on medical devices (EUDAMED)[31] with a harmonised nomenclature through the European Medical Device Nomenclature (EMDN)[32].

Production of medical devices requires a high degree of cleanliness, purity, chemical stability and thermal resistance. In the final products (substance, mixtures and articles), PFAS properties like temperature resistance, dielectric strength as well as very high autoclavability, chemical resistance, oil repellence, water repellence, sliding properties and good biocompatibility are important.

The majority of medical devices are introduced to the EEA market via imported articles containing PFAS.

Main medical devices containing PFAS are listed below. Each mentioned sub-use will be discussed in more detail in the section below.

- Fluorinated meshes and wound treatment;
- Medical textiles;
- Medical implants;
- Tubes and catheters;
- Coatings;
- Cleaning and heat transfer: engineered fluids;
- Sterilization gases;
- Packaging;
- Electronic equipment;
- Diagnostic laboratory testing;
- Metered Dose Inhalers (MDI);
- Others.

[31] https://ec.europa.eu/tools/eudamed/#/screen/home, date of access: 2022-12-15.
[32] https://webgate.ec.europa.eu/dyna2/emdn/, date of access: 2022-12-15.

A.3.10.1.1. Implantable medical devices

Meshes, wound treatment products (bandages, surgical tapes, surgical staples), tubes and catheters are covered in separate sections.

Polymers in medical implants are listed in Table A.99 in the appendix (McKeen, 2014). Polymers are used for medical implants, with PTFE being the most abundant fluoropolymer. Fluoropolymers such as PVDF and FEP are also used as biocompatible materials.

A.3.10.1.2. Fluorinated meshes and wound treatment

The most frequently used textile implants worldwide are hernia meshes. The closure of the defect is important and is one of the most common surgical procedures. More than one million operations are implanted every year in Europe. Porous membranes containing ePTFE (expanded PTFE) or PVDF are used as mesh material or patches, because they reduce adhesion, one of the possible complications in hernia reinforcement.

Also, part of medical and silicone tapes and wound dressings rely on PFPE-enabled release liners for their function. Surgical staples leverage a PBSF surfactant as a coating to approximate skin for surgical or acute wounds.

A.3.10.1.3. Tubes and catheters

Tubes play a role in many medical operations, such as cardiovascular, neurovascular and peripheral blood vessel treatment, atrial fibrillation, endoscopy (pulmonary endoscopy, colonoscopy), endometrial ablation (against abnormal menstrual bleeding) and vitreoretinal surgery. There is a growing demand for minimally invasive procedures. Especially high lubricity (smoothness) of the catheters is a desired quality in medical applications (Bates and Campbell, 2015). Additionally, the use of catheters is a cost-effective technique compared to more invasive procedures.

Catheter tubes are usually made of ePTFE because this provides a very smooth surface and minimizes the need to use force. There are limitations of PTFE that include low tensile strength, wear resistance, creep resistance and radiation resistance. Therefore, FEP is sometimes used since FEP has better impact strength and wear resistance, yet slightly higher frictional properties and lower resistance to thermal stress cracking than PTFE (Teng, 2012). Finally, ePTFE is sterilizable without loss of these properties. PVDF is applied in connection devices for catheters, for instance with peritoneal catheters.

A.3.10.1.4. Coatings

Coatings are applied in catheters, metal stents, catheter balloons, plunger stoppers, needle shields, and membranes. Fluoropolymers are often used as coating because of their advantageous properties. For example, PTFE limits the ability of bacteria and other infectious agents to adhere to catheters which reduces infections. For the same reason PTFE is used as coating on protective clothing and other textiles in the hospital environment. In some cases, e.g. for plunger stoppers, the fluoropolymer coating prevents compounds from leaching into the drug product.

Fluoroplastics (mainly elastomers) allow for protein-resistant and sterile filters, tubings, O-rings, seals and gaskets for kidney dialysis machines, and immuno-diagnostic instruments.

PFAS coatings, mainy polymeric PFAS, can be successfully deposited on many different types of surfaces, including metals, plastics and elastomers. Specific deposition applications include hypodermic needles, surgical and cutting blades, blood bags, filters and PVC tubing.

Metered dose inhalers are made of an aluminium casing with a fluorinated coating, to prevent interaction of the medical ingredient with the casing. A way of coating of aluminium metered dose inhalers is done with a polymer layer of PFA or FEP. The main coatings mentioned during the CfE are listed in Table A.100.

A.3.10.1.5. Cleaning and heat transfer: engineered fluids

For cleaning and heat transfer, so-called engineered fluids are often used. Engineered fluids is a term used for fluorinated fluids. These fluids are used in applications such as electronics, cooling, heating, testing, as well as chip technology. Engineered fluids are also used in medical devices.

Perfluorinated engineered fluids can be used to deposit a wide variety of coatings, including silicone, PTFE and heparin. These coatings can be deposited on many different types of surfaces, including metals, plastics and elastomers. Specific deposition applications include hypodermic needles, surgical and cutting blades, blood bags, filters and PVC tubing. Engineered fluids are also applied as solvents during chemical reactions, as inert media, and in microfluidic applications.

A.3.10.1.6. Sterilization gases

Ethylene oxide can be used as a sterilant either alone or diluted with other gases to make non-flammable mixtures. A mixture of 12% by weight ethylene oxide and 88% chlorofluorocarbon-12 (CFC-12) (12/88) had previously been widely used for this purpose.

Hydrochlorofluorocarbons (HCFCs) were introduced as drop-in replacement for ethylene oxide/CFC-12 mixtures but have been phased out in Europe, because of the Montreal Protocol legislation.

A.3.10.1.7. Packaging

PFAS, especially fluoropolymers, are widely used in medical packaging applications. Packaging components like ampoules, single and multi-dose containers, bottles (also in caps and actuators), cartridges; pressurized containers, syringes and vials are known to (partly) contain PFAS, especially fluoropolymers.

Liquid drug products for injection (e.g. vials, prefilled syringes) are packed in closed container systems. These types of packaging are mostly a combination of glass (vial, barrel) and elastomers (stoppers, plungers, seals). Because of the extended period of contact between the drug product and packaging, elastomer extractables could leach into the drug product, potentially affecting the product safety. ETFE or PTFE coated elastomeric components are often used to minimize interaction between the drug and the packaging. As this kind of packaging is in direct contact with the drug product, they are part of the drug product registration.

PTFE is also used in ophthalmic solutions packaging. It acts as hydrophobic membrane in certain ophthalmic solutions' packaging, allowing the venting of air, while retaining fluid within the container, preventing leakage. In blister packaging also fluoropolymers are applied[33]. And packaging of operating tools can contain fluoropolymers as well. Over-the-counter pharmaceuticals and animal health packaging often contains PCTFE. PCTFE has high moisture barrier when compared to other extrudable thermoplastic films, which makes PTFE coatings popular in packaging materials.

For many medical devices specific packaging materials are used which are permeable for ethylene oxide. Ethylene oxide is only permitted for sterilization of medical devices. Shelf-life studies (and possible sterilisation process) need to be performed before an authorization is

[33] For instance https://www.nichrome.com/blog/importance-of-blister-packaging-in-the-pharma-industry/ or https://www.pharmaceutical-technology.com/contractors/packaging/tekni/, date of access for both: 2022-12-15.

granted.

A.3.10.1.8. Electronic equipment

Although electronics is a separate use section, it should be noted that numerous electric medical devices such as scanners, screens etc. qualify as electronic devices. In electronics, PFAS is mainly applied in cables and wires, printed circuit boards and in (LCD) screens. See for more details the Electronics and Energy section A.3.12.

A.3.10.1.9. Diagnostic laboratory testing

Examples where PFASs are used in laboratory equipment include precision refrigeration (blood bank refrigerator, vaccine storage), ultra-low temperature freezers or cryogenic storage, refrigerated centrifuges for sample separation, process chillers for precise temperature control and freeze-drying equipment. PFASs are also used in in vitro diagnostic devices. See Table A.101 in the appendix for additional information on main applications in this area.

A.3.10.1.10. Vision applications – contact lenses and ophthalmic lenses

For ophthalmic lenses, PFAS-based coatings are applied to lenses which make them easy to clean, hydrophobic, oleophobic and scratch resistant. These coatings are industry standard, and customers expect this performance from their spectacles.

Rigid gas permeable contact lenses rely on PFAS currently and typically use fluoromethylacrylates. Major suppliers of the blanks for rigid gas permeable contact lenses are based outside the EU and supply the blanks (referred to as buttons within this industry) into the EU where they are then formed into contact lenses for specific customers by EU companies. The buttons are then converted into contact lenses for two main uses: fitting sets and prescription lenses. Prescription lenses typically may need replacement every 12 months.

A.3.10.1.11. Propellants in Metered Dose Inhalers (MDI)

Fluorinated gases are also applied in metered dose inhalers (MDI) where they act as a propellant for the active pharmaceutical ingredient (API). In 1987, the Montreal Protocol was signed and called for the elimination of CFC propellants.

Metered-Dose Inhalers (MDIs) are typically used for the treatment of asthma and other respiratory conditions. These devices are regulated under the Aerosol Dispenser Directive. MDI, nasal sprays and nebulizers are used to administer pharmaceuticals directly into the lungs. This enables the achievement of high active pharmaceutical ingredient concentrations, while minimizing systemic exposure. The best-known application of MDI is the treatment of patients with COPD or asthma. Additionally, treatment of cystic fibrosis, chronic lung infections, influenza, osteoporosis, pulmonary hypertension has been reported (Stein and Thiel, 2017). The number of pMDI (pressured MDI) is 20 million per year.

A.3.10.1.12. Membranes used for venting of medical devices

Hydrophobic/oleophobic membranes based on PTFE and PET with fluorinated C6 based side chain coatings are used for (sterile) venting of several medical devices, for example cell culture devices, analytical devices, blood tube systems for dialyzer systems, tube systems for eye surgery.

A.3.10.1.13. Others

Fluoropolymers, especially PTFE, are applied in e.g. sealant (tape or monofilament/cord) and in devices such as breathing air devices, medical ventilators and oxygen supply systems. Furthermore, surgical trays, surgical tools, filters, dilator, pharmaceutical stoppers contain PFASs. PFAS are also used in contact lenses. An additional list of (minor) uses is listed in

Annex B based on stakeholder feedback from the second consultation in summer 2021.

In Table A.37, an overview of fluoropolymers in medical devices is given. In Table A.99 (Appendix), the PFAS polymers used in medical implants, a subcategory of medical devices, are listed in detail. Stakeholders provided several additional uses for PFASs in medical devices, these are listed in Table A.103 in the Appendix.

Table A.37. Fluoropolymers used in medical devices.

(Key) fluoropolymers	Uses (examples)
PVDF (Kynar®, Solef®); polyvinylidene fluoride	Coating: • Packaging • Hoses and seals As useful material: • Membranes in cochlear implants • Catheters
PTFE/PFA (Teflon®) Polytetrafluoroethylene/ Perfluoroalkoxy	Coating: • Guide wires • Catheters • Stone catchers • Polypectomy snares • Anti-adhesive coating • Handles • Speculars • Obturator bars As useful material: • Multi-lumen catheter • High-purity transfer line • Working channels in flexible endoscopes • Seals • Heat shrink tubing • Insulation of wires, cables and complex electronic components
ECTFE (HALAR®); Ethylene- chlorotrifluoroethylene	Coating: • Electrosurgery/monopolar and bipolar high-frequency surgery • Biopsy forceps with high-frequency connection • Coagulation probes • Papillotomes for use in high-frequency surgery

Below, the main PFAS substance groups that are applied in medical devices are described in more detail.

A.3.10.1.14. PFAAs and PFAA precursors

Trifluoroacetic acid (TFA) is used in analytical and production processes. It is an additive to the mobile phase in high-performance liquid chromatography applications. There are also many ingredients that are used as TFA salt.

A.3.10.1.15. Fluorotelomers

Fluorotelomers are being used for their contamination-resistant properties in medical textiles to protect doctors, nurses and researchers against contact with microbiological contaminants, such as viruses or bacteria, for example in surgical gowns and drapes. The COVID-19 crisis has highlighted the importance of such traditional fluorotelomer applications, such as medical barrier fabrics for (COVID-19) masks, surgical gowns and drapes.

Fluorotelomers are used in woven and non-woven fabrics, textiles for the treatment of patients (such as bandages, absorption mats, hernia mats) and textiles in medical applications and medical laboratories (such as filter membranes).

A.3.10.1.16. Fluorinated gases

Fluorinated gases are used in contrast agents for different imaging techniques and as propellants in metered dose inhalers (MDI).

Orally inhaled CFC propellants for metered dose inhalers are exempted from the elimination of CFC propellant (Montreal Protocol ban) until medically acceptable alternatives are available. This has led to the development of HFA-propellants which are more environmentally friendly than the CFC-propellants. Currently no ozone-depleting MDI-propellants are on the market, although they still fall in the list of greenhouse gasses.

There are two main propellants used in MDI: HFC-134a (in scope), and to a smaller extent HFC-227ea (in scope). These fluorinated gases are used as propellants because they have properties that cannot be easily found in other chemical structures. A propellant must have the right density, viscosity, temperature operating range and must be inert, in order to be able to deliver the intended amount of active pharmaceutical ingredient to the patient. The propellant must be non-toxic as well. HFC-134a, HFC-227ea fulfil these criteria. A less fluorinated HFC is currently under development as a propellant: HFC-152a (outside scope).

A.3.10.1.17. Polymeric PFASs

Polymeric PFASs, like PTFE and PVDF, are used in several components of medical devices. The applications include components, such as valves and connectors, where the specific mechanical, chemical or biocompatibility properties of these materials are required. Most of in-body implantable tubes (e.g. probes, stents) consist of or are coated with fluoropolymers due to their bio-inertness. Fluoropolymers are the most widely applied PFAS type within medical devices.

Fluoropolymer tubes are used in various medical operations. The tubes are mostly made of fully consolidated, sintered PTFE tubes. PTFE (tradename Teflon) is used for instance as coating on vascular guidewires to ensure its smooth progress in the vascular system and prevent vascular trauma and the risk of blood clots. PTFE tubings are used in instruments dispensing easily contaminated or chemically active material. Washable parts in instruments are also often coated with PTFE to reduce the risk of cross contamination. Additionally, PTFE can provide anti-finger printing and anti-fouling properties.

PTFE tubes are used in working channels for endoscopes, in inner tubes for catheters and as indwelling needle tubes. Keyhole surgery, heat shrink sleeving, delivery tubes, coating of temperature sensors, lab equipment and auto-sampling devices are further PTFE applications. PFTE is widely applied as coating on catheters, metal stents, catheter balloons, and membranes, but also on protective clothing and other textiles in the hospital environment.

A more permeable form of PTFE is ePTFE, which contains micropores that make it permeable to air. Expanded PTFE is often used in the form of cord, sealing tape or tubing. ePTFE is also used to produce a mesh-like structure for implants, which whilst being soft, strong and flexible, is also very porous. When implanted, this allows body-tissue to grow seamlessly into it, making it an excellent material for use in vascular grafts, hernia repair and other reconstructive surgery.

Other fluoropolymers, such as FEP and PFA, are applied in the medical field as well. PVDF, for example, is used in filter devices. PVDF as pure material is widely used as sutures, surgical meshes in wound healing. Fluoropolymers are also used to provide stain (lipid, protein) resistance and oxygen permeability on copolymers for Rigid Gas Permeable contact lenses.

Fluoroplastics are applied when high dielectric insulation is critical to the proper function of electronics that rely on high frequency signals such as defibrillators, pacemakers and CRT, PET and MRI imaging devices. PTFE, PVDF, etc. are also often used in electronic medical devices (see also section A.3.12). PFOA is used as well in electronic medical devices. In the PFOA restriction, some exemptions for medical devices (and medical textiles) are mentioned (ECHA, 2020).

PTFE and PVDF are used as well in several components for analytical instruments. The applications include components, e.g. valves, tubing and connectors, where the specific mechanical, chemical, and/or biocompatibility properties of these materials are required. PTFE is also used in ophthalmic solutions.

Fluoropolymers are also used as coating on the inside of pressurised metered dose inhalers (pMDI). The polymer-concentration on the pMDI is 0.05 - 0.1% w/w.

Finally, fluoropolymers are also used for packaging of medical and operating tools as well as packaging of medical drugs. For example, PTFE is used in ophthalmic solution packaging. Good moisture barrier, bio-chemical inertness, chemical resistance, high crystal clarity (if required) and nonflammability are characteristics for the selection of these materials. Fluoropolymers have good machineability and can be used without retrofitting packaging machinery. Fluoropolymers used in the pharmaceutical packaging sector are subject to requirements of the EU legislation on regulation of medicinal products for human or veterinary use (i.e., Regulation (EC) 726/2004 (EC, 2004), Directive 2001/83/EC (EC, 2001b), Directive 2001/82/EC) (EC, 2001a).

Fluoroelastomers

Fluoroelastomers form flexible polymeric materials that are particularly suitable as seals, stoppers, films, tubes, o-rings etc.

The resistance of fluoroelastomers to irradiation is an important quality in medical applications. Exposure to radiation can cause unwanted molecular cross-linking in the polymer which affects both performance and function.

Fluoroelastomers are used in all kinds of **sealing applications**, particularly when high levels of chemical resistance and durability are essential. Fluoroelastomers are used in seals and bearings for machines and equipment for the health and medical segment as well as parts for manufacturing of medical devices. Fluoroelastomers are also used in cables and wires of medical equipment.

There are two very different sets of elastomer usage in medical devices, each with different technical and legal requirements.

- Elastomer usage in non-invasive medical devices and equipment
- Elastomers used in invasive medical procedures and implantable devices

Perfluoropolyethers

PFPE (perfluoropolyethers) are not intended for incorporation in medical and pharmaceutical products and applications in which the product will be temporarily or permanently implanted. When the product is used for applications where the finished device is implanted into the body, no residual solvent may remain on the parts. PFPE is used as coating for ophthalmic lenses. It is also being applied in medical equipment such as phthalmoscopy. PFPE is also used in cardiovascular implants. Segregated hydrofluoroethers (HFEs) can also be used as reaction media or inert media and in microfluidics applications for medical testing applications.

Segregated hydrofluoroethers (HFEs) can also be used as reaction media or inert media and in microfluidics applications for medical testing applications. Fluids are used as heat transfer agents in medical equipment and laboratory diagnostic devices, in freeze drying applications in the manufacture of pharmaceuticals. They are used for industrial use only and are not intended for use in a medical device or drug. An overview of polymeric PFAS is given in Table A.102 as well as in Table A.105.

A.3.10.1.18. PFAS liquids for cleaning and heat transfer fluids: engineered fluids

Cleaning applications include the cleaning of metal and plastic parts, such as orthopaedic, dental and spinal implants, artificial hearts, heart valves, catheters, needles and stents. Often engineered (fluorinated) fluids are used for cleaning and rinsing. The mentioned solvents are intended for industrial use only and are not intended for use as a medical device or drug.

Perfluorinated engineered fluids are replacements for n-propyl bromide, trichloroethylene (TCE), ozone-depleting solvents such as HCFC-225 and HCFC-141b, and HFCs with high global warming potential.

For heat transfer in medical equipment (e.g. surgical lasers) and laboratory diagnostic devices other PFAS fluids like 1-methoxyheptafluoropropane and 3-ethoxyperfluoro(2-methylhexane) are used.

An overview of to what extent specific PFASs (types) are used throughout the medical devices industry is presented in Figure A.20. This information was provided by the members of Spectaris (a German industry association for the high-tech business sector). An overview of other uses is mentioned in Table A.106.

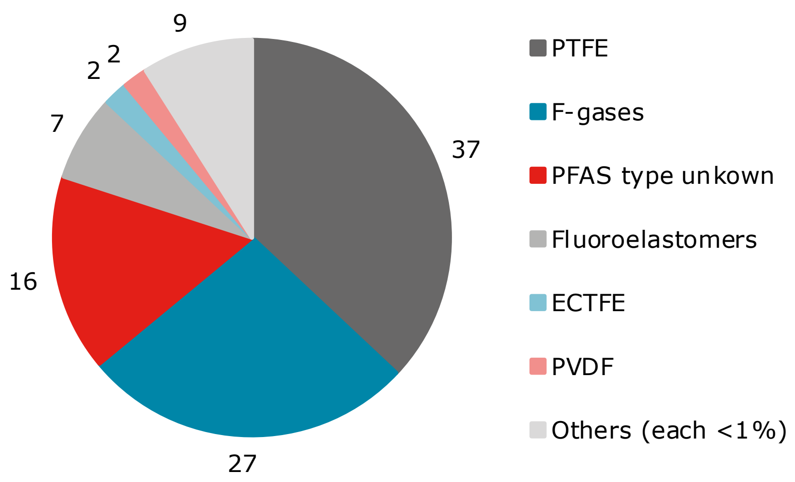


Figure A.20. Proportion of PFASs (types) applied in the medical device industry , according to members of Spectaris (an industry association).

A.3.10.2. Volumes

Most medical devices are authorized for EEA via imported articles containing PFAS.

A.3.10.2.1. PFAAs and PFAA precursors

Side-chain fluorinated PFAS are used as surfactants and coatings, also in medical devices. Based on stakeholder information the yearly use in EEA is >800 t (Table A.38).

Table A.38. Yearly total volume of side-chain fluorinated PFASs as surfactants and coatings in EEA.

Polymer name	Usage (t/y) in EEA
C6-side-chain fluorinated PFAS surfactants and coatings	>800
Total	**>800**

A.3.10.2.2. Fluorinated gases

A total approximately 33 000 t (midpoint) fluorinated gases are used in industrial processes related to medical devices like MDI's, medical lasers according to the ECHA database. Disaggregation of the tonnage to medical devices in scope is not always possible, however.

On top of the mentioned tonnage, fluorinated gases are used in exempted uses such as anaesthetics, contrast media and pharmaceutical use which is exempted as well (HCWH, 2019).

Three gases are responsible for 99.9% of the medical fluorinated gases reported (based on data from ECHA search and response to the CfE). In table Table A.104 in the appendix the greenhouse warming potential of these gases is listed as well as the importance of HFC-134a. HFC-134a is the most used gas, followed by HFC-227ea and HFE-152a (HFE-152a is outside scope). Generic worldwide use of these three main medical gases is mentioned in (Booten et al., 2020).

The volume of fluorinated gases for metered dose inhalers (MDI's) has been estimated in three different ways: production based on stakeholder information, ECHA database information, and MDI sales data/a report of Health Care Without Harm (HCWH, 2019). Volumes ranged between:

- 6 000 t/y (stakeholders);
- 400 t/y (HCWH and MDI sales data);
- 15 000 - >30 000 t/y (ECHA volumes, including volumes for export: amongst others HFC-134a: 12 000 - 20 000 t/y, HFC-227ea >3 000 t/y and HFC-152a 650- 6 500 t/y. All numbers including production for export).

Stakeholder information (6 000 t/y) was used for impact assessment.

A.3.10.2.3. Polymeric PFASs

Based on the response of the sector to the CfE, a volume between 3 200 – 12 000 t/y (midpoint 8 500 t/y) was calculated.

Table A.39 lists the volume of individual polymeric PFASs. In some case the volumes are not reported or reported as sum of a variety of polymers.

Table A.39. Overview of usage and/or production volumes of polymeric PFASs. Also mentioned in Table A.40.

Polymer name	Usage (t/y) in EEA
PTFE[a]	1 300-10 000
FEP	>200
PVDF	10-100
PFA	23-32
others incl. lumped	1 700
Total	**3 233 - 12 032**

[a] For medical masks, one producer mentioned 13 t/y for the EEA market. See also the research by EPA-DK (2021). For surface protection of rubber stoppers for pharmaceutical syringes and vials, one producer mentioned 60 t/y for the EEA market. Contact lenses: 5 t/y.

PCTFE fluoropolymers used in human and veterinary medicinal products packaging in the EU in 2015 - 2020 were considered by stakeholders in average to be around 1 000 t/y.

In Table A.40, an overview of all PFAS volumes in medical devices is presented.

Table A.40. Yearly total PFAS volume in EEA per main medical use category.

	PFAAs and PFAA precursors (t/y)			**Fluorinated gases (t/y)**			**Polymeric PFAS (t/y)**			**Total PFASs (t/y)**		
	Low	Midpoint	High	Low	Midpoint	High	Low	Midpoint	High	Low	Midpoint	High
Propellants in MDI				160	3 080	6 000*				160	3 080	6 000
Fluorinated gases used in industrial processes related to medical application (For instance medical lasers)	2	2	2	20 000	30 000	40 000				20 002	30 001	40 002
Other applications e.g. heat	477	1 585	2 692							477	1 585	2 693
Coatings and surfactants in medical devices	800	800	800				3 233		12 032	4 033	8 433	12 832
Total for all medical device uses categories	**1 279**	**2 387**	**3 495**	**20 160**	**33 080**	**46 000**	**3 233**	**7 633**	**12 032**	**24 672**	**43 100**	**61 527**

*: Estimate confirmed by stakeholder.

A.3.10.3. Summary

Because of PFAS properties (bio-inertness, flexibility, resistance to various solvents, ability to withstand aggressive sterilization procedures, chemical and temperature resistance, etc.), PFAS is broadly applied in medical devices.

PFASs found in medical devices are fluorinated gases and fluoropolymers. Fluoropolymers can be found in the following applications, ranging from invasive products like implants, tubes and valves to non-invasive products like medical textiles, meshes and surfactants. Fluorinated gases can be found in the following applications, from MDI propellant use to use in medical lasers and heat transfer agents.

The medical technology sector is a highly complex sector, with multi-tiered global supply chains that may comprise six or more layers of suppliers. This leads to a large degree of uncertainty when reporting PFAS use volumes, and likely to an underestimation of the total tonnage. Especially for PFASs used in the production of medical devices, in engineered fluids, in vitro diagnostic products, and analytical equipment, volume data is lacking. PFAS volumes are significant, especially for polymers and fluorinated gases. With the current available information, annual use is estimated at 25 000 – 62 000 t.

A.3.11. Transport

A.3.11.1. Uses

Products and articles used in the transportation sector containing PFAS are very diverse. The transportation sector encompasses the sub-sectors automotive, maritime, aviation, and railway.

The PFAS containing products and articles in the transportation sector are divided into subgroups according to their application and are presented in Table A.41.

Table A.41. Overview of uses of PFASs in the transportation sector.

Transportation - subgroup	Examples
Body-, hull-, and fuselage construction	PFASs and especially polymeric PFASs are important for body-, hull-, and fuselage construction e.g. as industrial feedstock or as functional chemicals. Examples are: • Release film for mould components for the manufacture of plastic parts (e.g. PTFE, ETFE). • Surface tension modifiers in plating processes during the body-, hull-, or fuselage construction (minimizing the generation of chromium mists).
Sealing applications[a]	Polymeric PFASs (e.g.fluoroelastomers such as FKM or fluoropolymers such as PTFE) are used to produce seals for various parts of transportation vehicles. Most of these parts belong to the propulsion system. Sealing applications with polymeric PFASs (e.g. PTFE) is likely the largest subgroup of PFASs applications in transportation: 60% or more of the fluoroelastomers produced are used in sealing applications in the transportation sector (information received by stakeholder). Examples are: • O-rings. • Seals in valves and gaskets. • Shaft or piston seals. • Seals for electronic devices such as NOx- and oxygen sensors in the exhaust monitoring. • Seals for battery electrodes in Li-Ion or dry cell batteries.
Combustion engine system	Most of the PFAS applications in combustion engine systems fall into the subgroup of sealing and coating applications. However, there are some special applications that are not covered under these subgroups e.g. non-woven textiles covering the engine bay area as acoustic insulation inside the vehicle engine compartment (treated with low molecular PFASs as well as with polymeric PFASs to achieve oil repellence and high temperature resistance and make them non-flammable).
Lubricants[a]	Lubricants based on polymeric PFASs (e.g. PTFE, PFPE) are used in transportation vehicles, mainly to reduce friction in a wide range of applications and over a wide range of temperatures. Examples are: • Bearings. • Chain guide in automotive engines. • Bushings (e.g. engine mount bush, stabilizer bush). • Fill-for-life lubricant in small gearboxes, actuators, or hydraulic cylinders (e.g. clutch systems). • Electric and thermal protection of connectors in electronic systems. • Weather strips.

Transportation - subgroup	**Examples**
	• Sunroof guiderail.
Hydraulic fluids	PFASs are used in hydraulic fluids e.g. as corrosion inhibitors. Examples are: • Steering systems. • Brake systems. • Systems for lifting and lowering of vehicle parts or cargo.
Electrical engineering and information technology[b]	PFASs play an important role in all electrical engineering and information technology in the transportation sector as they are an integral part of the manufacturing processes for semiconductors and in some cases also of the semiconductor itself. Examples are: • Computer-based systems e.g. control systems, telecommunication, safety systems. • Data transmission: Optical fibres made of fluoropolymers are used for data transmission where electromagnetic interference is a concern. The fluoropolymer serves as a low refractive index layer. • Batteries: Fluorinated polymer seals are used (see sealing applications). Often PVDF is used for such purposes. Fluorinated gases are used in HVACR-systems to cool down/heat traction batteries of electric vehicles. Polymeric PFASs are used as coating for the separator film in Li-Ion batteries. • Fuel cells: Perfluoropolymeric Sulfonyl Fluoride Ionomers act as a binder and proton conductor in the catalyst layers in fuel cells. PTFE is part of the gas diffusion layer and controls the hydrophobicity of the components, which in turn regulates the water management of a fuel cell. • Other electricity-based processes specific to the transportation sector (e.g. disinfection of ballast water using UV-radiation).
Coating and finishes	Polymeric PFASs are used in the transportation sector for coating applications e.g. PTFE, ETFE, PFA, or FEVE. Examples are: Coating of cables in the selective catalytic reduction system for diesel engines (ad blue). Coating of diesel and gasoline particle filter hoses. Turbo charger hoses and coolant lines, engine coolant lines and oil cooler lines. UV-stable coatings (e.g. paint protection for transportation vehicles for cosmetic and protective reasons e.g. FEVE is used as coating for car wrappings). Coating of insulation materials to lower their thermal conductivity resulting in better insulating properties. Glass surface treatment with fluoroalkylsilanes for non-stick properties to achieve permanent water and stain repellence and thus improve the visibility for the vehicle operator in bad weather conditions; small use but expected to increase; no alternatives available. High abrasion resistance in windshield wipers or brake pads. Use of polymeric PFASs for the coating of trim materials of transportation vehicles to achieve stain protection and give surfaces a valuable feel and look. Use in the treatment of textiles e.g. for seats, carpets, roof linings, to give the textiles water and dirt repellent properties (for the treatment of textiles usually side-chain fluorinated polymers are applied)[c]. Anti-fouling coatings on ship hull can contain PFASs to increase their stability as well as hydrophobic properties.
HVACR-systems in	PFASs are used in the functional fluids of heating, ventilation, air

Transportation - subgroup	Examples
transportation vehicles[d]	conditioning and refrigeration (HVACR)-systems. Examples for the different applications for such functional fluids are: Use of fluorinated gases in the various HVACR-systems in transport vehicles for passenger cabin air conditioning or transport refrigeration. Special heat transfer fluids (e.g. Methoxyheptafluoropropanes) for the immersion-cooling/heating of electronic equipment. Use as cleaning fluids. Use as blowing-agents.
Lifesaving and fire protection	• Airbags. • Seatbelts (retractor mechanism only). • Life jackets. • Life raft.

Other uses related to transportation	There are a few transportation-related applications of PFASs which do not fall into one of the previous subgroups, or for which information on the application is not sufficient to allocate them to one of the subgroups. Examples are:
	• Reflective and protective coatings for traffic signs/roads
	  o Surface-treated pavement marking tapes and beaded retroreflective sheeting (used for driver and pedestrian safety).
	  o ETFE film is used as an anti-graffiti overlay for traffic signage.
	• Adhesive tape as paint replacements (e.g. for marking of aircrafts). The product provides a chemical resistant surface for the aircraft, as well as reducing the aircraft's surface energy.
	• Flotation fluids in gyroscopes (mainly used in aircrafts ("artificial horizon") but also in trains (inclination sensors), and road vehicles (navigation system and control systems).
	• Wheel weights: Acrylic foam tape; PFASs are used as stabilising agent in production of tape layer, which is used to affix the weight to the wheel surface. A fluoropolymer incorporated in the weight provides weatherability and reduces the potential of the weight to corrode.
	• Cover sheets for new vehicles

[a] Also covered in section A.3.15 on lubricants
[b] Also covered in section A.3.12 on electronics
[c] Also covered in section A.3.3 on textiles
[d] Also covered in section A.3.9 on HVACR

A.3.11.1.1. Body-, hull-, and fuselage construction

PFAS containing products, especially polymeric PFASs are known on the one hand for their long-life and durability and, on the other hand for their flexibility and stability at low weight. Polymeric PFASs show high performance over a wide range of harsh operating conditions like heat, cold, chemicals or radiation. Many fluoropolymers prevent the propagation of flames or the generation of smoke. Above that, several of these polymers are non-flammable. Additionally, PFASs can alter the properties of surfaces due to their amphiphilic nature. They can, e.g. act as surfactants. In plating processes PFASs are therefore used to minimize the generation of chromium mists (see also A.3.5 Metal plating).

Due to the properties describe above, fluoropolymers are important industrial consumables for body, hull-, and fuselage construction.

PFAS based surface tension modifiers are used in plating processes during the body-, hull-, or fuselage construction. Furthermore, polymeric PFASs (e.g. PTFE, ETFE) are used as release film for mould components from the manufacture of plastic parts. Membrane textiles are used in mould-injection processes of carbon fibre composite parts due to their good release properties. Polymeric PFASs are also used as sound absorbers in a craft body. In aerospace, strips of PTFE are used to improve the wear resistance of moving parts as well as miscellaneous fixation of parts for internal or external hull. In automotive vehicles some exterior parts are fixed with tape that contains 0.1-1% PFASs to gain heat, weather and general wear resistance as well as increased flexibility (stakeholder information).

In planes, the sidewalls often contain PFASs (because of hygienic reasons). The same applies for the overhead bins.

A.3.11.1.2. Sealing applications

60% or more of the fluorelastomers (e.g. FKM) produced are used in sealing applications in the transportation sector (stakeholder information). Polymeric PFASs are used in sealing applications because of the following properties:

- Durability against aggressive chemicals e.g. lubricants, fuels, electrolytes, cooling agents and other fluids.
- Good sealing properties (avoidance of permeation, impermeability to gases) over a wide range of temperatures and under influence of aggressive chemicals.
- Good compression stress resistance over a wide range of temperatures and under influence of aggressive chemicals.

The main function of seals in transportation crafts is to protect parts from dust and aggressive chemicals (e.g. lubricants, fuels, electrolytes) thus ensuring functionality and reducing service intervals. Another function of seals is to prevent leakage (e.g. in fuel injectors) which results also in an emission reduction.

O-rings made from polymeric PFASs are the most common product used for sealing. Depending on the application, specially formed polymeric PFASs are used. Polymeric PFASs are used as seals in valves and gaskets, as shaft or piston seals, as seals for electronic devices such as NO_X- and oxygen sensors in the exhaust monitoring, or as seals for battery electrodes in Li-Ion or dry cell batteries.

The PFAS content which is necessary to fulfil the desired function depends on the material which is used and the application. In the consultation, stakeholders provided numbers ranging from 60% (in case of FKM use) to up to 70 – 100% (in case of PTFE use).

A.3.11.1.3. Combustion engine system

Currently, combustion engines in all transportation sectors are based on combustion of either fuel, diesel or natural gas. In the future, more systems using alternative fuels like hydrogen or electric propulsion systems can be expected.

In the core engine, as well as in the exhaust system, heat and pressure conditions are extreme. In addition, petrol-based fuels and partially also exhaust gases are aggressive and corrosive chemicals. So, the fuel system with storage tanks and fuel hoses, or turbo charger hoses, as well as seals and valves have to be protected from destruction by fuels. PFAS containing materials are robust materials which are resistant against heat, pressure and corrosive chemicals and also have a low friction coefficient. Further, these materials are much lighter than e.g. metal-based materials. Therefore, PFASs are used in large quantities in combustion engine systems. The main use of PFAS containing materials in combustion engines are in sealing and coating applications. Non-woven textiles are applied as cover in the engine bay area of many vehicles as acoustic insulation inside the vehicle engine compartment. They are treated with PFASs for oil repellence and high temperature resistance and make them non-flammable.

PTFE is used to produce mono-wall tubes and hoses (not coatings) for applications like turbo chargers, exhaust gas recirculation, diesel particulate filters, or the engine brake. Guides for pistons and piston rods are also made of PTFE.

FFKM are used in numerous gas turbine engines for aircrafts to achieve higher engine efficiency as it allows the use of high thermal stability oils which in turn allow for higher engine temperatures lowering fuel emissions (Thomas, 2003).

A.3.11.1.4. Lubricants

The use of PFASs in lubricants is described in the section below.

A.3.11.1.5. Hydraulic fluids

There is not much information available on PFASs in hydraulic fluids. One stakeholder mentioned that PFASs are used as anti-erosion agent which is added to the hydraulic fluid. The anti-erosion agent contains several fluorinated cyclohexanes and trace amounts of unidentified residual fluorochemicals (most likely a by-product of the manufacturing process). The anti-erosion agent is added to address in-services issues. This information specifically focused on hydraulic fluids in aerospace, but this might also be valid for other sectors of transportation.

Hydraulic fluids are used in the transportation sector in steering systems, brake systems or other special applications such as systems for lifting and lowering of vehicle parts or cargo. Applications in the aerospace sector include:

- Aircraft flight control systems, actuators for flying surfaces.
- Aircraft landing gear.
- Actuators in defence systems. These include, but are not limited to steering mechanisms, munitions loading systems, turrets.

It is unclear if all hydraulic fluids in the transportation sector are fluorinated or only those for specific applications.

A.3.11.1.6. Electrical engineering and information technology

PFASs play an important role in all electrical engineering and information technology in the transportation sector as they are an integral part of the manufacturing processes for semiconductors and in some cases also of the semiconductor itself. PFASs also play an important role in batteries and fuel cells. A.3.12 The use of PFASs in electronics and semiconductors is described in section A.3.12. The use of PFASs in batteries and fuel cells is described in section A.3.13. Only the information that is not already provided in section A.3.12 or in section A.3.13 is included in this chapter.

PTFE based printed circuit boards are used in the automotive sector to create patch antennas for 77 GhZ automotive radar sensors which are used for different safety applications such as distance sensors or blind spot detection. This application is potentially relevant also for other transportation sectors.

A fluorinated functional fluid is used as dielectric fluid in traction enclosures for the rolling stock of trams to cool high voltage electronic components e.g. traction insulated gate bipolar transistors. Currently, HFC are used for this application, but it is expected that there will be a switch to HFO or Hydrofluoroethers (HFE) like Opteon or other PFAS fluids.

To disinfect ballast water, ships are equipped with a ballast water treatment reactor that is usually installed in the engine room. The ballast water treatment reactor uses UV-radiation. In the process of generating UV-radiation, electrostatic charge of parts of the reactor may occur which may cause fires. In addition, UV radiation leads to an enforced erosion especially of polymers. From the sea water entering the UV reactor, most water sediments have to be removed. Therefore, an upstream A filter cascade is an essential part of a ballast water treatment system to prevent corrosion of components. To prevent fires and erosion, polymeric PFASs that are heat resistant, prevent electrostatic charges and are inert against erosion by UV radiation and, when in contact with water, resistant against saltwater are used. Therefore, polymeric PFASs are required for a save and reliable operation of many devices installed on board a ship, like ballast water treatment systems.

A.3.11.1.7. Coating and finishes

Polymeric PFASs are used in coating applications in the transportation sector because of their good performance over a wide range of temperatures (anti crack resistance and low volumetric expansion), abrasion resistance, fire resistance and resistance to aggressive chemicals as well as their hydrophobic and anti-fouling properties. In some special coating applications, polymeric PFASs are used because of their dielectric properties, low thermal conductivity, non-stick properties and UV-stability. Use of polymeric PFASs as coating of cables in the selective catalytic reduction system for diesel engines (ad blue, a fuel additive) or coating of diesel and gasoline particle filter hoses helps diesel exhaust emission reduction. In aerospace turbine engines, PTFE fibres in fan blade wear strips enhance low friction performance, thus increasing engine efficiency, with consequential reductions in fuel consumption and emissions. Insulation materials are coated with polymeric PFASs to lower their thermal conductivity resulting in better insulating properties

Different polymeric PFASs are used in the transportation sector for coating applications including PTFE, ETFE, PFA, or FEVE.

Fluorinated polymer coatings are used to achieve heat resistance, and resistance to aggressive chemicals in all kinds of engine hoses, like turbo charger hoses and coolant lines, engine coolant lines, brake hoses, or oil cooler lines.

UV-stable coatings are used to protect paint of transportation vehicles. An example includes the use of FEVE as coating for car wrappings. Fluorinated polymer coatings are also used as automobile brightness enhancement film or matte films to achieve good coating quality and to enhance appearance. Other trim materials in transportation vehicles are coated with polymeric PFASs to enhance appearance. In convertibles, a coating, containing PFASs, on the convertible top, provides repellence against dry soil and against the impact of cleaning agents like white spirit, as well as a dynamic rain repellence.

PTFE, ETFE or PFA are used for lubrication free bearings to achieve a low friction in combination with low stiffness and high temperature resistance. Such bearings are used in various places in transportation vehicles e.g. in ball joints, belt tensioners, decoupled pulleys, dual mass flywheels, solenoid valves, clutch release, steering torque sensors, seat height adjustment, pedal work, seat folding mechanism, headrest height adjustment and centre console lid.

Insulation materials are coated with polymeric PFASs to lower their thermal conductivity resulting in better insulating properties.

Glass surfaces are treated with fluoroalkylsilanes or PFPE (functionalized PFPE e.g. silanes or acrylates) to achieve permanent water and stain repellence and thus improve visibility. The fluoroalkylsilanes polymerizes to siloxanes with polyfluoroalkyl side e-chains. The siloxane backbone will form covalent bond with glass (ECHA, 2017).

The surface of exterior sensors or cameras can be coated with PFPE to achieve durable anti-fouling of the surface. In some cases, PFPE is also used because of its low refractive index.

In windshield wipers coatings are used to achieve high abrasion resistance. Polymeric PFASs used as coating on brake pads provide better brake efficiency and help absorb pressure, compared to non-fluorinated brake pad coatings. In high voltage insulators, which are in direct contact with the carbon strip of the pantographs (the power pickups for overhead lines on locomotives) coatings are also used. The pantographs are exposed to high electric fields, rain, contaminants, electric arcs and mechanical constraints, temperature changes and sun radiation. They must be self-cleaning to avoid getting electrically conductive. For heavy machinery, PTFE wax is used to coat parts which need a high abrasion resistance (e.g. containers, excavators).

In the interior of transportation vehicles, polymeric PFASs are used for the coating of trim materials to achieve stain protection and give surfaces an expensive feel and look. PFASs are used to provide water and dirt repellence to textiles used in the interiors of transportation vehicles e.g. seats, carpets and roof linings. Generally, side-chain fluorinated polymers are applied. Apart from water and dirt repellence, PFASs also improve safety because of their fire-protective properties of fluoropolymers.

Anti-fouling coatings on ship hull can contain PFASs to increase their stability and to give them more hydrophobic properties (Glüge et al., 2020).

PFASs are used in reflective and protective coatings for traffic signs and roads. Examples include surface-treated pavement marking tapes and beaded retroreflective sheets which are applied for driver and pedestrian safety. ETFE films are used as an anti-graffiti overlay for traffic signage. Machinery, that is used in the production of tyres, is partly coated with polymeric PFASs (e.g. the curing mould) because of non-stick properties.

The PFAS content which is needed to achieve the desired function depends on the material to which the coating is applied. Stakeholders estimate a range from 1% (PTFE waxes), <5% (windshield coatings to achieve water repellence) - 100%.

A.3.11.1.8. HVACR-systems in transportation vehicles

HVACR-systems are used to control the ambient conditions of various compartments of transport vehicles. Examples are the air-conditioning (AC) system to cool/heat the passenger cabin of a car for personal comfort and to minimise accidents due to heat-fatigue. Furthermore, filters of the AC-system ensure that the air which arrives in the passenger cabin is free from particulate matter. Larger refrigeration systems are necessary to transport cooled and frozen produce. Furthermore, fluorinated gases are used as heat-exchange media in systems to cool down or heat batteries in electric vehicles because of their dielectric properties. This may also be applicable to electric vehicle charging stations and charging cables.

The use of PFASs in HVACR is included in section A.3.9.

High Efficiency Particulate Air (HEPA) filters for AC-systems are produced using PTFE. According to stakeholder information, PTFE is needed to manufacture filters with microstructures which are necessary for the filter to meet the set requirements. HEPA filters are commonly used for aeroplane AC-systems but are also increasingly used in road transport vehicles.

A.3.11.1.9. Lifesaving and fire protection

PFASs provide important functions to lifesaving and fire protection systems in all kinds of transportation vehicles due to their specific properties which are outlined in the chapters above.

Most of the applications of PFASs in lifesaving and fire protection systems are covered under the respective chapters for coatings and finishes and sealing applications. PFASs are used in:

- Life jackets.

- Life rafts.
- Airbag systems (likely the housing, airbag material).
- Seatbelts (retractor mechanism only).
- Fluoropolymer insulation on the cables of brake wear sensors, in collision prevention or adaptive cruise control systems.
- Fluoropolymer tubing in ABS.
- Emergency ventilation blowers in tunnels.

The products mentioned are often made of durable age-resistant polyamid fabrics[34]. By incorporation of trifluoromethyl groups into the backbone or as side-chain of polyamides, an increased thermal and mechanical stability as well as a low friction coefficient of the polymers are achieved (Zhou et al., 2019). The low friction coefficient and the age-resistance are required for save operations in case of accidents. Additionally, a high temperature resistance is needed in some cases as the systems are required to work reliably also in case of fires.

PFASs are used as flame retardants and anti-dripping additives in polymers e.g. in interiors of transportation vehicles.

2-Bromo-3,3,3-trifluoro-1-propene (2-BTP) is used in hand-held fire extinguishers in aircrafts or in fire extinguishers for protection of critical infrastructure such as national defence systems or power grid and power generation (see also A.3.9). The fire primarily is extinguished by increasing the heat capacity of the atmosphere, extracting heat from the flame, thus lowering the flame temperature to the point of extinction. The fluorinated gas is non-conductive and chemically inert and thus suitable to extinguish fires of electronic components.

A.3.11.1.10. Other uses related to transportation

Adhesive PTFE based tape serves as a substitute for paints e.g. for marking of aircrafts. The products provide a chemically resistant surface for the aircraft and reduce the aircraft's surface energy.

PFASs are also used in flotation fluids in gyroscopes. These are mainly used in aircrafts to provide a "artificial horizon" but also in trains (inclination sensors), and road vehicles (navigation system and control systems). The function of PFASs in these flotation fluids is unclear.

In wheel weights, which are used to balance wheels of transportation vehicles, a (acrylic foam tape layer is used to affix the weight to the wheel surface. Furthermore, a fluoropolymer incorporated into in the weight provides weatherability and reduces the potential of the weight to corrode.

Sealing and lubrication applications play an important role in the transportation of fuel rods for nuclear power plants, according to stakeholder information. But no specific information was provided.

PFASs are also used in cover sheets for new vehicles. No stakeholder information for this specific use was provided but considering the large numbers (>15 000 000) of yearly manufactured road vehicles (ACEA, 2020).

[34] https://www.hella.com/techworld/de/Technik/Elektrik-Elektronik/Airbag-System-3083/, date of access: 2021-11-24.

A.3.11.2. Volumes

Table A.42 provides an overview of the different PFASs used in the transportation sector, their applications and (where available) the volumes used. All numbers presented refer to the EEA, unless stated otherwise. A detailed explanation of the origin of the volumes presented is provided after Table A.42.

Table A.42. PFASs used in the transportation sector. All numbers presented refer to the EEA, unless stated otherwise.

PFASs	Volumes used in transportation sector (t/y)[a]	Source
Polymeric PFASs e.g. PTFE, ETFE, PFPE, PFA, FEVE, FKM	Stock volume: in EEA registered road vehicles: 97 216 and 222 208[a] t Yearly volume: used in newly manufactured road vehicles: 6 410 - 14 653 t	Stakeholder information + calculation by the Dossier Submitters
Side-chain fluorinated polymers e.g. C6-SCFP	Volume unknown. Used for impregnating textiles and to equip non-woven textiles for different applications like wheel arch liners and sound and dash insulators to reduce noise, vibration and harshness.	Stakeholder information
Ionomers e.g. perfluoropolymeric sulfonyl fluoride	Volume unknown. Used in electronics (e.g. LED or in fuel cells)	Stakeholder information
Fluoroalkylsilanes	Yearly volume: <1	Stakeholder information
PFASs in HVACR applications[b] e.g. R1234yf (tetrafluoropropene), R134a (1,1,1,2-tetrafluoroethane), R-407C [blend of R-32 (difluoromethane), R-125 (pentafluoroethane), and R134a (1,1,1,2-tetrafluoroethane)], 1-methoxyheptafluoropropane • 2-BTP	Yearly volume: ca. 12 222 in EEA in newly manufactured road vehicles for passenger comfort Yearly volume: ca. 1 010 filled into newly manufactured products for transport refrigeration Yearly volume: 10 – 100 in handheld fire extinguishers in aircrafts	Stakeholder information, publicly available information and calculations by the Dossier Submitters based on this information Stakeholder information
Low molecular C6 telomer substances	Yearly volume: 100 – 1 000 t/y for initial technical textile finishing (unclear if this figure only relates to textiles used in transportation applications)	Stakeholder information

[a] Note that PlasticsEurope mentions 15 500 – 18 500 t for the transport sector (not only cars; 2020 and 2015 figures resp.). Fluoropolymer Market update (Wood, 2022).
[b] Volumes in the transport sector are not used for environmental or socio-economic impact assessment. A general impact assessment for all PFAS in HVACR applications in all sectors has been made.

A.3.11.2.1. Low molecular C6 telomer substances

Low molecular C6 telomer substances are used for a for initial technical textile finishing in an amount of 100 – 1 000 t/y. It remains unclear if this figure only relates to textiles used in transportation applications or if it is a general figure for the treatment of textiles.

A.3.11.2.2. Side-chain fluorinated polymers

According to stakeholder information side-chain fluorinated polymers are used for impregnating textiles and to equip non-woven textiles for different applications like in wheel arch linters and sound and dash insulators to reduce noise, vibration and harshness. A different stakeholder provided input that 10 – 100 t/y of C6-SCFP are used for this application in the EEA.

A.3.11.2.3. PFAS in HVACR systems

HVACR-systems

According to stakeholder information the following amounts of PFAS containing heat exchange media are used in the HVACR-systems of road vehicles to cool/heat the passenger cabins:

- Ca. 0.6 kg/personal vehicle;
- Ca 1 kg/unit per truck;
- Ca 6 kg/unit per bus.

In 2019, 15 769 041 passenger vehicles were manufactured and registered in the EU (ACEA, 2020). For trucks and busses, the number of newly registered vehicles was used as proxy for newly manufactured vehicles. In 2019, 2 503 992 new trucks (sum of light and heavy commercial vehicles) and 42 838 new busses were registered in the EU (ACEA, 2020). This amounts to a total number of newly registered vehicles of 18 315 844. Using the information on the amount of PFASs per vehicle, the total annual volume of PFASs in HVACR-systems of road vehicles amount to 12 222 t.

Approximately 1 010 t/y is filled into newly manufactured HVACR-systems for transport refrigeration (stakeholder information), see also A.3.9.2.

PFASs in life saving and fire protection systems

One stakeholder provided information on the use of 2-BTP in hand-held fire-extinguishers in aircrafts. According to this information 10 – 100 t/y are sold for this application in the EEA.

A.3.11.2.4. Polymeric PFASs

According to stakeholders, in 2018, 65 000 t of polymeric PFASs were sold worldwide in the automotive sector. Using the number of vehicles produced worldwide in 2019 (79 095 104[35]), this results in approximately 800 g of polymeric PFASs per vehicle. This number is in line with "350 g of fluoropolymer per car" as was estimated by Améduri (2020). With a total amount of 277 759 682 registered vehicles in the EEA, this amounts to a stock of polymeric PFASs of between 97216 and 222 208 t in all road vehicles (cars, vans, trucks, busses) registered in 2020 (ACEA, 2020).

Using the number of newly registered vehicles in 2019 that was used to calculate the fluorinated gases use, a total volume of polymeric PFASs of between 6 410 and 14 653 t is estimated (A.3.11.2).

Regarding other sectors of transportation (aerospace, marine, railway) only limited information was provided. One stakeholder provided input from market research reports. One of these reports estimated that market size for fluoropolymers (without PVDF) was 12 800 t for 2020 for the EMEA (Europe, Middle East and Africa) region. However, it is unclear if this figure relates to the transportation sector. Another report estimated the market size of

[35] https://www.vda.de/de/aktuelles/zahlen-und-daten/jahreszahlen/automobilproduktion, date of access: 2021-11-22.

fluoroelastomers in the automotive and aerospace sector to be 5 355 t for 2020.

Body-, hull-, and fuselage construction

For fuselage construction in the aerospace sector information was provided that 100 – 1 000 t/y are used by one stakeholder in the form of PTFE strips or miscellaneous fixation parts for internal hull.

Sealing applications

Stakeholders provided different estimations on the used volume in sealing applications. The total European demand for fluoroelastomers for sealing applications is in the range of 1000 – 10 000 t/y, and for PTFE it is in the range of 100 – 1 000 t/y. Another stakeholder uses 100 – 1 000 t/y of PTFE for sealing applications in cars. A different stakeholder uses of 10 – 100 t/y of polymeric PFASs to produce seals for marine vessels.

Lubricants

One stakeholder mentioned an annual use of PTFE of 1 000 – 10 000 t to produce lubricants for maintenance free bearings and sliding elements. Another stakeholder used 0.1 – 0.2 g of fluorinated lubricants "per component" in automotive applications. However, no details were provided on the number of parts of automotive vehicles that need lubrication. Another stakeholder mentioned a European demand of 100 – 1 000 t/y of fluoropolymers for lubrication.

Electrical engineering and information technology

Various stakeholders provided input on the volumes of polymeric PFASs used in electric engineering and information technology in the transport sector. The information is summarised in Table A.43.

Table A.43. Stakeholder information on the volumes of polymeric PFASs used in electric engineering and information technology applications.

Polymeric PFASs (if specified)	Range (t/y)	Specific application (if provided)
PTFE	100 – 1 000	
FEP	100 – 1 000	
PVDF	1 000 – 10 000	Energy storage in electric cars: used as binder and for the ion-permeable separator in batteries and membranes
Porous PTFE	100 – 1 000	For the ventilation of electronic components in road vehicles (e.g. housings of electronic equipment such as lamps)
PTFE	100 – 1 000	PTFE tape for cable electrical insulation in aircrafts
PTFE	10 – 100	Cable conduit in aircrafts
	100 – 1 000	For the ventilation of electronic components in road vehicles (e.g. housings of electronic equipment such as lamps, control units) and for tank ventilation (e.g. fuel and urea tanks) in road vehicles
Ionomers e.g. perfluoropolymeric sulfonyl fluoride		Used in ion exchange membranes (IEMs) that provide mechanical and chemical stability while delivering high proton conductivity. It separates anode and cathode, but facilitates the transport of hydrogen-ions from the anode to the cathode side

Coatings and finishes

Various stakeholders provided input on the volumes of polymeric PFASs used for coatings and finishes. The information is summarised in Table A.44.

Table A.44. Polymeric PFASs volumes used in coatings and finishes according to stakeholder information.

Polymeric PFASs (if specified)	Range (t/y)	Specific application (if provided)
PTFE	100 – 1 000	Interior coating systems for public transportation vehicles
PTFE	100 – 1 000	production of PTFE lined hoses
PTFE	100 – 1 000	Production of braking hoses
PTFE	10 - 100	Production of hoses for hydraulic fluids and fuel for aircrafts

A.3.11.3. Summary

Because of the vast range of properties, PFASs are widely used in the transport sector. PFASs are used in body-, hull and fuselage construction; sealing applications and lubricants; fuel engine systems; hydraulic fluids; electrical engineering and information technology; coatings and finishes; HVACR-systems and lifesaving and fire protection. Stakeholders estimate a stock of polymeric PFASs in the automotive subsector of 100 000 t (rounded number) and an annual volume of between 6 000 and 14 500 t (rounded numbers). The main fluoropolymers used are PTFE, PVDF, FEP and fluoroelastomers. For the other subsectors (besides automotive), nor for PFAA, PFAA precursors and side-chain polymers estimates could be made. Volumes of PFASs in HVACR systems amount to 12 000 t/y (rounded number) in newly manufactured vehicles and 1 000 t/y (rounded number) filled into newly manufactured products for transport refrigeration.

A.3.12. Electronics and semiconductors

A.3.12.1. Uses

Glüge et al. (2020) identified uses of PFASs in the electronics industry and listed the main properties of PFAS. Uses and properties were confirmed by a stakeholder and additions were made by this stakeholder. Also, literature and publicly available sources were consulted. roperties of PFASs relevant to the electronics industry and those that are relevant specifically to the semiconductor industry are included in Table A.45, whereas an overview of uses in products and components, is provided in Table A.46.

Table A.45. PFAS properties relevant to the electronics and semiconductor industry – Literature and publicly available sources, complemented by a stakeholder.

Industry	Identified properties
Electronics	Non-reactive, stable, low surface tension, non-sticking, high purity, low dielectric constant, low off-gassing, ensuring vacuum environment, low dissipation factor, ultra- thin, resistant to oil, resistant to water, resistant to sulphur, high volume/surface resistivity, high dielectric breakdown strength, piezoelectric and pyroelectric properties, dipoles, hydrophobic, good solubility in polymers, optically clear, low loss insulation, flame resistance, thermal stability, low refractive indices, good heat conductivity, good evaporative cooling, acidic, insulation.
Semiconductor	Heat resistance, low dielectric constant, clearness, plasma resistance, high photosensitivity, ability to generate acids, low surface tension, Marangoni effect, low refractive index, acidic, non-reactive, stable, non-corrosive, temperature uniformity, generation for reactive oxygen/fluoride species, chemical resistance, high purity, anti-adhesion, insulation, barrier properties, thermal stability.

Table A.46. Uses in electronic products and components (including semiconductors) – Literature and publicly available sources, complemented by a stakeholder.

Product / component	Used as/for
Wires and cables	Insulator
Printed Circuit Boards	Fibre reinforced layer, coating
Flat panel displays	Reduce static electricity build-up, reduce dust attraction
Multilayer circuit board	Bonding ply composition
Capacitators	Separation of high voltage components
Polymer optical fibres	Transparency, flexibility, low refractive index
LCD	Provide liquid crystal with dipole moment, moisture sensitive coating
Tactile sensor	
Gauge wire	
Audio transducers	
Piezoelectric panels	
Electroluminescent lamps	Coating
Razors	Friction reduction
Acoustical equipment	Provide electrical signal
5 G communication equipment	
Semiconductor, photoresist matrix	Change solubility when exposed to light
Semiconductor, wafers	Wafer thinning, non-stick coating on carrier wafer
Semiconductor	Antireflective coating

PFASs are not only used in electronic products and components to enhance their functionality, but also in the production process of those products or components. Here, the latter is divided into two use categories: process chemicals (e.g. solvent, grease, deposition fluid) and production tools/equipment that are used in the process (e.g. valves, containers, tubes). Table A.47 provides an overview of the uses in the production process that were identified by Glüge et al. (2020). The information was checked and complemented by a stakeholder.

Table A.47. Uses of PFASs in the production process of electronics and semiconductor products and components. Complemented by a stakeholder.

Used as / for	**Specification**	**Industry**	
		Electronics	**Semiconductor**
Testing fluid	Wafer testing, electronics testing	X	X
Heat transfer fluid	Submersion cooling, chemical vapour deposition	X	X
Solvent	Cleaning, deposition of lubricants, ultra clean seals and damping material	X	X
Additive	Additive to lubricants	X	
Cleaning	Drying, etch cleaning, remove cured epoxy resins, remove dielectric film build up	X	X
Sealing	Technical equipment in contact with chemicals or reactive plasma		X
Carrier fluid	Dissolve lubricants. See also A.3.15	X	
Fluid for lubricant deposition	See also A.3.15	X	
Etching	Etching of piezoelectric ceramic filters, wetting agent, reduce reflection of etching solution, dry etching	X	
Quenching	Controlling diffusion of acid		X
Rinsing	Removing developer		X
Developing	Control of development process		X
Working fluid			X
Photosensitizer	Increase Photosensitivity		X
Photo acid generator	Generate strong acids		X
Ultra-pure chemical	Ultra-pure environment, submersion in process chemicals		X
Technical equipment for handling, storage and transport	Ultra-pure environment		X

In Table A.48, an overview of the identified uses and properties of PFASs in the electronics industry (excluding semiconductors) is provided based on input from stakeholders. In general, the information received varied in level of detail pertaining to substance, sub-uses, application(s) and sectors. For instance, not all substances were associated with a use or function, stakeholders sometimes listed properties of each PFAS without specifying details in application etc. Due to limited information, use categories are roughly split between electronic products and components and uses in the production process of those products or components.

Table A.48. Uses and properties of PFASs in the electronics industry identified by stakeholders.

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFASs
Wires and cables	Heating cables, coaxial cable	• Precise and constant transmission • Stable insulation under high temperature conditions • Moldability • Low particulation • UV-resistance • Chemical/radiative resistance at elevated temperatures • Dielectric and thermal properties • Resistance to corrosion • Water and oil resistant • Stress crack resistance longevity/durability • Flex life • Light weight • Low density • Fire retardancy Low mechanical friction	Insulated wires and cables in electrical, energy and semiconductor applications (this includes data cable/5G, LAN cables, automotive parts, medical, sub-sea, aerospace, clean room production etc).	PTFE, PFA, ETFE, FEP, FEPM, PFPE
Coating of electronic components	Membranes	• Hydrophobic/oleophobic coating, can also act as gas barrier so some electronic components can be in proximity to corrosive gases, • Adhesion to copper • Anti-adhesive • Excellent dielectric performance for low signal loss • High water- and oil- repellence to provide protective coating • Antireflective • Low surface tension	Printed circuit boards, switches, connectors, relays, resistors, capacitors, transformers, inductors, integrated circuits, display device, small motors and bearings present in electronic devices like PCs, automobile, game machine, various home applications, mechanical equipment. Touch screen coating and various electronics also in smart phones. Feedstock for plasma polymerization coatings of electronic components and devices to provide a protective nanolayer. Micro Electro-Mechanical Systems, Conformal and anti-solder coating, copper clad laminates, hard disk.	PTFE, FEP and PFA, 2-(perfluorohexyl)ethyl acrylate, 2-(Difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro-propane, 1,1,1,2,2,3,3,4,4-Nonafluoro-4-methoxy-butane, PFHxA

Use category	**Sub-use**	**Properties**	**Area of use/application(s)**	**Examples of PFASs**
Electronic components	Vent filters	• Air permeability • Water pressure resistance • Liquid repellent • Heat-resistant • Durability • Chemical resistance • Weatherability • Dustproof characteristic	Vent filter for automobile electrical components such as Electronic Control Unit, battery box, motor control substrate case, lamps and power windows modules etc. Vent filters for home appliances such as electric toothbrushes and washable shavers	PTFE, Fluoropolymers
	Sound-permeable membrane	• Air permeability • Water pressure resistance • Liquid repellent • Acoustic characteristics	Sound-permeable membrane for mobile phones and digital cameras	PTFE
	Air filter	• Particle collection efficiency • Pressure loss • Durability • Repeated dust release characteristics • Filtration • Chemical resistance • Water resistant • Dustproof • Tensile strength	Air filter for vacuum cleaner/air purifier	PTFE
	Tactile switch components	• Heat-resistant • Tensile strength • Durability		PTFE
	Printed circuit boards	• Dielectric performance, • Low signal loss, • Adhesion to copper and laminate • Thermal resistance • Heat conductivity • Electrical insulation • Oil/water repellent • Low refractive index • Chemical resistance • Mold release	Blended into the matrix to reduce signal losses in new 5G and higher speeds,	PFA

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFASs
	Antennas and membranes	• Reduction of dielectric loses • Prevention of signal losses • Water repellent • Surface tension • Contact angle	Mobile phones	PTFE, PFA
	Liquid crystal displays (LCD)	• Strong dipole • No surface activity • Antistatic • Conductivity	Displays for computer monitors, TV's, control units (medical device, cars), laptops, smart phones and tablets. Surface protection.	Non polymeric PFASs, PFHxA.
	Organic light-emitting diode (OLED)	-	Displays and lights for consumers (smart phones, tablet, TV, monitor)	Non-polymeric PFASs , PFHxA.
	Optical fibres (Polymer optical fibre)	• Low signal loss, • Integration friendly • Transmittance/low signal loss property	Core and cladding. Transmission media in-vehicle data communication systems, to achieve safe driving or auto-pilot system (Advanced Driver Assistance Systems, ADAS, and self-driving cars)	F-PMMA
	Rod lenses	-	Small portable scanning printing equipment, including barcode readers	F-PMMA
	Others	• Flame retardant • Anti-fouling • Smoothness • Hydrophobic/oleophobic	Displays, touch screen, sensors, foldable smartphone, scintillator panels, high temperature film capacitors, potentiometers, copy machine, cable and fault locator.	PTFE
Unspecified		• Heat-resistant • Realisability • Dimensional stability • Tensile strength • Control and Influence of • Tribological properties • Flame retardancy • Wear protection • Melt behaviour	Unspecified	PFHxA, Fluoropolymers

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFASs
		• Antistatic/Antidust agent • Visual effect • Low Surface tension		
Anti-drip agent		-	In electrical enclosures, connectors, appliances, consumer electronics (mobiles, TV, laptops, computer hardware, building and construction parts/articles, automotive batteries, equipment housing, lighting etc.	PTFE, 1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene and tetrafluoroethene
Fire protection fluid		-	In electrical substation or electrical control rooms, data centres, telecommunications switch rooms, computer control rooms, airport control towers, clean rooms, and computer-controlled manufacturing operations.	1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone[a]
Heat transfer fluids			Heat transfer fluids for liquid immersion cooling	(Z)-1,1,1,4,4,4-Hexafluoro-2-buten[a], Butane, 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro-, 2,3,3,4,4-pentafluoro-5-methoxy-2,5-bis[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]tetrahydrofuran, Perfluamine, 1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone, 2-(Trifluoromethyl)-3-ethoxydodecafluorohexane, Reaction mass of 1,1,2,2,3,3,4,4,4-nonafluoro-N,N-bis(nonafluorobutyl)butan-1-amine and 1,1,2,2,3,3,4,4,4-nonafluoro-N-[1,1,2,3,3-hexafluoro-2-

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFASs
				(trifluoromethyl)propyl]-N-(1,1,2,2,3,3,4,4,4-nonafluorobutyl)butan-1-amine.
Sealing for electronic components		• Temperature and chemical resistance • Abrasion resistance • Oil resistance	Sealing for LCD, home appliance production equipment. Sealing for reducer of industrial robot for automation. Sealing for hard disk of servers	Fluorinated gases
Solvent		-	For a variety of materials, including lubricants, coatings, silicones, and in industrial cleaning formulations. Solvent to post process 3D printed articles	
Aerosol/ Solvent cleaning of electronics components		• Drying/rinsing agent • Optics cleaning • Particulate/ionic removal • Precision cleaning		Fluorinated gases[a] 2-(Difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro-propane, 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-(trifluoromethyl)pentane
Lubricant			Hard disk drives	PTFE, PFA, ETFE, PFPE, Tetrabutylphosphonium Perfluorobutylsulfonate
Lubricating oil[b]		• Chemical resistance • Heat resistance • Cleanliness	-	PFPEs and PCTFE base oils
Lubricant deposition[b]			Various electronic applications	(Z)-1,1,1,4,4,4-Hexafluoro-2-buten, Butane, 1,1,1,2,2,3,3,4,4-nonafluoro-4-methoxy-, Butane, 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro-

[a] Covered in section A.3.9 on fluorinated gases
[b] Covered in section A.3.15 on lubricants

In Table A.49, an overview of the identified uses of PFASs in the semiconductor industry is provided based on input from stakeholders. Uses identified in the semiconductor industry were primarily focused on semiconductor manufacturing and related equipment that is used to produce semiconductors. PFAS offer several essential functionalities including coating ability for making uniform and thin films on wafers, photo-imaging ability for printing electronic circuits, and durability to etchant for making electronic circuits.

Table A.49. Uses and properties of PFASs in the semiconductor industry identified by stakeholders.

Use category	Sub-use	Properties	Examples of PFAS
Semiconductor manufacturing			
Photolithography	Photoacid generators	• Strong electronegativity of F atom in the complex resist/chemical matrix allows for controlled generation of strong acid upon exposure to UV light	Fluorinated salts
Photolithography	Antireflection coatings	• Low dielectric constant • Low refractive index • Good thermal stability • Good barrier properties	Acrylate and methacrylate-based copolymers
Photolithography	Topcoats and Embedded Barrier Layers	• Hydrophobicity	Fluoropolymers
Photolithography	Surfactants	• Uniformity in coating with minimal effect on properties provided by other critical resist/chemical ingredients (i.e., without impact to refractive indexes)	Non-polymeric PFASs (non-ionic)
Photolithography	Filters	• Chemical resistance	Fluoropolymers
Nanoimprint Lithography		• Low surface adherence	Fluoropolymers
Plasma Etch and Wafer Cleaning		• Anisotropic etching capabilities	PFC, HFC and HFO gases
Wafer	Wet etch	• Wetting agents • Selective metal oxide removal	Fluorinated organic acids

Use category	**Sub-use**	**Properties**	**Examples of PFAS**
Vapour deposition chamber	Cleaning	• Provision of reactive fluoride to enable cleaning of surfaces	PFC, HFC and HFO gases
Heat Transfer Fluids		• High precision temperature control imparted by thermal stability • Viscosity vs temperature characteristics • Specific heat • Electrical conductivity characteristics	Hydrofluoroethers, perfluoropolyethers (including PFPMIE), and other fully fluorinated liquids (perfluorinated amines and perfluoroalkylmorpholines, PFPE, Butane, 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro-, 2,3,3,4,4-pentafluoro-5-methoxy-2,5-bis[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]tetrahydrofuran, Perfluamine, 1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone
Vacuum pump	Vacuum fluid	• Thermally stable • Non-flammable and insoluble in water, acids, bases and most organic solvents	Fluorocarbon ether polymers of polyhexafluoropropylene oxide,
Thermal Testing of Semiconductor Devices (in-line and end of line)		• High precision temperature control imparted by thermal stability • Viscosity vs temperature characteristics, • Specific heat and electrical conductivity characteristics	Hydrofluoroethers, perfluoropolyethers (including PFPMIE), and other fully fluorinated liquids (perfluorinated amines and perfluoroalkylmorpholines, Reaction mass of 1,1,2,2,3,3,4,4,4-nonafluoro-N,N-bis(nonafluorobutyl)butan-1-amine and 1,1,2,2,3,3,4,4,4-nonafluoro-N-[1,1,2,3,3-hexafluoro-2-(trifluoromethyl)propyl]-N-(1,1,2,2,3,3,4,4,4-nonafluorobutyl)butan-1-amine
Advanced Semiconductor Packaging	Encapsulants and Thermal Interface Materials	Temperature resistance Beneficial material flow Wetting, degassing and composite homogeneity	Fluoropolymers
Advanced Semiconductor Packaging	Flux	• High-temperature thermal stability (>160 C)	Surfactants
Advanced Semiconductor Packaging	Temporary Adhesives	• Solubility in organic solvents, low dielectric constants, and high	Fluorinated Tetracarboxylic acid anhydride derivatives, aromatic diamines, acrylate and methacrylate-based copolymers

Use category	Sub-use	Properties	Examples of PFAS
		thermal and thermo-oxidative stability	
Advanced Semiconductor Packaging:	Hydrophobic coating/hermetic seal packages	• Unique hydrophobicity	Fluoropolymers
Semiconductor Manufacturing Equipment & Infrastructure - Enabling Uses of Fluoropolymer Articles (polymer parts embedded within manufacturing equipment, spare parts and infrastructure, piping, tubing, gaskets, etc.)		• Chemical resistance • Low volatility/high stability • Thermal resistance • Cleanliness • UV resistance • Flame resistance	Fluoropolymers (i.e., teflon, viton, PTFE, PFA, FEP, ETFE, PVDF, FFKM, etc)
Release sheet for thermocompression bonding process of semiconductor chips		• Heat-resistant • Releasability • Flexibility • Tensile strength	PTFE
Data Centres - Immersion Cooling of Semiconductor Devices/Servers		• High precision temperature control imparted by thermal stability • Viscosity vs temperature characteristics • Specific heat and electrical conductivity characteristics • Non flammable • Material compatibility • Ease of IT hardware maintenance	Perfluoroalkanes, Hydrofluoroethers, perfluoropolyethers (including PFPMIE), fluoroketones and other fully fluorinated liquids (perfluorinated amines and perfluoroalkylmorpholines, 2,2,3,3,5,5,6,6-octafluoro-4-(trifluoromethyl)morpholine, Perfluamine, Reaction mass of 1,1,2,2,3,3,4,4,4-nonafluoro-N,N-bis(nonafluorobutyl)butan-1-amine and 1,1,2,2,3,3,4,4,4-nonafluoro-N-[1,1,2,3,3-hexafluoro-2-(trifluoromethyl)propyl]-N-(1,1,2,2,3,3,4,4,4-nonafluorobutyl)butan-1-amine, 2,2,3,3,5,5,6,6-octafluoro-4-(trifluoromethyl)morpholine, Methyl Perfluoropropyl Ether, 2-(Difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro-propane,

Use category	Sub-use	Properties	Examples of PFAS
			1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone.
Production, storage, usage of high-purity chemicals		• Chemical transportation	PVDF
Semiconductor Products and components			
Photoresist	Epoxy, case masking	• Resistance to fire, grease, stain, etc.	Fluorotelomer-related compounds
Plastics such as PC/ABS		• Flame retardancy	Perfluoroalkane sulfonic acids (PFSA), their salts and esters
Fluoroelastomers, polymers including polyimides, polyamides, polyesters, polycarbonate		• Cross linking agent for fluoroelastomers, monomer, high temperature composites and electronic materials	Bisphenol AF and its salts
Adhesive, coating, lubricant[a]		• Solvability	Perfluoroalkylethers

[a] Covered in section A.3.15 on lubricants.

Based on input from stakeholders and information from literature (Glüge et al., 2020), 163 PFASs were identified at being in use or used at some point in the electronics and semiconductor industry combined. Glüge et al., 2020 further identified 93 PFASs as being patented for use in the electronics and semiconductor industry and two PFASs as analytically detected.

Of the 163 PFASs identified at being in use or used at some point in the electronics and semiconductor industry, 48 are polymeric PFASs (18 fluoropolymers, 11 side-chain fluorinated polymers, 16 PFPE and three unknown), 114 are non-polymeric PFASs (42 ionic and 72 non-ionic of which 17 are fluorinated gases) and one is unknown.

A.3.12.2. Volumes

In Table A.50 and Table A.51, a summary is provided of the yearly use volumes in the electronics and semiconductor industries in the EEA in 2020, as provided by stakeholders.

The estimates are based on responses of 27 out of the 30 companies' active in the electronics/semiconductor industry; three companies did not provided quantities.

Table A.50. Estimated yearly PFASs use in the electronics and semiconductor industry in the EEA.

	C2- C3 (non-ionic) PFAS substances (t/y)		**PFAAs ≥C4 (t/y)**		**Side-chain fluorinated polymers (t/y)**		**Total PFAAs and PFAA precursors (t/y)**		**Total fluorinated gases (t/y)**		**Fluoro polymers (t/y)**		**PFPE (t/y)**		**Total polymeric PFASs (t/y)**		**Total PFASs (t/y)**	
	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	**low**	**high**
Total electronics and semiconductors	159	221	671	1 315	11	13	**841**	**1 549**	**140**	**140**	1 551	4 063	9	552	**1 560**	**4 615**	**2 541**	**6 304**

Table A.51. Estimated yearly PFASs use in the electronics and semiconductor industry in the EEA. (Midpoint used in impact assessment)

	C2- C3 (non-ionic) PFAS substances (t/y)	**PFAAs ≥C4 (t/y)**	**Side-chain fluorinated polymers (t/y)**	**Total PFAAs and PFAA precursors (t/y)**	**Total fluorinated gases (t/y)**	**Fluoro polymers (t/y)**	**PFPE (t/y)**	**Total polymeric PFASs (t/y)**	**Total PFASs (t/y)**
	midpoint	midpoint	midpoint	midpoint	midpoint	midpoint	midpoint	midpoint	**midpoint**
Total electronics and semi-conductors	190	993	12	**1 195**	**140**	2 807	281	**3 088**	**4 423**

According to stakeholders, approximately 65% of the PFASs used are polymeric PFASs. The semiconductors industry accounts for approximately 45% of the polymeric PFASs use and approximately 7% of the non-polymeric PFAS use.

Stakeholders indicate the use of an amount of 140 t of 12 different fluorinated gases. The Fluorinated gases are mostly used as a solvent cleaner. Between 400 and 840 t/y were reported to be used as intermediate.

The main polymeric PFASs used in the electronics and semiconductor industry are PTFE, PFA, PVDF, ETFE and FEP. FEP is highly used for Local Area network (LAN) cabling (fire resistance).

The main non-polymer ionic PFAS used in the electronics and semiconductor industry is perfluorobutanesulfonate (PFBS), a surfactant. The non-polymer non-ionic PFASs are mainly solvent cleaners and heat transfer fluids.

A.3.12.3. Summary

Because of the vast range of properties, PFASs are widely used in the electronics and semiconductors industry. PFASs are used in products and components to enhance their functionality and in the process to make those products and components. Stakeholders report an estimated annual use of between 2 500 and 6 300 t (rounded numbers). Approximately 65% of the PFASs used are fluoropolymers. The main fluoropolymers used are PTFE, PFA, PVDF, ETFE and FEP. The main non-polymeric ionic PFAS is perfluorobutanesulfonate (PFBS), a surfactant. Non-polymeric non-ionic PFASs are mainly used as solvent cleaners and heat transfer fluids. The semiconductor industry accounts for approximately 45% of the polymeric PFASs and approximately 7% of the non-polymeric PFASs.

A.3.13. Energy sector

A.3.13.1. Uses

Glüge et al. (2020) identified uses of PFAS in the energy industry and listed the main properties of PFASs. For this study, both the uses and properties were confirmed by a stakeholder and additional uses and properties were added. Also, literature and publicly available sources were consulted (JRC, 2018)[36]. PFASs properties are included in Table A.52.

Table A.52. PFAS properties relevant to the energy industry - literature and publicly available sources, complemented by a stakeholder.

Industry	Identified properties
Energy	Chemical/thermal resistance, ion transportation, high weatherability, high transparency, corrosion resistance, oleophobic, hydrophobic, low surface tension, stable, non-reactive, acid gas scrubber, heat absorption, conductivity, capacity to dissolve gases, bipolar, resistance to acids, and highly oxidizing species, wettability, heat conductivity, high dielectric strength, low global warming potential, forms no residue, dirt repellence, high vapour barrier, high transparency, particular and chemical filtration.

An overview of PFAS uses in the energy industry is provided in Table A.53.

Table A.53. PFASs uses in the energy industry – literature and publicly available sources, complemented by a stakeholder.

Energy facility/unit	Use as/for
Solar collector	Front and back sheet, adhesive
Photovoltaic cells	Adhesive to hold mesh cathode in place
Heat exchanger	Coating
Coal based power plant	Acid gas scrubber, separation of gases, filter
Nuclear power plant	Sealing for aggressive chemicals
Lithium batteries	Binder for electrodes, prevent thermal runaway reaction, oxygen transport, electrolyte, sealing
Vanadium redox batteries	Ion exchange membrane
Zinc batteries	Prevent formation of dendrites, hydrogen evolution and electrode corrosion due to adsorption to electrode
Alkaline batteries	Surfactant
Flow batteries	Membranes
Battery systems	Cooling
Fuel cells	Membranes, sealing, binding
Power transformers	Cooling liquid
Gas insulated equipment	Insulation
Electrical components	Testing Fluid
Electrical substations	Fire protection fluid
Unknown	Heat transfer fluid

In Table A.54, an overview of the identified uses and properties of PFASs in the energy industry is provided, based on input from stakeholders. In general, the information received varied in the level of detail pertaining to substance, sub-uses application(s) and sectors. For instance, not all substances were associated with a use or function, stakeholders sometimes

[36] https://www.engineeredfluids.com/post/are-pfas-the-next-pcbs, date of access: 2022-12-16.

listed properties of each PFAS without specifying details in application etc.

Table A.54. Identified uses and application of PFASs in the energy industry identified by stakeholders.

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFAS
Solar collector			Solar array bearings (for tracking systems)	PTFE
Photovoltaic cells	Film/coating Tape	Water repellency • Soil repellency • Thermal stability • Electric stability • Weather resistance (UV, humidity, temperatures) • Sand abrasion • Antifouling • Barrier properties • Light weight • Low flammability Extreme durability	Front and back sheets of PV modules (The PV back sheet is designed to protect the inner components of the module, specifically the photovoltaic cells and electrical components from external stresses as well as act as an electric insulator)	PVDF, ETFE, FEVE, PFPE
Wind energy	Film/coating and cables as well	• Durability Weatherability	Wind Blade Protection Coating (prevent moisture in the air from affecting curing process), Windmill towers[a,b]. Release film for wind turbines.	FEVE, ETFE, Perfluorobutane sulphonamide
	Lubricant		Used as lubricants/oils/greases for wind turbines[a,b]	PTFE
Coal based power plant	Heat exchanger tubing Filters	• High temperature resistance • Steam resistant • UV and chemical inert	Power plants	PTFE, Fluoropolymers

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFAS
		• Durability • High flexibility Particulate filtration		
Nuclear power plant	Infrastructure: Gasket material	Containing aggressive acid and alkaline media	Closed vessels	PTFE
PEM fuel cells	Membrane electrode assemblies (MEA); Gas Diffusion Layer (GDL)/Microporous layer, Gaskets, sealant.	• Hydrophobic agent (avoid flooding of the cell) • Binder • Electrical insulator • Conductor • Chemical resistant • Thermal resistant • Mechanical resistant Durability	Transportation (automotive, aviation etc.), zero-emission powertrains for cars and buses[c], backup power for critical systems and remote locations, portable generators and compact charging devices, Combined heat and power systems for homes and commercial buildings, mobile power systems for material handling equipment such as forklifts	PTFE
	Membrane electrode assemblies (MEA); membrane	• Best association of conductivity, chemical stability and mechanical strength Hydrophobic (PTFE backbone)	Separates protones and electrons and provides the proton conductivity (thereby producing electric current) while separating the reactants: hydrogen and air (oxygen), in the case of a fuel cell	Perfluoroalkane sulfonic acids (PFSA) or perfluoroalkylether sulfonic acids (PFAE) ionomers, PTFE
	Membrane electrode assemblies (MEA); Microporous layers (MPL)	Hydrophobic	MPL are placed inside an MEA to prevent water leakage, ensure insulation, and improve contact between GDL and the electrode	PTFE
	Sealant		Seal on MEA[b]	Fluoropolymers, fluoroelastomers
PEM electrolyser/PEM fuel cells	Sealing materials; gaskets	• Inert Chemical resistant	[b]	Fluoropolymers, fluoroelastomers

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFAS
PEM electrolyser				PFSA ionomer, PTFE
Lithium-ion batteries	Seals, electrode binders, separator films/coatings, electrolyte additives, thermal management pack/module	• Cooling Electric stability	Use to contain aggressive electrolytes	Fluoroelastomer, PVDF
Batteries	Battery fluid, Compounds for separator films, Binder		Rechargeable batteries	
Flow batteries	Ionomer membranes Ion exchange membrane	• Ionic resistance • Mechanical properties • Durability • Chemical stability • Corrosion resistance Thermal resistance	Rechargeable batteries Sealing for aggressive chemicals[b]	Fluoropolymers
Electro-lysis technologies (not PEM)	Equipment: gaskets, tubes, inline of pipes/tanks	• Stability • Durability • Mechanical compression Creep characteristics and chemical resistance	Alkaline water electrolysis (technology for large scale hydrogen production)	Polymeric PFASs: PTFE, FKM, PVDF, TFM (chemically modified PTFE), FEP, ECTFE, PFA, PFPE
Oil and gas appli-cation	Equipment: gaskets, tubes, inline of pipes/tanks. Wires and capacitors.	• Inert, • Hydrophobic • Chemical and temperature resistant • Corrosion protection barrier • High mechanical strength and resistance • Air permeability Flexibility/ ductility	[d]	

Use category	Sub-use	Properties	Area of use/application(s)	Examples of PFAS
Others	Switchgears High Voltage DC Converter Valves	• Chemical and temperature resistant • Dielectric properties Flame retardancy	Used as insulation gas in Medium & High Voltage Switchgear Power Transmission Technologies Used in conversion of electric power (AC to DC) due to their chemical and thermal properties. Used in polycarbonates.	Fluoropolymers; PTFE, PVDF. Non-polymeric PFASs; PFBS, C4-FN and C5-FK

[a] Covered in section A.3.14 on construction products
[b] Covered in section A.3.15 on lubricants
[c] Covered in section A.3.11 on transport
[d] Covered in section A.3.16 on petroleum and mining

Based on input from stakeholders and information from literature (Glüge et al., 2020), 40 PFASs were identified at being in use or used at some point in the energy industry. Glüge et al. (2020), further identified 13 PFASs as being patented for use in the energy industry and four PFASs as analytically detected.

Of the 40 PFASs identified as being in use or used at some point in the energy industry, 23 are polymeric PFASs (15 fluoropolymers, two side-chain polymers, five PFPE and one unknown) and 17 are non-polymeric PFASs (six ionic and 11 non-ionic of which one is a fluorinated gas).

A.3.13.2. Volumes

A summary of the use volumes in the energy industry in the EEA is presented in Table A.55 and Table A.56. The estimates are based on responses of 30 companies active in the energy industry. Based on data from the Urban mine platform on the volume of lithium-ion batteries (157 000 t/y) and estimations from stakeholders that the PFASs content (PTFE and PVDF) in batteries is around 1%, the volume of polymeric PFASs in batteries was estimated at 1 600 t/y. It should be noted that the lithium-ion battery data from the Urban Mine platform also contains data on batteries used in electric vehicles. No PFAS volume data is available for other types of batteries (e.g. flow batteries)[37].

[37] http://www.urbanmineplatform.eu/homepage, date of access: 2022-12-16.

Table A.55. Estimated yearly PFASs use in the energy sector in the EEA.

	C2- C3 (non-ionic) PFAS substances (t/y)		**PFAAs ≥C4 (t/y)**		**Side-chain fluorinated polymers (t/y)**		**Total PFAAs and PFAA precursors (t/y)**		**Fluoropolymers (t/y)**		**PFPE (t/y)**		**Total polymeric PFASs (t/y)**		**Total PFASs (t/y)**	
	low	high	low	high	low	high	low	high	low	high	low	high	low	high	**low**	**high**
Total	233	233	20	20	40	41	293	294	2 590	2 917	2	3	2 592	2920	**2 884**	**3 214**

Table A.56. Estimated yearly PFASs use in the energy sector in the EEA. (Midpoint used in impact assessment)

	C2- C3 (non-ionic) PFAS substances (t/y)	**PFAAs ≥C4 (t/y)**	**Side-chain fluorinated polymers (t/y)**	**Total PFAAs and PFAA precursors (t/y)**	**Fluoropolymers (t/y)**	**PFPE (t/y)**	**Total polymeric PFASs (t/y)**	**Total PFASs (t/y)**
	Midpoint	Midpoint	Midpoint	Midpoint	Midpoint	Midpoint	Midpoint	**Midpoint**
Total	233	20	41	294	2 754	3	2 756	**3 049**

According to stakeholders, the main polymeric PFASs used in the energy industry are PTFE, PFA and a PFSA-ionomer, which account for 65%, 14% and 5% of the total fluorinated polymer use, respectively.

A.3.13.3. Summary

Because of the vast range of properties, PFASs are widely used in the energy industry. Stakeholders report an estimated annual use of between 2 900 and 3 200 t (rounded numbers). Approximately 84% of the PFASs used are polymeric PFASs. The main fluoropolymers used are PTFE, PFA and a PFSA-ionomer, which account for 65%, 14% and 5% of the total fluoropolymer use respectively. Literature sources indicate an annual volume of PFASs (mainly PVDF and PTFE) in batteries of 1 600 t.

A.3.14. Construction products

A.3.14.1. Uses

PFASs have many uses in construction products and the building industry, including in architectural membranes and other roofing materials, wires and cables, paints and coatings/impregnations, sealants, adhesives, and more. They are applied because they have desirable technical functions such as wetting, weatherproofing, UV resistance, corrosion prevention, chemical and thermal resistance, friction reduction, durable, soil and water resistance.

Table A.57 provides identified use categories, sub-uses, technical function and examples of PFASs in building materials/construction products based on Glüge et al. (2020), Fernández et al. (2021), OECD (2022) and stakeholder input.

It should be noted that there are some overlaps between the use categories in Table A.57 – e.g. between the broad category coatings and paints and some more sector specific uses like the metal sector. It should also be noted that there are some overlaps between some use categories in the table and uses described in other sections of Annex A. The use category wires and cables are included in the table for the sake of completeness, as this category is in general handled in section A.3.12 (Electronics and semiconductors). The same goes for the foam blowing agents that is included in section A.3.9 (Applications of fluorinated gases).

Table A.57. Identified PFAS uses, technical function and examples of PFAS in building material/construction products based on literature and stakeholder input.

Use category	Sub-use(s)	Technical functions	Examples of PFASs
Roofing	Architectural membranes including fluoropolymer films (ETFE) and fabrics or fiber glass coated/laminated with fluoropolymers in e.g. stadium roofs, greenhouses, flexible solar panels	Durability, chemical and UV resistance, light weight, low maintenance, wetting during application of film	Fluorinated polymers e.g. PTFE, ETFE, FEP, PVDF Non-polymeric PFASs e.g. PBSF, HCFO-1233zd[1]
	Weatherproofing Membranes made of materials such as synthetic rubber, polyvinyl chloride (PVC), polyolefin, or other heavy-duty thermoplastics, and coated with a fluoropolymer layer. Used for e.g. flat-type roofs	Durability and stain resistance, moisture control and solar reflectivity	Fluoropolymers
Wires and cables	Electrical cable and wire insulation (in e.g. air conditioner units, computers, light fixtures and heated flooring), PTFE-impregnated plastic or a fiberglass-based tapes for electrical	Flexible, durable, temperature resistance	PTFE, PCTFE, ETFE, FEP, PVDF

Use category	Sub-use(s)	Technical functions	Examples of PFASs
	applications (e.g. to wrap bundles of wires), gasket hoses		
Skidways	Skidways for constructions	Low moisture absorption, strong weather resistance, chemical inertness, electrical and thermal insulation	PTFE
Construction bearings	Bridge bearings	Water repellence and low friction	Polymeric PFASs e.g. PTFE, PCTFE, ETFE, PVDF, FKM
Sealings and adhesives	Sealing of porous materials such as stone, grout, unglazed tile, and concrete in e.g. kitchen and bathroom tilework, and stone, tile or concrete flooring. Also used in exterior applications such as patios, staircases, foundations, and parking garages. PTFE tape (and liquid/paste pipe thread sealant) is also a type of sealing used to seal e.g. pipe connections	Create a smooth, water-resistant protective barrier that increases resistance to oil, water, stains, snow, ice, and graffiti	Polymeric PFASs e.g. PTFE and acrylate- and urethane -based side-chain fluorinated polymers Non-polymeric PFASs: e.g. fluorosurfactant
	Adhesives for e.g. tiles, flooring, drywall, ceiling, wood-related materials and molded structures. Tapes for structural glazing are also included as well as caulks to fill gaps and crevices, creating a water-proof seal in building facings, elevators and furniture	Increase the strength of the bond adhering materials together by increasing wettability and/or enhance the penetration into substrates	Polymeric PFASs e.g. fluoroelastomers Non-polymeric PFASs: fluorosurfactants
Household application	PTFE tape (also PTFE tape for professional applications like for drinking water, compressed air systems and installation of windows and doors)		PTFE
	DIY sealant and adhesive products as e.g. foam mounting tapes and squares, and damage-free hanging solutions for e.g.	For DIY sealant and adhesive, see sealants and adhesives above	Polymeric PFASs e.g. PTFE and acrylate-, urethane- and siloxane-based side-chain fluorinated polymers Non-polymeric PFASs:

Use category	Sub-use(s)	Technical functions	Examples of PFASs
	pictures		e.g. fluorosurfactant
Processing aids (PA)	For production of certain types of construction products (articles) The PAs is not part of the final product.	Specific uses confidential	Non-polymeric PFASs (surfactant or solvent)
Polymer processing additives (PPA)	Used as internal lubricant/additive/ polymeric processing aid in thermoplastics (e.g. PE and PP) thermo setting plastics and elastomers	Eliminate of melt fracture (shark-skin effect), improve wear and abrasion resistance, reduce coefficients of friction (COF), make surfaces easier to clean, increase melt tension and strength, and improve processability and mould release, reduce of die build-up, improve of the surface finish with high gloss levels, increase production start-up, reduce pressure, increase output at constant die pressure and temperature, lower energy consumption	Micro-powder PTFE, high-MW PTFE, PVDF, PFPE
Other polymer additives	Flame retardants (e.g. PFBS as additive to polycarbonate resins). High-MW PTFE additive as drip suppression of burning plastics. PFHxS-Li^+ as antistatic. Coating of plastics with fluoropolymers. Pigments	Flame retardant. Antidrip additive. Antistatic agent to prevent the buildup of static electricity and dissipate the electric charge formed on the substrate	Polymeric PFASs e.g. PTFE, High-MW PTFE, PVDF Non-polymeric PFASs: PFBS, PFHxS-Li^+, pigments
Foam blowing agents/additives	Foam insulation for e.g. polyurethane and other foam formulations	Reduce thermal conductivity	Fluorinated gases[1]
Wood sector	Wetting agent and sealers in coatings/paints/ varnishes/lacquers for wood substrate	Improve levelling and spreading and increase resistance to oil, water and stains	Polymeric PFASs e.g. acrylate-, urethane- and siloxane-based side-chain fluorinated polymers Non-polymeric PFAS: e.g. fluorosurfactants
	Resin/adhesive for particleboard/chipboard/ low-density fiberboard	Urea–formaldehyde adhesive resins: Improved cold-water swelling and internal bond strength	Non-polymeric PFASs: fluorosurfactants

Use category	Sub-use(s)	Technical functions	Examples of PFASs
Glass sector	Surface treatment/coating of glass building/construction materials such as windows, doors, and mirrors	Increase the durability of glass and limit the buildup of dust and debris on glass surfaces. Wetting agent during coating step	Polymeric PFASs e.g. PTFE, PCTFE Non-polymeric PFASs e.g. PBSF
Metal industry /sector	Coating/painting of metal (including coil coating). Exterior finishes for large buildings, bridges, and industrial structures, in addition to high touch metal surfaces such as elevators and sanitary fixtures. Metal entrances, doors, and door components (hinges, frames, latches, handles, locks, etc) may be coated with PFAS	Protects metal building products against weathering and staining and increases corrosion resistance. Coatings also used to increase the energy efficiency of metal roofs and exterior walls (by increasing reflectivity), to keep snow and ice from sticking to roofs and gutters and to aid in the penetration of coated roofing nails	Polymeric PFASs e.g. PTFE, FEP, PVDF, FEVE and silane/siloxane-based side-chain fluorinated polymers
Outdoor electrical energy components	Surface-protective films/coatings for wind turbine blades	Resistance to rain erosion of the blades. Weathering (UV and oxidation attacking resin in composite), abrasion and light impacts. Prevention of moisture in the air from affecting curing process.	Polymeric PFAS: FEVE, ETFE Non-polymeric PFASs: Perfluorobutane sulphonamides
	Surface coatings for solar panels of glass or ETFE	Resistance to weathering and rain, and also maintain a clean surface and reduce dirt build-up, which can block light and reduce conversion efficiency	Polymeric PFASs e.g. FEP fluoropolymer and silane/siloxane-based side-chain fluorinated polymers
Surface protection	Surface treatments of both absorbing and non-absorbing surfaces (e.g. glass, enamel, ceramics, metal, stone, concrete and linoleum, laminated plastic floor). Often sol-gel method is used for creating (polymerisation of) a nanometer thin film on the surface.	Make surfaces durable, soil and water resistant	Polymeric PFASs e.g. acrylate-, urethane- and silane/siloxane-based side-chain fluorinated polymers
Architectural coatings and paints	Coating of surfaces of bridges and buildings, including anti-graffiti coating	Corrosion resistance, thermal stability, flame resistance, weather resistance, UV durability	Polymeric PFAS: PTFE, PVDF, ECTFE, FEVE, FEP, PFPE & acrylate- and silane/siloxane-based side-chain fluorinated

Use category	Sub-use(s)	Technical functions	Examples of PFASs
			polymers
	Fluorinated additives in paints to achieve specific finishes and durability requirements on buildings and constructions	Wetting and levelling agents that lower surface tension for even flow and spread. Provide non-stick, dirt and stain resistant, oil- and water-repellent, and anti-corrosive properties. Binders that join ingredients together and/or help impregnate the substrate to decrease bubbling and peeling. De-aerator to decrease bubbling.	Polymeric PFASs e.g. PVDF, FEVE, ECTFE, PTFE, FEP, PFPEs Non-polymeric PFASs: surfactants, pigments

[1] HCFO-1233zd(E) is used as foam blowing agent in e.g. roofing. Fluorinated gases/foam blowing agents are covered in section A.3.9.

In Glüge et al. (2020), the following industries and use categories are considered to be relevant for the use of construction products within the building industry: building and construction, coatings, paints, and varnishes, production of plastic and rubber, plastic, rubber and resins, wood processing, treatment and coating of metals, pipes, pumps, fittings and liners, sealants and adhesives, stone, concrete and tile (treatment), wire and cable insulation, gaskets and hoses. Based on this, 76 PFASs were identified as (potentially) being in use or used at some point in construction products. Glüge et al. (2020) further identified 67 PFASs as being patented for use in construction products. Sub-uses that were clearly out of scope of being considered construction products (e.g. mold release agents in production of plastic and rubber that is covered in section A.3.15) was removed from the count.

Of the 76 PFASs identified at being in use or used at some point in construction products, 28 are polymeric PFASs (15 fluoropolymers, nine side-chain fluorinated polymers, three PFPEs, and one 'unknown'). 47 are non-polymeric (30 ionic and 15 non-ionic) and one substance is considered as 'unknown', as no information was available on its chemical identity.

Several substances are used across different use categories of building materials/construction products. This is also reflected in Table A.57, where e.g. PTFE is mentioned in almost all use categories.

A.3.14.2. Volumes

In Table A.58 the estimated annual volumes of PFASs in building materials/construction products uses in the EEA are given. The estimate for polymeric PFASs is based on input from stakeholders whereas the estimate for non-polymeric PFASs is based on the split between polymeric PFASs and non-polymeric PFASs in the categories 'building and construction' and coatings and paints' in Glüge et al. (2020). The reason for using this approach is that the input from stakeholders on the annual volume of non-polymeric PFASs is considered to be too low.

The total annual volumes of PFASs for the construction sector in table Table A.58 has the following caveats:

i) The data on polymeric PFASs provided by stakeholders likely does not cover all relevant users.
ii) The data provided on polymeric PFASs was, in some cases, not clearly split by uses, and it can't be excluded that it may include some double counting (when different supply chain stages report volumes for the same products).
iii) Where data has been provided as ranges, the upper bounds have been used to quantify a 'worst-case' scenario.
iv) Estimations of annual volumes of non-polymeric PFASs is partly based on Glüge et al. (2020). This approach has uncertainties but is used in lieu of better data. The volumes can't be split by uses.

Table A.58. Estimated PFASs volumes in building materials/construction products used in the EEA.

		Volume (t/y)		
		Range		Midpoint
PFAAs and PFAA precursors	**Side-chain fluorinated polymers**	13	40	27
	Non-polymeric PFASs	974	2 365	1 670
Polymeric PFASs*		4 254	10 320	7 287
Total PFASs		**5 241**	**12 725**	**8 983**

*Polymeric PFASs here only refers to fluoropolymers as no information on PFPEs was received

PTFE, ETFE and PVDF make-up 97% of the reported total usage of fluoropolymers in building materials/construction products. The remaining 3% covers a range of fluoropolymers including fluoroelastomers such as FKM, FFKM and THV.

Wood (2022) estimated the total quantity of fluoropolymers sold in the construction sector in the EEA in 2020 to be 4 500 t, which is similar to the lower end for fluoropolymers in Table A.58. It is, however, not clear if Wood (2022) included the same uses as is included Table A.57.

Stakeholders only provided input on acrylate-based side-chain fluorinated polymers which is different to Glüge et al. (2020), who also identified the use of urethane- and silane/siloxane-based side-chain fluorinated polymers. The volumes in Table A.58 for side-chain fluorinated polymers might therefore be an underestimation.

A.3.14.3. Summary

Because of the wide range of properties, PFASs are widely used in construction products. An annual PFASs use of between 5 000 and 13 000 t (rounded numbers) is estimated based on literature and numbers reported by stakeholders. Approximately 81% of the PFASs used are polymeric PFASs. The main fluoropolymers used are PTFE, ETFE and PVDF which account for 97% of the total fluoropolymer use.

A.3.15. Lubricants

A.3.15.1. Uses

Uses and properties of PFAS-based and PFAS containing lubricants were identified by stakeholders and in literature (Ebnesajjad S. & Morgan R (Eds.), 2019; Glüge et al., 2020; Rudnick, 2020).

Ebnesajjad S. & Morgan R (Eds.) (2019) separates lubricants into five categories, low viscosity lubricants, engine oils, greases, solid/dry-films, and release-agents. It should, however, be noted that the same commercial products are sometimes used as low viscosity, dry film, or release-agent lubricants.

An overview of PFAS seen in lubricants is given in Table A.103.

A.3.15.1.1. Low viscosity lubricants

According to Ebnesajjad S. & Morgan R (Eds.) (2019) the fluid phase for low viscosity lubricants is typically either mineral oil or synthetic oil. Low viscosity lubricants can be 100% base oil, but they often contain solid additives, such as e.g. micro-powder PTFE, graphite, molybdenum disulphide (MoS_2), tungsten disulphide (WS_2) or boron nitride (BN). Dispersants or wetting agents can be used to assure particle suspension. Besides this, other additives like rust inhibitors can be added. Fluorosilicone oils can also be used as base oils (Ebnesajjad S. & Morgan R (Eds.), 2019).

A.3.15.1.2. Engine oil

Engine oil is a low viscosity lubricant. The most common base oil in engine oil is mineral oil. However, synthetic base oil is occasionally also used (Somayaji, 2008). Micro-powder PTFE can/may be added as an anti-wear additive. However, the use of PTFE in engine oils is rather limited due to its inherent instability in oil, the risk of oil filter clogging, as well as difficulties with recycling (JRC, 2016). Engine oil is only mentioned here for the sake of completeness and will not be discussed further in this section on lubricants.

A.3.15.1.3. Grease

Grease is basically a base oil that contains a thickening agent to increase its viscosity. Greases are typically produced using mineral, synthetic or plant-derived oils. Thickening agents may be soaps or it can be a solid with a high surface area. According to Ebnesajjad S. & Morgan R (Eds.) (2019) micro-powder PTFE can be used as thickener/solid additive/fortifier alone or in combination with other thickeners, however, most greases based on mineral oils do not use fluoropolymers as thickeners. The use of PFASs as thickeners is more common for some synthetic oils (PFPEs, oligomer PCTFE, polyalphaolefin oils, fluorosililicone oils). When used alone, the PTFE level ranges from 20-40% and when used together with other thickeners the range is from 3-40% (Ebnesajjad S. & Morgan R (Eds.), 2019). Micro-powder PTFE is often used as thickener in PFPE-based greases. Silica, micro-powder PTFE and/or high-MW PCTFE is commonly used as thickener in PCTFE-based greases (base oil of oligomer/low-MW PCTFE) (Rudnick, 2020).

A.3.15.1.4. Solid/Dry films

Easy volatilisation of the liquid is usually important for these applications, therefore, the fluid phase for dry films can be oil but is more likely to be water, a very low-MW hydrocarbon, or a polar organic compound such as isopropanol or acetone, as these will evaporate before end use. After evaporation of the solvent, the solid additive (e.g. graphite or micro-powder PTFE) will be left as a dry film. Dry film lubricants may be applied multiple times (Ebnesajjad S. & Morgan R (Eds.), 2019).

A.3.15.1.5. Release-agents

Release-agents can be considered as a special case of dry film use. Release-agents are also known as anti-blocking agents, surface lubricants, parting agents, or slip-aids. They are used particularly in the manufacture or modification of (thermo)plastic and elastomer shapes, preventing sticking and build-up of resin on process equipment._ External lubricants are typically coated from liquid suspension or solution on a mould or contact surface by (aerosol)spraying or brushing. Most external release-agents must be applied multiple times as resin is processed. Internal lubricants/release-agents are incorporated into the resin before the forming or processing of the plastic or elastomeric part. Internal lubricants (release-agents/slip-agents) is therefore a type of processing aid (PA) (Ebnesajjad S. & Morgan R (Eds.), 2019). Internal lubricants are not considered a lubricant as such and is mentioned here for the sake of completeness.

As described above the most common PFASs in lubricants are polymeric PFASs like micro-powder PTFE (solid additive), PFPE (base oil) and PCTFE (base oil). According to Ebnesajjad S. & Morgan R (Eds.) (2019) other polymeric PFASs such as polyfluorosiloxane/fluorosilicone oils (base oils or additives), FEP and PAVE (additive) are occasionally also present in lubricants.

Non-polymeric PFASs such as dispersants/wetting agents in lubricants and solvents in lubricants and lubricant applications (e.g. cleaning before adding a lubricant) are sometimes also used.

A.3.15.1.6. PFPE, PCTFE and fluorosilicone base oils

PFPE, PCTFE and fluorosilicone oils can be used directly as lubricants, or they can be used as base oil for greases (Rudnick, 2020). PFPE are fluids known to be chemically inert, have low outgassing, are thermally stabile (service temperature range from approx. -80 ºC to approx. 350 ºC (depending on the type of PFPE)), are non-flammable and radiation resistant. The vapour pressure and volatility of the PFPE oils vary with average MW so that higher-viscosity (higher MW) oils generally have lower volatility losses (Rudnick, 2020). Commonly used thickening agents for PFPE-greases are finely divided silica, 'attapulgus clay', montmorillonite, ammeline, boron nitride, talc, calcium carbonate, zinc oxides, micro-powder PTFE and FEP (Rudnick, 2020). PFPE greases are especially used for applications that require performance over a significant temperature range and wherein oxygen-resistance is needed. For PFPE greases thickened with micro-powder PTFE, DuPont (Chemours) and Solvay make a point of saying that special grades of PTFE are used for the thickening (Ebnesajjad S. & Morgan R (Eds.), 2019).

PCTFE lubricants are known to have good lubricity, to be chemically inert to a high number of aggressive chemicals, be non-flammable, have low outgassing, be thermally stabile, radiation resistant, have high dielectric strength, high density and low compressibility (Rudnick, 2020). PCTFE-based greases (base oil of oligomer/low-MW PCTFE) thickened with silica, micro-powder PTFE and/or high-MW PCTFE is commercially available (Rudnick, 2020).

Fluorosilicone oils (polyfluorosiloxane oils) can resists oxidation, harsh chemicals, fuels, has a low evaporation and a wide service temperature range (-40 to 204 °C). Greases based on fluorosilicone oils can be thickened with amorphous fumed silica, PTFE and organics (Dow Corning, 2005).

A.3.15.1.7. Micro-powder PTFE as additive in lubricants

The extremely low coefficient of friction of (micro-powder) PTFE in combination with its good thermal stability makes it attractive as a solid lubricant additive. Micro-powder PTFE is compatible with PFPE and PCTFE. It is therefore used as additive in low viscosity lubricants based on PFPE and PCTFE and is also used as thickener and additive in PFPE, PCTFE and fluorosilicone greases. Micro-powder PTFE is also used as a solid additive in non-PFAS based low viscosity lubricants and greases as well in dry-film lubrication/external release-agents where the solvent can be PFASs or a non-PFASs.

Examples of uses of dry-film lubrication ((Ebnesajjad S. & Morgan R (Eds.), 2019) and input from stakeholders) include glass cloth for automotive (bushings for car door hinges, trunk lids, seats and wipers), electronics (bushings for office machines), hydraulics (cylindrical bushings for hydraulic machinery), industrial machinery (thrust washers for conveyor belts), food processing (industrial, retail or Quick Service Restaurants) and consumer use (bike chains and waterproof zippers).

A.3.15.1.8. Lubricant additives other than micro-powder PTFE

According to Ebnesajjad S. & Morgan R (Eds.) (2019) there are many types of low-MW PFASs (besides micro-powder PTFE) that may be used as additives for lubricants including fluorosurfactants and fluorinated or partially fluorinated alkanes, ethers, amines, esters, and metal salts of alkyl phosphates. The low-MW PFASs are typically used in specialised applications such as for recording media, hydraulic fluids, firearms, and conveyor chains but recent patents have also described their use in internal combustion engines. Perfluoropolyether and perfluoroalkyl phosphates, phosphonates, and salts thereof have been disclosed as lubricants for magnetic media lubrication. They were applied from solution in a hydrofluoroether solvent. Essentially the same compounds have been disclosed as corrosion inhibitors for perfluoropolyethers oils and grease (Rudnick, 2020).

A.3.15.1.9. PFAS-based solvents used in lubricants and lubricant applications

Various PFAS-based solvents (functional fluids) are applied in relation to lubrication. Based on input from stakeholders generally, these uses can be divided in:

- PFAS-based carrier and deposition solvent as part of a lubricant dispersion. According to industry, these processes take place in closed system where the evaporated solvent is captured, and VOC regulations complied with.
- Cleaning agents:
    - This can be for cleaning parts/articles to be lubricated (to avoid contamination of the lubricant), or

It can be for maintenance. Specific examples have been provided by an industry stakeholder referring to PFAS-based solvents: "*PFAS are essential for cleaners, which are used to clean switch cabinets or fuse boxes as well as transformers in power plants and wind power under voltage/high voltage. For equipment that cannot be shut down, there is no alternative. For large production facilities (e.g. automotive plants), cleaning can be performed with these products in full operation. The alternative is usually to stop the entire production line to perform the cleaning. The financial cost is very high.*"

Please note that these solvents used for cleaning are NOT part of the lubricants.

A.3.15.1.10. Properties of PFAS-based lubricants and specific properties

According to industry stakeholders, PFAS-based lubricants are used in situations where they are superior in terms of technical performance compared to other lubricants and/or where other types of lubricants would not be technically feasible. Temperature resilience, chemical inertness and a very low friction coefficient are often referred to as key aspects, but also other properties are illuded to. Below, the main properties referred to – alone or in combination are listed:

Temperature resilience. Use in outdoor environments (incl. aerospace, airplanes, offshore) and/or in equipment which can become very hot (e.g. ovens, heaters, corrugated paper machinery, steel mills and printers). The temperature resilience of fluorinated lubricants is a key property. E.g. lubricated bearings can be used in almost any application subject to high and/or low temperatures.

Use when chemical inertness is crucial, including production of oxidising/reactive chemicals (including acids and alkalis, aggressive gases such as ammonia or chlorine) and to prevent reaction with oxygen in other applications (preventing fire, self-ignition, and explosion). The latter includes e.g. breathing equipment in hospitals (e.g. moving parts in respirators, lubrication of cannulas, lubrication of artificial joints) and diving equipment. This property combined with pressure shock resistance is also important for some applications. Quote from an industry stakeholder: "*Only PFPE can achieve oxygen pressure shock resistance for greases/pastes beyond 30 bar. This is essential for valve manufacturers and oxygen processing industries, such as the steel industry or the medical sector.*" The 'slide-ability' is associated with the fact that PFPE lubricants have the highest film thickness of all base oils.

Related to the above, these lubricants are also resistant to radiation which is important in aerospace and nuclear power plant applications, and resistant to electric current, which is important in many electrical applications.

Further related to the above, the non-solubility in water is also of importance for avoiding the lubricant in interacting and possibly degrading following contact with water and moist.

Low vapour pressure preventing outgassing (e.g. one benefit is lifetime lubrication of some parts, rather than frequent re-lubrication of e.g. bearings or in fine instruments where maintenance is difficult). Low outgassing is also important for many vacuum pumps and combined with the inertness preventing degradation products, this is also key in clean-room production such as for wafers, semiconductors, and other high-tech equipment and for some aerospace applications. This is also considered vital for electrical contacts in many applications, optical instruments (e.g. cameras) and light housings where lubricant condensate needs to be minimized.

A very low friction coefficient which is in particular important in applications were rotating or sliding movements need lubrication. For micro-powder PTFE a stakeholder states: "*They also possess very low coefficients of friction, typically 0.01 for PTFE lubricant powders, allowing for excellent non-stick properties…*" NB! It shall be noted that PFASs are not applicable for 'high load'. Quote from an industry stakeholder: "*PTFE doesn't carry load very well (here molybdenum disulphide is the best - PTFE films rupture at 5 000 psi, whereas molybdenum disulphide films rupture at 500 000 psi), but PTFE is beneficial as a friction modifier in finished grease formulations.*" The very low friction coefficient combined with inertness and low outgassing is also crucial for many applications within electronics.

Noise and vibration reduction. The low friction coefficient will in turn reduce noise and vibrations and is e.g. in relation to the automotive industry pointed at as an additional benefit from the use of fluorinated lubricants.

Good chemical compatibility with metals, elastomers, and plastics/polymers of PFPEs. Combined with some of the above properties, PFAS-based lubricants are often applied to reduce friction between plastic parts e.g. in electronics, electromechanical applications, and in plastic gears.

"Less need for lubrication". In combination, the above properties are often referred to by industry when arguing that the need for maintenance and re-lubrication is low or not needed. This ageing stability in turn might lead to less environmental impact in terms of lower amount/ less resources needed and longer lifetime of equipment. This in turn also reduces the lifetime costs for maintenance. This aspect is also elaborated by Grechin et al. (2018), who furthermore elaborated how PFAS-based lubricants, even though more expensive than PFASs-free lubricants can lead to a lower total cost of ownership due to decreased operating/maintenance costs.

Olfactorily hardly noticeable. Combined with low vapour pressure/low outgassing this prevents odour in e.g. car applications where smell is no longer allowed. Alternatives to PFAS-based lubricants might result in emission of VOC, which is no longer allowed within the car industry. In combination with the above properties many industrial stakeholders refer to the low toxicity of PTFE and PFPEs as key issue in relation their approval for use in medical technology, food processing and drinking water applications. Many stakeholders highlight that in many applications it is the combination of specific tribological properties that make PFASs-based lubricants the preferred choice in high-performance applications.

Many stakeholders highlight that in many applications it is the combination of specific tribological properties that make PFASs-based lubricants the preferred choice in high-performance applications. Table A.59 below gives a non-exhaustive list of PFAS uses in lubricants, based on literature and information from stakeholders. The properties that are listed, are identified as most important by the stakeholders or presented in literature (Ebnesajjad S. & Morgan R (Eds.), 2019; Glüge et al., 2020; Rudnick, 2020).

Table A.59. Non-exhaustive list of PFASs uses in lubricants based on literature and information from stakeholders.

Branch / sector	Application	Properties	PFASs (and concentration examples provided by stakeholders)
Food sector	Chains and bearings (e.g. in ovens)	High temperature applications (e.g. ovens)	PFTE (90-99%; 30-70%) PFPE (60-75%; 30-70%)
	Lifetime lubrication in micro-amounts in closed parts. Moving mechanical parts, semi-closed. Lubricants and lubricant sprays for incidental food contact (NSF-H1[1][a]).	"Unique tribological function", chemical stability, temperature resilience	PTFE (1-10%) PFPE (80-90%)
	As a lubrication additive on the inside coating of metal food and beverages containers - it enables filling without damaging the coating.	'Slide-ability'	PTFE (2.5–100%)
Civil/ military aircrafts and aerospace	Combustion engines	High temperature	PTFE (5-50%)
	Hydraulic systems incl. control valves.	Anti-erosion, temperature resilience, chemical stability	Potassium decafluoro(pentafluoroethyl)cyclohexanesulphonate ('low concentration' in ppm range) 'PFAS' (another stakeholder refers to 'a PFAS' without further specification (50 ppm)
	Bearings	Thermo-oxidative stability, low vapour pressure, low flammability, chemically inert	PTFE (30-70%) PFPE (30–70%)
	Actuators of jet engines, and landing gears	Temperature, wear resistance, chemically inert, high-pressure stability, minimal oil bleed	PTFE (10-30%)

Branch / sector	**Application**	**Properties**	**PFASs (and concentration examples provided by stakeholders)**
	Engine starter spline shafts, hydraulic pumps splines and fuel pump splines in aircraft engines.	High/low temperature, low volatility	PFPE (grease)
	Brake and hydraulic fluids	High temperature	PFPE
	Bearings, gears and ball screws in electro-mechanical actuator. PFPE greases used due to wide operating window (-70 to 180 °C), low starting torque and anti-fretting properties.	High/low temperature	PFPE (grease)
	Couplings, valves, regulators and seals (PFPE greases) in oxygen systems in space and aviation applications.	Contact with reactive, corrosive or explosive liquids and gases (oxygen compatibility and long-time stability)	PFPE
	Moving parts of astronauts' pressure suits.	Non-flammability	PFPE (oil)
	Bearings of antenna arrays on spacecraft's	Minimise wear and does not migrate to other parts of the system.	PFPE (oil)
	Bearings that permit extension of the paddle arms supporting solar cells on spacecraft's	Minimise ware and does not migrate to other parts of the system.	PFPE (oil)
	Slide wire of potentiometers in spacecraft's	Minimise wear and does not migrate to other parts of the system.	PFPE (oil)
	O-ring lubrication in spacecraft's	Contact with reactive, corrosive or explosive liquids and gases (inertness to fuels and oxidants)	PFPE (oil & grease)
	Flotation fluids in gyroscopes in aircrafts and missiles	Damping/reducing frictional loss	PCTFE (oil)
	Hydraulic oil and heat transfer fluids for aircrafts	Non-flammable, high temperature	PCTFE (oil)
	Oxygen delivery system to spacecraft oxidizer tanks	Contact with reactive, corrosive or explosive liquids and gases	PCTFE (oil)
	Breathing systems in airplanes and submarines	Low outgassing, Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE
Military – defence application s	Various military lubrication functions (e.g. aircraft and electronics)	Not specified	PTFE
Automotive	Combustion engines	High temperature	PTFE (5-50%)

Branch / sector	Application	Properties	PFASs (and concentration examples provided by stakeholders)
	Friction reduction in various mechanical devices including automotive brake system components.	Low friction, chemical stability, compatibility with seals, noise reduction	PFPE (base oils) PFTE (lubricating aid and thickener)
	Bearings and throttle sensors	Temperature resistance, non-stick properties, good slide-ability	PTFE PFPE
	ESP systems in cars to measure turning speed of the wheels and many other applications.	Viscosity regulation, temperature resilience, water repellence, chemically resistant	PTFE
	Automotive Electrical Components and Auxiliary Components	Temperature resilience, chemical stability, arc-resistant, low vapour pressure/little outgassing	PTFE PFPE
	Mechanisms of the sliding of doors and windows	Temperature resilience	PTFE (10-30%)
	Mould release agents, assembly aids, grease for e.g. throttle sensors, bearings, moveable parts, seat rail, door hinge, switch actuation. NB! Unclear whether 'mould release' shall be seen a 'lubricant use'.	Non-stick, chemical stability, slide-ability, temperature, water repellence	PTFE (1-100%)
	Automotive interior. PFPE lubricants used to reduce noises, itch or judder where different materials come into contact. Lifetime lubrication.	Various	PFPE
	Window wiper motors, electronic waste gate actuators, O-rings in fuel connectors (combustion engines), intake manifolds shaft and seals, Exhaust gas recirculation (EGR) valves, overrun clutches, alternator bearings and water pumps. PFPE lubricants used for these applications due to high-temperature stability, chemical resistance and material compatibility.	High temperature	PFPE
		Several stakeholders refer to "Lifetime lubrication" of 'various car parts', which would otherwise need to be re-lubricated every year if more mainstream	

Branch / sector	**Application**	**Properties**	**PFASs (and concentration examples provided by stakeholders)**
		lubricants were used	
Trains	Valves in powertrains	High temperature resilience; chemical resistance	PTFE PFPE
	Train door lubrication	Temperature resilience	PTFE (10-30%)
Nuclear	Bearings in pumps	Resistance to degradation caused by radiation, no-sludge and gum formation	PFPE
	Laboratory glassware to prevent locking	Temperature reliance and chemical inertness	PTFE
	Bearings and other moving parts	Low friction	PTFE
	Critical bearings, manipulator greases for nuclear waste handling, fuel manufacturer equipment lubrication, compaction equipment lubrication for example.	Chemically inert, temperature resilience, low friction	Fluoropolymer (not further specified)
	Anti-galling thread lubricant for stainless steel assemblies	Contact with reactive, corrosive or explosive liquids and gases	PCTFE
	Lubricant for processing uranium hexafluoride	Resistance to degradation caused by radiation	PCTFE
	Oil for use in nuclear service	Hydrogen-free oil	PCTFE (oil)
	Lubrication of controls for nuclear applications		PCTFE (grease)
Watch-making	Lubricants and greases	Very high stability, extremely low pour point, anti-wear additives, excellent water demixion, extremely low surface tension, etc.	Polymeric PFASs + From C3 to C6 fluorinated chains (not further specified)
Hearing loss applications	Vacuum pumps and bearings during production. Note that it is not clear whether the PFASs as lubricant also plays a role in the final products.	Temperature resilience and low degradation/chemical stability, UV-resistance	PFPE PTFE
Electronics (including semi-conductor; see A.3.12)	Electric circuit breakers	Temperature resilience, chemical stability, arc-resistant, low vapour pressure/little outgassing	PTFE
	Semi-conductors manufacturing: Multiple uses, such as wafer handling mechanisms, vacuum grease,	Low friction	PFPE PTFE

Branch / sector	**Application**	**Properties**	**PFASs (and concentration examples provided by stakeholders)**
	linear guides of multibeam inspection stage, source mirror actuators, and several other bearing applications.		
	Working fluid and seals in vacuum pumps exposed to aggressive environment	Contact with reactive, corrosive or explosive liquids and gases	PFPE (oil)
	Emergency smoke ventilation fans in e.g. tunnels.	Temperature resilience (the fans need to function at 400 °C for 2h)	PFPE (grease)
	Grease for sliding contacts in electric switch and for pushbuttons	Non-oxidizable, non-flammable, lifetime lubrication	PFPE
	Rack and pinion disk drive lubricant	Temperature resilience	PFPE
	Spindle and actuator bearings in disk drives	Temperature resilience	PFPE
	Top coating lubricant on computer disc drives	Low outgassing	PFPE
	Vacuum pump oil for semi-conductor manufacturing equipment	Temperature resilience, low outgassing	PCTFE (oil)
	Vacuum pump oil for equipment used to plasma-desmear multilayer printed circuit boards	Temperature resilience, low outgassing	PCTFE (oil)
	Inert grease for semi-conductor processing equipment	Chemically inert	PCTFE (grease)
	Vacuum pump oil for equipment used to plasma clean electronics and medical devices	Temperature resilience, low outgassing	PCTFE (oil)
	Instrument fill fluids where strong oxidizing agents prelude the use of glycerine or silicon oil fill fluids e.g. Diaphragm seals, pressure gauges, manometers, dead weigh testers and sensors.	Chemical stability in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oil)
Laboratory supplies, equipment, and instrumentation	Diagnostically and optical equipment: Lubrication of moveable parts, for instance ball-bearings in various applications where parts need to be moved without friction	Low outgassing	PTFE PFPE
	Bearings, jewels, and pivots in many kinds of instruments	Not specified	PFPE

Branch / sector	Application	Properties	PFASs (and concentration examples provided by stakeholders)
	Optical instruments and light housings where lubricant condensate needs to be minimised.	Low outgassing	PFPE
	Wax coating to protect glass from attack by aggressive compounds	Chemical stability in contact with reactive, corrosive or explosive liquids and gases	PCTFE (grease/wax)
	Vacuum pump oil for mass spectrometers		PCTFE (oil)
Hospital equipment (see A.3.10)	Valves, fittings, O-rings, pressure gauges in oxygen enriched environments (ventilators)	Very low vapour pressure. Long-term stability and functionality.	PFPE/PFTE
	Medical injection device (Syringe, pumps, pens)	Low friction	Fluorocarbon gel (not further specified)
	Hospital (and home oxygen systems/units). Hyperbaric oxygen chambers. Anaesthesia machines. Nitrous oxide systems.	Life-supporting systems where an oxygen-enriched atmosphere (>23% O2) or high-pressure air is required	PCTFE (oils and greases)
Renewable energy (see A.3.13)	Wind power – lubrication of screws, nuts, magnetic anchors, bolts etc.	Low friction; very good wear-resistant and tribologically irreplaceable properties	PTFE (0.25–25%)
	Wind power (bearings)	High temperature resilience; chemical resistance	PTFE PFPE
	Fuel cell technology – assembly aid e.g. grease for O-rings	Excellent tribological properties, very good friction properties, eliminate noise, easy assembly	PTFE PFPE
	Energy storage and energy conversion via hydrogen such as PEM – bearings and as lubricant additive in plastics	Temperature, low outgassing (vacuum, applications)	Fluoropolymer (not further specified)
Off-shore/ Oil & gas (see A.3.16)	Lubrications of screws, nuts, magnetic anchors, bolts etc.	Low friction; very good wear-resistant and tribological properties	PTFE (0.25–25%)
	Casing/tubing sealants for high-definition threads in high chrome steel	Not specified	PTFE
	Bearings	Thermo-oxidative stability, low vapour pressure, low flammability, chemically inert	PTFE (30-70%) PFPE (30–70%)
	Sealing systems for centrifugal and rotary pumps	Chemically stable in contact with reactive, corrosive or explosive	PCTFE (oils)

Branch / sector	Application	Properties	PFASs (and concentration examples provided by stakeholders)
		liquids and gases	
	Anti-seize lubricant for drilling tools in hydrogen sulphide environments		PCTFE
	Alkylation lubricant (compatible with HF and sulphuric acids)		PCTFE
	Instrument fill fluid for oil exploration equipment		PCTFE
Chemical industry	Machinery for production of oxidising chemicals	PFASs-based lubricants do not react with oxygen and thereby lower/prevent the risk of fire, auto ignition and explosion compared to other types of lubricants	PTFE
	Bursting discs and gaskets for heat exchangers, synthesis units and reactors	Chemical inertness	PTFE
	Valves, fittings, couplings, O-rings and seals exposed to reactive and corrosive chemicals.	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PFPE
	Chlorine (and bromine) industry: Vacuum pump oils, compressor oil, valve and plug cock grease, lubrication for chlorine vaporiser, valve stem lubricant, assembly and repair of chlorine cylinder valves, tank car maintenance (valves), thread lubricant	Chemical resistance in aggressive environment	PCTFE (oils and greases)
	Sealing systems for centrifugal and rotary pumps. Sealing systems for rotary agitators and mixers in reactive chemical processes. Sealants for flange faces.	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oils)
	Lubricants for equipment used in the fluorination process for blow-moulding polyethylene bottles and gasoline tanks	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE
	Sulphur trioxide spill control mixture	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oil slurried with hollow glass beads)

Branch / sector	Application	Properties	PFASs (and concentration examples provided by stakeholders)
Bulk gas industry	Oxygen service - lubricants for remote control solenoid valves, thread lubricant, instrument fill fluid, rotary meter lubricant, diaphragm compressor oil, vacuum pump oils for evacuating oxygen cylinders and bulk (cryogenic) storage tanks, vacuum pump oils for oxygen plasma cleaning, bearing grease for liquid oxygen (LOX) pumps and lubricant for compressors in portable oxygen plants	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oils and greases)
	Welding gases - lubricants for bearings in LOX pumps and vacuum pump oils for evacuating oxygen cylinders	Low outgassing, Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oils)
	Helium service - oil for helium compressors and lubricants for helium regulators	Low outgassing, Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (Oils)
	Carbon dioxide pump oil	Low outgassing	PCTFE (Oils)
Metal-working industry (see A.3.5)	Cutting/drawing/forming oil for processing refractory metals such as tantalum, molybdenum, tungsten, rhenium, titanium and niobium		PCTFE
	Manufacture of woven wire and cable for safe use in aggressive applications	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE
	Additive to other cutting oils for enhanced tool life		PCTFE
	Machining of high nickel alloys		PCTFE
Steel industry (see A.3.5)	Grease for swivel joints in oxygen delivery systems and oxygen heating systems	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (grease)
Water and wastewater treatment	Wastewater chemicals - lubricants that are compatible with water treatment chemicals that are used in chlorinators, pumps valves etc.	PCTFE lubricants are compatible with e.g.: oxygen, ozone, hydrogen peroxide, chlorine, calcium hypochlorite, sodium hypochlorite and chlorinated cyanurates	PCTFE

Branch / sector	**Application**	**Properties**	**PFASs (and concentration examples provided by stakeholders)**
	Swimming pool chemicals - lubricants compatible with compacting equipment for tableting swimming pool chemicals	PCTFE lubricants are compatible with e.g.: calcium hypochlorite and chlorinated cyanurates	PCTFE
	Lubricant encased within peristaltic pumps which are used in applications of the potable water industry for chemical dosing	Chemical inertness	Not specified
Diving equipment	Diving Equipment with O_2 contact	PFAS-based lubricants do not react with oxygen and thereby lower/prevent the risk of fire, autoignition and explosion compared to other types of lubricants	PTFE
	Valves, fittings, O-rings, pressure gauges in oxygen enriched environments	Long-term stability and functionality are crucial	PFPE
	Diving gear	Life-supporting systems where an oxygen-enriched atmosphere (>23% O2) or high-pressure air is required	PCTFE (oil and grease)
Handicap assistant equipment (medical devices, see A.3.10)	Prosthesis, orthosis, wheelchair, exoskeleton etc.; piston and gear wheel applications; Lubricant additive in plastic components	Temperature resilience, chemically resistant, non-stick, not flammable, noise reduction	PTFE
Paper	Roller bearings of corrugated paper machinery	High temperature resilience	PTFE (3-100%) PFPE (3-100%)
	Lubrication processes in relation to pulp-bleaching chlorine, sodium chlorate, chlorine dioxide, oxygen and hydrogen peroxide.	Chemical compatible with chlorine, sodium chlorate, chlorine dioxide, oxygen and hydrogen peroxide	PCTFE
Plastics	Polymer processing industry (injection mould lubrication). Often micro-powder PTFE is added as lubrication/polymer processing additive to the polymer before processing (internal lubrication). Lubrication of ejector pins, sliders, folding units and sliding surfaces in plastic injection moulding tools (external lubrication).	Temperature resilience, low friction	PTFE (5-30%) PFPE (5-30%)

Branch / sector	Application	Properties	PFASs (and concentration examples provided by stakeholders)
	Lubrication on silicone cable accessories	PFPE is compatible with silicone	PFPE
	Bearings that support chains that runs through an oven. Plastic films are generally heat-treated in continuous ovens at high temperatures (>200 °C)	High temperature resilience	PFPE
Rubber/ tire industry	Lubrication of tire moulds to reduce galling, roughing or warping at movable joints.	High temperature resilience	PFPE (grease)
Textile (see A.3.3)	Bearings that support chains that runs through an oven. Textiles are generally heat-treated in continuous ovens at high temperatures (>200 °C).	High temperature resilience	PFPE
Pharma-ceutical industry	Clean room applications (including robots in clean room)	Low outgassing	PFPE
Consumer (see A.3.6)	Dry-film lubrication of bike chains		PTFE
	Dry-film lubrication of Waterproof zippers		PTFE
Other sectors and industrial applications not specifically mentioned above[b]	Chains, bearings/ball-bearings/sliding bearings, pivots, valves, and self-operated regulators	Various	PFTE PFPE Various PTFE and PFPE combinations
	Plain bearings for e.g. hinges, seat recliners, vibration dampers, chain tensioners, shock absorbers, pumps, ropeway suspensions, etc.		
	All kinds of industrial machines with moving parts		
	Valves		
	Dry lubrication for assembly of bolts, screws nuts and joints in general		
	Various 'oxygen service' applications, i.e., lubrication in systems with a high risk of contact with high oxygen concentration (e.g. when applying some types of pumps).		
	Mechanisms and devices under high vacuum		
	Offices machines, including heaters and printers		

Branch / sector	Application	Properties	PFASs (and concentration examples provided by stakeholders)
	Power tools		
	Lifts and escalators		

[a]"NSF-H1" is an approval system for food-grade lubricants.
[b] Agriculture, construction, fluid power, process industries, robots and robotics, 3D printing at industrial scale, power and energy distribution, district energy and building automation, metallurgy and mining, marine equipment, pulp and paper, machinery sector (e.g. snow blowers, lawn movers, gears and belts of conveyers)

A.3.15.1.11. Name and other identifiers of PFASs used in lubricants

Based on input from stakeholders and information from literature (Glüge et al., 2020) 38 PFASs was identified at being in use or used at some point in lubricant applications. Glüge et al. (2020) further identified three PFASs as being patented for use in lubricant applications.

Of the 38 PFASs identified at being in use or used at some point in lubricant applications 19 are polymeric PFASs (15 PFPEs, four fluoropolymers and one other), 18 are non-polymeric PFASs (15 non-ionic and three ionic) and one substance is considered as unknown, as no information was available on its chemical identity.

Six of the 15 identified PFPE are used as base oils in lubricants and two are used as additives. For the last seven identified PFPE, the properties in lubricants is not available.

Most of non-polymeric PFAS-based solvents identified are fluorinated liquids often called functional or engineered fluids. These substances are also mentioned in section A.3.9 and A.3.10.

In Table A.107 of the appendix examples of PFASs used in lubricant applications are provided.

A.3.15.2. Volumes

In Table A.60 the estimated annual volumes of PFASs in lubricant uses in the EEA is given. The estimates are primarily based on input from stakeholders.

Table A.60. Estimated PFASs volumes in lubricants used in the EEA in 2020.

PFAS use	Volume (t/y)		Comments
	Range	Midpoint	
Base oil	300 - 800	550	This covers only PFPE base oils as no information on the volume of other PFASs-based base oils like PCTFE and fluorosilicon oils was received.
Micro-powder PTFE additive	800 – 1 200	1 000	
Other additives than PTFE	1 - 10	6	
PFAS-based carrier and deposition solvents	35 - 75	55	
PFAS-based cleaning solvents	35 - 75	55	
Total PFASs	**1 171 – 2 160**	**1 666**	

Wood (2022) estimated the total quantity sold in the EEA of fluoropolymers used in lubricants to be 1 500 t in 2020 which is higher than for fluoropolymers (PTFE) in Table A.60.

According to information received from an industry stakeholder, between 1 000 and 5 000 t fluorinated lubricants are produces in the EU per year. Note that this volume includes other components than PFASs.

No data has been identified to quantify in any detail the share between formulation, import and export of lubricants containing PFASs, although one estimate is that about 90% of lubricants used in the EU are manufactured in the EU. This estimate has been challenged by stakeholders in the second stakeholder consultation based on the high PFPE manufacturing capacity in EU (Solvay Solexis (Italy)). A stakeholder also states that: "*In recent years, there has also been an uptick in the EU importation of PFPE base oils from emerging Chinese producers*".

Further it shall be noted that there is international trade in articles containing PFASs-based lubricants (in cars, pumps, bearings, etc.). No quantitative data on these trade aspects have identified or received.

A.3.15.3. Summary

Because of the wide range of properties, PFASs are widely used in lubricants, either as (part of) base oils (PFPEs and PCTFE), as micro-powder additive (PTFE), or in very low volumes as other additive (wide range of PFASs) or as a solvent. Stakeholders report an estimated annual PFASs use of between 1 200 and 2 200 t (rounded numbers). Approximately one third of the PFASs used are (part of) base oils and two thirds are micro-powder additives.

A.3.16. Petroleum and mining

A.3.16.1. Uses

Because of the vast range of properties PFASs are also used in the petroleum and mining industries. A summary for the general public was made available (NEA, 2021a).

First the uses of non-polymeric PFASs are described for both the petroleum and mining industry followed by the uses of polymeric PFASs.

A.3.16.1.1. Use of non-polymeric PFASs in petroleum industry

The uses of PFASs in the oil and gas industry, as discussed by Glüge et al. (2020), and defined according to the OSPAR0F[38] categorisation of chemicals used in the oil and gas sector, are the following:

- Drilling fluids: Fluorinated surfactants act as a foaming agent that initiates and extends the fractures in the formation. Stimulation chemicals: fluorinated surfactants have become more commonly used in enhanced oil and gas recovery (EOR) to support the displacement of the oil/gas from the underground sand and rock formations.
- Production chemicals: PFAS-based products are commonly used as anti-foaming agents.
- Water and gas tracers: PFAS-based tracers are used as water and gas tracers to map oil and gas reservoirs. They are considered low risk and can be detected at extremely low concentrations.
- Other uses: Evaporation of liquid fuels (e.g. gasoline) can be prevented by an aqueous surface film containing anionic surfactants, including PFAS-based chemicals (Glüge et al., 2020). The same properties may be exploited in the containment of gas and oil within transport of petroleum products. However, this has so far not been confirmed in active use in Europe. Oil spills on water can be contained and prevented from spreading by a chemical barrier consisting of a fluorinated surfactant (Glüge et al., 2020). Further minor use of PFAS as extraction solvents in analytical equipment for oil content analysis has been identified.
- EOR may be performed after production in a well has already been conducted for a while in order to support the displacement of the oil or making it easier to flow by altering its properties and thereby increase the production. Data collected during the consultation indicated minimal use of PFASs for enhanced oil/gas recovery stimulation products in Europe. There are no identified products currently on the market for this application.

A.3.16.1.2. Use of non-polymeric PFASs in mining industry

In the mining sector, PFASs (including both PFCA salts and PASF compounds) are reported to have been used, for example to increase the extraction efficiency in copper and gold mining. Based on the Glüge et al. (2020) review, the specific functions provided by PFAS in the mining sector include the following:

- Use as an acid mist suppressing agent in mineral recovery.
- Agents to increase wetting of the sulfuric acid or cyanide used to leach ore, enhancing the amount of metal recovery.
- Use as hydrocarbon foaming agent.
- Fluorinated surfactants used in ore floating to create stable aqueous foams to separate the metal salts from soil.
- Use in the recovery of metal salts from aqueous solutions.

[38] The Oslo and Paris convention for the Protection of the Marine Environment of the North-East Atlantic.

It is unclear to what extent these practices are currently required/utilised in Europe and hence if/which PFAS compounds are currently being used for these applications. It has been indicated, based on input by industry, that non-polymeric PFASs are not being used widely in the mining sector in Europe. However, no further input has been received to definitively confirm the level of ongoing use, and the specific application of PFASs in this sector.

A.3.16.1.3. Uses of fluoropolymers in the petroleum industry

A wide range of fluoropolymers such as fluoroplastics and fluoroelastomers are identified as being used in the oil and gas industry. The most common use for these materials in this sector is in the components of the equipment and piping used in extraction, transport and storage of petroleum resources.

Oil and gas transport and storage equipment

Pipes and tubes used in the production and transportation of oil are generally large and for economic reasons are typically manufactured from carbon steel rather than more expensive corrosion resistant alloy (Glüge et al., 2020). Lining the interior surface of oil well pipes with fluorocarbons, such as PTFE, can help to prevent or reduce oil-induced corrosion, caused by its acidic nature. Lining the exterior of offshore pipes also protects them from corrosion through sea water. Furthermore, fluoropolymers are used in leak proofness layers for flexible pipes conveying oil or gas and for elastic tubes for submersible pumps.

Fluoropolymers are widely used in the equipment and piping used in extraction machinery or infrastructure. Based on the input from industry (manufacturers, suppliers, and downstream users, through CfE responses and further consultation), the main uses for fluoropolymers include the production of the following components used in oil and gas extraction equipment. In Table A.61 a summary of uses in the petroleum industry is given.

Table A.61. Main PFASs uses in petroleum industry.

Examples of sub-uses of fluoropolymers in the petroleum industry	
• Lining of piping, flowmeters and fittings, compensator joints, fluid-handling components, process vessels, tanks, storage and transport containers	• Filtration equipment (e.g. HEPA filters - a synthetic composite with ‘expanded’ PTFE membrane)
• Flexible risers and flowlines	• Vibration dampers
• Liners in the high-pressure lines used in offshore choke and kill systems	• Packer elements
• Seals used in downhole drilling operations (e.g. flange sealing applications, wellhead and Christmas tree equipment)	• Pneumatic actuators, pneumatic regulating devices
• Valve bodies	• Blow-out preventors
• Valve packing	• Stators and “mud motors”
• Valve seals, elastic tubes	• Submersible pumps
• O-rings	• Pump liners
• Pipe gaskets	• Packaging vents – leaking and rupturing
• Capacitive sensors and their connecting cables	• Dispensers, nozzles, compressors
• Ball valves,	• Subsea hydraulic couplers
• Fluid transfer equipment	• Heat exchangers
• Flexible pipes	

The key functional property that makes fluoropolymers important in this sector is the extreme durability and capability of maintaining their form and mechanical strength and corrosion resistance under the extreme environments found in down hole drilling (e.g. high temperature, high pressure, presence of steam and harsh chemicals).

Fluoroelastomers have elastomeric properties resulting from crosslinking at molecular level. Fluoroelastomers are widely used to produce components (e.g. seals, liners, valves, O-rings, gaskets and packer elements). Other properties include e.g. rapid gas decompression resistance, extrusion resistance and resistance to compression fluids.

<u>Cables</u>

Polymeric PFASs are used in the cable insulation for communication cables in oil and gas drilling. For example, the resistance of several fluoropolymers to harsh chemicals and heat have allowed them to be used and marketed in numerous wire and cable applications in the onshore and offshore oil and gas sector, including electrical downhole cables, fibre optic downhole cables and hybrid electric/fibre cables. Cable insulation made from PFA, PVDF, FEP or ETFE can withstand extremely high temperatures near the bottom of the well.

A.3.16.1.4. Use of fluoropolymers in mining

There are indications of fluoropolymer use (fluoroplastics and fluoroelastomers) in the mining sector in Europe. However, very limited input from the mining industry was provided.

The key applications for which PFAS-based chemicals are used in the petroleum and mining industries are summarised in Table A.62. While it is expected that PFASs will be used in refineries of petroleum products, no data was available on current products, or their volumes of use in Europe in the CfE. It is not clear if refineries are covered by the use category of chemical processing where the use of PTFE gaskets for petroleum refineries (e.g. Philips alkylation process) has been noted.

Table A.62. Summary of polymeric PFASs used in the petroleum and mining industries.

Use	**Sub-use**[a]	**Property**
Petroleum exploration and production	Drilling fluid/production chemicals[b]	Fluorosurfactants and anti-foaming agents
	Stimulation chemicals	Enhanced oil/gas recovery stimulation products
	Water and gas tracers	Tracers used to map oilfields
	Other	Chemicals used in the storage or containment of oil and gas
		Fluoropolymer used in pipeline, valves, gaskets, O-rings, seals, cable and wiring insulation, flexible pipes
Mining applications[c]	Extraction of ores and minerals	Acid mist suppressing agent
		Wetting agents
		Hydrocarbon foaming agent (Flotation)
		Fluorinated surfactants used in ore floating (Flotation)
	Equipment	Fluoropolymer used in pipes, cables, hoses, conveyor belts, gaskets, bearings, membranes

[a] For petroleum extraction, as defined under the Harmonised Mandatory Control System under OSPAR Decision 2000/2. This does not apply to mining.

[b] Referred to as 'Chemicals used in the actual production and processing of hydrocarbons' under OSPAR

[c] Uses not covered under OSPAR Decision 2000/2.

A variety of PFASs (non-polymer PFASs, fluoropolymers) are used in petroleum and mining. Around 100 substances (with and without CAS numbers) are identified in this sector. The list of PFASs used in this sector is not provided here as it is partly reported in the Glüge et al. (2020) recent publication and partly due to Confidential Business Information.

A.3.16.2. Volumes

For the forward-looking trends (2020-2050), it is noted that petroleum production is expected to decline significantly in Europe over this period (Table A.63). It is, however, noted that the demand for PFAS-based tracer and anti-foaming agents and fluoropolymers is expected to increase in future years due to harsher conditions for future oil and gas exploration and production applications.

Table A.63. Baseline projections (including UK) for volumes of PFASs and fluoropolymers used (t/y) in the petroleum and mining sector.

	Compound	**Estimated volume of PFASs (t/y)**				
		1990	2000	2010	**2020 range**	**2020 midpoint**
Water and gas tracers	PFAS-based tracers	0.0	0.3	0.6	**1.0**	**1.0**
Production chemicals	Fluorosiloxane-based antifoaming agents	0.0	1.1 - 2.8	2.3 - 5.6	**3.4 - 8.5**	**6**
Fluoro-polymers (all)	-	2 000 - 4 300	2 500 - 5 400	3 000 - 6 400	**3 500 – 7 500**	**5 500**

A.3.16.2.1. Water and gas tracers

According to stakeholder information fluorinated alkanes are used as tracers in certain cases, depending on reservoir characteristics and the range of other tracers used. Industry input notes that such tracers are used sporadically in small (10-15 kg) quantities[39]. Additional data, provided by national authorities on the basis that the chemical identity of the tracers is confidential, demonstrates that other PFAS-based compounds are also used as tracers in the oil and gas sector in quantities at about 1.0 t/y. Hence, the volumes of PFAS-based tracers of confidential identity represent the main bulk (ca. 99%) of PFAS used for this application, and a total volume of use is estimated at 1.0 t/y.

A.3.16.2.2. Production chemicals

Information on the volumes of production and sales of fluorinated polysiloxane-based anti-foaming agent products in Europe has been provided by a small number of suppliers (two) as part of the CfE. In the absence of information of the current market share of hese suppliers, it has not been possible to produce an estimate for total levels of production and sales of these products on the European market. However, data has been provided from national authorities to allow an estimate of current total volumes of use in Europe is ~170 t/y.

[39] https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, date of access: 2022-12-16.

A.3.16.2.3. Stimulation chemicals

Very little information on specific oil/gas well stimulation products currently being marketed and sold in the EU has been obtained. Information on current production or use of these products in Europe was not divulged in any responses to the CfE. When manufacturers or suppliers were contacted in direct consultation they did not know if these products were currently being marketed or used. Therefore, to the best of knowledge of the Dossier Submitters the use of PFAS-based products for well stimulation is likely to be minimal in Europe.

A.3.16.2.4. Fluoropolymer applications

Based on stakeholder input from one supplier a very approximate estimate has been derived for the use of fluoropolymers in the sector at 3 500 to 7 500 t/y in 2020. Estimates for historic use volumes of fluoropolymers were developed with basis in the assumption that fluoropolymer use in 1950 was 0 and that the trend in levels of sale have grown with linear progression from 0 kg in 1950 up to present volumes in the 2020 baseline. Very little information on volumes of fluoropolymer products specific for petroleum and mining are available. However, in the consultation one stakeholder commented that the estimated volumes might be underestimated.

A.3.16.3. Summary

Because of the vast range of properties PFASs are widely used in the petroleum and mining industries. In petroleum exploration and production PFASs are used as e.g. drilling/fluid production chemicals, stimulation chemicals and water and gas tracers. A wide range of fluoropolymers are identified as being used in the oil and gas industry. The most common use is in the components of the equipment and piping used in extraction, transport and storage of petroleum resources. In mining, PFASs are applied for e.g. extraction of ores and minerals and in several equipment (e.g. in pipes, cables, hoses and membranes). A very approximate estimate has been derived from this assessment, suggesting the estimated total sales of fluoropolymers in Europe in 2020 for use in the petroleum and mining sector is 3 500 to 7 500 t/y.

A.3.17. Active substances in Plant Protection Products (PPP), Biocidal Products (BP) and Medicinal Products (MP)

A.3.17.1. Uses

Active substances in Plant Protection Products (PPP), Biocidal Products (BP), and Medicinal Products (MP) are considered being somewhat different chemically from other PFAS subgroups. Generally, these active substances are substances that are characterized by the presence of one or more CF_3-group(s) in their molecular structure[40], mostly aromatics. Introducing this group in the molecular structure of biologically active substances could alter specific properties, such as stability and lipophilicity.

A side effect of the introduction of the CF_3-groups in the molecular structure, is that metabolites and/or degradation products can be formed that are extremely stable and potentially hazardous. Trifluoroacetic acid (TFA) is one of the possible major metabolites/degradation products for these types of substances. TFA is extremely persistent in the environment.

In this chapter an overview is given of active substances in PPP, BP and active pharmaceutical ingredients (API) in MP, regulated in the EU by their respective regulations (Table A.64).

Table A.64. Active substances in PPP, BP and MP and their respective regulations.

Uses	Legislation
Active substances in plant protection products	Regulation (EC) No 1107/2009 (PPPR)
Active substances in biocidal products	Regulation (EU) No 528/2012 (BPR)
Active pharmaceutical ingredients (API) in human and veterinary medicinal products	Directive 2001/83/EC (human); Regulation (EC) 726/2004 (human and veterinary)

To provide an impression of the amount of PFAS used as active substances in MP, PPP or BP, a non-exhaustive overview of these substances is given in Table A.108 to Table A.110 in the Appendix:

- A search for PFAS within the scope of the current chemical definition yielded 48 hits for active substances in PPP (see Table A.108). Some of them are listed being active substances in PPP as well as in BP.
- A search on ECHA's webpage for EU biocidal active substances containing fluorine yielded nine biocidal active substances that fulfil the current PFAS definition. These substances are currently approved as biocidal active substances and include the product types PT18 (insecticides), PT08 (wood preservatives), PT14 (rodenticides), PT07 (film preservatives), PT09 (fibre, leather, rubber, polymer preservatives), PT10 (building material preservatives), and/or PT 21 (antifouling agents) (see Table A.109).
- A search for substances following current PFAS definition, yielded 65 medicinal products authorised in the EU. It is also indicated whether the medicinal product appears on the WHO essential medicines list. The anatomical/therapeutical group (assigned by WHO) and CAS no are added. The ATC is a drug classification system that classifies the active substances of medicinal products according to the organ or system on which they act and their therapeutic, pharmacological, and chemical properties (see Table A.110).

[40] Co-formulants present in PPP, BP, and MP may also be defined as PFAS. These substances are not covered here.

A.3.17.2. Volumes

These substances will be shortly mentioned, but no detailed information on volumes, emissions and alternatives will be collected and assessed since in Annex E the proposal is outlined to exempt these regulated substances from the restriction.

As indicated in Table A.65, a rough estimation of less than 5% of total PFASs is the already regulated PPP, BP and MP: 0.2% for active pharmaceutical ingredients in medicinal products and 2% for the active substances in plant protection products. No data was available on active substances in biocidal products.

Table A.65. PFAS numbers, used as active substances in PPP, BP, and MP.

Use	Amount EU	Details and assumptions
PFAS Active Pharmaceutical Ingredients (API) in human medicines	>500 t/y >0.2% compared to total PFAS	Human use numbers, prescribed medicines, numbers are extrapolated to EU based on number of inhabitants. At human use, the non-prescribed medicines (also known as over the counter (OTC) sold medicines) are not considered. This estimation is on human use only. Per- and polyfluorinated gases used in propellants are not included. When a substance is used as propellant it is not considered an API. Whereas when the same substance is used as an anaesthetic, it is considered an API.
PFAS Active Pharmaceutical Ingredients (API) in veterinary medicines		No information on volumes is available.
PFAS active substances in Plant Protection Products	5 479 t/y 2% compared to total PFAS	• Rough estimation based on ratio of PFAS PPP/total PPP in NL times total PPP in EU. o Total PPP in NL (2019) is 9 294 t/y (according to The Netherlands Food and Consumer Product Safety Authority (NVWA)) o PFAS PPP in NL (2019) is 152 t/y (1.6% of total PPP in NL) (NVWA) o Total PPP in EU is 335 000 t/y (Eurostat)
PFAS active substances in Biocidal Products		No information on volumes is available.

A.3.17.3. Summary

PFASs used as active substances in PPP, BP and MP are generally characterized by the presence of one or more CF3-group(s) that have been introduced in their molecular structure to alter properties such as stability and lipophilicity. At least 48 active substances in PPP were identified as PFASs, 9 active substances in biocidal products in various PT groups and 65 active substances in medicinal products. However, these active substances were exempted from this assessment. Based on extrapolated data from the NL on use and prescribed medicines, volumes are estimated to be >500 t/y for API in human medicines and for active substances in PPP the volume was estimated to be 5 479 t/y. No data was available for BP and veterinary medicines.

A.3.18. Waste

A.3.18.1. Introduction

REACH does not cover substances, mixtures and articles when they enter the end-of-life stage and become waste. However, the methodology for the REACH identification of risks of a substance for the environment and human health should take the waste stage into consideration (ECHA, 2010).

Waste stage is the end-of-life stage. There will be delay between production and waste stage: Products put on the market will, depending on the substance/mixture/article lifetime, enter the waste stage (far) later. Applications with longer lifetimes i.e., passenger cars or construction material might have highly deviating waste quantities compared to production volumes in the same year. Also, EEA import/export disbalances might lead to deviating waste tonnages compared to production tonnages.

For destruction or recovery of fluorinated gases (partly) specific regulations exists and it must be reported to EU as part of the F-gas regulation (UBA, 2021). When prices rise, recovery and reclamation become more important. Generally, waste streams for small residential appliances such as small air conditioning units, differs from the end-of life treatment for large commercial and industrial systems: For the smaller appliances collection, storage and treatment is organized under WEEE regulation. For the larger systems certified technical personnel is needed for the mandatory recovery of the Fluorinated gases according to the F-gas Regulation.

Specific regulation does not exist for PFASs other than F-gases/fluorinated gases.

In this section an overview of waste collection and waste treatment is provided. Objects or substances that have become waste are not within the scope of REACH. However, PFASs in waste are important for the identification of risks of a substance for human health and the environment. The information in this section is based on information from the individual studies (volumes) in A.3.3 to A.3.17.

To identify waste streams that contribute most to human and environmental exposure the following factors are of relevance:

- Waste streams with high volumes in the EU/EEA
- Waste streams with high average PFAS concentration or freight.
- Waste streams with high recycling rates.
- Waste streams with high releases into the environment (landfilling, land application, recycling).

A.3.18.2. Fate of waste from use sectors

The following four use sectors of PFASs were therefore studied in more detail:

1. TULAC (textiles solely)
2. Food contact material and packaging (paper & board solely)
3. Electrical and electronic equipment (WEEE)
4. Transport: End-of-life-vehicles (ELV)

Other uses also reach the end-of-life stage. For some uses the solid waste stage is less relevant i.e. because of most emissions are expected during use. See Table A.66 and Table A.67 below. This applies for ski wax, consumer mixture, metal plating and cosmetics for instance. The latter two will have emissions but mostly directly via water to WWTP. Uses, other than the 4 mentioned above, are not elaborated on in detail, but waste stage emissions in Annex B.9. will calculated using ERCs.

Table A.66. PFAS entering the solid waste stage. In light green the uses for which the waste stage is described in more detail because it is considered of higher relevance.

PFAS use	Polymeric PFASs	Fluorinated gases	PFAAs	Open application (low PFAS load entering waste stage)	Articles (high relevance for waste stage & recycling if ticked)
Lubricants	x		x	x	
TULAC	x		x		x
Food contact materials and packaging	x		x		x
Consumer mixtures			x	x	
Construction products	x		x		x
Cosmetics				x	
Metal plating	x			x	
Ski wax				x	
Transportation	x				x
Petroleum & Mining				x	
Medical applications	x	x	x	x	x
HVACR		x		x	x
Electronics, semiconductor	x	x	x		x
Energy	x		x		x

Table A.67. PFAS tonnages entering the solid waste stage (t/y in EEA).

Use	Tonnages enter solid waste stage (t/y)
TULAC	50 853
FCM & packaging	24.565
Manufacturing of metal products and metal plating	984
Consumer mixtures	**
Cosmetics	**
Ski wax	1
HVACR decommissioning	19 724
Medical devices	8 500
Transport	6 410
Electronics and semiconductors	3 752
Energy*	2 995
Construction products	6 495

Use	Tonnages enter solid waste stage (t/y)
Lubricants	1 447
Petroleum and mining	1
PPP, BP and MP	**

*: Waste from the energy sector is expected to sharply increase as many of the first windmills from 20-25 years ago are currently replaced. Amount of accruing blade material from stripping down wind turbines in Germany alone: 20 000 t/y. (Windmill blades are often coated with fluoropolymers). For solar panels the same is applicable: Sharply increasing waste volumes. (And solar panels front- and back sheet are often coated with fluoropolymers).
**: Waste stage emissions of lesser importance (use phase emissions of most importance).

Additionally, PFASs in sewage sludge were investigated as this is a potentially important indirect source for PFAS emission in the waste stage.

Finally common waste treatment methods, which are applicable for almost all PFAS uses, haven been studied: landfilling and incineration. Next to that also land application/composting and recycling have been studied. Emissions from waste treatment (waste collection emissions exempted because of lacking data) are mentioned in Annex B.9.

A.3.18.2.1. Waste collection

Waste is collected by private or municipal waste collection services. Via bins and containers waste is loaded on/into trucks and lorries and transported to pre-sorting/waste transfer stations or directly to final treatment such as landfilling or waste incinerators.

For PFAAs the production waste of PFAS manufacturers is of importance as was seen in the Netherlands where PFAA/PFASs polymerization aids were spread broadly via waste collection companies. For fluorinated gas appliances collection specific regulations exist as mentioned above.

For end-of-life fluoropolymer applications, commercial and industrial waste streams are the most relevant. A smaller proportion of fluoropolymers ends up in municipal waste. In Figure A.21 an overview of fluoropolymer waste is plotted based on data of PlasticsEurope (Conversio, 2022). The chemical industry, automotive, electronics & semiconductor and Medical & Pharma are the largest contributors to fluoropolymer waste in Europe (Table A.68).

Statistical gaps exist between officially collected waste and waste generated.

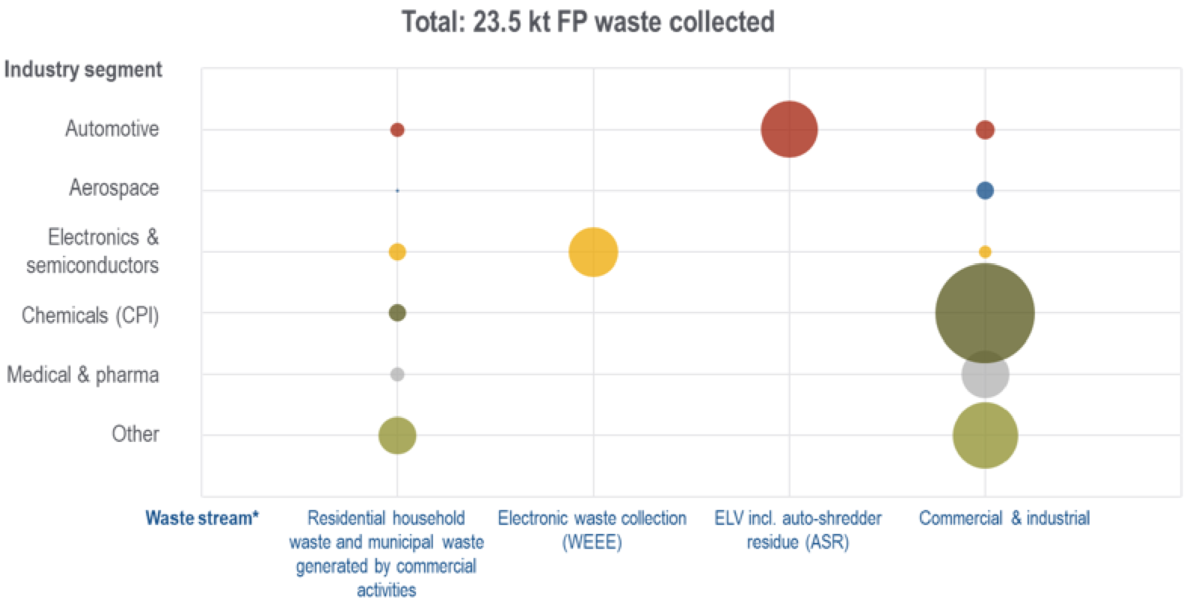


Figure A.21. Fluoropolymer waste collection in Europe (2020) and main sectors based on stakeholder information.

Table A.68. Collected fluoropolymer waste in Europe in 2020 per industry segment.

Industry segment	**Collected fluoropolymer waste in 2020 (in kt)**
Transport (automotive only)	3.5
Aerospace	0.3
Electronics & semiconductor	2.7
Medical & Parma	2.3
Chemical industry	9.4
Other	5.3
TOTAL	23.5

A.3.18.2.2. Textile waste

Watson et al. (2018) estimated that an average of 36% of textile is collected separately, in seven EU countries (DE, DK, FR, IT, NL, SE and UK, years assessed 2010-2016).

The overall amount of textile entering a specific waste treatment option cannot be determined precisely e.g. because of a lack of data on the share of textile waste in "Health care and biological wastes". A high share of textiles enters "Household and similar waste" (64% are not collected separately). Most of this waste category is incinerated (with or without energy recovery) or is disposed of in landfills. It is therefore assumed that the largest proportion of textile waste is treated accordingly. In line with this, it was stated by Boiten (2021) that 87% of the total fibre input in Europe is ultimately destined for landfill or incineration, with significant leakages into natural environments.

Generally, it must be noted, that apparel and other textiles which are reused can contribute to the global distribution of PFASs. Considering the average lifetime of textiles and apparel, it can be estimated that if a full ban of PFASs was to take place in 2025, PFAS concentration will still be present in waste streams until 2037 and beyond, dependent on the increase of recycling.

Export of second-hand textile outside EEA is likely also of relevance.

A.3.18.2.3. Waste from FCM – paper and board packaging

The yearly EEA quantity of PFAS used in paper and board packaging was estimated between 827 and 4 962 t, based on intentionally added PFASs (Hollins, N/A).

According to a stakeholder *"PTFE coated/printed materials need to be correctly collected, sorted and recycled. In recycling processes PTFE waxes should be removed before releasing washing water into the environment ".* As PTFE is persistent, it likely stays either in the recycled paper or aluminium and/or is released to water. Non polymeric PFASs are also likely to be present in lacquers and ink applied to (food contact) paper.

The average lifetime of food packaging can be assumed to be around one year based on information on plastic packaging (Conversio, 2018), but could be higher for other applications such as cupcake forms.

Depending on the food collection system in place within the country and sometimes the municipality, the collection of these items can differ. Food-contact articles and thermal paper, wet-proof and/or greaseproof impregnated and/or glued paper and cardboard[41] shall be disposed of in the residual waste in Germany (UBA, 2020c). Similar approaches are assumed for other European countries as paper for recycling must be kept separate from other waste as contaminated papers are not acceptable for recycling (EPRC, 2021).

The reality, however, can differ, and items can be and are partly disposed of via the separately collected paper waste.

Within Eurostat "Paper and cardboard waste" encompasses waste from paper and cardboard packaging (15 01 01) as well as paper and cardboard waste from mechanical treatment (19 12 01) and separately collected fractions (20 01 01) (EC, 2010). Considering the findings on the littering of plastic waste from UBA (2020b) it is not unlikely, that part of PFAS-containing paper and cardboard waste fractions are not accounted for in Eurostat waste data as they enter into the environment directly via littering.

Within Eurostat, the waste fraction "Household and similar waste" contains bulky waste (20 03 07) as well as street-cleaning residues (street-cleaning residues). Based on Eurostat data from 1990-2001 bulky waste presents a share of on average 8% of household and similar waste. This is based on data reported for 2000 and 2001 for several European countries (European Communities, 2003).

In the "Paper and Cardboard" waste stream all of the waste amount in EEA is treated by recovery through recycling (see Appendix), except a minor amount in Western Europe that is recorded under energy recovery (R1). Considering that FCM packaging end up in the paper and cardboard waste stream to a limited extent, it is likely, that a large share of FCM is either landfilled, incinerated or composted if it is disposed of as residual waste.

With regards to the fraction of paper in household waste (see Appendix), the Netherlands

[41] such as posters, coffee-to-go cups, fast food wrappers, baking paper, muffin forms as well as solid, empty paper packaging such as pizza cardboard packaging, varnished, glazed or chromo papers, and boards produce with plastic varnishes or films as well as papers with adhesives applications which cannot be easily separated such as sticky notes, self-adhesive seals for envelopes.

report around 20% of the paper in the household residual waste based on samples taken (Rijkswaterstaat, 2017). Germany states that around 5.2% of the residual household waste corresponds to waste paper, other European countries indicated shares of around 21 to 30% of the paper in residual waste (BMUV, 2020; Zero Waste Europe, 2020). Based on the calculated average, as no information on all EEA countries is available, an average share of paper and cardboard in the household/residual waste of 19% can be assumed.

Considering the average lifetime of FCM and especially paper and board packaging, it can be estimated that if a full ban of PFASs was to take place in 2025, PFAS concentrations will likely decrease within a few years depending however on paper recycling.

A.3.18.2.4. WEEE

The quantity of PFAS used in WEEE including the semiconductor and the energy industry is estimated with a midpoint of around 5 800 t/y. Substances regulated under the F-gas Regulation were not considered within this estimation.

With regards to exports, a study conducted by the Basel Coordination Centre for Africa (BCCC) and the United Nations University (UNU) found many incorrectly or completely undeclared WEEE exported to Nigeria during the research period (2015 to 2016). Appropriate disposal or recycling leading to the destruction of the PFAS content is not necessarily ensured in the importing countries. Thus, the disposal of WEEE in recipient countries may contribute to the global distribution of PFASs and thus to possible risks to human health and the environment.

The WEEE Directive currently does not contain any explicit provisions or requirements concerning PFASs. Furthermore, despite the applicable regulatory framework of the WEEE Directive, illegal or unsound treatment may take place, creating a risk of emissions of PFAS contained in WEEE into the environment.

Finally, while Regulation (EC) No 1013/2006 on shipments of waste prohibits the export of WEEE to non-OECD countries for recovery, recycling and disposal, illegal export can occur (Odeyingbo et al., 2018). WEEE which is illegally transported to non-OECD countries could in turn undergo unsound treatment methods leading to emissions of PFASs and risks to the environment in these countries.

In some cases, batteries will be treated together with the WEEE categories as batteries and accumulators are installed permanently. However, batteries must be removed under Article 12 (3) of the Batteries Directive (Directive 2006/66/EC)[42] which in practice applies to some applications (batteries in TV remotes). Data on the battery waste stream (alkaline, lead, Ni-Cd and other batteries) has been considered. No assumptions were made on the possible quantities of batteries within WEEE as information is lacking and batteries should be removed prior to treatment.

Especially lithium-ion batteries are used heavily and the growth due to electrification of transport is extreme. These batteries contain PVDF (a binder) in about 1-1.4%. In the end-of-life stage risks related to toxicity and toxic emissions of lithium-ion batteries become apparent and amplified. These emissions, including PFAS emissions, are of high risks since chemical transformation processes are not well understood. Incomplete combustion (temperatures <850 °C) of fluoropolymer cathode materials but also fluorinated ingredients in the electrolyte can lead to the formation of various persistent PFASs. Potential products of the thermolysis of fluoropolymer binder (often PVDF or FEP) are: Short and long chain perfluoroalkyl acids (PFAAs); and CF4 (Zackrisson and Schellenberger, 2020).

In the end-of-life stage the risks related to toxicity, fire and high voltage in the lithium-ion

[42] It is understood, that batteries and accumulators according to Article 12 should be removed but in some applications, removal is not practically possible (permanently installed batteries) as such these are assumed to be treated within the WEEE.

life cycle become apparent and amplified. Lithium-ion batteries are a green technology but contain different hazardous substances, that can be emitted especially during e.g. fire events. These emissions are of high risks since chemical transformation processes are not well understood so far.

Generally, the recycling and re-use of WEEE can contribute to the global distribution of PFASs, especially if they are sold as used equipment to developing countries without appropriate treatment capacities. The mechanism of extended producer responsibility (EPR) as laid down in the WEEE Directive additionally enables Member States to lay financial and/or organisational responsibility on producers of EEE concerning proper collection and treatment of WEEE. A recent report by the ECA (2021)indicated that currently only two Member States are on track to achieve the collection targets set for 2019 thereby putting the EU in danger of not meeting its ambitious targets for the collection of WEEE. It should also be noted that the WEEE Directive currently does not contain any explicit provisions or requirements concerning PFASs.

A.3.18.2.5. End-of-Life-Vehicles (ELV)

As cars have a long average lifespan, cars sold many years ago may enter the end-of-life stage today. Cars have an average lifetime of 17 up to 20 years (EC, 2019). As lower number of cars were sold 20 years ago, the PFAS load entering waste stage from end-of-life vehicles is lower than the PFAS tonnage (about 6 400 t) put on the market today. The PFAS load, especially the fluoropolymer share in ELVs (usually around 12 years old), is significantly lower compared to modern cars put on the market.

In 2019, almost 16 million cars were put on the market according to ACEA. The Heinrich Böll Foundation's European Mobility Atlas 2021 mentions that every year, around 12 million cars leave European roads. Using Eurostat data for 2019, around 6.9 million ELVs were statistically covered for EU27 + 1.6 million from the UK. This means that there are still large statistical gaps between the total number of ELV leaving the European roads and the number of ELVs officially collected.

The quantity of PFASs used in vehicles in the EU corresponds to between **6 000 and 14 500 t/y** (see also A.3.11.3). This tonnage will grow strongly as in modern (electric) cars more PFASs are used. Plastics Europe mentioned in their report on fluoropolymer industry in Europe, that transport, as one of their key sectors, has the highest shares of fluoropolymer sales in 2015 with 15 500 t (Wood, 2022). Within the U.S. transport is ranked as the second most important sector in terms of production value following electronics (Fluoropolymer Industry, 2018).

As most PFAS-applications in vehicles are textiles and polymer applications, the relevant fraction in which PFASs from ELV end up are non-ferrous materials from shredding also referred to as shredder heavy fraction (SHF) and the shredder light fraction (SLF). The SLF is a mixed fraction and includes, for example, textiles, foams, plastics and plastic films as well as broken glass, paint residues and wood (BDSV, 2012). Median values calculated based on several literature sources indicate that a share of about 74% of plastics ends in the SLF. Median values calculated for the SHF indicate a share of 4% of plastics (BKV, 2020; Martens, 2011; UBA, 2016; UBA, 2020a).

In the future, it is expected that the quantities of vehicles placed on the market will increase (Kuhnert et al., 2018). Next to that a shift to electric cars or hybrid electric cars is expected. In Germany, around 14% of all newly registered passenger cars in 2020 had an electrically powered engine (battery-electric, plug-in, fuel cell) (KBA, 2021). On the European market, the average share of new passenger plug-in electric cars lies at 11.4% in 2020 (Kane, 2021). For relevant waste streams, this means increasing quantities of SLF and SHF.

Améduri (2020) estimated an increase to 1 – 2 kg PFASs/car in the future. With regards to disposal, data do not indicate if this refers to incineration without energy recovery or simply landfilling. In several Member States, it is still allowed to dispose of SLF in landfills other countries require a pre-treatment of the SLF before landfilling (Mehlhart et al., 2018). Generally, neither the recycling process nor landfilling destroys the PFAS content within the relevant fractions. Both paths can contribute to the distribution of PFASs in the environment.

The Heinrich Böll Foundation’s European Mobility Atlas 2021 mentions that every year, around 12 million cars leave European roads due to total loss after an accident, economic write-off, non-compliance or a change in design preferences. Up to two thirds of vehicles leaving the European roads are handled in authorised recycling facilities. About one million cars are exported as used vehicles to non-EU countries. It is unclear how the other ca. 3 million cars are handled (Heinrich-Böll-Stiftung, 2021).

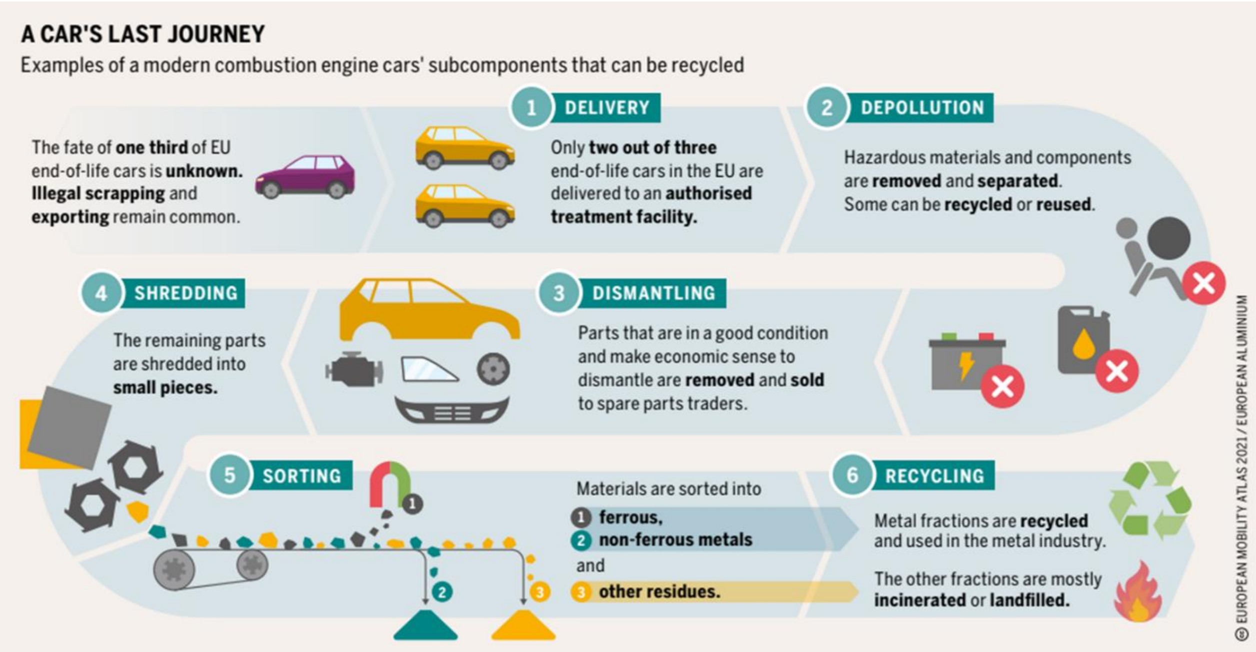


Figure A.22. A car's last journey. Source: European Mobility Atlas 2021.

A.3.18.2.6. Landfilling

A considerable part of the European waste is still being landfilled, but percentages vary a lot among the European member states (more landfilling in Central and Eastern Europe) as well as in time (declining landfilling share) (CMS, 2013). The percentages also vary among the different waste types.

Many modern landfills are equipped with a plastic liner capturing the leachate. However, this is not always the case for older landfills (Lang et al., 2017). In Europe the landfill directive (1999/31/EC) stipulates, that all newly constructed landfills need to be equipped with “a geological barrier and a bottom liner during the operational/active phase”, however it is unclear how many landfills in Europe are currently equipped with liners.

According to Eurostat 96% of the landfilled waste was non-hazardous waste with only 4% being hazardous, which is then deposited on the respective landfill. The exact number of landfills and landfill types is unknown, however according to Eurelco there are an estimated 500 000 (former) landfills in Europe with 90% preceding the EU-landfill directive 1999/31/EC. ECHA (2012) on the other hand provides default values for a landfill scenario stating that there are approximately (active) 8 400 landfills in Europe from which ~400 are for hazardous,

~5 000 for non-hazardous and ~3 000 for inert waste. The data is however from 2006 and should be used with caution. According to Eurelco is can be stated with reasonable safety tha Europe host more than 500 000 (f) landfills[43].

Landfills have more or less a symbiotic relationship with Waste Water Treatment Plants (WWTP) as landfills send leachate to WWTP and WWTP send sludge to landfills.

A.3.18.2.7. Incineration

According to the Fluorpolymer Group (a subgroup of Plastics Europe) more than 50% of the fluoropolymers in the market stays in use for many years. Overall ~23 kt of fluoropolymer waste was disposed of in 2017 according to the Fluoropolymer Group of PlasticsEurope

Incineration of PFAS containing waste is currently seen as the most effective treatment option for (party) destroying PFASs. The fluorine in the PFASs will end up in either the bottom/fly ash or the flue gas. Incineration has been used as a method of destroying other halogenated organic chemicals such as polychlorinated biphenyls (PCBs) and ozone-depleting substances (ODSs). High temperatures and long residence times break the carbon-halogen bond, after which the halogen can be scrubbed from the flue gas. PFAS compounds are however more difficult to break down due to fluorine's electronegativity.

The Confederation of European Waste-to-Energy Plants (CEWEP) reported 4 992 waste-to-energy (WtE) plants which treated a total of 96 million tonnes of waste thermally in 2019[44]. According to the waste incineration (WI) BREF there were 470 municipal solid waste incinerators in Europe in 2019 with a total capacity of 87.44 million t/y (JRC, 2019). The WI BREF reported 121 hazardous waste incinerators in Europe in 2019 with a total capacity of 6.75 million tonnes of waste per year, however the exact incineration conditions are unknown. Table A.69 summarises this information.

Table A.69. Summary of numbers and capacity of European waste incinerators.

Source	Number of non-hazardous incinerators	Number of hazardous waste incinerators	Capacity/incinerated waste [million t]
PRTR	472		
CEWEP	492		96
WI-BREF	470		87.44
WI-BREF		121	6.75

A.3.18.2.8. Recycling

Europe is striving to achieve a circular economy and to increase its circular material use rate. Products from recycled materials are only possible if substances of concern, such as PFASs, are avoided in products as much as possible. This is usually not the case in the typical recycling processes of the considered waste streams. Hence, PFASs are often maintained in the economic cycle and may pose an obstacle to produce safe products from recycled materials. Especially paper & board, plastic packaging and WEEE waste streams are relevant from a recycling perspective.

A.3.18.2.9. Sewage sludge from urban wastewater treatment

Sewage sludge is generated in WWTP by separating undissolved particles from water, which is done in lagoons or basins. As WWTP receives waters from urban and industrial sources

[43] https://eurelco.org/2018/09/30/data-launched-on-the-landfill-situation-in-the-eu-28/#:~:text=With%20a%20reasonable%20safety%20level,the%20Landfill%20Directive%20(1999), date of access: 2022-12-16.

[44] https://www.cewep.eu/waste-to-energy-plants-in-europe-in-2019/, date of access: 2022-12-20.

sludge can contain PFASs originating from the production and use phase of PFAS products (e.g. cosmetics).

The most recent data was used to calculate the amount of sewage sludge for the EEA. Moreover, it must be noted, that the data reported within Eurostat on production does not align with the volumes treated as waste, which was also found by Bianchini et al. (2016) who highlighted the structural lack of homogeneity and reliability on the Eurostat data on sewage sludge.

Generally, the total quantities fluctuate slightly but remain between 5.78 and 6.53 million tonnes per year since 2011. Within the EEA sewage sludge from urban wastewater treatment is disposed of or recovered (land application) in roughly equal proportions.

Bianchini et al. (2016) reported, that due to the Landfill Directive (1999/31/EC) amounts of sewage sludge disposed of in landfills will rapidly decrease in upcoming years as Member States reduce the amount of biodegradable waste sent to landfills by 2016.

In Eastern Europe, an increasingly larger percentage of households connected to treatment plants can be expected. Here, agricultural use of the sludge is still considered as the preferred disposal method. The reuse of biosolids as soil improver/fertilizer in arable crops represented the most used disposal/recovery option in some European countries. This has led to restrictions in the use of biosolids with Directive 86/278/EEC. However, an evaluation of the directive in 2014 has found shortcomings also with regards to contaminations such as PFASs. These are currently not regulated. Most countries in the EU have prohibited the use of untreated sludge on land, while some Member States (France, Ireland, and the UK) permit the use of untreated sludge (Collivignarelli et al., 2019). Currently, among the EU-27 countries France, Finland, Germany, Ireland, Italy and Spain have the highest share of biosolids recycled to land.

The sewage sludge mass flow (Appendix) indicates that a possible yearly total of 0.27 t of PFASs are not destroyed within the EEA. Especially the application on farm land poses a risk, as PFASs can enter directly into the environment. This has been seen to cause massive problems in Raststatt Germany as wel as in Wisconsin, USA[45].

Literature and measurement campaigns clearly show that precursors make a significant contribution to the total load of PFASs in WWTPs. WWTPs usually receive wastewater from both industry and households. PFAS concentrations are higher in wastewater with a high proportion of industrial wastewater. PFASs concentrations in industrial wastewater can be up to a factor of 1 000 higher. Literature also shows that the quantities and type of PFASs depend very much on the type of industry. Due to the large number of PFAS compounds and the many use categories of these substances, tracing the origin of specific PFASs in wastewater is difficult (STOWA, 2021). STOWA measurements showed that PFAS concentrations in the outgoing wastewater were often found to be higher than in the incoming wastewater. According to the researchers there are both known and unknown PFAS compounds present in the incoming wastewater. Currently, unknown PFAS compounds cannot be detected and measured due to their instability. According to the researchers, these unstable, undetected PFAS precursors are partly converted into stable PFAS (where all available sites are occupied by fluorine atoms), which can be measured. This leads to the higher concentrations found in the treated wastewater. These findings confirm existing foreign research.

Several of the analysed PFAS use waste streams have a high likelihood of adding PFASs into the waste streams and in cases where the PFASs are not destroyed, these waste streams can contribute to the global distribution of PFASs via recycling or other treatment options. Especially textile waste presents a high PFAS load in waste and a high share of PFASs not

45 https://www.theguardian.com/environment/2022/sep/19/us-states-toxic-sewage-sludge-pfas-farmers, date of access: 2022-12-16.

destroyed during its treatment. Similarly, the paper packaging applications of FCM can be seen as a possible source of PFASs into the environment due to the high share of recycling of paper. Further waste streams considered in the present investigation such as ELV and WEEE could grow strongly in the coming years. (Especially the market for electric vehicles, which contain more PFASs, likely will grow strongly). This will further contribute to the issue of the ubiquitous occurrence of PFASs.

It is hard to estimate the effects of a total PFAS ban on the future PFAS concentration in sludges. As the sludge is generated in the WTTP, which receive waters from many different sources including landfills, it can be estimated, that PFASs will be present in sludge for many years following a PFAS ban. Additionally, sludge from urban WWTP presents a high risk as around half of the waste sludge is directly spread on arable land.

A.3.18.2.10. Land application/composting

Organic waste can be further reused via composting or through the application on land. In the case of sewage sludge, 50% is reused through these two methods, however these methods are not suitable for the destruction of PFASs. As such it is assumed, that through the use as compost and other land applications of organic waste, PFASs are not significantly destroyed in reasonable time frames, in contrast they can be considered as directly released to the environment.

A.4. Uses advised against by the registrants

The analysis in this Annex XV dossier is based on substances that have been identified as being used in various applications.

No review of registration dossiers for all the potentially relevant PFAS has been undertaken in terms of identifying any specific uses that are advised against by the registrants.

Appendices to Annex A

Appendix A.2. Manufacture, import and uses

Table A.70. PFAS from the OECD and REACH registry database combined. Substances identified as fluorinated gases are indicated in bold.

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
19430-93-4. This is a monomer for a fluoropolymer	n:2 fluorotelomer olefins	1-hexene, 3,3,4,4 5 5,6,6,6-nonfluoro-	100 – 1 000	
80793-17-5	**Hydrofluorocarbons (HFC)**	**Octane, 1,1,1,2,2,3,3,4,4 5 5,6,6-tridecafluoro-**	**0 – 10**	**5**
355-04-4	**perfluoroalkanes**	**Pentane, 1,1,1,2,2,3,3,4 5 5 5-undecafluoro-4-(trifluoromethyl)-**	**100 – 1 000**	**550**
2043-57-4	n:2 fluorotelomer iodides	Octane, 1,1,1,2,2,3,3,4,4 5 5,6,6-tridecafluoro-8-iodo-	Intermediate use only	
80806-68-4	other fluorotelomer-based non-polymers	1-nonanol, 4,4 5 5,6,6,7,7,8,8,9,9,9-tridecafluoro-	Intermediate use only	
647-42-7	n:2 fluorotelomer alcohol	1-octanol, 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluoro-	Intermediate use only	
34451-26-8	n:2 fluorotelomer-thiol derivatives	1-octanethiol, 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluoro-	0 – 10	
73609-36-6	#N/A	Silane, dichloromethyl(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl)-	10 – 100	
85857-16-5	n:2 fluorotelomer silanes	Silane, trimethoxy(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl)-	10 – 100	
375-72-4	perfluoroalkanesulfonyl halides	1-butanesulfonyl fluoride, 1,1,2,2,3,3,4,4,4-nonafluoro-	Intermediate use only	
101947-16-4, a PFOA precursor	n:2 fluorotelomer	Silane, triethoxy(3,3,4,4 5 5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl)-	Confidential	

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
	silanes			
144317-44-2	Perfluoroalkane sulfonic acids (PFSAs) + salts	Sulfonium, triphenyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	Confidential	
52299-25-9	perfluoroalkyl phosphinic acids	Phosphinic acid, P,P-bis(1,1,2,2,3,3,4,4,4-nonfluorobutyl)-	0 – 10	
38565-52-5	fluorotelomer epoxides	Oxirane, 2-(2,2,3,3,4,4 5 5,6,6,7,7,7-tridecafluoroheptyl)-	Intermediate use only	
297730-93-9	hydrofluoroethers	Hexane, 3-ethoxy-1,1,1,2,3,4,4 5 5,6,6,6-dodecafluoro-2-(trifluoromethyl)-	10–100 / confidential	
26650-09-9	n:2 fluorotelomer-thiol derivatives	Thiocyanic acid, 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl ester	Intermediate use only	
27619-89-2	n:2 fluorotelomer sulfonyl based compounds	1-octanesulfonyl chloride, 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluoro-	Intermediate use only	
17527-29-6	n:2 fluorotelomer acrylates	2-propenoic acid, 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl ester	100–1 000	
1228350-17-1	fluorotelomer methacrylates (other)	2-propenoic acid, 2-methyl-, 4,4 5 5,6,6,7,7,8,8,9,9,9-tridecafluorononyl ester	0 – 10	
307-35-7	perfluoroalkane sulfonyl halides	1-octanesulfonyl fluoride, 1,1,2,2,3,3,4,4 5 5,6,6,7,7,8,8,8-heptadecafluoro-	Intermediate use only	
2144-53-8	n:2 fluorotelomer methacrylates	2-propenoic acid, 2-methyl-, 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl ester	100 – 1 000	
56773-42-3	Perfluoroalkane	Ethanaminium, N,N,N-triethyl-, 1,1,2,2,3,3,4,4 5 5,6,6,7,7,8,8,8-	0 – 10	

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
	sulfonic acids (PFSAs) + salts	heptadecafluoro-1-octanesulfonate (1:1)		
34454-97-2	Perfluoroalkanesulfonamidoethanols	1-butanesulfonamid, 1,1,2,2,3,3,4,4,4-nonafluoro-N-(2-hydroxyethyl)-N-methyl-	100 – 1 000	
67584-55-8	perfluoroalkane sulfonyl (meth)acrylates	2-propenoic acid, 2-[methyl[(1,1,2,2,3,3,4,4,4-nonfluorobutyl)sulfonyl]amino]ethyl ester	100 – 1 000	
34455-29-3	n:2 fluorotelomer sulfonyl based compounds	1-propanaminium, N-(carboxymethyl)-N,N-dimethyl-3-[[3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-, inner salt	100 – 1 000	
42532-60-5	perfluoroalkyl cyanide	Propanenitrile, 2,3,3,3-tetrafluoro-2-(trifluoromethyl)-	≥1 to <10	
756-12-7	perfluoroalkyl ketones	2-butanone, 1,1,1,3,4,4,4-heptafluoro-3-(trifluoromethyl)-	1 – 10	
756-13-8	perfluoroalkyl ketone	**3-pentanone, 1,1,1,2,2,4 5 5 5-nonafluoro-4-(trifluoromethyl)-**	**100 – 1 000 +**	**550**
132182-92-4	hydrofluoroethers	Pentane, 1,1,1,2,2,3,4 5 5 5-decafluoro-3-methoxy-4-(trifluoromethyl)-	10 – 100	
1187-93-5	perfluoroalkyl ethers/ alkenes	Ethene, 1,1,2-trifluoro-2-(trifluoromethoxy)-	100 – 1 000	
62037-80-3	Per- and polyfluoroether carboxylic acids (PFECAs)	Propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-, ammonium salt (1:1)	10 – 100	
90622-71-2	perfluoroalkyl iodides	Alkyl iodides, C6-18, perfluoro	Intermediate use only	
68391-08-2	n:2 fluorotelomer alcohols	Alcohols, C8-14, γ-ω-perfluoro	Intermediate use only	
85631-54-5	n:2	2-Propenoic acid, γ-ω-perfluoro-	10 – 100	

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
	fluorotelomer acrylates	C8-14-alkyl esters		
375-50-8	perfluoroalkyl iodides	Butane, 1,1,2,2,3,3,4,4-octafluoro-1 4-diiodo-	Intermediate use only	
375-80-4	perfluoroalkyl iodides	Hexane, 1,1,2,2,3,3,4,4 5 5,6,6-dodecafluoro-1,6-diiodo-	Intermediate use only	
85995-91-1	n:2 fluorotelomer iodides	Alkyl iodides, C8-14, γ-ω-perfluoro	Intermediate use only	
306-94-5	perfluoroalkanes	Naphthalene, 1,1,2,2,3,3,4,4,4a 5 5,6,6,7,7,8,8,8a-octadecafluorodecahydro-	0 – 10	
335-27-3	**perfluoroalkanes**	**Cyclohexane, 1,1,2,2,3,3,4 5 5,6-decafluoro-4,6-bis(trifluoromethyl)-**	**0 – 10**	**5**
338-83-0	perfluoroalkyl amines	1-Propanamine, 1,1,2,2,3,3,3-heptafluoro-N,N-bis(1,1,2,2,3,3,3-heptafluoropropyl)-	≥1 000 to <10 000	
382-26-3	Hydrofluoroethers	Propane, 1,1,1,3,3-pentafluoro-3-methoxy-2-(trifluoromethyl)-	Intermediate use only	
382-28-5	other per - and polyfluoroalkyl ether based substances	Morpholine, 2,2,3,3 5 5,6,6-octafluoro-4-(trifluoromethyl)-	100 – 1 000	
1800-91-5	**n:2 fluorotelomer olefins**	**1,9-Decadiene, 3,3,4,4 5 5,6,6,7,7,8,8-dodecafluoro-**	**0 – 10**	**5**
15290-77-4	**Hydrofluorocarbons (HFC)**	**Cyclopentane, 1,1,2,2,3,3,4-heptafluoro-**	**0 – 10**	**5**
19190-61-5	Per- and polyfluoroether carboxylic acids (PFECAs) esters	Butanoic acid, 2,2,3,3,4,4-hexafluoro-4-[(1,2,2-trifluoroethenyl)oxy]-, methyl ester	0 – 10	
25628-08-4	Perfluoroalkanesulfonic acids	Ethanaminium, N,N,N-triethyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	0 – 10	

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
	(PFSAs) + salts			
34455-22-6	n:2 fluorotelomer sulfonyl based compounds	1-Octanesulfonamide, N-[3-(dimethylamino)propyl]-3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluoro-	Intermediate use only	
59493-72-0	other per - and polyfluoroalkyl ether based substances	1-Propanaminium, 3-[[4-[(heptadecafluorononen-1-yl)oxy]benzoyl]amino]-N,N,N-trimethyl-, iodide (1:1)	Confidential	
96383-55-0	n:2 fluorotelomer-based non-polymers	2-Propenoic acid, 2-chloro-, 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl ester	10 – 100	
102061-82-5	Perfluoroalkane sulfinic acids (PFSAs) + salts	1-Butanesulfinic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, sodium salt (1:1)	Confidential	
103055-07-8		Benzamide, N-[[[2 5-dichloro-4-(1,1,2,3,3,3-hexafluoropropoxy)phenyl]amino]carbonyl]-2,6-difluoro-	Confidential	
130841-23-5		Benzene, 1 4-dichloro-2-(1,1,2,3,3,3-hexafluoropropoxy)-5-nitro-	Confidential	
161075-00-9		1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd., reduced, fluorinated	100 – 1 000	
220133-51-7	Perfluoroalkane sulfonic acids (PFSAs) + salts	Sulfonium, dimethylphenyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	Confidential	
220689-12-3	Perfluoroalkane sulfonic acids (PFSAs) +	Phosphonium, tetrabutyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	1 +/ confidential	

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
	salts			
332350-93-3	other sulfonyl-based non-polymers	Phosphonium, triphenyl(phenylmethyl)-, salt with 1,1,2,2,3,3,4,4,4-nonafluoro-N-methyl-1-butanesulfonamide (1:1)	Confidential	
371771-07-2	Side-chain fluorinated aromatics	1,2-Benzenedicarboxamide, N1-[1,1-dimethyl-2-(methylsulfinyl)ethyl]-N2-[2-methyl-4-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]phenyl]-	Intermediate use only	
874288-98-9	perfluoroalkyl ether halides	Ethane, 1,2-dichloro-1-[difluoro(trifluoromethoxy)methoxy]-1,2,2-trifluoro-	Intermediate use only	
908020-52-0	Per- and polyfluoro ether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-(1,1,2,2,2-pentafluoroethoxy)ethoxy]-, ammonium salt (1:1)	10 – 100	
919005-14-4	Per- and polyfluoro ether carboxylic acids (PFECAs)	Propanoic acid, 2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy]-	Intermediate use only	
958445-54-0	Per- and polyfluoro ether carboxylic acids (PFECAs) esters	Propanoic acid, 2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy]-, methyl ester	Intermediate use only	
1189052-95-6	n:2 fluorotelomer phosphonic acids	Phosphonic acid, P-(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl)-, sodium salt (1:1)	0 – 10	
1190931-27-1	Per- and polyfluoro ether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[[2,2,4 5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy]-, ammonium salt (1:1)	10 – 100	
1190931-39-5	Per- and polyfluoro ether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[[2,2,4 5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy]-, potassium salt (1:1)	Intermediate use only	

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
1190931-41-9	Per- and polyfluoroether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[[2,2,4 5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy]-	Intermediate use only	
13846-22-5	perfluoroalkyl ethers/ alkenes	Propane, 1,1,2,2,3,3-hexafluoro-1,3-bis[(1,2,2-trifluoroethenyl)oxy]-	Intermediate use only	
203929-12-8	n:2 fluorotelomer olefins	1-Hexene, 3,3,4,4 5 5,6,6-octafluoro-6-iodo-	Intermediate use only	
36097-07-1	n:2 fluorotelomer-thiol derivatives	1-Butanethiol, 4-[(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-	0 – 10	
428-59-1	perfluoroalkyl epoxides	Oxirane, 2,2,3-trifluoro-3-(trifluoromethyl)-	100 – 1 000	
88992-45-4	n:2 fluorotelomer-thiol derivatives	1-Propanaminium, 2-hydroxy-N,N,N-trimethyl-3-[(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-, chloride (1:1)	10 – 100	
62880-93-7	n:2 fluorotelomer-thiol derivatives	1-Propanesulfonic acid, 2-methyl-2-[[1-oxo-3-[(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]propyl]amino]-, sodium salt (1:1)	10 – 100	
76-19-7	**Perfluoroalkane**	**Propane, 1,1,1,2,2,3,3,3-octafluoro-**	**100 – 1 000**	**450**
754-12-1	**Perfluoroalkane**	**2,3,3,3-tetrafluoroprop-1-ene**	**≥1 000 to <10 000**	**4 500**
29118-24-9	**Hydrochlorofluoroolefins**	**(E)-1,3,3,3-tetrafluoroprop-1-ene**	**≥1 000 to <10 000**	**4 500**
102687-65-0	**N/A**	**(1E)-1-chloro-3,3,3-trifluoroprop-1-ene**	**≥1 000 to <10 000**	**4 500**
357409-09-7	**Hydrofluorocarbons**	**1,1,1,2-tetrafluoroethane;hydrobromide**	**Not registered**	**unknown**
406-58-6	**Hydrofluorocarbons**	**1,1,1,3,3-pentafluorobutane**	**Confidential**	**unknown**
460-73-1	**Hydrofluorocarbons**	**1,1,1,3,3-Pentafluoropropane**	**1 000+**	**1 000**

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
374-27-6	**Hydrofluoroolefins**	**3,3,4,4,4-pentafluorobut-1-ene**	**1 – 10**	**5**
811-97-2	**Hydrofluorocarbons**	**Norflurane (HFC-134a)**	**≥10 000 to <100 000**	**55 000**
354-33-6	**Hydrofluorocarbons**	**Pentafluoroethane (HFC-125)**	**≥10 000 to <100 000**	**55 000**
138495-42-8	**Hydrofluorocarbons**	**(S,S)-1,1,1,2,2,3,4 5 5 5-decafluoropentane; reaction mass of: (R,R)-1,1,1,2,2,3,4 5 5 5-decafluoropentane**	**≥10 to <100/ confidential**	**55**
677-56-5	**Hydrofluorocarbons**	**1,1,1,2,2,3-Hexafluoropropane (HFC-236cb)**	**Not registered**	**unknown**
420-46-2	**Hydrofluorocarbons**	**1,1,1-trifluoroethane**	**≥1 000 to <10 000**	**4 500**
690-39-1	**Hydrofluorocarbons**	**1,1,1,3,3,3-hexafluoropropane**	**100 – 1 000**	**450**
SUBTOTAL OECD list Fluorinated gases				**131 080**
Source: OECD, ECHA 2020 Only the first 72 substances in the table (up to CAS no 76-19-7) appear in the OECD database of PFAS. There are also fluorinated gases not in the OECD list. Some important substances, including volume range, are presented below				
116-15-4	**Perfluorinated olefins**	**Hexafluoropropene, HFC 1216** Not in the main OECD list - only appears as a "related chemical"	**≥10 000 to <100 000**	**55 000**
79-38-9	N/A	Chlorotrifluoroethylene Not in the main OECD list - only appears as a "related chemical"	1 000 to <10 000	5 500
406-58-6	**Hydrofluorocarbons**	**1,1,1,3,3-pentafluorobutane, HFC-365 mfc**	**No info. Production capacity Solvay Taveaux: 15 000 t: Booten et al. (2020)**	**15 000**
306-83	**Hydrochlorofluorocarbons**	**2,2-dichloro-1,1,1-trifluoroethane, HCFC-123**	**Intermediate use only**	**2 000**
204-075-2	**Perfluoroalkanes**	**Octafluorocyclobutane**	**≥10 000 to <100 000 (import only)**	**55 000**

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
Fluorinated gases not included in OECD fluorinated gas list				**127 000**
SUBTOTAL Fluorinated gases both included or excluded from OECD fluorinated gas list				**258 530**
Stakeholders input from the second stakeholder consultation (Manufactured in/sold in EEA (and UK))				
1064698-37-8	N/A	3M Fluorinert Liquid Fluid FC-40	≥100 to <1 000	550
1093615-61-2	N/A	3M Fluorinert Liquid Fluid FC-770 Reaction mass of 2,2,3,3 5 5,6,6-octafluoro-4-(1,1,1,2,3,3,3-heptafluoropropan-2-yl)morpholine and 2,2,3,3 5 5,6,6-octafluoro-4-(heptafluoropropyl)morpholine	≥10 to <100	55
2187449-42-7	N/A	3M Performance Fluid PF 5056 Reaction mass of perfluoro(dimethyl - N - Butylamine) and perfluoro (methyl - di - N - propylamine) and perfluoro (dimethyl - N - propylamine and 2,2,3,3 5 5,6,6, octafluoro-4-(trifluoromethyl)morpholine and perfluoro-N-pentane	≥10 to <100	55
2176446-38-9	Perfluoroalkanes	3M Performance Fluid PF 5058 Reaction mass of perfluoro(dimethyl - N - Butylamine) and perfluoro (methyl - di - N - propylamine) and perfluoro (dimethyl - N - propylamine and 2,2,3,3 5 5,6,6, octafluoro-4-(trifluoromethyl)morpholine and perfluoro-N-pentane	≥10 to <100	55
3709-71-5	Perfluorinated olefins	3M FA-188 Foam Blowing Additive (2E)-1,1,1,2,3,4,5,5,5-Nonafluoro-4-(trifluoromethyl)-2-pentene	≥ 100 to <1 000 Additive	550
375-03-1	Hydrofluoroether	1-methoxyheptafluoropropane	No info	
163702-08-7	Hydrofluoroether	2-(Difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro-propane	>10 t for reaction mass	10
163702-07-6	Hydrofluoroether	1,1,1,2,2,3,3,4,4-nonafluoro-4-methoxy-butane	>10 t for reaction mass	10
163702-06-5	Hydrofluoroether	2-(difluoromethylethoxy)-1,1,1,2,3,3,3-heptafluorpropane	No info	
163702-05-4	Hydrofluo	1-Ethoxy-1,1,2,2,3,3,4,4,4-	No info	

CAS No[1][2]	PFAS category (OECD)	Chemical Name	REACH registered volume band (t/y)	Midpoint
	roether	nonafluorbutane		
Total fluorinated gases (based on stakeholder consultation)				>1 285
TOTAL Fluorinated gases manufactured/processed in EEA				**259 815**

[1] The first 72 substances (up to CAS no. 76-19-7) were identified by filtering the OECD database for "REACH Registered" substances and obtaining the registered volume data from the ECHA database.
[2] The bold substances in this table have been identified as fluorinated gases in PFAS scope however they are not included in the OECD database of PFAS. As discussed, the numbers for total fluorinated gas volumes in this study were obtained from the stakeholder consultation and the total volume data provided in the EEA report.

It has been noted that there can be some ambiguity in the definition of "F-gas" (in or outside PFAS scope). From a purely chemical and physical perspective, an F-gas could be considered as any substance that contains at least one fluorine atom and is a gas at standard temperature and pressure. This is a very wide definition and is likely the reason why some F-gas substances that meet this description (and do or do not meet the PFAS definition as well) do not appear in the OECD database.

Table A.71. Volume bands of PFASs non-polymers with unsaturated bonds.

CAS No	Name	Volume band/ (t/y)
1187-93-5	Trifluoro(trifluoromethoxy)ethylene	100-1 000
1623-05-8	1,1,1,2,2,3,3-heptafluoro-3-[(trifluorovinyl)oxy]propane	100-1 000
1644-11-7	1,1,1,2,3,3-hexafluoro-2-(heptafluoropropoxy)-3-[(trifluorovinyl)oxy]propane	1-10
10493-43-3	Trifluoro(pentafluoroethoxy)ethylene	1-10
13846-22-5	1,1,2,2,3,3-hexafluoro-1,3-bis[(trifluorovinyl)oxy]propane	Not available – intermediate use only
19190-61-5	Methyl 2,2,3,3,4,4-hexafluoro-4-[(1,2,2-trifluoroethenyl)oxy]butanoate	0
29514-94-1	1,1,2,2-tetrafluoro-2-[(trifluorovinyl)oxy]ethanesulfonyl fluoride	1-10
442-390-9	1,1,2,2,3,3-hexafluoro-1-trifluoromethoxy-3-trifluorovinyloxypropane	10-100
700874-87-9	1-[Difluoro(trifluoromethoxy)methoxy]-1,2,2-trifluoroethylene	10-100
TOTAL (rounded)		**220-2 200**
Source: Wang et al. (2020), OECD database and the ECHA dissemination sites.		

Table A.72. Volume bands of perfluoroethers non-polymers with saturated bonds.

CAS No	Name	Volume band/ (t/y)
382-28-5	2,2,3,3,5,5,6,6-octafluoro-4-(trifluoromethyl)morpholine	100-1 000
62037-80-3	Ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate	10-100
144728-59-6	2-(1,2-dichloro-1,2,2-trifluoroethoxy)-1,1,2,2-tetrafluoroethanesulfonyl fluoride	N/A
874288-98-9	1,2-dichloro-1-[difluoro(trifluoromethoxy)methoxy]-1,2,2-trifluoroethane	N/A
919005-14-4	2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy]propanoic acid	N/A
957209-18-6	2,3,3,4,4-pentafluoro-2,5-bis(1,1,1,2,3,3,3-heptafluoropropan-2-yl)-5-methoxytetrahydrofuran	1-10
161075-00-9	Hexafluoropropene, oxidized, oligomers, reduced, fluorinated	100-1 000
Total (rounded)		**210-2 100**

Source: Wang et al. (2020), OECD database and the ECHA dissemination sites.

Table A.73. A summary of annual imports of PFAS chemicals from third countries into EU-27.

PFAS group	Year									
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Fluoropolymers (t)	22 194	31 122	29 644	29 070	32 004	29 706	33 072	38 202	46 008	36 149
Fluoropolymer – YoY Growth (%)		40	-5	-2	10	-7	11	16	20	-21
Fluorinated gas – Volumes (t)	7 005	9 722	12 249	14 106	16 773	13 970	18 781	23 631	27 456	19 191
Fluorinated gas – YoY Growth (%)		39	26	15	19	-17	34	26	16	-30
PFAA (precursors) and others PFAS Volumes (t)	87 644	79 881	85 354	75 540	77 157	77 881	83 267	105 334	110 281	103 583
Other PFAS – YoY Growth (%)		-9	7	-11	2	1	7	27	5	-6

Source: https://ec.europa.eu/eurostat/web/international-trade-in-goods/data/database, date of access: 2022-12-20.

Table A.74. A summary of annual exports of PFAS chemicals from EU-27 into third countries (t).

PFAS group	Year									
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Fluoropolymer – Volumes (t)	29 535	28 469	26 595	23 323	27 360	26 546	26 107	27 068	30 167	28 718
Fluoropolymer – YoY Growth (%)		-4	-7	-12	17	-3	-2	4	11	-5
Fluorinated gas – Volumes (t)	9 559	7 459	7 116	7 415	8 507	12 360	18 242	16 443	13 660	10 371*
Fluorinated gas – YoY Growth (%)		-22	-5	4	15	45	48	-10	-17	-24
PFAA (precursors) and other PFAS - Volumes (t)	90 728	98 378	128 659	133 519	131 424	115 358	99 810	122 130	127 711	131 866
Other PFAS – YoY Growth (%)		8	31	4	-2	-12	-13	22	5	3

Source: https://ec.europa.eu/eurostat/web/international-trade-in-goods/data/database, date of access: 2022-12-20.

*Remark from stakeholder: The export figures shown above (Eurostat extract) are far too low as only export of bulk gases is presented. According to EEA the bulk export of F-gases was about 26 000 t in 2019. An unknown number of F-gas volume in exported equipment must be added to this volume.

Appendix A.3.2. Fluoropolymer applications, including fluoroelastomers

Table A.75. Non-exhaustive overview of common commercial FPs and their applications – part 1 of 2.

Fluoropolymers	**TULAC**	**Food contact, packaging**	**Consumer mixtures**	**Lubricants, construction products**	**Cosmetics**	**Metal plating**	**Ski waxes**
Cross reference dossier	Table A.16	A.3.4	Table A.84	Table A.57 and Table A.3.15	Table A.29	Table A.27 and Table A.83	A.3.8
Fluropolymers estimated use volumes (t/y)	**High: 109 544 Low: 33 091** Table A.18	**High: 20 430* Low: 15 330*** **Addressed as "polymeric PFAS, but main use are fluoropolymers.* Table A.26	**Range: 800 to 1 200*** **Micropowder PTFE* Table A.60	**High: 10 320 Low: 4 254** Table A.58	**N/A** Table A.31 and Table A.32	**High: 960 Low: 960** Table A.28	**N/A** *There is only total PFAS (polymeric and non-polymeric) volumes of 1.6 t presented in the dossier in the summary of* A.3.8.
Key applications	For PPE and felt fabrics for filtration	For processing equipment	As there are already non-PFAS alternatives on the market with satisfactory functionality	For industrial or professional settings under harsh conditions	As there are already non-PFAS alternatives/ non-PFAS coatings on the market with satisfactory functionality	For processing under harsh conditions	As there are already non-PFAS alternatives on the market with satisfactory functionality

Fluoropolymers	**TULAC**	**Food contact, packaging**	**Consumer mixtures**	**Lubricants, construction products**	**Cosmetics**	**Metal plating**	**Ski waxes**
Thermoplastics							
Polytetrafluoroethylene (PTFE)	Linings Tapes Seals Filters Laminates Waterproof & stain repellent clothing Architectural & carpet coatings Fabrics	Laminates Cook Ware, Beverage cans, Piping, gaskets, equipment, etc. in industrial production of food and food ingredients are also lined/coated with PTFE. Seals for food process applications (Coffee machines, valves etc.) Scrappers	Lubricants e.g lubricants for string instruments as PTFE micropowder	Lubricants: Micro-powder PTFE as solid additives Construction products: Resistant components and coatings such as glassfiber coatings Pipes Fittings	Micro beads or micropowder used in e.g leave-on products such as mascara and rinse-off products such as hair bleaches. Bulking	Chemical processing	Ski wax components
Sulfonated tetrafluoroethylene (PSEPVE)							
Perfluoro methyl alkoxy copolymer (MFA)		Non stick					
Polychlorotrifluoroethylene (PCTFE)		Packaging and barrier films		Lubricants: Base oil			
Fluorinated ethylene propylene (FEP)	Felt fabrics for filtration	Food processing and packaging equipment					

Fluoropolymers	**TULAC**	**Food contact, packaging**	**Consumer mixtures**	**Lubricants, construction products**	**Cosmetics**	**Metal plating**	**Ski waxes**
Polyvinyldifluoride (PVDF)		Beverage tubings and hoses Conveyor beltings	Guitar strings and piano keys	Fluid handling systems, valves, pumps and water piping. Resistant paints Architectural coatings.			
Fluoroethylene vinyl ether (FEVE)				Architectural coatings			
Ethylene (E) copolymer of CTFE (ECTFE)		High strength films Food processing and packaging equipment		Pipes and components			
Perfluoroalkoxy alkane (PFA)		Food processing and packaging equipment		Industrial and architectural coatings			
Ethylene copolymer of TFE (ETFE)		Food processing and packaging equipment		Building textiles			
THV (a semicrystalline three component terpolymer of the given monomers)	Bag liners			Flexible and resistant coatings Multilayer barrier coatings			
Elastomers							

Fluoropolymers	**TULAC**	**Food contact, packaging**	**Consumer mixtures**	**Lubricants, construction products**	**Cosmetics**	**Metal plating**	**Ski waxes**
High fluorine terpolymers of VDF/HFP/TFE and VDF/PMVE/TFE		Table A.81					
VDF/PMVE/TFE perfluoro elastomers		Table A.81					
Ethylene/TFE/PMVE elastomers		Table A.81					
Vinylidene fluoride-hexafluoropropylene copolymer (FKM)		Food packaging materials Food processing equipment					

NOTE: PFAS production and waste are not included in this table, since they are out of scope concerning fluoropolymer uses and applications

Table A.76. Non exhaustive overview of common commercial FPs and their applications – part 2 of 2.

Fluoropolymers	**Transport**	**Medical devices**	**Fluorinated gases**	**Electroncics and semiconduc tors**	**Energy**	**Petroleum mining**	**Other sectors/use s** ***"This column include uses and***
Cross reference dossier	A.3.11, Table A.41, Table A.42	Table A.37, Table A.99 and Table A.105	Not relevant	Table A.48 and Table A.49	Table A.54	A.3.16 and Table A.62	Some "other uses" are mentioned in Table A.83
Fluropolymers estimated use volumes (t/y)	**Range: 6 000 to 14 500** *"Stakeholders estimate of polymeric PFAS where the major volumes are fluoropolymers according to stakeholders (rounded numbers)"*	**High: 12 032 Low: 3 233** Table A.40	**Not relevant**	**High:4 615 Low: 1 560** Table A.50	**High: 2 920 Low: 2 592** Table A.55	**Range: 3 500 to 7 500** Table A.63	**N/A**
Key applications	For equipment, installations and components	For sensing and biomedical devices and implants	Not relevant	Electronic equipment and components for their maintained	Energy storage systems and components for their maintained	For processing under harsh conditions	For processing under harsh conditions.

Fluoropolymers	**Transport**	**Medical devices**	**Fluorinated gases**	**Electroncics and semiconductors**	**Energy**	**Petroleum mining**	**Other sectors/uses** ***"This column include uses and***
	that operate under harsh conditions			functionality	functionality		
Thermoplastics							
Polytetrafluoroethylene (PTFE)	Chemical processing equipment	Biomedical devices such as breathing air devices, medical ventilators and oxygen supply systems.		Wire and cable insulation Semiconductor manufacturing	Li ion batteries Membranes for hydrogen production and electrochemical processes Systems for storage, transport, and production of hydrogen	Chemical processing industry	Chemical processing industry Production of filter systems for industrial plants. 3D-printing Printing inks Processing aid in thermoplastics, thermos-setting plastics and elastomers Antidrip additive in plastics Sealing components for radioactive waste processing systems

Fluoropolymers	**Transport**	**Medical devices**	**Fluorinated gases**	**Electroncics and semiconductors**	**Energy**	**Petroleum mining**	**Other sectors/uses** ***"This column include uses and***
Sulfonated tetrafluoroethylene (PSEPVE)					Membranes for hydrogen production and for electrochemical processes		
Perfluoro methyl alkoxy copolymer (MFA)		Biologic applications		Semiconductor electronics Optoelectronic devices			
Polychlorotrifluoroethylene (PCTFE)	Cryogenic seals	Pharmaceutical packaging		Electrical packaging Lighting Semiconductor processing			
Fluorinated ethylene propylene (FEP)		Medical components		Cable and wire Insulation Semiconductor wet bench equipment	Systems for storage, transport, and production of hydrogen	Chemical processing equipment	Fluid handling Chemical processing equipment
Polyvinylfluoride (PVF) *a partial fluorinated fluoropolymer and therefore not a PFAS*	Flammability lowering coatings of airplane interiors			Wire and cable insulation. Electronic component such as photovoltaic module back sheets	Solar panels		

Fluoropolymers	**Transport**	**Medical devices**	**Fluorinated gases**	**Electroncics and semiconductors**	**Energy**	**Petroleum mining**	**Other sectors/uses** ***"This column include uses and***
				Adhesive for coating and lamination			
Polyvinyldifluoride (PVDF)	Flammability lowering coatings of airplane interiors	Sensing and biomedical devices Membranes in cochlear implants and Catheters Food and pharmaceutical processing		High purity semiconductors Wire and cable isolators Sensors	Solar panels Energy storage devices such as Li ion batteries Separator in Electric Vehicle (EV) batteries		Filaments for additive manufacturing for e.g 3D printing General chemical processing Production of filter systems for industrial plants. Pipe and pumping applications
Fluoroethylene vinyl ether (FEVE)	Coating and finishes						
Ethylene (E) copolymer of CTFE (ECTFE)	Membranes for fuel cells	Medical devices		Flame resistant wire and cable insulation			Industrial acids and corrosives storage
Perfluoroalkoxy alkane				Resistant		Chemical	Fluid handling

Fluoropolymers	**Transport**	**Medical devices**	**Fluorinated gases**	**Electroncics and semiconduc tors**	**Energy**	**Petroleum mining**	**Other sectors/use s** ***"This column include uses and***
(PFA)				components and fittings Electrical insulation. Semiconductor manufacturing		processing equipment	Chemical processing equipment Production of filter systems for industrial plants.
Ethylene copolymer of TFE (ETFE)	Automotive and mass transit cabling Fuel tubing and fittings. Seals	Oxygen respirator components		Wire and cable insulation Wet bench equipment Radomes		Chemical processing equipment	Chemical processing equipment Military and defence equipment (for instance munition, bullet proof vests) Greenhouse glass coatings Sealing components for radioactive waste processing systems
THV (a semicrystalline three component terpolymer of the given monomers)	Fuel hoses			Wire and cable insulation Optical fibres	Solar panels Lighting		Safety glass

Fluoropolymers	**Transport**	**Medical devices**	**Fluorinated gases**	**Electroncics and semiconductors**	**Energy**	**Petroleum mining**	**Other sectors/uses** ***"This column include uses and***
Elastomers							
High fluorine terpolymers of VDF/HFP/TFE and VDF/PMVE/TFE	Table A.13			Table A.13		Table A.13 industrial	Table A.13 industrial
VDF/PMVE/TFE perfluoro elastomers	Table A.13			Table A.13		Table A.13 Industrial	Table A.13 industrial
Ethylene/TFE/PMVE elastomers	Table A.13			Table A.13		Table A.13 industrial	Table A.13 industrial
Vinylidene fluoride-hexafluoropropylene copolymer (FKM)		Table A.102			Li ion batteries	Table A.13 industrial	Table A.13 Sealing components for radioactive waste processing systems

NOTE: PFAS production and waste are not included in this table, since they are out of scope concerning fluoropolymer uses and application.

There is a column "other sectors/uses" in Table A.75 and Table A.76, where certain uses of fluoropolymers could not be allocated to any of the sectors specified in the dossier. These uses and applications may though be relevant to other sectors and applications not mentioned in the dossier. Some of these uses such as "Fluid handling and Chemical processing equipment" appear to be horizontal and can refer to any type of process industry that handles chemical processes and fluids in some form.

There are a number of uses and applications for unspecified fluoropolymers for which limited information was available as shown below in Table A.77.

Table A.77. Uses and applications for unspecified fluoropolymers for which limited information was available.

Uses and applications for unspecified fluoropolymers for which limited information was available	**Use description**	**Remarks**
Extrusion and moulding (non-stick)	Extrusion and moulding processes for technical rubber parts and fittings	Use of FP for plastics and rubbers processing is not covered in the dossier
Professional cleaning and polishing	Fluoropolymer coatings and components enable preventing corrosion and facilitating cleaning	Use of FP in professional cleaning and polishing is not covered in the dossier
Pyrotechnics	Fluorine containing oxidizers, primarily polymers, are extensively used in pyrotechnic compositions	Use of FP in pyrotechnics is not covered in the dossier
Artificial turfs (AT)	Unclear if and how FP would be used in AT	Laura et al test results of total fluorine, suggest that the fluorine in synthetic AT materials (i.e., not including organic fill) consists mostly of non-extractable, non-PFAA precursors, such as fluoropolymers. It cannot be ruled out that contributions from inorganic fluorine species may occur in the turf that could not be extracted in water.

Some thermoplastic fluoropolymers such as sulfonated tetrafluoroethylene (PSEPVE), perfluoro methyl alkoxy copolymer (MFA) and a range of fluoroelastomers are not described in terms of uses but only mentioned in the dossier.

Sectors mentioned in the dossier are named slightly differently in the literature sources found in the reference list. Examples are automotive and aerospace, that can be included in the transportation sector, that also covers other means of transportation than automotive and aerospace such as marine vessels.

Polyvinylfluoride (PVF) is a partial fluorinated fluoropolymer and therefore not a PFAS, which could be an alternative fluoropolymer to polymeric PFAS such as PVDF and PTFE for certain applications in transport, electronics, and the energy sector.

Appendix A.3.3. Textiles, upholstery, leather, apparel and carpets

Table A.78. Requirements/Standards relating to PPE (specific technical standards) – Industry Data commissioned by the EC (Wood, 2020).

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
Surgical drapes and gowns Medical applications	Medical applications	EN 13795	Mechanical resistance, microbiological purity and a barrier effect against liquids: Resistance to microbial penetration Resistance to liquid penetration in reference to achieve a reasonable physiological comfort	Surgical drapes, gowns and clean air suits, used as medical devices for patients, clinical staff and equipment	As a medical device, textiles used in operating rooms have to be conform to the requirements of the European Medical Devices Directive 2007/47/EC (modified 93/42/EEC)
Protective textiles against infection	Medical applications	EN 14216	Maximum protection against infection over blood and secretions rejection. High hydrolyses stability (repeated 130 °C hot steam disinfection, often repeated laundry)	Medical infection prevention surgery blankets, surgery protection aprons etc.	
Protective clothing against infective agent	Medical applications	EN 14126	Performance requirements and test methods for maximum protection against infections like Ebola	PPE for workers in hospital laundries, Ebola -emergency	
Awnings (Strong dynamic water-repellence)	Outdoor technical textiles	EN 20811	Determination of resistance to water penetration. Hydrostatic pressure test min. 200 cm ; 10 mbar/min	All Textiles	
		EN ISO 4920	Determination of resistance to surface wetting (spray test)	Textile fabrics	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
		AATCC 22	Water Repellency: Spray Test	Not specified	
		EN 29 865	Determination of water-repellency of fabrics by the Bundesmann rainshower test	Textiles	
		EN ISO105-B04	Colour fastness - Part B04: Colour fastness to artificial weathering: Xenon arc fading lamp test	Textiles	
		DIN 53931	Determination Of The Resistance Of Textiles To Mildew; Growth Test	Textiles	Other Standards that are indirectly related to the use of FC
		EN ISO 12947 (1-4)	Determination of the abrasion resistance of fabrics by the Martindale method	Textiles	
		ASTM D4032	Test Method for stiffness of fabric by circular bend procedure	Not specified	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
Hand and arm protection	PPE for industrial and professional use (other than sportswear)	EN 420:2010-03	Specifies the requirements applicable to all protective gloves relevant test methods and the general requirements such as resistance of the glove material against water penetration. It shall be used in conjunction with specific product standards.	Protective gloves	The standard deals with particular aspects of quality, health and safety. The standard is used in conjunction with specific product standards as a basis for the placing on the market of protective gloves under the Directive 89/686/EEC for personal protective equipment. The use of protective gloves is not limited to individual sectors, but affects many areas of life and work in different branches.
		EN 388:2003	Protective gloves against mechanical risks	Protective gloves	The standard is to apply in combination with DIN EN 420:2003-12
		EN 374:2003	Specifies the requirements for gloves to protect the user against chemicals and/or micro-organisms and defines terms to be used	Protective gloves	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
		EN 407:2004	This standard specifies thermal performance for protective gloves against heat and/or fire: a) Resistance to flammability b) Contact heat resistance c) Convective heat resistance d) Radiant heat resistance e) Resistance to small splashes of molten metal f) Resistance to large splashes of molten metal	Protective gloves	
		EN 511:2006	This standard applies to any gloves to protect the hands against convective and contact cold down to –50 °C.	Protective gloves against cold	a. Resistance to convective cold b. Resistance to contact cold c. Penetration by water (0 or 1) 0 = water penetration 1 = no water penetration.
		EN 421:2010	This standard applies to gloves to protect from ionising radiation and radioactive contamination.	Protective gloves	To protect from radioactive contamination it is important that, the glove has to be liquid proof and it needs to pass penetration test EN 374
		EN 659	Not specified	Protective gloves for firefighters	
		EN 12477	Requirements such as burning behavior, contact heat and convective heat, small splashes	Gloves giving protection from manual metal welding	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
		EN 50237	This standard applies to insulating gloves and mitts made of plastic or elastomer for use without over-gloves for mechanical protection. Gloves for working at nominal voltages up to 7500 V.	Gloves for Electricians	
Protective Clothing	PPE for industrial and professional use (other than sportswear)	EN 340	Requirements and test methods for protective clothing for fire-fighting	Protective clothing The outer fabric is woven from 75% meta-aramid, 23% para-aramid and 2% antistatic fibres. The fabric is laminated with water vapour permeable membrane made of bi-component expanded PTFE-film.	The European Standard specifies: Protective clothing, Clothing, Performance, Grades (quality), Ergonomics, Anthropometric characteristics, Fitness for purpose, Classification systems, Clothing sizes, Ageing (materials), Compatibility, Marking, Instructions for use
		EN 943	Part 1: Performance requirements for ventilated and non-ventilated 'gas-tight' (Type 1) and 'non-gas-tight' (Type 2) chemical protective suits Part 2: Protective clothing against liquid and gaseous chemicals, including liquid aerosols and solid particles. Part 2: Performance requirements for "gas-tight" (Type 1) chemical protective suits for emergency	Protective clothing against liquid and gaseous chemicals, including liquid aerosols and solid particles	

Product	**Applicable TULAC category**	**Standard**	**Function tested**	**Scope**	**Further details**
			teams (ET)		
		EN ISO 6529	Determination of resistance of protective clothing materials to permeation by liquids and gases	Protective clothing - Protection against chemicals	e.g. PPE for police uniform, workers in chemistry parks, oil platforms, mineral-oil industry etc.
		EN 14325	Test methods and performance classification of chemical protective clothing materials, seams, joins and assemblage	Protective clothing - Protection against chemicals	
		EN 368	Resistance of materials to penetration by liquids No degradation, >80% run off and no penetration to the innermost surface	Protective clothing - Protection against liquids	Confirmed by ocular inspection after use of: – petroleum products – inorganic acids 36% – inorganic bases 40% – alcohols – sodium hypochlorite 10%
		EN 31092	Water-vaping resistance (Ret) Max 11 m^2 Pa/W	Polyamide fabric	
		EN14605	Performance requirements for clothing with liquid-tight (Type 3) or spray-tight (Type 4) connections, including items providing protection to parts of the body only e.g. maximum gasoline/chemical repellency for worker in the chemical industry, high durability professional washing and dry	Protective clothing against liquid chemicals (acids)	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
			cleaning.		
		EN 13982	Part 1: Performance requirements for chemical protective clothing providing protection to the full body against airborne solid particulates (type 5 clothing)	Protective clothing for use against solid particulates	
		EN 13034	Performance requirements for chemical protective suits offering limited protective performance against liquid chemicals (Type 6 equipment)	Protective clothing against liquid chemicals	
		EN ISO 11612	Protection against heat and flame - Minimum performance requirements: A: Minimum protective performance with respect to flame spread (test method EN ISO 15052) B: Performance with respect to insulation against convective heat (test method EN ISO 9151) C: Performance with respect to insulation against heat radiated (test method EN ISO 6942) D: Performance with respect to insulation against aluminum spraying (test method EN ISO 9185) E: Performance with respect to insulation against cast iron spraying (test method EN ISO 9185) F: Performance with respect to insulation against heat through contact (test method EN ISO 12127)	Clothing to protect against heat and flame e.g. oil-drilling protective wear with maximum high oil- and chemical (fracking) repellency, high durability against repeated laundry/ dry cleaning etc.	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
		EN ISO 11611	This standard specifies minimum basic safety requirements and test methods for protective clothing including hoods (head), aprons, sleeves and gaiters (feet).	Protective clothing for use in welding and allied processes	This PPE protects against spatter, short contact time with flame, radiant heat from the arc, and minimizes the possibility of electrical shock by short-term, accidental contact with electrical conductors in normal conditions of welding. Test methods: EN ISO 15025, EN ISO 6942, EN ISO 9150
		EN ISO 343	Specifies the requirements and test methods for materials and the seams of clothing designed to give protection against precipitation (rain, snow), mist and ground moisture	Protective clothing - Protection against rain	Value X stands for the waterproofing of the article. There are 3 classes derived from the amount of pressure the fabric can withstand: 3 is the highest (i.e. the most waterproof) and 1 is the lowest. Value Y stands for the breathability of the fabrics (plus all the layers used in the article). There are 3 classes for breathability. Class 1 = the lowest and

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
					Class 3 = the highest
		EN 14058	Articles are divided in three classes depending on their thermal resistance (insulation). With the test method two optional features can be tested: the water vapour resistance and thermal insulation.	Protective clothing - Garments for protection against cool environments	Clothing certified with this standard includes: Thermal resistance Air permeability Penetration of water. Water vapour resistance Thermal insulation

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
Other Protective clothing	PPE for industrial and professional use (other than sportswear)	EN 1073	This standard is for requirements and test methods for ventilated protective clothing against particulate radioactive contamination	Protective clothing against radioactive contamination	Protective clothing, Radiation protection, Radioactive materials, Contamination, Clothing, Particulate air pollutants, Industrial overalls, Protective suits, Performance testing, Splitting tests, Leak tests, Gas resistance tests, Water tightness tests, Dust-tightness tests, Perforating tests, Tear tests, Chemical-resistance tests, Abrasion resistant materials, Protective coatings, Breathing apparatus, Visors, Air, Gas flow, Flow measurement, Seams, Design, Occupational safety, Performance, Wear resistance, Strength of materials, Classification systems, Marking, Instructions for use, Testing conditions.

Product	**Applicable TULAC category**	**Standard**	**Function tested**	**Scope**	**Further details**
		EN 50286	Not specified	Electrical insulating protective clothing for work on low-voltage installations	
		EN 61482	Determination of the arc rating of flame resistant materials for clothing	Live working - Protective clothing against the thermal hazards of an electric arc	
		EN 1149-5	This European Standard specifies material and design requirements for electrostatic dissipative clothing, used as part of a total earthed system, to avoid incendiary discharges	Protective clothing - Electrostatic properties	These anti-static clothing are compliant and designed for use in an ATEX (EXplosive ATmosphere) working environment where a risk of explosion is possible, e.g. tank truck driver.
Protective clothing for firefighters	PPE for industrial and professional use (other than sportswear)	EN 469 (mentioned standards therein: EN ISO 24920, EN ISO 6530	Requirements: • Flame spread (test method ISO 15025) • Convective heat (test method EN 367) • Radiant heat (test method ISO 6942) • Heat resistance (test method ISO 17493) •Water repellence, dimensional stability, resistance to chemicals	PPE worn during structural firefighting to protect mainly against heat and flame.	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
Protective clothing for military	PPE for industrial and professional use (other than sportswear)	EN ISO 14419	The C-combat suit shall be water and oil repellent, Oil repellence, min 5 and resistance to surface wetting, min 5 according to EN 24920 (spray test). Both new and washed/dried materials shall be tested. Wash/dry procedure (three wash/dry cycles): The C-combat suit shall be possible to be washed in 60 °C and then tumble dried of a maximum of 80 °C for at least 3 times according to ISO 6330 with maintained protective ability. The C-combat suit shall be water and oil repellent and be tested according to ISO 2811 (Determination of resistance to water penetration –hydrostatic pressure test.) The C-combat suit shall be able to be washed in 60 ºC for at least 3 times with no loss in protective ability. The C-combat suit shall be able to be dried in a tumble dryer in a temperature of a maximum of 80 ºC with no loss in protective ability The permeability of the C-combat suit shall not be lower than 40 mm/s when using a pressure drop of 100Pa according to SS-EN ISO 9237:1995 (Textiles - Determination of the permeability of fabrics to air)	Protective C(hemical)-combat suit, Viscose FR	
		EN 29865	Water repellency, water absorption, after 3 washes (25%) Water repellency after 3 washes (min. 4)	PES Fabric	
		EN ISO 4920 EN ISO 6330	W Spray test-before wash/after 3 washes (min. 5/min) 60 °C 8.5 tumble dry	PES Fabric	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
		EN ISO 6350	Penetration and Repellency to Liquid chemicals	Fabric Viscose FR	
Protective clothing for police	PPE for industrial and professional use (other than sportswear)	TLP 9004 (mentioned standards therein: EN ISO 24920, EN ISO 14419, EN 228, EN ISO 6530	Oil- and water-repellency, fuel repellency	PPE clothing for police	
Protective clothing for fire fighters, police, military and chemical protection	PPE for industrial and professional use (other than sportswear)	TL 8305-0020	Maximum oil- and water-repellency, fastness to repeated washing cycles (mentioned standards therein: EN 29865, EN ISO 14419	Technical delivery condition uniform twill	
		TL 8305-0023, TL 8305-0302, TL 8305-0335, TL 8305-0336 (mentioned standards therein: EN 29865, EN ISO 14419)	Maximum water-, oil-repellency after repeated washing.	Technical delivery condition for uniform double-twill, medium-fine twill and woven fabric	
Protective/Safety footwear	PPE for industrial and professional use (other than sportswear)	EN ISO 20345	Maximum repellence concerning dangerous liquids, chemicals, blood etc.	PPE shoes	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
		EN ISO 20346			
		EN ISO 20344 test methods, DIN EN 12568 test methods			
	Medical applications	EN 455	Disposable medical protective footwear		
Ready made garments - Impact from above with high energy droplets	PPE for industrial and professional use (other than sportswear)	EN 14360	Maximum water repellency because of high dynamic energy at 150-200 km speed of water droplets	Protective off shore jackets and trousers on boats and ships, protective motor cycle wear	
Protective clothing for agricultural workers	PPE for industrial and professional use (other than sportswear)	ISO 27065	Performance requirements for protective clothing worn by operators applying liquid pesticide	e.g. protective suits in agriculture application of pesticides	
Protective clothing for automobile (racing) drivers	Professional Sports clothing	FIA-Standard 885	Maximum protection against fuel, heat and flame	e.g. outer garments, socks, shoes, balaclava hoods and gloves	
Fuel cells	Outdoor technical textiles	Safety Standards of International Electro-technical Commission (IEC)	Maximum resistance to hydrolysis und acid conditions e.g. treated non-woven carbon fibre separator in phosphoric acid conditions	Certified carbon fibre nonwoven for fuel cell	

Product	**Applicable TULAC category**	**Standard**	**Function tested**	**Scope**	**Further details**
Filters	Outdoor technical textiles	VDI 3677 Blatt 3:2012-11	Long-term temperature resistance, stability	Filters for wasted air/incineration plants	
Roofing textiles	Outdoor technical textiles	DIBT-Certified	Maximum dynamic water repellency, maximum dirt repellency, UV-stability long lifecycle	Protective architecture textiles (Energy saving, UV-protection), e.g. lightweight textile roofing systems	
Textile components of aircraft parts	Outdoor technical textiles	Airbus-Certified	Maximum release properties, air permeability	Membrane textiles for in mould injection processes of carbon fibre composite parts	
Textile components of automobile parts	Outdoor technical textiles	Audi-Standard LAH 893-80	Maximum repellency against dry soil and white spirit, heavy dynamic rain repellency, maximum performance because of high impact (>200 km/h) of raindrops	e.g. convertible tops	
Textile components of automobile parts	Outdoor technical textiles	AATCC TM 118-oil repellency: hydrocarbon resistance test	96 hours fuel rejection ; maximum fuel rejection of e.g. non-woven engine compartment interior/cushion (safety feature in case of fire), strong oil/fuel-repellency of flame-retardant nonwoven/PU-foam motor compartment sound cushions.	non woven engine compartment interior/cushion (safety feature in case of fire), nonwoven/PU-foam motor compartment sound cushions	

Product	Applicable TULAC category	Standard	Function tested	Scope	Further details
Textile components of automobile parts	Outdoor technical textiles	Other- Automotive Standards for Oil repellency	Repellency- resistance to wetting by oily liquids, hydrophobicity	e.g. fuel, oil, coolant-repellent, inflammable nonwoven for safety cushion/sound absorbing automotive parts	

Appendix A.3.4. Food contact materials and packaging

Table A.79. Summary of data used for estimating PFAS (surfactants) volume in Paper and Board Food Packaging.

	Geographical coverage	**Data**		**Source**
			t	
Total Paper and Board (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/t): Average = 537 Maximum = 1200	Dinsmore (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% CfE 0.4 – 1.0%	Range is: 0.4 – 1.2% (dry weight)	(BfR, 2020; FDA-US, 2021)
Estimate of the proportion of total* paper packaging that contains PFAS	Not specified (assumed EU)	Up to 1% (assume 0.5 – 1.0%)		Estimate (see Table A.22)
Total organic fluorine content of throwaway packaging	EU	Oil-beading compostable: 680 mg/kg TOF Oil-beading takeaway paper: 480 mg/kg TOF Oil-spreading or soaking paper/board: 14.5 mg/kg TOF		Straková et al. (2021)

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.

Table A.80. Substances (indicative list with some examples) used in FCM and packaging.

Substance	**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 (TFE)	PTFE	9002-84-0	$(C_2F_4)_n$	Cooking and baking equipment, coated rubber	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 FKM, fluoroelastomers (1,1- Difluoroethylen - hexafluoropropenpolymer) Ethene, 1,1,2,2-tetrafluoro-, homopolymer (PTFE) Ethylene-tetrafluoroethylene copolymer (ETFE) FKM Perfluoroelastomer (FFKM) Tetrafluoroethylene-perfluoropropylene copolymer (FEP)		64706-30-5 64706-30-65 PTFE: 9002-84-0; VDF-co-HFP/FKM#1: 9011-17-0; - - FEP: 25067-11-2 -		Liquid processing equipment Rubber components	No data
Perfluoroalkyl(C6-C16) phosphates of bis(2-hydroxyethyl)amine or Diethanolamine salts of mono- and bis(1H,1H,2H,2H-	No data	65530-64-5	NH2+(CH2CH2OH)(O)P(O-)(OCH2CH2CnF2n+1)2	Food, non-food and feed packaging	Additive

Substance	Abbreviation	CAS number	Chemical formula	Use	Function/ regulatory listing
perfluoroalkyl(C8-C18) phosphates [mono- and di-PAP, FT]					

Table A.81. PFAS that have been identified for all food contact and packaging use. Entries have been organised according to chemical groupings in this table. Source: see note at the end of the table.

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
Perfluorooctanoic acid, ammonium salt	PFOA	3825-26-1	$C_8H_4F_{15}NO_2$	Consumer cookware Industrial food processing and food transport equipment Food & feed packaging	PPA listed in Reg. 10/2011. No longer used.
Perfluorooctane sulfonic acid	PFOS	1763-23-1	No data	Food & feed packaging	No longer used.
Perfluoroheptanoic acid	No data	375-85-9	$C_7HF_{13}O_2$	Food & feed packaging	No data
Perfluorohexanoic acid	(PFHxA)	307-24-4	$C_6HF_{11}O_2$	Food & feed packaging	No data
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 cookware Industrial food processing and food transport equipment Food & feed packaging	PPA in Reg. 10/2011. Substitute for PFOA
Hexafluoropropylene	No data	116-15-4	C_3F_6	Consumer cookware	Monomer in Reg. 10/2011.
Perfluoroalkyl vinyl ethers: Perfluoro*methyl vinyl ether* Perfluoro*ethyl vinyl ether* Perfluoropropyl *vinyl ether*	*e.g.* PFMVE PFEVE PFPVE	*e.g.* 1187-93-5 10493-43-3 1623-05-8	C_3F_6O (PFMVE) C_4F_8O (PFEVE) $C_5F_{10}O$ (PFPVE)	Consumer cookware Industrial food processing and food	Monomers listed in Reg. 10/2011.

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
				transport equipment	
Perfluoroalkyl phosphonic acids	(PFPAs)	40143-76-8, 40143-78-0, 52299-26-0, 63225-55-8	No data	Non-food packaging	Coating for polyethylene film used e.g. for packaging toys and foodstuff.
Perfluoroalkyl phosphinic acids	(PFPiAs)	40143-77-9, 40143-79-1, 52299-27-1, 63225-54-7	No data	Non-food packaging	
Ammonium perfluoroalkyl carboxylate	No data	6130-43-4, 4149-60-4, 4234-23-5, 4288-72-6	NH_4^+ CnF2n+1COO– (4149-60-4)	Non-food P&B packaging	Coating for polyethylene film used e.g. for packaging toys and foodstuff. PFAS that have been patented for use in paper packaging for non-food articles
1-Alkanol, **1H,1H,2H,2H-** perfluoro-, 1-(hydrogen sulfate), ammonium salt (1:1)	No data	63225-56-9, 63225-57-0, 63225-58-1, 63225-59-2	No data	Non-food packaging	Coating for polyethylene film used e.g. for packaging toys and foodstuff
Chlorotrifluoroethylene	No data	79-38-9	$ClCF=CF_2$	Consumer cookware	Monomer Listed in 10/2011. (The monomer is not a PFAS, the polymer is a PFAS).
Vinylidene fluoride	No data	75-38-7	CH_2CF_2	Consumer cookware	Monomer Listed in 10/2011. (The monomer is not a PFAS, the polymer is a PFAS).
(Perfluorobutyl)ethylene	No data	19430-93-4	$C_6H_3F_9$	Consumer cookware	Monomers listed in Reg. 10/2011.
Potassiumperfluorobutanesulfonate	No data	29420-49-3	$C_4F_9KO_3S$	Food & feed packaging	No data
Perfluoropolyether (PFPE) or Perfluoropolyether dicarboxylic acid,	No data	76415-97-9, 69991-62-4	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
ammonium salt					
Perfluoro-1,2-dimethylcycloalkane	No data	306-98-9	C_8F_{16}	Food & feed packaging	No data
6:2-8:2 or 8:2-8:2-di polyfluoroalkyl phosphate ester (PAP)	No data	No data	No data	Food & feed packaging	No data
8:2, 10:2, 12:2, 14:2 or 16:2 fluorotelomer alcohol (FTOH) and mono-phosphate or di-phosphate	No data	No data	No data	Food & feed packaging	No data
Phosphoric acid, mono- and bis(gamma, omega-perfluoroalkyl) esters, compounds with diethanolamine	No data	No data	No data	Food & feed packaging	No data
Pentanoic acid, 4,4-bis [(gamma-omega-perfluoro-C8-20-alkyl)thio] derivatives, compounds with diethanolamine	No data	71608-61-2	No data	Food & feed packaging	No data
3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate, or methacrylate acetate	No data	17527-29-6	No data	Food & feed packaging	No data
3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl methacrylate, acetate and/or malate	No data	2144-53-8	$C_{12}H_9F_{13}O_2$	Food & feed packaging	No data
1-Octanesulfonamide, N-ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro	No data	No data	No data	Food & feed packaging	No data
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	No data	No data	No data	Food & feed packaging	No data
N-(2-Hydroxyethyl) perfluorooctyl sulphonamide	No data	1691-99-2	No data	Food & feed packaging	No data
Acrylic acid, N-methylperfluorooctanesulfonamido-ethyl ester	No data	25268-77-3	No data	Food & feed packaging	No data
(Perfluorooctylsulfonylaminopropyl)trimethylammonium iodide	No data	68310-75-8	No data	Food & feed packaging	No data
2-Propenoic acid, 2-amino]ethylester[ethyl[(tridecafluorohexyl)sulfonyl]-	No data	1893-52-3	No data	Food & feed packaging	No data
2-Propanoic acid, 2-((ethyl(pentadecafluorohep	No data	No data	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
tyl)-sulfonyl) amino)ethyl ester					
Acrylic acid, 2-[methyl[(nonafluorobutyl) sulfonyl]ethylester amino]	No data	No data	No data	Food & feed packaging	No data
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)	No data	No data	No data	Food & feed packaging	No data
2,3,3,4,4,5,5-Heptafluoro-1- pentene	No data	1547-26-8	$C_5H_3F_7$	Consumer cookware	Monomer Listed in 10/2011.
				Food & feed packaging	Comonomer, in combination with the comonomers ethylene and tetrafluoroethylene, in the manufacture of fluoropolymers.
				Non-food packaging	
Perfluoro[(2-ethyloxy-ethoxy)acetic acid]	No data	No data	$C_6HF_{11}O_4$	Industrial food processing and food transport equipment	Temperature resistant polymer coating systems for frying, cooking and baking utensils
Perfluoro[(2-ethyloxy-ethoxy)acetic acid]], ammonium salt	No data	908020-52-0	$C_6HF_{11}O_4$ (+ NH_3)	Consumer cookware	Monomer and emulsifier (PPA) Listed in 10/2011.
Sodium 4-perfluorononyloxy-benzenesulphonate	No data	e.g. 59536-17-3	$C_{15}H_4F_{19}NaO_4S$	Consumer cookware	Monomer and emulsifier (PPA)
Perfluoro[2-(poly(n-propoxy))propanoic acid] *or p*erfluoropolyether carboxylic acid	No data	51798-33-5	$(C_3F_6O)_n$ $C_6HF_{11}O_3$	Consumer cookware	Monomer and emulsifier (PPA) Listed in 10/2011.
Perfluoro acetic acid, α-substituted with the copolymer of perfluoro-1,2-propylene glycol and perfluoro-1,1-ethylene glycol, terminated with chlorohexa-fluoropropyloxy groups	No data	329238-24-6	C_3F_6ClO-[CF_2-$CF(CF_3)$-O]n-[$CF(CF_3)$-O]m-CF_2COOH	Consumer cookware	PPA Listed in 10/2011.
				Industrial food processing and food transport equipment	PPA in Reg. 10/2011 – specification: Up to 0.5% w/w in the polymerisation of fluoropolymers that are processed at

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
					temperatures at or above 340 °C and are intended for use in repeated use articles
2H-perfluoro-[(5,8,11,14-tetramethyl)-tetraethyleneglycol ethyl propyl ether]	No data	37486-69-4	No data	Consumer cookware	PPA Listed in 10/2011.
perfluoro{acetic acid, 2-[(5- methoxy-1,3-dioxolan-4-yl)oxy]}, ammonium salt	No data	1190931-27-1	No data	Consumer cookware	PPA Listed in 10/2011.
3H-perfluoro-3-[(3-methoxy-propoxy)propanoic acid], ammonium salt	ADONA	958445-44-8	No data	Consumer cookware	PPA Listed in 10/2011.
Polytetrafluoroethylene; *a polymer of:* tetrafluoroethylene	PTFE	9002-84-0 116-14-3	$(C_2F_4)_n$	Consumer cookware	Monomer and PPA Listed in 10/2011.
				Industrial food processing and food transport equipment	
				Food & feed packaging	Additive (in micropowder form) for other plastics to get better non-sticking properties for these plastics.
				Non-food packaging	
Polytrifluoroethylene	No data	No data	No data	Non-food packaging	Food packaging foils.
Polychlorotrifluorethyene	(PCTFE)	9002-83-9	No data	Non-food packaging	Food packaging films, pharmaceutical blister packaging. High barrier film.
Polyvinylidene fluoride	PVDF	24937-79-9	$(C_2H_2F_2)n$	Industrial food processing and food transport equipment	Used for solid and lined pipes, fittings, valves, pumps, tower packing, and tank and trailer linings for fluid-handling applications.

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
Vinylidene fluoride-hexafluoropropene copolymer	No data	9011-17-0	$(CH_2CF_2)x$-$(CF_2CFCF_3)y$	Food & feed packaging	No data
A dipolymer made from HFP and vinylidene fluoride (VF).	No data	9011-17-0 1478-61-1	No data	Industrial food processing and food transport equipment	A fluoroelastomer designed for finished parts, which are compliant with the regulations of the U.S. Food and Drug Administration (FDA) 21 CFR 177. 2600(c)(4)(i).
VF and HFP copolymers	No data	9011-17-0	No data	Industrial food processing and food transport equipment	Monomers in Reg. 10/2011
VF, HFP and tetrafluoroethylene (TFE) copolymers	No data	25190-89-0	$(CF_2CF_2)x$-$(CF_2CFCF_3)y$-(CF_2CH_2)	Industrial food processing and food transport equipment Food & feed packaging	Monomers in Reg. 10/2011
Poly (hexafluoropropyleneoxide) , polymer with 3-N-methylaminopropylamine, N, N,dimethyldipropylenetriamine and poly (hexamethylenediisocyanate) with a fluorine content of 59,1%	No data	No data	No data	Food & feed packaging	No data
Reaction product of hexamethylene-1,6-diisocyanate (homopolymer), transformed with 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol with a fluorine content of 48%	No data	No data	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
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%	No data	647-42-7	No data	Food & feed packaging	No data
Hexane, 1,6-diisocyanato-, homopolymer, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol-blocked	No data	357624-15-8	No data	Food & feed packaging	No data
Copolymer of 1,1-difluoroethylene, tetrafluoroethylene, trifluoro methyl trifluorovinyl ether and a halogenated alkene, optionally cured with triallyl isocyanurate and 2,5-dimethyl-2,5-di(tert-butylperoxy)hexane	No data	No data	No data	Food & feed packaging	No data
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(trifluoro methyl)-1,2-ethanediyl]]-blocked	No data	1279108-20-1	No data	Food & feed packaging	No data
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]]	No data	No data	No data	Food & feed packaging	No data
Other HFP copolymers e.g. with TFE	HFP	116-15-4	C_3F_6	Industrial food processing and food transport equipment	Monomer in Reg. 10/2011

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
Copolymer of hexafluoropropylene, TFE, and perfluoroethyl vinyl ether	No data	116-15-4 (hexafluoropropylene) 116-14-3 10493-43-3 (vinyl ether)	No data	Food & feed packaging	No data
A copolymer of propylene, TFE, and 3,3,3-trifluoropropene cured with a salt of a quarternary ammonium compound and phenol, 4,4'-(2,2,2-trifluoro-1-(trifluoromethyl)ethylidene)bis-	No data	115-07-1 116-14-3 677-21-4 (trifluoropropene)	No data	Food & feed packaging	No data
A copolymer of TFE and trifluoromethyl trifluorovinyl ether, and optionally employing a halogenated alkene.	No data	116-14-3 1187-93-5 (ether)	No data	Food & feed packaging	No data
2-Propen-1-ol, reaction products with pentafluoroiodoethane-TFE telomer, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine	No data	464178-90-3	No data	Food & feed packaging	No data
1-Hexene, 3,3,4,4,5,5,6,6,6-nonafluoro-, polymer with 1,1,2,2-tetrafluoroethene	No data	82606-24-4	$(C_6H_3F_9.C_2F_4)x$	Food & feed packaging	No data
2,3,3,4,4,5,5-Heptafluoro-1-pentene polymer with ethene and TFE	No data	94228-79-2	$(C_5H_3F_7.C_2H_4.C_2F_4)x$	Food & feed packaging	No data
Perfluoroalkoxy alkanes (PFA); *a copolymer of:* Perfluoroalkyl vinyl ether, *and* tetrafluoroethene	PFA	e.g. 26655-00-5, 1623-05-8 116-14-3	$C_7F_{14}O$	Consumer cookware	Polymer. Non-stick coating for pans and facilitates cleaning of the cookware.
				Industrial food processing and food transport equipment	Monomer in Reg. 10/2011.
Perfluoroethylene propylene, *or* Fluorinated Ethylene Propylene (FEP); *is a copolymer of:* Hexafluoropropene (see	FEP	25067-11-2 116-15-4 116-14-3	$(C_3F_6.C_2F_4)_n$	Consumer cookware	Polymer for coating cookware, such as frying pans and articles for oven baking,

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
above), *and*-tetrafluoroethylene					moulded articles for industrial use, and for use in non-porous (very good chemical resistance) films with excellent abrasion resistance.
				Industrial food processing and food transport equipment	Monomers in Reg. 10/2011
Silicone Rubber, fluorinated	No data	64706-30-65	No data	Industrial food processing and food transport equipment	A silicone-based fluoroelastomer.
Siloxanes and silicones, methyl-phenyl, methyl-3,3,3-trifluoropropyl	No data	1643944-25-5	No data	Industrial food processing and food transport equipment	Used as a lubricant, or a component of, bearing grease to lubricate facer roll bearings in paper and paperboard manufacturing.
				Food & feed packaging	No data
Glycine, N,N-bis[2-hydroxy-3-(2-propenyloxy)propyl]-, monosodium salt, reaction products with ammonium hydroxide and pentafluoroiodoethane-tetrafluoroethylene telomer	No data	220459-70-12	No data	Food & feed packaging	No data
Glycine, N-ethyl-N-[(heptadecafluorooctyl)sulfonyl]-, potassium salt, or nonafluorobutyl or tridecafluorohexyl or pentadecafluoroheptyl	No data	2991-51-7 67584-51-4 67584-53-6 67584-62-7	No data	Food & feed packaging	No data
Diphosphoric acid, polymers with ethoxylated reduced Me esters of reduced polymerized oxidized TFE. This substance is also known	No data	162492-15-1 with phosphorous pentoxide 1314-56-3 or	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
as: phosphate esters of ethoxylated perfluoroether, prepared by reaction of ethoxylated perfluoroether diol.		pyrophosphoric acid 2466-09-3.			
Diphosphoric acid, polymers with ethoxylated reduced methyl esters of reduced polymerized oxidized TFE	No data	200013-65-6	No data	Food & feed packaging	No data
Diphosphoric acid, polymers with ethoxylated reduced methyl esters of reduced polymerized oxidized TFE. Fomblin HC/P2-1000. This substance is also known as phosphate esters of ethoxylated perfluoroether, prepared by reaction of ethoxylated perfluoroether diol with phosphorous pentoxide or pyrophosphoric acid	No data	200013-65-6 (reduced methyl esters) 162492-15-1 (perfluoroether diol) 1314-56-3 (pentoxide) 2466-09-3 (acid)	No data	Food & feed packaging	No data
Diphosphoric acid, polymers with methyl esters reduced ethoxylates oxidized reduced polymerized tetrafluoro ethylene	No data	No data	No data	Food & feed packaging	No data
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	No data	1012783-70-8	$(C_{11}H_7F_{13}O_2.C_5H_8O_3.(C_2H_4O)_nC_6H_6O_3.(C_2H_4O)_nC_3H_4O_2)_x$	Food & feed packaging	No data
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-	No data	1158951-86-0	$(C_{11}H_7F_{13}O_2.C_6H_{10}O_3.C_4H_6O_2.(C_2H_4O)_nC_3H_4O_2)_x.xNa$	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
propenoate, sodium salt					
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	No data	1878204-24-0	$(C_{12}H_9F_{13}O_2.C_6H_{10}O_3.C_3H_4O_2)xxNa$	Food & feed packaging	No data
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	No data	1206450-10-3	$(C_{11}H_7F_{13}O_2.C_6H_{10}O_3.C_6H_9NO.C_3H_4O_2)xxNa$	Food & feed packaging	No data
Phosphoric acid ester of ethoxylated perfluoropoly-etherdiol	No data	200013-65-6 162492-15-1 1314-56-3 2466-09-3	No data	Food & feed packaging	No data
Diphosphate ester of N-ethyl perfluorooctane sulfonamido ethanol (N-EtFOSE)	No data	No data	No data	Food & feed packaging	No data
N,N',N''-[phosphinylidynetris(oxyethane-2,1-diyl)]tris[N-ethylheptadecafluorooctane-1-sulphonamide]	No data	2250-98-8	No data	Food & feed packaging	No data
1-Butanaminium, N,N,N-tributyl-, hexafluorophosphate(1-)	No data	3109-63-5	No data	Food & feed packaging	No data
N-Ethyl-N-(2-hydroxyethyl)perfluorooctanesulfonamide phosphate, diammonium salt [SN-mono-PAP/PFPA]	No data	67969-69-1	No data	Food & feed packaging	No data
1-Octanesulfonamide, N, N'-(phosphinicobis(oxy-2, 1-ethanediyl))bis(N, ethyl-1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-, ammonium salt)	No data	30381-98-7	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
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	No data	Food & feed packaging	No data
Ethanol, 2,2′-iminobis-, compd. with α,α′-[phosphinicobis (oxy-2,1-ethanediyl)]bis[ω-fluoropoly(difluoromethylene)] (1:1)	No data	65530-64-5	NH2+(CH2CH2OH)(O)P(O−)(OCH2CH2CnF2n+1)2	Non-food P&B packaging	PFAS that have been patented for use in paper packaging for non-food articles
Perfluoroalkyl substituted phosphate ester acids, ammonium salts formed by the reaction of 2,2-bis[([gamma], [omega]-perfluoro C4-20 alkylthio) methyl]-1,3-propanediol, polyphosphoric acid and ammonium hydroxide	No data	No data	No data	Food & feed packaging	No data
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	No data	No data	No data	Food & feed packaging	No data
Ammonium salts of esters from reaction with 2,2′-bis perfluoralkyl substituted phosphoric acid formates [(alfa, omega-perfluoro C4-C20 alkylthio) methyl] -1,3-propanediol, polyphosphoric acid and ammonium hydroxide	No data	No data	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
Ammonium-bis- (N-ethyl-2-perfluoralkylsulfonamidoethyl) phosphate cannot contain more than 15% ammonium mono(N-ethyl-2-perfluoralkylsulfonamidoethyl) phosphate	No data	No data	No data	Food & feed packaging	No data
Ammonium bis (N-ethyl-2-perfluorooctansulfonamidethyl) phosphate with maximum content of 15% ammonium mono (N-ethyl-2-perfluorctansulfonamidethyl) phosphate	No data	No data	No data	Food & feed packaging	No data
Ammonium-bis- (N-ethyl-2-perfluorooktansulfonamidethyl) phosphate with maximum content of 15% ammonium mono (N-ethyl-2-perfluoroktansulfonamidethyl) phosphate	No data	1071022-26-8	$(C_{12}H_9F_{13}O_2.C_{10}H_{19}NO_2.C_4H_6O_2.C_3H_4O_2)x.xC_2H_4O_2$	Food & feed packaging	No data
Diethanolamine salts of mono- and bis (1H,1H,2H,2H perfluoroalkyl) phosphates where the alkyl group is even-numbered in the range C8-C18 and the salts have a fluorine content of 52.4% to 54.4% as determined on a solids basis.	No data	No data	No data	Food & feed packaging	No data
Diethanolamine single (1H,1H,2H,2H -perfluoro-alkyl) phosphate and dual-(1H,1H,2H,2H-perfluoro-alkyl) phosphate.	No data	No data	No data	Food & feed packaging	No data
Diethanol amino salts of mono- and bis (1H, 1H, 2H, 2H-perfluoroalkyl) phosphates	No data	No data	No data	Food & feed packaging	No data
2-Propenoic acid, 2-methyl-, 2-(dimethylamino)ethyl ester, polymer with 1-ethenyl-2-pyrrolidinone and	No data	1334473-84-5	$(C_{11}H_7F_{13}O_2.C_8H_{15}NO_2.C_6H_9NO)x.xC_2H_4O_2$	Food & feed packaging	No data

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate, acetate					
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)	No data	68228-00-2	No data	Food & feed packaging	No data
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	No data	1345817-52-8	No data	Food & feed packaging	No data
2Butanedioic 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	No data	1345817-52-8	$(C_{12}H_9F_{13}O_2.C_6H_{10}O_3.C_5H_6O_4.C_4H_6O_2)_x.xNa$	Food & feed packaging	No data
Perfluoropentanoic acid Perfluoropentadecanoic acid	PFPeA PFPeDA	2706-90-3 and 141074-63-7	No data	Industrial food processing and food transport equipment	Perfluoropenta acids (PFPEs) are used as lubricants during production, processing, and packaging of food.
Copolymer of TFE, PFMVE and 1-Butene, 4-bromo-3,3,4,4-tetrafluoro-, polymer with ethene, 1,1,2,2-tetrafluoroethene and 1,1,2-trifluoro-2-(trifluoromethoxy)ethene. intended to be cross-linked with triallylisocyanurate	No data	105656-63-1	$(C_4H_3BrF_4.C_3F_6O.C_2H_4.C_2F_4)_x$	Industrial food processing and food transport equipment	Monomers in Reg. 10/2011
				Food & feed packaging	No data
A copolymer of TFE and PFMVE modified with 1,3,5-triallyl isocyanurate or 1,3,5-triallyl cyanurate and	No data	26425-79-6 (TFE and PFMVE)	No data	Industrial food processing and food	Monomers in Reg. 10/2011

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-1,9-diene, manufactured and characterised as further described in the notification				transport equipment	
A copolymer of TFE and perfluoromethylvinyl ether (PFMVE) modified with 1,3,5-triallyl isocyanurate (TAIC) and 3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-1,9-diene, manufactured and characterized as further described in the notification	No data	26425-79-6	No data	Food & feed packaging	No data
A copolymer of TFE and PFMVE \ modified with 3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-1,9-diene and 1,3,5-triallyl cyanurate or 1,3,5-triallyl isocyanurate	No data	26425-79-6	No data	Food & feed packaging	No data
A perfluorocarbon cured elastomer (PCE) produced by terpolymerizing TFE, PFMVE and perfluoro-6,6-dihydro-6-iodo-3-oxa-1-hexane, and subsequent curing of the terpolymer with triallylisocyanurate and 2,5-dimethyl-2,5-di(t-butylperoxy)hexane	No data	116-14-3 (TFE) 1187-93-5 (PFMVE) 106108-22-9 (perfluoro-alkane) 193018-53-0 (terpolymer) 1025-15-6 (triallylisocyanurate) 78-63-7 (hexane)	No data C_4F_8O No data No data No data No data	Industrial food processing and food transport equipment Food & feed packaging	Monomers in Reg. 10/2011
A perfluorocarbon cured elastomer (PCE) produced by terpolymerizing TFE, , perfluoro-2,5-dimethyl-3,6-dioxanonane vinyl ether, and perfluoro-6,6-dihydro-6-iodo-3-oxa-1-hexene, and subsequent curing of the terpolymer with triallylisocyanurate and 2,5-dimethyl-2,5-di(t-	No data	116-14-3 2599-84-0 (vinyl ether) 106108-22-9 (hexene) 106108-23-0 (terpolymer) 1025-15-6	No data	Food & feed packaging	No data

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
butylperoxy)hexane		78-63-7			
Perfluorocarbon cured elastomers produced by polymerizing perfluoro (methyl vinyl ether) with TFE and perfluoro(8-cyano -5-methyl -3,6-dioxa -1-octene, followed by curing with trimethylallyl isocyanurate and/or triallyl isocyanurate, and with 2,5 -dimethyl -2,5-di (t-butylperoxy) hexane and as further described in this notification	No data	1187-93-5 (methyl vinyl ether) 116-14-3 69804-19-9 (per fluoro octene) 6291-95-8 1025-15-6 78-63-7	No data	Food & feed packaging	No data
A perfluorocarbon-cured elastomer (PCE) produced by terpolymerizing TFE perfluoro (2,5-dimethyl-3,6-dioxanone vinyl ether) and perfluoro (6,6-dihydro-6-iodo- 3-oxa- 1-hexene) and subsequent curing of the terpolymer by crosslinking with triallylcyanurate and vulcanizing with 2,5-dimethyl- 2,5-di (t-butylperoxy) hexane, as a 68% dispersion on finely divided silica	No data	116-14-3 (TFE) 2599-84-0 (vinyl ether) 106108-22-9 (perfluoro alkene) 106108-23-0 (terpolymer) 101-37-1 (triallycyanurate) 78-63-7 (hexane)	No data	Industrial food processing and food transport equipment Food & feed packaging	Monomers in Reg. 10/2011
1,9-Decadiene,3,3,4,4,5,5,6,6-,7,7,8,8-dodecafluoro-, polymer with TFE and trifluoro (trifluoromethoxy)ethene manufactured and characterized as further described in the notification.	No data	190062-24-9 (trifluoro ethene)	No data	Industrial food processing and food transport equipment Food & feed packaging	Monomers in Reg. 10/2011
3-cyclohexane-1-carboxylic acid, 6-((di-2-propenylamino)carbonyl)-,(1R,6R), reaction products with pentafluoroiodoethane-	No data	No data	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
tetrafluoroethylene telomer, ammonium salts					
Copolymer of 1,1-difluoroethylene, hexafluoropropene, TFE, and a halogenated alkene, optionally cured with triallyl isocyanurate and 2,5-dimethyl-2,5-di(tert-butylperoxy)hexane	No data	No data	No data	Food & feed packaging	No data
1-Propene,1,1,2,3,3,3-hexafluoro-polymer with 1,1-difluoroethene and TFE modified with triallyl isocyanurate and 3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-1,9-diene, manufactured and characterised as further described in the notification.	No data	25190-89-0 (polymer with ethene and TFE)	No data	Industrial food processing and food transport equipment Food & feed packaging	Monomers in Reg. 10/2011
Tetrafluoroethylene-hexafluoropropylene-vinylidene fluoride copolymers	No data	25190-89-0	$(CF_2CF_2)x$-$(CF_2CFCF_3)y$-(CF_2CH_2)	Food & feed packaging	No data
Tetrafluoroethylene-ethylene-3,3,4,4,5,5,6,6,6-nonafluoro-1-hexene terpolymer	No data	68258-85-5	No data	Food & feed packaging	No data
Ethene, 1,1,2,2-tetrafluoro-, polymer with 1,1,2-trifluoro-2-(1,1,2,2,2-pentafluoroethoxy)ethene	No data	31784-04-0	$(CF_2CF_2)x$-$(CF_2CFOC_2F_5)y$	Food & feed packaging	No data
Ethene, tetrafluoro-, polymer with 1,1-difluoroethene and trifluoro(trifluoromethoxy)ethene modified with 1,3,5-triallyl isocyanurate (TAIC) and 3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-1,9-diene, manufactured and characterized as further described in the notification	No data	56357-87-0	No data	Food & feed packaging	No data
Poly(hexafluoro-propylene oxide)	No data	25038-02-2	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
A polymer produced from TFE and 1,1,2,2-tetrafluoro-2-((1,2,2-trifluoroethenyl)oxy) ethane sulfonyl fluoride. The polymer is hydrolysed and may optionally be further neutralized to its ammonium salt.	No data	116-14-3 (TFE) 29514-94-1 (fluoride)	No data	Industrial food processing and food transport equipment Food & feed packaging	Monomers in Reg. 10/2011
Ethene, tetrafluoro-, polymer with 1,1-difluoroethene and trifluoro(trifluoromethoxy)ethene modified with 1,3,5-triallyl isocyanurate (TAIC) and 3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-1,9-diene, manufactured and characterized as further described in the notification	No data	56357-87-0 (ethene, fluoro, polymer mixture)	No data	Industrial food processing and food transport equipment	Monomers in Reg. 10/2011
Fluorocarbon cured elastomer produced by copolymerizing TFE and propylene and subsequent curing of the copolymer with triallylisocyanurate and 2,2'bis-(t-butylperoxy) diisopropylbenzene.	No data	116-14-3 (TFE) 115-07-1 (propylene) 27029-05-6 (copolymer) 1025-15-6 (triallylisocyanurate) 25155-25-3 (2,2'bis-(t-butylperoxy) diisopropyl benzen)	No data	Industrial food processing and food transport equipment Food & feed packaging	Monomers in Reg. 10/2011
Fluorocarbon cured elastomer produced by copolymerizing tetrafluoroethylene and propylene and subsequent curing of the copolymer with triallylisocyanurate and 2,2'-bis(tert-butylperoxy) diisopropylbenzene	No data	116-14-3 (TFE) 115-07-1 (propylene) 1025-15-6 (triallylisocyanurate) 25155-25-3 (benzene)	No data	Food & feed packaging	No data

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
Fluorocarbon cured elastomer produced by copolymerizing TFE and propylene and subsequent curing with triallylisocyanurate or triallylcyanurate and 2,2’-bis(tert-butylperoxy) diisopropylbenzene	No data	116-14-3 115-07-1 1025-15-6 101-37-1 (triallylcyanurate) 25155-25-3	$(C_6H_3F_9.C_2H_4.C_2F_4)x$	Food & feed packaging	No data
Ethylene tetrafluoroethylene copolymer	ETFE	25038-71-5	No data	Industrial food processing and food transport equipment	Monomer in Reg. 10/2011
Chlorotrifluoroethylene	ECTFE	79-38-9	No data	Industrial food processing and food transport equipment	Monomer in Reg. 10/2011
Copolymer of TFE, PFMVE and 1-iodo-2-bromotetra-fluoroethane intended to be cross-linked with triallylisocyanurate	No data	No data	No data	Food & feed packaging	No data
Copolymer perfluoroalkylacrylate	No data	No data	No data	Food & feed packaging	No data
Copolymers of 2-(perfluoroctylsulfonylamino methyl) ethylmethacrylate, 2,3-epoxypropylmethacrylate, ethoxyethylacrylate and methacryloylmethyl-trimethylammoniumchloride	No data	No data	No data	Food & feed packaging	No data
Copolymers of 2-perfluoroalkylethyl acrylate, 2-N,N-diethylaminoethyl methacrylate, glycidyl methacrylate, acrylic acid, and methacrylic acid2	No data	No data	No data	Food & feed packaging	No data
Copolymer of 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctylacrylate, 2-hydroxyethylacrylate, polyethylenglycolmonacryla	No data	No data	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
te and polyethylenglycoldiacrylate with a fluorine content of 35.4 – 45.1%					
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	No data	1440528-04-0	No data	Food & feed packaging	No data
Copolymer of 2-dimethylaminoethylmethacrylate and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctylmethacrylate, N-oxide, acetate, with a fluorine content of 45%	No data	No data	No data	Food & feed packaging	No data
Copolymer with 2,2'-ethylendioxydiethyldimethacrylat, 2-hydroxyethyl-methacrylate and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctylmethacrylate, acetate and/or malate	No data	No data	No data	Food & feed packaging	No data
Copolymer with 2-hydroxyethylmethacrylate, methacrylic acid, itaconic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctylmethacrylate, sodium salt	No data	No data	No data	Food & feed packaging	No data
Copolymer with 2-hydroxyethylmethacrylate, vinylpyrrolidon, acrylic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctylacrylate, sodium salt, with a fluorine content of 41.9%	No data	No data	No data	Food & feed packaging	No data
Copolymer with methacrylic acid, 2-hydroxyethylmethacrylate, polyethylenglycolmonacrylate and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctylacrylate,	No data	No data	No data	Food & feed packaging	No data

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
sodium salt with a fluorine content of 45.1%					
Perfluoroalkyl acrylate copolymer (CAS Reg. No. 92265-81-1) containing 35 to 40 weight percent fluorine, produced by the copolymerization of ethanaminium,N,N,Ntrimethyl-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	No data	92265-81-1	No data	Food & feed packaging	No data
Copolymers of 2-perfluoroalkylethyl acrylate, 2-N,N-diethylaminoethyl methacrylate, and glycidyl methacrylate.	No data	247047-61-6	No data	Food & feed packaging	No data
Copolymer of 2-perfluoroalkylethyl acrylate, 2-(dimethylamino)ethyl methacrylate, and oxidized 2-(dimethylamino)ethyl methacrylate	No data	479029-28-2 (2-(dimethylamino)ethyl methacrylate	No data	Food & feed packaging	No data
Copolymer of perfluorohexylethyl methacrylate, 2-N,N-diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, malic acid salt	No data	1225273-44-8	$(C_{14}H_{22}O_6.C_{12}H_9F_{13}O_2.C_{10}H_{19}NO_2.C_6H_{10}O_3)x.xC_4H_6O_5$	Food & feed packaging	No data
Copolymer of perfluorohexylethyl methacrylate, 2-N,N-diethylaminoethyl methacrylate, 2-	No data	863408-20-2	$(C_{14}H_{22}O_6.C_{12}H_9F_{13}O_2.C_{10}H_{19}NO_2.C_6H_{10}O_3)x.xC_2H_4O_2$	Food & feed packaging	No data

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, acetic acid salt					
Copolymer of perfluorohexylethyl methacrylate, 2-N,N-diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, acetic acid salt or malic acid salt.	No data	863408-20-2 or malic acid salt 1225273-44-8	No data	Food & feed packaging	No data
2,3-Epoxypropyl methacrylate - 2-ethoxyethyl acrylate - N-methylperfluorooctane-sulfonamidoethyl acrylate - trimethylethanolammonium chloride methacrylate, copolymer	No data	92265-81-1	No data	Food & feed packaging	No data
2-(Perfluorooctyl sulfonyl aminomethyl) ethyl methacrylate, copolymer [copolymer of fluorinated (meth)acrylate polymers]	No data	No data	No data	Food & feed packaging	No data
Methacrylic acid, 2-(dimethylamino)ethyl ester, polymers with gamma-omega-per- fluoro-C8-14-alkyl acrylate, acetates, N-oxides	No data	479029-28-2	No data	Food & feed packaging	No data
Methacrylic acid, 2-(dimethylamino)ethyl ester, polymers with gamma-omega-per- fluoro-C8-14-alkyl acrylate, N-oxides	No data	783306-31-0	No data	Food & feed packaging	No data
Perfluoroalkyl acrylate copolymers including: Perfluoroalkyl acrylate copolymer (Foraperle 321) 2-Propenoic acid,2-methyl-, 2-(dimethylamino) ethyl ester, polymers with g-w-perfluoro-C10-16-alkyl acrylate and vinyl acetate, acetates	No data	152521-13-6, 90451-86-8 196316-34-4	No data	Food & feed packaging	No data

Substance Name*	**Abbre-viation**	**CAS Number****	**Chemical Formula**	**Use**	**Function and Regulatory Listing†**
Acetic salts of the copolymer of perfluoroalkylethylacrylate, vinyl acetate and dimethyl aminoethylmetacrylate	No data	No data	No data	Food & feed packaging	No data
2-(Diethylamino)ethyl methacrylate – 2,3-epoxypropyl methacrylate – perfluoroalkyl(C4-C18)ethyl acryl	No data	No data	No data	Food & feed packaging	No data
2-(Dimethylamino)ethyl methacrylate – perfluoroalkylethyl acrylate – vinyl acetate, copolymer	No data	No data	No data	Food & feed packaging	No data
Fluorinated polyurethane anionic resin prepared by reacting perfluoropolyether diol, isophorone diisocyanate, 2,2-dimethylolpropionic acid and triethylamine	No data	328389-91-9 (polyurethane) 88645-29-8 (diol) 4098-71-9 (diisocyanate) 4767-03-7 (acid) 121-44-8 (triethylamine)	No data	Food & feed packaging	No data
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 triethylenetetraamine with a fluorine content of 54%	No data	* 355-43-1	No data	Food & feed packaging	No data
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	No data	464178-94-7	No data	Food & feed packaging	No data
Piperazinium, 1- (2-hydroxyethyl) -1-methyl-4-(perfluoro-1-oxoalkyl) -, chloride (1:1)	No data	103555-98-2	Cl–CnF2n+1C(O)NC4H8N+(CH3) CH2CH2OH	Non-food P&B packaging	PFAS that have been patented for use in paper packaging for non-food articles

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
Poly(oxy-1,2-ethanediyl), α-sulfo-ω-[(perfluoroalkyl)oxy]-, sodium salt	No data	138226-34-3	NH4+ CnF2n+1OC6H4SO3–	Non-food P&B packaging	
Poly(oxy-1,2-ethanediyl), α-[2-[[(pentadecafluoroheptyl) sulfonyl]propylamino]ethyl]-ω-hydroxy	No data	138226-35-4	CnF2n+1SO2N(C3H7)CH2CH2 (OCH2CH2)x OH	Non-food P&B packaging	
Poly(oxy-1,2-ethanediyl), α-[[4-[(perfluoroalkyl)oxy] phenyl]methyl]-ω-[[4-[(nonadecafluorononyl)oxy] phenyl]methoxy]	No data	138226-36-5	CnF2n+1OC6H4CH2(OCH2CH2)x OCH2C6H4O CnF2n+1	Non-food P&B packaging	
Ethanol, 2-[2-[(perfluoroalkyl)oxy]ethoxy]-, dihydrogen phosphate, disodium salt	No data	138473-75-3	2 Na+ CnF2n+1CH2OCH2CH2O CH2CH2OPO32–	Non-food P&B packaging	
Ethanol, 2-[methyl(perfluoroalkyl)amino]-, hydrogen phosphate (ester), ammonium salt	No data	138473-76-4	NH4+ PO2–(OCH2CH2N (CH3)CH2CH2CnF2n+1)2	Non-food P&B packaging	
Benzenesulfonic acid, 4-[(perfluoroalkyl)oxy]-, ammonium salt (1:1)	No data	138473-77-5	NH4+ CnF2n+1OC6H4SO3–	Non-food P&B packaging	
Carbamic acid, [(perfluoroalkyl)sulfonyl]propyl-, sodium salt	No data	138473-78-6	Na+ CnF2n+1SO2N(C3H7)COO–	Non-food P&B packaging	
Glycine, N-ethyl-N-(perfluoro-1-oxoalkyl)-, ammonium salt	No data	138473-79-7	NH4+ CnF2n+1C(O)N(C2H5)CH2 COO–	Non-food P&B packaging	
1-Propanaminium, N-(carboxymethyl)-N,N-diethyl-3-[propyl[(perfluoroalkyl)sulfonyl]amino]-, inner salt	No data	138473-80-0	CnF2n+1SO2N(C3H7)CH2CH2 CH2N+(C2H5)2CH2COO–	Non-food P&B packaging	
Poly(oxy-1,2-ethanediyl), α-[2-[[(perfluoroalkyl) sulfonyl]propylamino]ethyl]-ω-[2-[[(perfluoroalkyl) sulfonyl]propylamino]ethoxy]-	No data	138570-74-8	CnF2n+1SO2N(C3H7)O(CH2CH2 O)xCH2CH2N (C3H7)SO2Cn F2n+1	Non-food P&B packaging	
Potassium perfluoroalkane sulfonate	No data	2795-39-3	K+ CnF2n+1SO3–	Non-food P&B packaging	

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-N,N,N-trimethyl-, chloride (1:1)	No data	38006-74-5	Cl– CnF2n+1SO2 NHCH2CH2 CH2N+(CH3) 3	Non-food P&B packaging	
1-Alkanesulfonamide, perfluoro-N-[2-(phosphonooxy) ethyl]-N-propyl	No data	64264-44-4	CnF2n+1SO2 N(C3H7)CH2 CH2OP (=O)(OH)2	Non-food P&B packaging	
Ethanol, 2,2′-iminobis-, compd. with α-fluoro-ω-[2-(phosphonooxy)ethyl]poly(difluoromethylene) (2:1)4a NH2+ (CH2CH2OH) CnF2n+1CH2 CH2OPO3H– not specified 65530-63-4	No data	65530-63-4	NH2+ (CH2CH2OH) CnF2n+1CH2 CH2OPO3H–	Non-food P&B packaging	
1-Propanaminium, N-(carboxymethyl)-N,N-dimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, inner salt	No data	90179-39-8	CnF2n+1OC6 H4CH2(OCH 2CH2)x OCH2C6H4O CnF2n+1	Non-food P&B packaging	
Piperazinium, 1-(2-hydroxyethyl)-1-methyl-4-(perfluoro-1-oxoalkyl)-, chloride (1:1)	No data	103555-98-2	Cl– CnF2n+1C(O)NC4H8N+(CH3) CH2CH2OH	Non-food P&B packaging	
Oxirane, 2-[[(perfluoroalkyl)oxy]methyl]-	No data	122193-68-4	CnF2n+1CH2 CH2OCH2C2 OH3 (n =6)	Non-food P&B packaging	
Poly(oxy-1,2-ethanediyl), α-sulfo-ω-[(perfluoroalkyl)oxy]-, sodium salt	No data	138226-34-3	NH4+ CnF2n+1OC6 H4SO3–	Non-food P&B packaging	
Poly(oxy-1,2-ethanediyl), α-[2-[[(pentadecafluoroheptyl) sulfonyl]propylamino]ethyl]-ω-hydroxy	No data	138226-35-4	CnF2n+1SO2 N(C3H7)CH2 CH2 (OCH2CH2)x OH	Non-food P&B packaging	
Poly(oxy-1,2-ethanediyl), α-[[4-[(perfluoroalkyl)oxy] phenyl]methyl]-ω-[[4-[(nonadecafluorononyl)oxy] phenyl]methoxy]	No data	138226-36-5	CnF2n+1OC6 H4CH2(OCH 2CH2)x OCH2C6H4O CnF2n+1	Non-food P&B packaging	
Ethanol, 2-[2-[(perfluoroalkyl)oxy]ethoxy]-, dihydrogen phosphate, disodium salt	No data	138473-75-3	2 Na+ CnF2n+1CH2 OCH2CH2O CH2CH2OPO 32–	Non-food P&B packaging	

Substance Name*	Abbre-viation	CAS Number**	Chemical Formula	Use	Function and Regulatory Listing†
Ethanol, 2-[methyl(perfluoroalkyl)amino]-, hydrogen phosphate (ester), ammonium salt	No data	138473-76-4	NH4+ PO2–(OCH2CH2N(CH3)CH2CH2CnF2n+1)2	Non-food P&B packaging	
Benzenesulfonic acid, 4-[(perfluoroalkyl)oxy]-, ammonium salt (1:1)	No data	138473-77-5	NH4+ CnF2n+1OC6H4SO3–	Non-food P&B packaging	
Carbamic acid, [(perfluoroalkyl)sulfonyl]propyl-, sodium salt	No data	138473-78-6	Na+ CnF2n+1SO2N(C3H7)COO–	Non-food P&B packaging	
Glycine, N-ethyl-N-(perfluoro-1-oxoalkyl)-, ammonium salt	No data	138473-79-7	NH4+ CnF2n+1C(O)N(C2H5)CH2 COO–	Non-food P&B packaging	
1-Propanaminium, N-(carboxymethyl)-N,N-diethyl-3-[propyl[(perfluoroalkyl)sulfonyl]amino]-, inner salt	No data	138473-80-0	CnF2n+1SO2N(C3H7)CH2CH2 CH2N+(C2H5)2CH2COO–	Non-food P&B packaging	

PPA = polymer processing additive

*PFAS identified as being used in packaging from Glüge et al. (2020), PFAS in Paper and Board for Food Contact (Trier et al., 2018), Per and polyfluoroalkyl substances (PFAS in food contact material (RIVM, 2019), Product – Chemical Profile for Food Packaging Containing Perfluoroalkyl or Polyfluoroalkyl Substances (DTSC, 2020), BfR recommendations (BfR, 2020), US EPA food contact database (FDA-US, 2021), some patents and individual EFSA opinion substance reports.

**CAS number where data available.

†Regulatory listing mainly refers to Commission Regulation (EU) No. 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food, but in some cases US EPA and other listing is specified.

Table A.82. PFAS Positively Identified as Used/Were Used in Consumer Cookware. Source: see note below table.

Substance Name	Abbreviation	CAS Number**	Chemical Formula	Function and Listing in EU Regulation 10/2011
Perfluorooctanoic acid, ammonium salt	PFOA	3825-26-1	$C_8HF_{15}O_2$	Listed in Reg. 10/2011. Short-Chain PFAS. Emulsifier (PPA), but no current use. Previously used in manufacture of PTFE as a PPA. Listed in 10/2011 as only to be used in repeated-use articles, sintered at high temperatures.

Substance Name	**Abbreviation**	**CAS Number****	**Chemical Formula**	**Function and Listing in EU Regulation 10/2011**
2,3,3,3-tetrafluoro-2-heptafluoropropoxy)-propinoic acid; *or* perfluoro[2-(n-propoxy)propanoic acid]	GenX, HFPO-DA, FRD-903	13252-13-6	$C_6HF_{11}O_3$	PPA in Reg. 10/2011. Emulsifier. Replacement for PFOA in production of PTFE. For use as top layer for cooking, baking and roasting utensils, used at max temperature of 230 °C.
Hexafluoropropylene	No data	116-15-4	C_3F_6	Monomer in Reg. 10/2011. For use in temperature resistant polymer coating systems for frying, cooking and baking utensils.
Perfluoroalkyl vinyl ethers: Perfluorom*ethyl vinyl ether* Perfluoro*ethyl vinyl ether* Perfluoropropyl *vinyl ether*	*e.g.* PFMVE PFEVE PFPVE	*e.g.* 1187-93-5 10493-43-3 1623-05-8	C_3F_6O (PFMVE) C_4F_8O (PFEVE) $C_5F_{10}O$ (PFPVE)	Monomers listed in Reg. 10/2011. For use in temperature resistant polymer coating systems for frying, cooking and baking utensils and moulded articles for industrial use. Anti-stick coatings. For manufacturing of PTFE for use as top layer for cooking, baking and roasting utensils, used at max temperature of 230 °C.
Chlorotrifluoroethylene	No data	79-38-9	$ClCF{=}CF_2$	Monomer Listed in 10/2011 (The monomer is not a PFAS, the polymer is a PFAS).
Vinylidene fluoride	No data	75-38-7	CH_2CF_2	Monomer Listed in 10/2011. (The monomer is not a PFAS, the polymer is a PFAS).
(Perfluorobutyl)ethylene	No data	19430-93-4	$C_6H_3F_9$	Monomers listed in Reg. 10/2011. Co-monomer. For use in polymers, sintered at high temperatures.

Substance Name	Abbreviation	CAS Number**	Chemical Formula	Function and Listing in EU Regulation 10/2011
2,3,3,4,4,5,5-Heptafluoro-1-pentene	No data	1547-26-8	$C_5H_3F_7$	Monomer Listed in 10/2011. For fluoro-copolymers for their application as a PPA.
Perfluoro[(2-ethyloxy-ethoxy)acetic acid]], ammonium salt	No data	908020-52-0	$C_6HF_{11}O_4$ (+ NH_3)	Monomer and emulsifier (PPA) Listed in 10/2011. For use in temperature resistant polymer coating systems for frying, cooking and baking utensils. as FCM.
Sodium 4-perfluorononyloxy-benzenesulphonate	No data	e.g. 59536-17-3	$C_{15}H_4F_{19}NaO_4S$	Monomer and emulsifier (PPA) Only for use in coatings on kitchen utensils for cooking, baking, roasting etc.
Perfluoro[2-(poly(n-propoxy))propanoic acid] *or* perfluoropolyether carboxylic acid	No data	51798-33-5	$(C_3F_6O)_n$ $C_6HF_{11}O_3$	Monomer and emulsifier (PPA) Listed in 10/2011. For the emulsion polymerisation of FPs.
Perfluoro acetic acid, α-substituted with the copolymer of perfluoro-1,2-propylene glycol and perfluoro-1,1-ethylene glycol, terminated with chlorohexa-fluoropropyloxy groups	No data	329238-24-6	C_3F_6ClO-$[CF_2$-$CF(CF_3)$-$O]_n$-$[CF(CF_3)$-$O]_m$-CF_2COOH	PPA Listed in 10/2011. For FPs that are processed at temperatures at or above 340 °C and are intended for use in repeated use articles. Listed in 10/2011 as FCM.
2H-perfluoro-[(5,8,11,14-tetramethyl)-tetraethyleneglycol ethyl propyl ether]	No data	37486-69-4	No data	PPA Listed in 10/2011. For use in FPs that are processed at temperatures at or above 300 °C (in repeated use) or 360 °C (in single use) articles.
perfluoro{acetic acid, 2-[(5- methoxy-1,3-dioxolan-4-yl)oxy]}, ammonium salt	No data	1190931-27-1	No data	PPA Listed in 10/2011. Emulsifier/ dispersing agent (PPA). For FPs processed at temperatures at or above

Substance Name	Abbreviation	CAS Number**	Chemical Formula	Function and Listing in EU Regulation 10/2011
				370 °C.
3H-perfluoro-3-[(3-methoxy-propoxy)propanoic acid], ammonium salt	ADONA	958445-44-8	No data	PPA Listed in 10/2011. Emulsifier for use in the polymerisation of FPs that are processed at temperatures at or above 190 °C.
Polytetrafluoroethylene; *a polymer of:* tetrafluoroethylene	PTFE	9002-84-0 116-14-3	$(C_2F_4)_n$	Monomer Listed in 10/2011. Polymer for coating cookware, such as coatings on frying pans and articles for oven baking, and moulded articles for industrial use. Temperature resistant polymer coating systems for frying, cooking and baking utensils. Non-stick baking paper, films, foil and cooking bags.
Perfluoroalkoxy alkanes (PFA); *a copolymer of:* Perfluoroalkyl vinyl ether, *and* tetrafluoroethene	PFA	e.g. 26655-00-5, 1623-05-8 116-14-3	$C_7F_{14}O$	Polymer. Non-stick coating for pans and facilitates cleaning of the cookware.
Perfluoroethylene propylene, *or* Fluorinated Ethylene Propylene (FEP); *is a copolymer of:* Hexafluoropropene (see above), *and-* tetrafluoroethylene	FEP	25067-11-2 116-15-4 116-14-3	$(C_3F_6.C_2F_4)_n$	Polymer for coating cookware, such as frying pans and articles for oven baking, moulded articles for industrial use, and for use in non-porous (very good chemical resistance) films with excellent abrasion resistance. Lower melting temperature than PTFE.

Note: PFAS positively identified as used in packaging from Glüge et al. (2020), PFAS in Paper and Board for Food Contact (Trier et al., 2018), Per and polyfluoroalkyl substances (PFAS in food contact material (RIVM, 2019), Product – Chemical Profile for Food Packaging Containing Perfluoroalkyl or Polyfluoroalkyl Substances (DTSC, 2020), BfR recommendations (BfR, 2020), US EPA food contact database (FDA-US, 2021) and individual EFSA opinion substance reports. **CAS number where available. PPA = polymer processing additive, 10/2011 is a reference to Commission Regulation (EU) No. 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food.

Appendix A.3.5. Metal plating and manufacture of metal products

Table A.83. PFAS used (or patented) in metal plating processes and in the manufacture of metal products.

Group/substance	EU market (t/y)	Source
Metal plating		
3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctanesulphonic acid (6:2 FTS)	10-100 (registration dossier, volume not limited to the use of metal plating)	(UBA, 2022)
N,N,N,-triethylethanaminium 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonate (derivate of PFBS)	1-10 (registration dossier, volume not limited to the use of metal plating)	(NEA, 2017)
Potassium 1,1,2,2-tetrafluoro-2-(perfluorohexyloxo)ethane sulfonate (F-53)	Unknown – not registered.	(KEMI, 2015; Wang et al., 2020)
Potassium 2-(6-chloro-1,1,2,2,3,3,4,4 5 5,6,6-dodecafluorohexyloxy)-1,1,2,2-tetrafluoroethane sulfonate (F-53B)		
Perfluoroalkyl phosphinic acids	1-10 (registration dossier, volume not limited to the use of metal plating)	Glüge et al. (2020)
Perfluorohexanesulfonamides	Unknown	
1-Alkanesulfonamide, N,N'-bis(2,3-dihydroxy propyl)-perfluoro-	Unknown	
Tridecafluoroheptanamide	Unknown	
Alkanamide, N,N-bis(2,3-dihydroxy propyl)-perfluoro	Unknown	
N-Alkyl perfluoroalkane sulfonamides	Unknown	
1-Alkanesulfonamide, N,N'-[phosphonicobis(oxy-2,1,ethanediyl)]bis[perfluoro-N-methyl)	Unknown	
Fluorinated (meth)acrylate polymers	Unknown	
Manufacture of metal products		
Potassium perfluorohexane-1-sulphonate	Unknown	Glüge et al. (2020)
Potassium undecafluorocyclohexanesulphonate	Unknown	
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-N,N,N-trimethyl-, chloride (1:1)	Unknown	
1-Propanaminium, N-ethyl-3-[[(perfluoroalkyl)sulfonyl]amino]-N,N-dimethyl-, ethyl sulfate (1:1)	Unknown	
N-[3-(Dimethylamino)propyl]-N-[(perfluoroalkyl)sulfonyl]-β-alanine	Unknown	
Cyclohexanecarboxamide, N-[3-(dimethyl amino)propyl]-1,2,2,3,3,4,4 5 5,6,6-undecafluoro-	Unknown	
1-Propanaminium, N-(2-carboxyethyl)-N,N-dimethyl-3-[[(1,2,2,3,3,4,4 5 5,6,6-undecafluorocyclohexyl)carbonyl]amino]-, inner salt	Unknown	
1-Propanaminium, N-(2-carboxyethyl)-3-[[[1,2,2,3,3,4 5 5,6, 6-decafluoro-4-(trifluoromethyl)cyclohexyl]carbonyl] amino]-N,N-dimethyl-, inner salt	Unknown	

Group/substance	EU market (t/y)	Source
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoroalkyl) sulfonyl]amino]ethyl]-ω-hydroxy	Unknown	
N-(2,3-dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxo-2-[[2-(trifluoromethyl)phenyl]azo] butyramide	100-1 000 (registration dossier, volume not limited to the use of manufacture of metal products)	
6:2 FTS	10-100 (registration dossier, volume not limited to the use of manufacture of metal products)	
3,3'-[(2-chloro-5-methyl-p-phenylene)bis[imino(1-acetyl-2-oxoethylene)azo]]bis[4-chloro-N-[2-(4-chlorophenoxy)-5-(trifluoromethyl)phenyl]benzamide]	10-100 (registration dossier, volume not limited to the use of manufacture of metal products)	
Reaction mass of ammonium(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl) hydrogen phosphate and ammonium bis(3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl) phosphate	1-10 (registration dossier, volume not limited to the use of manufacture of metal products)	
Polytetrafluoroethylene (PTFE)	Unknown	
Polyvinylidene fluoride (PVDF)	Unknown	
Siloxanes and silicones, di-Me, Me 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl	Unknown	
Siloxanes and silicones, di-Me, Me 3-(1,1,2,2-tetra fluoro ethoxy)propyl, Me 3,3,4,4 5 5,6,6,7,7,8,8,8-tridecafluorooctyl	Unknown	
Hexafluoropropylene polymer (HFP)	Unknown	
Polychlorotrifluoroethylene (PCTFE)	Unknown	
Ethylene tetrafluoroethylene copolymer (ETFE)	Unknown	
Fluorinated ethylene propylene (FEP)	Unknown	
Ethylene-chlorotrifluoroethylene copolymer (ECTFE)	Unknown	
Perfluoralkoxy polymer (PFA)	Unknown	
Ethylene-tetrafluoroethylene-hexafluoro propylene copolymer	Unknown	
Hexafluoropropylene-tetrafluoroethylene-vinylidene fluoride copolymer (THV)	Unknown	
Ethylene-hexafluoropropylene-perfluoropropyl vinyl ether-tetrafluoroethylene copolymer	Unknown	
Hexafluoropropylene-perfluoropropyl vinyl ether-tetra fluoroethylene-vinylidene fluoride copolymer	Unknown	
Ethane, 1,1,2,2-tetrafluoro-1-(2,2,2-trifluoro ethoxy-)	Unknown	
Pentane, 1,1,1,2,2,3,4 5 5 5-decafluoro-	Unknown	
Cyclopentane, 1,1,2,2,3,3,4-heptafluoro-	1-10 (registration dossier, volume not limited to the use of manufacture of metal products)	
Fluororubber (FKM, FFKM, FPM)	Unknown	
Fluorosilicone (FVMQ)	Unknown	

Appendix A.3.6. Consumer mixtures

Table A.84. Examples for specific PFAs used for certain applications (Glüge et al., 2020).

Use	Name	CAS number
General cleaning agents	Potassium *N*-ethylperfluoroalkane-sulfonamido acetate	67584-51-4 67584-52-5 67584-53-6 67584-62-7 2991-51-7
	Ammonium (n:2) fluorotelomer phosphate monoester	65530-71-4
	3,3-Dichloro-1,1,1,2,2-pentafluoropropane	422-56-0
	Methyl perfluoroalkyl ether	22410-44-2 375-03-1 163702-07-6
Cleaning agents for dishes and glasses	Perfluoroalkylcarboxylic acids (PFCAs)	375-22-4 335-67-1
Glass cleaners	Potassium *N*-ethyl perfluoroalkane-sulfonamide acetate	67584-53-6 2991-51-7
Carpet and upholstery cleaners	Perfluoroalkylphosphonic acids (PFPAs) Perfluoroalkylphosphinic acids (PFPiAs)	40143-76-8 40143-78-0 52299-26-0 40143-77-9 610800-34-5 1240600-40-1 1240600-41-2 40143-79-1 500776-81-8
Dry cleaning of metals, glass, ceramics, etc.	Ethyl perfluoroalkyl ether	163702-05-4
Guitar strings and piano keys	Polyvinylidene fluoride, PVDF	24937-79-9
Lubricants for string instruments	PTFE micropowder	9002-84-0
Anti-fog agents	Fluorotelomer alcohols (FTOHs) and fluorotelomer ethoxylates (FTEOs): 6:2FTOH; 8:2 FTOH; 10:2FTOH; 6:2FTEOs	647-42-7 678-39-7 865-86-1 52440-44-4
Coating for Guitar strings	PTFE (polytetrafluoroethylene)/FEP (fluorinated ethylene propylene)/ETFE (ethylene tetrafluoroethylene)	9002-84-0 25067-11-2 25038-71-5
Cleaning for optical devices	1,1,1,2,2,3,4,5,5,5-Decafluoropentane	138495-42-8
Floor polish	Potassium *N*-ethylperfluoroalkane-sulfonamidoacetate	67584-51-4 67584-52-5 67584-53-6 67584-62-7 2991-51-7

Products sampled in 2016 were analysed for PFBA, PFBS, PFHxA, PFHxS, PFOA, PFNA, PFDA, PFOS, 4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 10:2 FTOH, 6:2 FTA, 8:2 FTA, 10:2 FTA, MeFOSA, EtFOSA, MeFOSE, EtFOSE; products sampled in 2014 were analysed for PFBA, PFBS, PFHxA, PFHxS, PFHpA, PFOA, PFNA, PFDA, PFOS, 4:2 FTOH, 6:2 FTOH, 8:2 FTOH, 4:2 FTS, 6:2 FTS, PFUnDa, PFDoDA, PFTriA, PFTeA, 6:2 diPAP, 6:2 mono-PAP, 8:2 diPAP, 8:2 mono-PAP. Errors in dealing with the units were corrected using Blom and Hanssen (2015). Blank cells symbolise that no PFAS could be detected (see Table A.85).

Table A.85. Sum of PFAS and TOF content for several consumer mixtures (Borg and Ivarsson, 2017).

Product	Year of product sampling	Sum (PFAS) [µg/L]	Total organic fluorine [µg/L]
Rinse aid 1	2016	0.75	<1 000
Rinse aid 2	2016	1.2	2 000
Floor polish	2016	1 840	18 500
Furniture polish	2016		<1 000
Car polish 1	2014	3 370	3 000
Car polish 2	2014	3 130	8 000
Dishwasher 1	2014	9 680	14 500
Dishwasher 2	2014	2.6	<1 000
Waterproofing textiles – Wash in	2014	660	<1 000

Table A.86. Measured PFAS content for several consumer mixtures(Blom and Hanssen, 2015; Borg and Ivarsson, 2017). Blank cells indicate that the PFAS in question could not be detected.

Product	Year of product sampling	PFBA [µg/L]	PFHxA [µg/L]	PFOA [µg/L]	PFDA [µg/L]	6:2 FTOH [µg/L]	8:2 FTOH [µg/L]
Rinse aid 1	2016			0.75			
Rinse aid 2	2016			0.75	0.47		
Shoe wax	2016			0.53			
Floor polish	2016	0.47		0.59		1834	
Furniture polish	2016						
Car wax 1	2016			1.4			
Car wax 2	2016			2.8			
Car polish 1	2014			0.47		263	3 110
Car polish 2	2014			0.509			31 130
Dishwasher 1	2014	1.12		0.555		391	9 290
Dishwasher 2	2014						2.62
Waterproofing textiles – Wash in 1	2014						630
Waterproofing textiles – Wash in 2	2014						680

Table A.87. Quantified PFAs content for a group of polishes and cleaners (Favreau et al., 2017). Samples were collected in 2012/2013 in Switzerland. In total, the product content was analysed regarding 41 different PFAS.

Product group	6:2 FTS		N-EtFOSE		6:2 FTOH	
	Occurrence	Content [mg/kg]	Occurrence	Content [mg/kg]	Occurrence above LOQ	Content [mg/kg]
Cleanser	0 out of 24	-	1 out of 24	1.2	1 out of 24	4
Polish	1 out of 18	0.1	0 out of 18	-	1 out of 18	26.0

Table A.88. Determined Fluorotelomers for cleaning products, waxes and sealants. The products were sampled in 2011 and 2013 in the USA (Liu et al., 2015).

Product group	Product number	6:2 FTOH [mg/kg]	8:2 FTOH [mg/kg]	10:2 FTOH [mg/kg]
Commercial carpet care liquid	A1	3.28	2.95	1.46
	A2	105		
	A3		0.194	
Household carpet/fabric-care liquids and foams	B1			
	B2		0.372	
Floor waxes and wood/stone sealants	C1	1.59	1.4	
	C2	4.01	0.442	
	C3	24.2	6.91	
	C4	331	92.4	
	C5	13.9	0.477	

Table A.89. Quantified PFAS in cleaners (Kotthoff et al., 2015). Six products were used for measuring PFAS except FTOHs and three products for FTOHs. The samples were collected in 2010 in Germany.

	PFOA [mg/kg]	PFOS [mg/kg]	PFTeA [mg/kg]	6:2 FTOH [mg/kg]	8:2 FTOH [mg/kg]	10:2 FTOH [mg/kg]
Maximum concentration	0.0011	0.0016	0.0008	38.7	547.1	81.9
Median concentration	0.0007	0.0012	0	38	63	22.6

Table A.90. Sum of 45 analysed PFAS and extractable organic fluorine (EOF) for several cleaning products sampled in 2021 in the Netherlands (Pancras, 2021).

Product	Sum (PFAS) [µg/kg]	Extractable organic fluorine [µg/kg]
Dishwash 1	0	590
Dishwash 2	6	10 000
Dishwash 3	4	1 200
Dishwash 4	7	630
Cleaning agent 1	5	4 600
Cleaning agent 2	5	470
Cleaning agent 3	6	250
Cleaning agent 4	8	460
Cleaning agent 5	16	150

Table A.91. Sum of 16 analysed PFAS and TOF for four different anti-fog sprays purchased online (Herkert et al., 2022).

Product	Sum (PFAS) [µg/kg]	Total organic fluorine [µg/kg]
Spray A	25 000	20 700
Spray B	327	221
Spray C	529	202
Spray D	566	190

Appendix A.3.7. Cosmetics

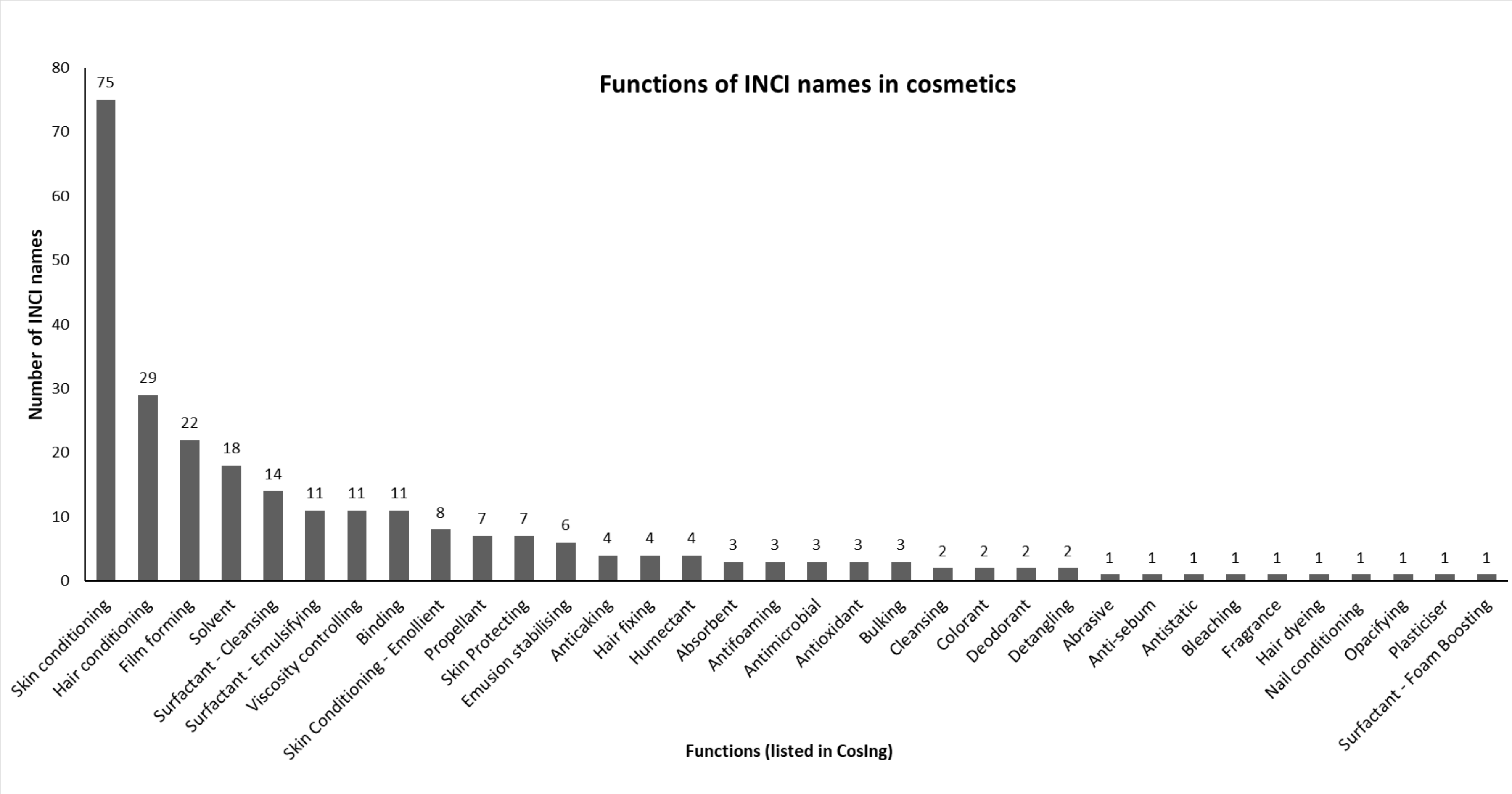


Figure A.23. Functions of INCI names in cosmetics. Searched for 169 INCI names in total in the CosIng database, for 9 INCI names the function section was empty or "not reported" was given as information. Total function count surpasses 160, as several INCI names have several listed functions.

Table A.92. PFAS INCI names found in cosmetic products in the different databases. Shown are only the most frequent found PFAS among all databases and the top ten ranked PFAS within each database (CosmEthics, Kemiluppen and ToxFox), rank within database (the number of products in which the according PFAS was found). Note that a hyphen (-) equals not found in this database, grey cells represent the top 10 ranked substances of all databases and/or within a database).

PFAS INCI names	CAS No	EC/List no	Fluorinated carbons	Covered by any existing or pending PFAS restriction	Rank CosmEthics (number of products)	Rank Kemiluppen (number of products)	Rank ToxFox (number of products)
PTFE	9002-84-0	618-337-2	fluoropolymer	**No**	1 (541)	1 (64)	1 (321)
C9-15 fluoroalcohol phosphate	223239-92-7	-	C9-C15	Existing, included in the PFOA restriction in POPs and the C9-C14 PFCAs restriction in REACH	3 (208)	3 (27)	3 (76)
Perfluorodecalin	306-94-5	206-192-4	C10/fully F	**No**	6 (64)	5 (13)	4 (70)
Perfluorooctyl triethoxysilane	51851-37-7	257-473-3	C6	Existing, included in the (3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl) silanetriol and TDFAs restriction in REACH	2 (232)	4 (14)	-
Perfluorononyl dimethicone	-	-	C9	Existing, included in the PFOA restriction in POPs and the C9-C14 PFCAs restriction in REACH	4 (111)	11.5 (5)	5 (60)
Polyperfluoromethylisopropyl ether	69991-67-9	615-044-1	C4	**No**	8 (55)	7 (9)	6 (55)
Octafluoropentyl methacrylate	355-93-1	206-596-0	C4	**No**	12 (31)	2 (31)	-
Acetyl trifluoromethylphenyl valylglycine	379685-96-8	609-497-4	C1	**No**	7 (63)	7 (9)	-
Methyl perfluorobutyl ether	163702-07-6	-	C4	**No**	11 (34)	7 (9)	-
Polyperfluoroethoxymethoxy	-	-	C1+C2	**No**	9 (47)	11.5 (5)	-

PFAS INCI names	CAS No	EC/List no	Fluorinated carbons	Covered by any existing or pending PFAS restriction	Rank CosmEthics (number of products)	Rank Kemiluppen (number of products)	Rank ToxFox (number of products)
difluoroethyl PEG phosphate							
Ammonium C6-16 perfluoroalkylethyl phosphate	65530-72-5/ 65530-71-4/ 65530-70-3	685-094-7/ 809-881-3/ 809-882-9	C6-C16	Existing, included in the PFOA restriction in POPs and the C9-C14 PFCAs restriction in REACH	14 (25)	10 (6)	-
Methyl perfluoroisobutyl ether	163702-08-7	605-340-9	C4	**No**	16 (23)	9 (7)	-
Trifluoropropyldimethyl/trimethylsiloxysilicate	-	-	C1	**No**	10 (42)	23.5 (1)	-
Polyperfluoroisopropyl ether	25038-02-2	626-882-2	C3	**No**	21.5 (7)	19 (2)	11 (1)
Trifluoromethyl C1-4 alkyl dimethicone	-	-	C1	**No**	25 (6)	-	8 (7)
PEG-8 trifluoropropyl dimethicone copolymer	-	-	C1	**No**	30 (3)	-	9 (2)
HC yellow no. 13	10442-83-8	443-760-2	C1	**No***	-	-	7 (16)
Polysilicone-7	146632-08-8	-	C8	Existing, included in the PFOS restriction in POPs	-	-	11 (1)
Polysilicone-10	-	-	unclear	unclear	-	-	11 (1)

* Included in the Cosmetics Regulation provisions: Annex III/26 (EC, 2022).

Appendix A.3.8. Ski wax

Table A.93. Examples of PFAS-based ski waxes, applications and normalised prices from a review in 2020.

Trade name	Supplier	Specific application (e.g ski, snowboard, glide wax, grip wax)	Normalised price (€/g, from supplier websites)
Glider for skis 1,Swix HF7 Violet	Swix	Ski, glide	1.006
Swix vr 55 krystal line grip wax silber-violet	Swix	Ski, glide, grip	0.38
Glider 1, Swix LF6 Blue	Swix	Ski, glide	0.23
Vauhti Quick HF Skin Care 80mL Red	Vauhti	Ski, snowboard, glide	0.34
SWIX FC10X CERA F/ 7045951824131	Swix	Ski	4
SWIX FC7X CERA F/ 7045951824117	Swix	Ski	4.5
5SKIGO C22 GUL/ 7393753630048	Skigo	Ski	2.33
TOKO JETSTREAM POWDER BLUE/7613186169350	TOKO JETSTREAM	Ski	3.8
BRIKO MAPLUS FP4/ 8028383990079	BRIKO MAPLUS	Ski	1.8
REX RACING SERVICE 63	rex	Ski	4.3
VAUHTI FC LDR/ 6419696087204	VAUHTI	Ski	5.4
GALLIUM GIGA SPEED MAXFLUOR/ 4948575107853	GALLIUM	Ski	6.33
SWIX HF MARATHON/ 7045951580778	Swix	Ski	1.93
SKIGO HF UNIVERSAL/ 7393753630208	SKIGO	Ski	1.22
TOKO HF HOTWAX/ 4250423601612	TOKO	Ski	0.68

Table A.94. Examples of fluorine-free waxes, applications and normalized prices from a review in 2020.

Trade Name	Supplier	Specific application (e.g ski, snowboard, glide wax, grip wax)	Normalised price (€/g, from supplier websites)
BP77 Base prep Hard 900 g BP77 Base prep Hard 100 g	Swix	Ski, snowboard, glide wax	0.09 0.08
BP88 Base Prep Medium,900 g BP88 Base Prep Medium, 180 g	Swix	Ski, snowboard, glide wax	0.11 0.11
BP99 Base Prep Soft, 180 g	Swix	Ski, snowboard, glide wax	0.09
CH10X Yellow, 0 °C/10 °C, 180 g, CH10X Yellow, 0 °C/10 °C, 60 g CH10X Yellow, 0 °C/10 °C,	Swix	Ski, snowboard, glide wax	0.18 0.14 0.09

Trade Name	Supplier	Specific application (e.g ski, snowboard, glide wax, grip wax)	Normalised price (€/g, from supplier websites)
900 g			
CH12X Combi, 54 g CH12X Combi, 900 g	Swix	Ski, snowboard, glide wax	0.17 0.08
CH3X Cold Powder, 30 g	Swix	Ski, snowboard, glide wax	0.91
CH5X Turquoise, -8 °C/ -14 °C, 180 g CH5X Turquoise, -8 °C/ -14 °C, 60 g CH5X Turquoise, -8 °C/ -14 °C, 900 g	Swix	Ski, snowboard, glide wax	0.15 0.17 n.a.
CH7X Violet, -2 °C/-8 °C, 180 g CH7X Violet, -2 °C/-8 °C, 60 g CH7X Violet, -2 °C/-8 °C, 900 g	Swix	Ski, snowboard, glide wax	0.09 0.20 0.09
CH8X Red, -4 °C/4 °C, 180 g CH8X Red, -4 °C/4 °C, 60 g CH8X Red, -4 °C/4 °C, 900 g	Swix	Ski, snowboard, glide wax	0.09 0.20 0.09
F4-100C Glidewax Liquid 100 mL F4-80NC liquid 80 mL F4-150C spray 150 mL F4-180 solid 180 g F4-60 solid 60 g F4-900 solid 900 g F4-75C paste 75 mL	Swix	Ski, snowboard, glide wax	0.14 0.15 0.09 0.14 0.20 0.15
F6LNC Blue liquid glide, -6 °C/-15 °C,80 mL	Swix	Ski, snowboard, glide wax	0.21
F7LNC Violet liquid glide 1 °C/-6 °C,80 mL	Swix	Ski, snowboard, glide wax	0.18
F8LNC Red liquid glide 0 °C/+10 °C, 80 mL	Swix	Ski, snowboard, glide wax	0.18
HS10 Yellow, 0 °C/+10 °C, 180 g HS10 Yellow, 0 °C/+10 °C, 60 g	Swix	Ski, snowboard, glide wax	0.19 0.28
HS5 Turquoise, -10 °C/ -18 °C, 180 g HS5 Turquoise, -10 °C/ -18 °C, 60 g HS5 Turquoise, -10 °C/ -18 °C, 900 g	Swix	Ski, snowboard, glide wax	0.19
HS6 Blue, -6° C/-12 °C, 180 g HS6 Blue, -6 °C/-12 °C, 60 g HS6 Blue, -6 °C/-12 °C, 900 g HS6 Blue liquid 125 mL	Swix	Ski, snowboard, glide wax	0.20 0.30 0.12 0.12
Marathon White Fluor Free, 40 g	Swix	Ski, snowboard, glide wax	0.93
Marathon Black Fluor Free, 180 g Marathon Black Fluor Free, 40 g	Swix	Ski, snowboard, glide wax	0.99 1.13
N15 Swix Skin Care N15 Swix Skin Care Spray 150 mL	Swix	Ski, snowboard, glide wax	

Trade Name	Supplier	Specific application (e.g ski, snowboard, glide wax, grip wax)	Normalised price (€/g, from supplier websites)
			0.17
N19 Glide Wax For Skin Skis	Swix	Ski, snowboard, glide wax	n.a.
Phantom	DPS	Ski, snowboard, glide wax	n.a.
Quick Wax	mountainFlow	Ski, snowboard	n.a.
Fast Wax	Nordic waxes	Ski	n.a.
Natural Skiwax bar Natural Skiwax spray Natural Skiwax paste Natural Skiwax stick Natural Skiwax fluid	Holmenkol	Ski	n.a.
Green Ice Wax	Green Ice Wax	Ski, snowboard	n.a.
Purl Wax	Purl	Ski, snowboard	n.a.
Wend Mf non-fluoro race bar with meadowfoam 300 g Wend Mf non-fluoro race bar with meadowfoam 100 g	Wend	Ski, glide	0.34 0.39
Fluoro-Free Competition (FFC) Series	Dominator	Ski, snowboard, glide wax	n.a.
ELITE	Dominator	Ski, snowboard, glide wax	n.a.
Start RG Race Glider Red	Start	Ski, snowboard, glide wax	n.a.
Start RG Race Glider purple	Start	Ski, snowboard, glide wax	n.a.
Start RG Race Glider blue	Start	Ski, snowboard, glide wax	n.a.
Start RG Race Glider green	Start	Ski, snowboard, glide wax	n.a.
Start RG Race Glider base	Start	Ski, snowboard, glide wax	n.a.
Universal yellow Solid Fluor Free	MAPLUS	Ski, snowboard	n.a.
Universal Red Solid Fluor Free	MAPLUS	Ski, snowboard	n.a.

Appendix A.3.9. Applications of fluorinated gases

Table A.95. Fluorinated gases currently in commercial use for Heating, Ventilation, Air Conditioning and Refrigeration (HVACR) and other uses – Organised by HFC Code (Source: Stakeholder consultation and literature review carried out during the development of the restriction proposal).

Substance	Code	CAS number	General use	Sub-use	Specific use
Fluoroform (trifluoromethane) (Not in scope)	HFC-23	75-46-7	Refrigeration (in blend, see R-473A)		
Difluoromethane (Not in scope)	HFC-32	75-10-5	Refrigeration and heat pumps	Domestic and commercial air conditioning	Split non-ducted units
				Domestic refrigeration	
				Industrial refrigeration	
				Transport refrigeration	
				Electronics cooling	
				Water and space heating heat pumps	
1,1,1,2,2,3,4,5,5,5-Decafluoropentane	HFC-43-10mee	138495-42-8	Solvents	Precision & electronics cleaning, commercial & industrial cleaning and carrier solvent & lubricants	
			Other	Immersion cooling of electronics	
Pentafluoroethane	HFC-125	354-33-6	Fire suppressant	Total flooding agent	Protection of high value assets and electrical equipment. Military aircraft engine nacelles.
1,1,1,2-Tetrafluoroethane	HFC-134a	811-97-2	Foam-blowing agents	Rigid polyurethane foam (commercial refrigeration and domestic appliances)	Commercial refrigeration
				Rigid polyurethane boardstock and panels	Continuous panel production
				Rigid polyurethane spray foam	Open-cell spray foam
			Propellants	Consumer propellants	Consumer products

Substance	**Code**	**CAS number**	**General use**	**Sub-use**	**Specific use**
				Commercial and industrial	Technical uses where non-flammability and inhalation safety required – air dusters and lubricant aerosols
			Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems, bottler coolers, ice cream cabinets, standalone plug-in displays.
				Industrial refrigeration	Data centre cooling
				Transport refrigeration	Refrigerated shipping containers
				Domestic and commercial air conditioning	Split non-ducted units – in areas with high ambient temperature, chillers
				Mobile air conditioning	New cars, air conditioning in trains
				Electronics cooling	
				Water and space heating heat pumps	
				Heat pump clothes dryers	
			Other	Plasma coating of HDPE	
1,1,1-Trifluoroethane	*HFC-143a*	*420-46-2*	*Used in blends (see below)*		
1,1-Difluoroethane (Not in scope)	*HFC-152a*	*75-37-6*	*Foam-blowing agents*	*Rigid polyurethane spray foam*	*Open cell spray foam*
				Extruded polystyrene foam (XPS)	*XPS*
			Propellants	*Consumer propellants*	*Consumer aerosols*
			Cover gases	*Magnesium casting*	
1,1,1,2,3,3,3-Heptafluoropropane	*HFC-227ea*	*431-89-0*	*Foam-blowing agents*	*Rigid polyurethane boardstock and panels*	*Rigid boardstock, continuous panel production*
				Rigid polyurethane spray foam	
				Rigid polyurethane pipe-in-pipe	*Block foam*

Substance	Code	CAS number	General use	Sub-use	Specific use
				and block foam	*manufacture/pipe insulation*
				Polyurethane integral skin	
				Phenolic foam	
			Fire suppressant	*Total flooding agent & streaming agent*	*Protection of high value assets and electrical equipment.*
1,1,1,3,3,3-Hexafluoropropane	*HFC-236fa*	*690-39-1*	*Fire suppressant*	*Streaming agent*	*Protection of high value assets and electrical equipment. Onboard aircraft.*
1,1,1,3,3-Pentafluoropropane	HFC-245fa	460-73-1	Foam-blowing agents	Rigid polyurethane foam (commercial refrigeration and domestic appliances)	Domestic appliances, commercial refrigeration
				Rigid polyurethane boardstock and panels	Rigid boardstock, continuous panel production
				Rigid polyurethane spray Foam	Closed-cell spray foam
				Rigid Polyurethane pipe-in-pipe and block foam	Block foam manufacture/pipe insulation
			Refrigeration and heat pumps	Domestic and commercial air conditioning	Chillers
			Solvents	Solvent in aerosols; precision & electronics cleaning and commercial & industrial cleaning	
1,1,1,3,3-Pentafluorobutane	HFC-365mfc	406-58-6	Foam-blowing Agents	Rigid polyurethane foam (commercial refrigeration and domestic appliances)	Commercial refrigeration
				Rigid Polyurethane (PU) Boardstock and Panels	Rigid boardstock, continuous panel

Substance	Code	CAS number	General use	Sub-use	Specific use
					production
				Rigid polyurethane spray Foam	Closed-cell spray foam
				Rigid polyurethane pipe-in-pipe and block foam	Block foam manufacture/pipe insulation
				Polyurethane integral skin	Skin foams
				Phenolic foam	Phenolic boardstock production/phenolic block foams
			Solvents	Solvent in aerosols; precision & electronics cleaning and commercial & industrial cleaning	
2-Bromo-3,3,3-trifluoroprop-1-ene	BTP, 2-BTP, Halotron BrX	1514-82-5	Fire suppressant	Streaming agent	Niche applications aviation/military to replace halon 1211
1-Chloro-1,2,2,2-tetrafluoroethane	HCFC-124	2837-89-0	Fire suppressant	Total flooding agent	Support existing/legacy systems.
1,1-Dichloro-1-fluoroethane (Not in scope)	HCFC-141b	1717-00-6	Foam-blowing agents	Rigid polyurethane (PU) Boardstock and Panels	Rigid boardstock (believed to be largely phased out)
			Solvents	Solvent in aerosols; precision & electronics cleaning and commercial & industrial cleaning	Largely phased out.
3,3-Dichloro-1,1,1,2,2-pentafluoropropane	HCFC-225ca/cb	422-56-0	Solvents	Solvent in aerosols; precision & electronics cleaning and commercial & industrial cleaning	Largely phased out.
1,1,-Difluoroethylene (Not in scope)	HFO-1132a	75-38-7	Refrigeration (in blend, see R-473A)		
2,3,3,3-Tetrafluoropropene	HFO-1234yf	754-12-1	Refrigeration and heat pumps	Domestic refrigeration	Domestic fridge/freezer
				Commercial refrigeration	Bottler coolers

Substance	Code	CAS number	General use	Sub-use	Specific use
				Industrial refrigeration	
				Mobile air conditioning	New cars
				Domestic and commercial air conditioning	Stationary air conditioning and chillers
			Other	Plasma coating of HDPE	
Trans-1,3,3,3-Tetrafluoroprop-1-ene	HFO-1234ze(E)	1645-83-6	Refrigeration and heat pumps	Domestic and commercial air conditioning	Stationary air conditioning and chillers
1,3,3,3-Tetrafluoropropene	HFO-1234ze(E)	29118-24-9	Foam-blowing agents	Rigid polyurethane foam (commercial refrigeration and domestic appliances)	Commercial refrigeration
				Rigid polyurethane spray foam	Open-cell spray foam
				Extruded polystyrene foam (XPS)	Emerging use as XPS
			Propellants	Consumer propellants	Non-flammable propellant and novelty aerosols
			Refrigeration and heat pumps	Domestic refrigeration	Domestic fried/freezer
				Commercial refrigeration	Bottler coolers
				Industrial refrigeration	Data centre cooling
				Heat pumps	Steam production
Trans-1,1,1,4,4,4-hexafluorobut-2-ene	HFO-1336mzz(E)	66711-86-2	Refrigeration and heat pumps	Domestic and commercial air conditioning	Chillers
				Water and space heating heat pumps	
Cis-1,1,1,4,4,4-Hexafluoro-2-butene	HFO-1336mzz(Z)	692-49-9	Foam-blowing agents	Rigid polyurethane foam (Commercial Refrigeration and Domestic Appliances)	Domestic appliances, commercial refrigeration
				Rigid polyurethane (PU) Boardstock and Panels	Emerging use as rigid boardstock
				Phenolic foam	Emerging use as phenolic boardstock production/phenolic block foams
			Propellants	Consumer propellants	
			Solvents	Solvent in aerosols; Precision &	

Substance	Code	CAS number	General use	Sub-use	Specific use
				electronics cleaning, commercial & industrial cleaning and carrier solvent & lubricants	
1-Chloro-2,3,3,3-tetrafluoropropene	HCFO-1224yd	3110-38-1	Refrigeration and heat pumps	Domestic and commercial air conditioning	Chillers
				Heat pumps	Steam production
(Z)-1-Chloro-2,3,3,3-tetrafluoropropene	HCFO-1224yd(Z)	111512-60-8	Foam-blowing agents	Rigid polyurethane foam (commercial refrigeration and domestic appliances)	
			Refrigeration and heat pumps	Water and space heating heat pumps	
			Solvents	Solvent in aerosols; Precision & electronics cleaning, commercial & industrial cleaning and carrier solvent & lubricants	
Trans-1-chloro-3,3,3-trifluoropropene	HCFO-1233zd(E)	102687-65-0;	Foam-blowing agents	Rigid polyurethane foam (commercial refrigeration and domestic appliances)	Domestic appliances, commercial refrigeration
				Rigid Polyurethane (PU Boardstock and Panels	Emerging use as rigid boardstock
				Phenolic foam	Emerging use as phenolic boardstock production/ phenolic block foams
			Refrigeration and heat pumps	Domestic and commercial air conditioning	Chillers
				Heat pumps	Steam production
			Solvents	Solvent in aerosols; precision & electronics cleaning, commercial & industrial cleaning and carrier solvent & lubricants	

Substance	Code	CAS number	General use	Sub-use	Specific use
Methoxytridecafluoro-heptene isomers	MPHE, SionTM	No data	Solvents	Precision & electronics cleaning, commercial & industrial cleaning and carrier solvent & lubricants	Methoxytridecafluoro-heptene isomers
			Other	Debinding agent, 3D printing	
Dodecafluoro-2-methyl-3-pentanone	FK-5-1-12	756-13-8	Cover gases	Magnesium casting	
			Fire Suppressant	Local streaming agent	
1,1,2,2-Tetrafluoro-1-(2,2,2-trifluoroethoxy) ethane	HFE-347pc-f2	406-78-0	Solvents	Precision & electronics cleaning, commercial & industrial cleaning	
Methyl perfluoropropyl ether	HFE-7000	375-03-1	Solvents	Carrier solvent & lubricants	
Methyl nonafluorobutyl ether + Methyl nonafluoroisobutyl ether	HFE-449mccc/ HFE-449s1 (HFE-7100)	163702-08-7 163702-07-6	Solvents	Precision & electronics cleaning, commercial & industrial cleaning and carrier solvent & lubricants	
			Other	Immersion cooling of electronics	
			Cover gas	Magnesium casting	
			Solvents	Cultural heritage paper preservation	
1-Ethoxy-nonafluorobutane	HFE-569mccc/ HFE-569sf2 (HFE-7200)	163702-05-4	Solvents	Precision & electronics cleaning, commercial & industrial cleaning and carrier solvent & lubricants	
			Cover gas	Magnesium casting	
3-Methoxyperfluoro(2-methylpentane)	HFE-7300	132182-92-4	Solvents		
3-Ethoxyperfluoro(2-methylhexane)	HFE-7500	297730-93-9	Solvents	Commercial & industrial cleaning	
			Refrigerant	Electronics cooling, military applications	
Hexafluoroisopropanol	HFIP	920-66-1	Solvents	3D printing processing liquid	

Substance	Code	CAS number	General use	Sub-use	Specific use
2,3,3,3-tetrafluoro-2-(trifluoromethyl)-propanenitrile	C4-FN	42532-60-5	Insulating gas	Electrical switchgear (high voltage)	
1,1,1,3,4,4,4-heptafluoro-3-(trifluoromethyl)-2-butanone	C5-FK	756-12-7	Insulating gas	Electrical switchgear (medium voltage)	
(E)-1,1,1,2,3,4,5,5,5-nonafluoro-4-(trifluoromethyl)- 2-pentene	FA-188	3709-71-5	Foam-blowing agents	Polyurethane foam, closed cell	
Perfluorohexane (n- and iso-)	FC-72/PF-5060	1064697-81-9	Solvents	Heat transfer agent	
				Cultural heritage paper preservation	
Perfluorotripropylamine (perfluamine)	FC-3283	338-83-0	Solvents	Heat transfer agent	
Perfluorotributylamine	FC-40/FC-3284	311-89-7 (1064698-37-8)	Solvents	Heat transfer agent	
			Other	Immersion cooling of electronics	
Perfluoro-N-propyl-morpholine (mixture of isomers)	FC-770	1093615-61-2	Solvents	Heat transfer agent	
Perfluoro-2-methylpentane	Flutec RC1	355-04-4	Foam-blowing agents	Rigid closed-cell PU/PIR insulation foam	
1,1,2,3,3,3-Hexafluoropropene, oxidized, polymd. (Perfluoropolyether, PFPE)	Galden HT-55 /HT-70	69991-67-9	Other	Immersion cooling of electronics	
HFC Blend (HFC-125/143a/134a)	R-404A	N/A	Refrigeration and heat pumps	Commercial refrigeration	Centralised supermarket systems, Condensing unit systems. Ice cream cabinets/ice machines, standalone plug-in displays
				Transport refrigeration	Refrigerated shipping containers, reefer ships

Substance	Code	CAS number	General use	Sub-use	Specific use
				Industrial refrigeration	Large-scale food storage and processing
HFC Blend (HFC-32/125/134a)	R-407A	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems
HFC Blend (HFC-32/125/134a)	R-407C	N/A	Refrigeration and heat pumps	Transport refrigeration	Reefer ships
				Domestic and commercial air conditioning	Self-contained units, Split non-ducted units, Multi-split units, Split ducted units, chillers
				Industrial refrigeration	Data centre cooling
				Mobile air conditioning	Trains
				Water and space heating heat pumps	
				Heat pump clothes dryers	
HFC Blend (HFC-32/125/134a)	R-407E	N/A	Refrigeration and heat pumps	Domestic and commercial air conditioning	
HFC Blend (HFC-32/125/134a)	R-407F	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems
HFC Blend (HFC-32/125/134a)	R-407H	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems
HFC Blend (HFC-32/HFC-125)	R-410A	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems
				Domestic and commercial air conditioning	Self-contained units, Split non-ducted units, Multi-split units, Split ducted units, chillers
					Variable Refrigerant Flow (VRF) air conditioning system
				Domestic refrigeration	
				Industrial refrigeration	Data centre cooling
				Transport refrigeration	

Substance	Code	CAS number	General use	Sub-use	Specific use
				Water and space heating heat pumps	
HFC Blend (HFC-125/134a/isobutane)	R-422A	N/A	Refrigeration and heat pumps	Industrial refrigeration	Large-scale food storage and processing
HFC Blend (HFC-125/134a/isobutane)	R-422D	N/A	Refrigeration and heat pumps	Industrial refrigeration	Large-scale food storage and processing
HFC Blend (HFC-125/143a/propane/ isobutane)	R-428A	N/A	Refrigeration and heat pumps	Industrial refrigeration	Large-scale food storage and processing
HFC Blend (HFC-125/143a/134a/ isobutane)	R-434A	N/A	Refrigeration and heat pumps	Industrial refrigeration	Large-scale food storage and processing
HFC/HFO Blend (HFC-32/152a/HFO-1234ze(E))	R-444B	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend (HFC-32/HFO-1234ze(E)/600))	R-446A	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend HFC-32/125/HFO-1234ze	R-447A	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend (HFC-32/125/HFO-1234ze (E))	R-447B	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend (HFC-32/125/134a HFO-1234yf/1234ze(E))	R-448A	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems, standalone display cases
HFC/HFO Blend (HFC-32 /125 /134a/HFO-1234yf)	R-449A (XP40)	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems, standalone display cases
				Heat pumps	
HFC/HFO Blend (HFC-32/125/134a HFO-1234yf)	R-449B	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems
HFC/HFO Blend (HFC-134a/HFO-1234ze(E))	R-450A	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems

Substance	Code	CAS number	General use	Sub-use	Specific use
HFC/HFO Blend (HFC-32/125/HFO-1234yf)	R-452A	N/A	Refrigeration and heat pumps	Commercial refrigeration	Condensing unit systems
				Transport refrigeration	New and retrofitted vehicles, low GWP replacement in refrigerated shipping containers
HFC/HFO Blend (HFC-32/125/HFO-1234yf)	R-452B	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend (HFC-32/HFO-1234yf)	R-454A	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend (HFC-32/HFO-1234yf),	R-454B	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend (CO2/HFC-32/HFO-1234yf)	R-455A	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/HFO Blend (HFC-32/134a/HFO-1234ze(E))	R-456A	N/A	Refrigeration and heat pumps	Transport refrigeration	Shipping containers
HFC/HFO Blend (HFC-32 /HFO-1234yf/1234ze(E))	R-459A	N/A	Air conditioning	Commercial and industrial air conditioning	Ducted self-contained units
HFC/CO2 blend (CO2/HFC-32/HFC-125)	R-469A	N/A	Refrigeration	Transport and industrial refrigeration	Ultra low-temperature applications such as reefers, chemical processes and environmental simulation
HFC/HFO/CO2 Blend (CO2/HFC-23/HFC-125/HFO-1132a)	R-473A	N/A	Refrigeration	Transport and industrial refrigeration	Ultra low-temperature applications such as reefers, chemical processes and environmental simulation
HFC Blend (HFC-125/143a)	R-507A	N/A	Refrigeration and heat pumps	Industrial refrigeration	Large-scale food storage and processing

Substance	Code	CAS number	General use	Sub-use	Specific use
HFC/PFC Blend (HFC-23/PFC-116)	R-508B	N/A	Refrigeration	Industrial refrigeration	Ultra low-temperature vaccine preservation
HFC/HFO Blend (HFO-1234yf/HFC-134a)	R-513A	N/A	Refrigeration and heat pumps	Domestic and commercial air conditioning	Chillers
				Transport refrigeration	Refrigerated shipping containers
				Commercial refrigeration	Condensing units
				Industrial refrigeration	Ultra low-temperature vaccine preservation
				Heat pumps	
HFC/HFO Blend (HFO-1234yf/HFC-134a)	R-513B	N/A	Refrigeration and heat pumps	Transport refrigeration	Low GWP replacement in refrigerated shipping containers
HCO/HFO Blend HFO-1336mzz(Z) / trans-1,2 dichloroethene (1130(E))	R-514A	N/A	Refrigeration and heat pumps	Domestic and commercial air conditioning	Chillers
HFC/HFO Blend (HFC-227ea/HFO-1234ze(E))	R-515B	N/A	Refrgeration and heat pumps	Domestic and commercial air conditioning	Chillers
Difluorochloromethane (HFC-22) 1-Chloro-1,2,2,2-tetrafluoroethane (HCFC-124) 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123) d-limonene	HCFC Blend A, NAF-S-III	75-45-6 2837-89-0 306-83-2 5989-27-5	Fire suppressant	Total flooding agent	Support existing/legacy systems.
1,1,1,2-Tetrafluoroethane (HFC-134a) Pentafluoroethane (HFC-125) Carbon Dioxide	HFC Blend B Halotron II,	811-97-2 354-33-6 124-38-9	Fire suppressant	Total flooding agent	Support existing/legacy systems.

The R notation used for blends in this table is a globally used commercial shorthand way of naming refrigerants established by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The R notation is a safety classification based on toxicity and flammability data (ASHRAE, 2021).

Table A.96. List of specific fluorinated gas substances identified in different commercial applications.

Entry	Substance	Code	Structure
1	Fluoroform (trifluoromethane)	HFC-23 (not in scope)	CHF3
2	Difluoromethane	HFC-32 (not in scope)	CH2F2
3	1,1,1,2,2,3,4,5,5,5-Decafluoropentane	HFC-43-10mee	CF3-CF2-CHF-CHF-CF3
4	Pentafluoroethane	HFC-125	CF3-CHF2
5	1,1,1,2-Tetrafluoroethane	HFC-134a	CF3-CH2F
6	1,1,1-Trifluoroethane	HFC-143a	CF3-CH3
7	1,1-Difluoroethane	HFC-152a (not in scope)	CHF2-CH3
8	1,1,1,2,3,3,3-Heptafluoropropane	HFC-227ea	CF3-CHF-CF3
9	1,1,1,3,3,3-Hexafluoropropane	HFC-236fa	CF3-CH2-CF3
10	1,1,1,3,3-Pentafluoropropane	HFC-245fa	CF3-CH2-CHF2
11	1,1,1,3,3-Pentafluorobutane	HFC-365mfc	CF3-CH2-CF2-CH3
12	1-Chloro-1,2,2,2-tetrafluoroethane	HCFC-124	CHClF-CF3
13	1,1-Dichloro-1-fluoroethane	HCFC-141b (not in scope)	CCl2F-CH3
14	3,3-Dichloro-1,1,1,2,2-pentafluoropropane	HCFC-225ca/cb	CF3-CF2-CHCl2
15	1,1,-Difluoroethylene	HFO-1132a (not in scope)	CH2=CF2
16	1-Chloro-2,3,3,3-tetrafluoropropene	HFO-1224yd(Z) *	CHCl=CF-CF3
17	1-Chloro-3,3,3-trifluoro-1-propene	HFO-1233zd(E) **	CHCl=CH-CF3
18	2,3,3,3-Tetrafluoropropene	HFO-1234yf	CH2=CF-CF3
19	Trans-1,3,3,3-tetrafluoroprop-1-ene	HFO-1234ze(E) ***	CHF=CH-CF3
20	1,3,3,3-Tetrafluoropropene	HFO-1234ze(E) ***	CHF=CH-CF3
21	Trans-1,1,1,4,4,4-hexafluorobut-2-ene	HFO-1336mzz(E)	CF3-CH=CH-CF3
22	Cis-1,1,1,4,4,4-Hexafluoro-2-butene	HFO–1336mzz(Z)	CF3-CH=CH-CF3
23	(Z)-1-Chloro-2,3,3,3-tetrafluoropropene	HCFO-1224yd *	CHCl=CF-CF3
24	Trans-1-chloro-3,3,3-trifluoropropene	HCFO-1233zd(E) **	CHCl=CH-CF3
25	2-Bromo-3,3,3-trifluoroprop-1-ene	BTP, 2-BTP, Halotron BrX	CH2=CBr-CF3

Entry	Substance	Code	Structure
26	Methoxytridecafluoro-heptene isomers	MPHE, SionTM	CF3-CF2-CF2-CF=C(OCH3)-CF2-CF3
27	Dodecafluoro-2-methyl-3-pentanone	FK-5-1-12 (fluoroketone)	CF3-CF(CF3)-C(=O)-CF2-CF3
28	1,1,2,2-Tetrafluoro-1-(2,2,2-trifluoroethoxy) ethane	HFE-347pc-f2	CF3-CH2-O-CF2-CHF2
29	Methyl perfluoropropyl ether	HFE-7000	CH3-O-CF2-CF2-CF3
30	Methyl nonafluorobutyl ether + Methyl nonafluoroisobutyl ether	HFE-449mccc/HFE-449s1 (HFE-7100)	CH3-O-CF2-CF2-CF2-CF3
31	1-Ethoxy-nonafluorobutane	HFE-569mccc/HFE-569sf2 (HFE-7200)	CH3-CH2-O-CF2-CF2-CF2-CF3
32	3-Methoxyperfluoro(2-methylpentane)	HFE-7300	CF3-CF2-CF(OCH3)-CF-(CF3)2
33	3-Ethoxyperfluoro(2-methylhexane)	HFE-7500	CF3-CF(CF3)-CF(OCH2-CH3)-CF2-CF2-CF3
34	Hexafluoroisopropanol	HFIP	CF3-CHOH-CF3
35	2,3,3,3-tetrafluoro-2-(trifluoromethyl)- propanenitrile	C4-FN	CF3-CF(CN)-CF3
36	1,1,1,3,4,4,4-heptafluoro-3-(trifluoromethyl)-2-butanone	C5-FK	(CF3)2-CF-C(=O)-CF3
37	(E)-1,1,1,2,3,4,5,5,5-nonafluoro-4-(trifluoromethyl)- 2-pentene	FA-188	CF3-CF=CF-CF-(CF3)2
38	Perfluorohexane (n- and iso-)	FC-72/PF-5060	CF3-(CF2)4-CF3
39	Perfluorotripropylamine (perfluamine)	FC-3283	(CF3-CF2-CF2)3N
40	Perfluorotributylamine	FC-40	(CF3-CF2-CF2-CF2)3N
41	Perfluoro-N-propylmorpholine (mixture of isomers)	FC-770	O-(CF2-CF2)2-N-CF2-CF2-CF3/O-(CF2-CF2)2-N-CF-(CF3)2
42	Perfluoro-2-methylpentane	Flutec RC1	CF3-CF2-CF2-CF-(CF3)2
43	1,1,2,3,3,3-Hexafluoropropene, oxidized, polymerized (Perfluoropolyether, PFPE)	Galden HT-55/HT-70	CF2=CF-CF3, oxidized and polymerized

Table A.97. Intended applications of EU-28 total supply of fluorinated gases. Source data reported in the F-gas Report (EEA, 2020).

Intended Applications of Bulk Supply	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Refrigeration, air conditioning and heating and heat transfer fluids	61 377	58 720	58 678	65 964	61 045	58 574	58 999	95 688	74 023	78 016	78 012	68 676	55 600
Foams, incl pre-blended polyols	14 286	15 284	11 709	11 503	9 234	8 526	8 202	12 967	9 572	10 157	11 521	11 083	11 041
Aerosols	9 090	11 131	8 425	9 547	7 808	10 950	9 690	8 954	9 421	8 728	10 300	9 109	8 964
Fire protection	649	491	531	1 677	2 508	1 451	1 385	1 858	818	585	502	324	130
Electrical Equipment	1 197	1 422	969	1 290	1 344	1 362	1 419	622	745	813	951	640	534
Semiconductor, photovoltaics and other electronics manufacture	127	301	184	265	243	169	71	1 057	715	755	924	897	769
Other or unknown applications	1 861	2 219	2 185	1 501	1 437	1 684	1 132	6 402	1 485	997	1 266	1 450	1 255
Totals (including SF_6)*	**88 586**	**89 569**	**82 681**	**91 749**	**83 620**	**82 715**	**80 898**	**127 547**	**96 779**	**100 050**	**103 475**	**92 179**	**78 293**
SF_6 quantities	1 810	1 860	1 435	1 522	1 502	1 490	1 535	716	909	1 004	1 225	843	727
Totals (excluding SF_6)	**86 776**	**87 709**	**81 246**	**90 227**	**82 118**	**81 225**	**79 363**	**126 831**	**95 870**	**99 046**	**102 250**	**91 336**	**77 566**

Notes: *SF_6 included in these figures but not separated out per application. SF_6 is primarily used in electrical equipment because of its excellent electrical insulation properties and in the manufacture of semiconductors; it also has other medical uses and as a cover gas in magnesium casting for installations using less than 850 kg SF_6/y until 2018 (sand casting may still be permitted). It is outside of the scope of this project however and therefore it has been deducted.

Table A.98. Estimation of quantities of Hydrofluoroolefins Used , as a Proportion of F-gases in Products and Equipment for EU-28. Source: EEA (2020).

Intended Applications of Bulk Supply Usage data for F-gases	**2016**	**2017**	**2018**	**2019**
Refrigeration, air conditioning and heating and heat transfer fluids	78 016	78 012	68 676	55 600
Foams, incl pre-blended polyols	10 157	11 521	11 083	11 041
Aerosols	8 728	10 300	9 109	8 964
Fire protection	585	502	324	130
Electrical Equipment	813	951	640	534
Semiconductor, photovoltaics and other electronics manufacture	755	924	897	769
Other or unknown applications	997	1 266	1 450	1 255
Totals (including SF_6)*	100 050	103 475	92 179	78 293
SF_6 quantities	1 004	1 225	843	727
Totals (excluding SF_6)	**99 046**	**102 250**	**91 336**	**77 566**
Usage data for unsaturated HFOs and HCFOs	6 305	13 400	17 767	18 350
HFO & HCFO Proportion of total (%)*	**6**	**13**	**19**	**24**
Notes: *HFOs are mainly used in mobile air conditioning and commercial refrigeration (stakeholder discussions).				

Appendix A.3.10. Medical devices

Table A.99. Medical implants and materials (Teo et al., 2016). Additions from stakeholder.

		PTFE	PE	PA	PDMS	PHA	PET	PP	Silicone	LCP	Parylene	PMMA	PEK	PI	SU8
Anestesiology	Epidural catheters	✓	✓	✓											
Cardiovascular	Pacemaker, implantable defibrillator/cardioverter, left ventricular assist device, heart valves, artificial blood vessels, catheters, suture material and pledgets	✓	✓	✓	✓	✓	✓	✓							
Dental	Dentures, dental implants, orthodontic wires, dental instrumentation											✓			
Ear, nose, throat	Cochlear implants, stapes implants, nasal implants for nose reconstruction		✓		✓				✓	✓	✓				
Gastroenterology and urology	Penile implants, neurostimulator in sacral nerve stimulation, foley catheter, artificial urinary sphincter implant, hernia or vaginal mesh	✓	✓	✓	✓	✓	✓	✓	✓						
General and plastic surgery	Synthetic blood vessels, breast implants, cheek, jaw and chin implants, lip implant, titanium surgical implants, hip implant, clamps for high frequency surgery	✓			✓		✓	✓	✓						
Hematology and pathology	Central venous access device, peripherally inserted central catheter	✓	✓	✓											
Neurology	Implantable pulse generator for deep brain stimulation, neuroprosthetiocs, cognitive protheses, catheters	✓	✓	✓	✓	✓				✓	✓			✓	✓
Opthalmic	dexamethasone intravitreal implant, retinal prothesis, artificial inocular lens, glaucoma valve, fluocinolone ophthalmic implant, orbital implant, catheters	✓	✓	✓								✓			
Orthopedic	Orthopedic implants, medical splints	✓	✓			✓	✓	✓	✓		✓	✓	✓		

Table A.100. Main coatings reported during the CfE and additional stakeholder information.

Product name	CAS number
SF-coat-AS-20280	2414599-48-9
SF-coat-SFE-X008	441049-46-2
AsahiGuard-AG-E082	746622-86-6
ETFE, PTFE, PCTFE	25038-71-5/9002-84-0/9002-83-9

Table A.101. Main applications of PFAS in technology (analytical, biological and laboratory) reported by stakeholders (RINA, 2021).

PTFE in wire and heat shrink, sensors, tubing/housing, gaskets, seals, O-rings, connectors, coatings of device surfaces such as mixing equipment, tip fittings and diaphragm pumps.
F-Gases as a carrier for analytical testing, and the following gases R-134a, R-404A, R-407F, R-410A, R-449A, R-452A, R-507A, R-508B and R-513A.
FKM (Polymer of 1,1-difluoroethene/1,1,2,3,3,3-hexafluoroprop-1-ene) and FFKM in O-rings, sealing surfaces, seals, diaphragms, vacuum pumps, gauges and controllers.
FFKO in vacuum pumps, gauges and controllers.
ETFE in diaphragms, hoses, valves, housings, pumps, sealing surface and seals.
ECTFE in vacuum pumps, diaphragm pumps, tubes, seals, bushes, cables and valves.
FEP-encapsulated FFKM O-ring in vacuum pumps, gauges and controllers.
FEP for non-reactive inert tubes/tubing, in liquid handling instruments, seals and bushes.
Fluoromethacrylate within pharmaceutical consumables and equipment as filters, hydrophobic and oleophobic membranes, connectors, seals and spacer materials.
PVDF for tubes, seals and bushes.
FPM and FFPM in O-rings in pumps.
Polychlorotrifluoroethylene PCTFE in laboratory equipment for liquid handling such as bottle top dispensers, bottle top burettes, tubes, seals, and bushes.
PFA in non-reactive inert tubes/tubing, in liquid handling instruments and for seals.
Perfluoro(tributylamine) as a reagent standard for mass spectroscopy.
PFPE-oils (perfluoroalkyl ethers/alkanes + aromatics - more than 10 ether linkages) as a lubricant.

Table A.102. Polymers and elastomers used in medical devices (including medical device production).

Polymer	Abbreviation	CAS number
fluoroelastomers	FKM	Multiple nr's
perfluoroelastomer	FFKM	
polychlorotrifluoroethylene	PCTFE	9002-83-9[a]
polyvinylidene fluoride	PVDF	9011-17-0
fluorosilicones fluorosilicone rubber	FVQM FVQM	63148-56-1 64706-30-5
polytetrafluorethene	PTFE	9002-84-0
poly(tetrafluoroethylene-co-perfluoro(propylvinyl ether))		26655-005
poly(ethene-co-chlorotrifluoroethene)	ECTFE	25101-45-5
tetrafluoroethylene-hexafluoropropene copolymer	FEP	25067-11-2
poly(ethylene-co-tetrafluoroethylene)	ETFE	25038-71-5
1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene and tetrafluoroethene	THV	25190-89-0
1-propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene, 1,1,1,2,2,3,3-heptafluoro-3-[(trifluoroethenyl)oxy]propane and tetrafluoroethene	THVP	68182-34-3

[a] main use as pharmaceutical packaging

Table A.103. List of additional uses of PFASs in medical devices (as mentioned by stakeholders).

PFAS substance	Additional uses
PTFE, PFA, FEP and some fluorinated surfactants	Are used to make printed circuit boards and formed or moulded components. Printed circuit boards are used in many applications including medical equipment.
Ethyl trifluoroacetate	Used in crown structures to label antibodies.
Hexafluoroisopropanol	Used for QC for oligonucleotides.
2,2,2-Trifluoroethyl methacrylate (TFEMA)	Incorporated into intra ocular lenses.
Ethyl trifluoroacetate and ethyl pentafluoropropionate	Used as raw materials to synthetise 2-NTA and BFPP. (2-NTA and BFPP are active molecules in are required for medical signal generation).
PBSF (perfluoro-1-butanesulfonyl fluoride)	Surgical staples use a PBSF surfactant as a coating to approximate skin for surgical or other acute wounds.

PFAS substance	**Additional uses**
C6-PFAS	Filters used in intensive-care ventilators and breathing systems. Packaging of sterilised medical devices; they provide a permeable bacterium barrier. Single-use detergent-proof washbowls. Wound dressing.
Perfluorohexyloctane (F_6H_8) + $C_{14}F_{13}H_{17}$ (CAS nr 133331-77-8)	Sterile eye drops- non-active invasive medical device- for ophthalmic use: for lubrication of dry, irritated eyes - stabilization of the tear film and relief of symptoms of dry eyes.
PTFE and PET with fluorinated C6 based side-chain coatings	Hydrophobic/oleophobic membranes. Are used for (sterile) venting of several medical devices, for example cell culture devices, analytical devices (e.g. PCR cartridges for Corona virus and other viruses and bacteria), blood tube systems for dialyzer systems, tube systems for eye surgery, microfluidic chips for "organ on a chip" pharmaceutical research systems, pharmaceutical packaging of liquids going into human body
C6-Fluoretelomer-acrylate-copolymer	In Surgical gowns, to create a protective liquid barrier.
	Surface protection of rubber stoppers for pharmaceutical syringes and pharmaceutical vials
PFTE	Printed circuit boards are envisioned to enable wireless charging of medical implants. This will allow for fewer large scale invasive surgeries to the patient, substantially reducing patient risk. Heat sealing for intravenous bags. Filters for medical masks. This includes COVID-19 mask, which are used in extreme numbers: 29 – 91 billion per year globally (Muensterman et al., 2022) Medical splints coatings to ensure the proper healing of fractured bones.
PFA or FEP	Polymer coating of aluminium MDI
Fluorinated monomers: hexafluoroisopropyl methacrylate (CAS 3063-94-3) Trifluoroethyl methacrylate (CAS 352-87-4) Bis (hexafluoroisopropyl) itaconate (CAS 98452-82-5)	Are used in the manufacture of plastics used in the production of permeable contact lenses. Usually, material content varies typically between 4% and 60% as a percentage of the finished polymer.
PFPE	Medical and silicone tapes, wound dressings are single-use disposable medical/surgical supplies, some of which rely on PFPE-enabled release liners for their function.
Fluoropolymer	Polyimide films with fluoropolymer resin are used for cryogenic bags for long term storage of various blood and tissue components that will not be compromised during the preservation process.
	Orthodontic wires for aligning teeth
	Ostomy bags (filters), AED’s, release liners.

Table A.104. Estimated fluorinated gas greenhouse warming potential (GWP) based on reported volumes of medical gases in the EU (responses to CfE and ECHA database) and assuming an emission factor of 0.1%.

CAS number	Substance	GWP	production volume (t/y) midpoint		CO_2 equivalents (t/y)	
811-97-2	HFC-134a	1 430	25 487	77.7%	36 446	77.1%
431-89-0	HFC-227ea	3 320	3 068	9.4%	10 186	21.6%
163702-08-7 163702-07-6	HFE7100	2 597	556	1.7%	165	0.3%
163702-06-5 163702-05-4	HFE7200	59	55	0.2%	3	<0.01%
375-03-1	HFE7000	575	8	<0.1%	3.2	0.0%
138495-42-8	HFC-43-10mee	1 640	5.5	<0.1%	1.6	0.0%
57041-67-5	desflurane	989	1	<0.1%	0.2	0.0%
26675-46-7	isoflurane	350	0.25	<0.1%	0.1	0.0%
28523-86-6	*sevoflurane*	216	0.25	<0.1%	0.1	0.0%
13838-16-9	*enflurane*	583	0.25	<0.1%	0.1	0.0%
151-67-7	*halothane*	41	0.25	<0.1%	0.0	0.0%
76-19-7	perfluoropropane (PFC-218)	8 830	0.25	<0.1%	1.3	0.0%
76-16-4	perfluoroethane (PFC-116)	12 200	0.15	<0.1%	1.2	0.0%
355-25-9	perfluorobutane (PFC-3-1-10)	8 860	0.1	<0.1%	0.4	0.0%
115-25-3	octafluorocyclobutane	10 300	0.05	<0.1%	0.3	0.0%
75-73-0	tetrafluoromethane	7 390	0.03	<0.1%	0.1	0.0%
	HFE7000		32 806	100%	47 252	100%

Table A.105. Other polymeric PFASs (non-PTFE).

Fluoropolymer	**Main properties which result in the uses**	**Uses**
Ethylenechlorotrifluoroethylene (ECTFE)	Chemically and biologically inert/unreactive, non contaminating, flexible	Laboratory, analytical and medical equipment, internal connection parts in vacuum pumps, diaphragm pumps, tubes, seals, bushes, cables and valves
Ethylenetetrafluoroethylene (ETFE)	Chemically and biologically inert/unreactive	Laboratory, analytical and medical equipment, internal connection parts in chemical resistant vacuum pumps, chemical resistant diaphragm pumps, housing cover, diaphragms, hoses, valves
Polyvinylidene fluoride (PVDF)	Non-reactive inert chemically stable, flexible, thermally resistant	Analytical instruments/measurement devices, tubes, seals, bushes
Fluoromethacrylate	Chemically and biologically inert/unreactive, durable, non-contaminating, flexible	Pharmaceutical consumables and equipment, tubes, seals and bushes. Liquid handling instrument parts in contact with media, water purification systems in dialysis
Fluorinated ethylene propylene (FEP)	Chemically and biologically inert/unreactive, durable, non-contaminating, flexible, suitable for tubes	Analytical instruments/measurement devices, tubes, for sealing applications, for laboratory liquid handling equipment

Table A.106. Other uses of PFAS.

Uses	**Main properties for uses**
Perfluoropolyether (PFPE) oils	Low outgassing behaviour, high vacuum capable, UV-stability, inert/unreactive, in manufacturing of analytical equipment (and micro electronics)
Pentadecafuorooctanoic acid (PFOA)	Non-implantable medical devices: Flexible medical endoscopes and video processors for image sensors for the chip lens.
Tris(nonafluorobutyl)amine, Heptacosafluorotributylaminie (PFTBA), fluorinert FC-43, Perfluorobutylamine	Analytical mass spectroscopy standard. Also used as solvent and blood substitute

Appendix A.3.15. Lubricants

Table A.107. Examples of PFASs used in lubricant applications.

CAS no	Name(s) as specified in the sources consulted	Use in lubricant application	PFAS type	PFAS Sub group
69991-67-9	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.	Base oil	Polymeric	PFPE Y
69991-61-3	Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd.	Base oil	Polymeric	PFPE Z
60164-51-4	Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], α-(1,1,2,2,2-pentafluoroethyl)-ω-	Base oil	Polymeric	PFPE K
113114-19-5	Oxetane, 2,2,3,3-tetrafluoro-, homoPolymer, fluorinated	Base oil	Polymeric	PFPE D
161075-14-5	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, Polymerized, reduced hydrolyzed	Additive	Polymeric	PFPE
370097-12-4	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd., reduced, hydrolysed reaction products with ammonia	Additive	Polymeric	PFPE-CO-NH_2
63148-56-1	Siloxanes and Silicones, Me 3,3,3-trifluoropropyl	Base oil/Additive	Polymeric	Other
9002-83-9	Polychlorotrifluoroethylene	Base oil/Additive	Polymeric	Fluoropolymer
9002-84-0	Poly(1,1,2,2-tetrafluoroethylene) (PTFE)	Additive	Polymeric	Fluoropolymer
67584-42-3[a]	Cycloalkanesulfonic acid, perfluoro(pentafluoroethyl)-, potassium salt (1:1)	Additive	Non-polymeric	Ionic
51798-33-5	Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethane diyl]], α-(1- carboxy-1,2,2,2-tetrafluoroethyl)-ω-[tetrafluoro (trifluoromethyl)ethoxy]-	Additive (surfactant)	Polymeric	PFPE-COOH
163702-05-4	Ethyl nonafluorbutyl ether OR Ethyl perfluoroalkyl ether	Solvent	Non-polymeric	Non-ionic
163702-06-5	Ethyl nonafluorisobutyl ether OR Ethyl perfluoroisobutyl ether	Solvent	Non-polymeric	Non-ionic
163702-07-6	Methyl nonafluorobutyl ether OR Methyl perfluoroalkyl ether	Solvent	Non-polymeric	Non-ionic
163702-08-7	Propane, 2-(difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro- OR Methyl perfluoroisoalkyl ether	Solvent	Non-polymeric	Non-ionic

[a]Also used as anti-erosion/anti-corrosion additive in aviation hydraulic fluids

Appendix A.3.17. Active substances in Plant Production Products (PPP), Biocidal Products (BP) and Medicinal Products (MP)

Table A.108. Non-exhaustive list of EU approved active substances for PPPs covered by the current PFAS definition.

Substance name	EC / List no	CAS no	CLH status/status under REACH	Classification adopted or proposed	Regulatory Program
Triflumoron/tritosulfuron (ISO) (containing ≤ 0.02% 2-amino-4-methoxy-6-(trifluormethyl)-1,3,5-triazine); 1-[4-methoxy-6-(trifluoromethyl)-1,3,5-triazin-2-yl]-3-[2-(trifluoromethyl)benzenesulfonyl]urea (containing ≤ 0.02% 2-amino-4-methoxy-6-(trifluoromethyl)-1,3,5-triazine)	604-291-0	142469-14-5	Withdrawn	Skin Sens. 1B, H317 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=10 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=10	Active substance in biocidal and plant protection products
Isoxaflutole (ISO); 5-cyclopropyl-1,2-oxazol-4-yl α,α,α- trifluoro-2-mesyl-p-tolyl ketone	604-222-4	141112-29-0	Adopted Submitted	Repr. 2, H361d Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=10 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=100 Repr. 2, H361d*** STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=10 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=100	Active substance in plant protection products
Triflusulfuron-methyl; methyl 2-(([([4-	603-146-9	126535-15-7	Adopted	Carc. 2, H351 Aquatic Acute 1, H400	Active substance in plant protection products

Substance name	EC / List no	CAS no	CLH status/status under REACH	Classification adopted or proposed	Regulatory Program
(dimethylamino)-6-(2,2,2-trifluoroethoxy)-1,3,5-triazin-2-yl]carbamoyl}[)sulfamoyl)-3-methylbenzoate				Aquatic Acute 1, M-factor=100 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=10	
Trifloxystrobin(ISO); methyl (E)-methoxyimino-(]((E)-α-[1-(α,α,α-trifluoro-m-tolyl)ethylideneaminooxy]-o-tolyl)[)acetate	604-237-6	141517-21-7	Adopted	Lact. Skin Sens. 1 Aquatic Acute 1 Aquatic Chronic	Active substance in plant protection products
Tefluthrin (ISO); 2,3,5,6-tetrafluoro-4-methylbenzyl (1RS,3RS)-3-[(Z)-2-chloro-3,3,3-trifluoroprop-1-enyl]-2,2-dimethylcyclopropanecarboxylate	616-699-6	79538-32-2	Adopted	Acute Tox. 2, H300 Acute Tox. 2, H310 Acute Tox. 1, H330 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=10 000 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=10 000	Active substance in plant protection products
Pyroxsulam (ISO); N-(5,7-dimethoxy[1,2,4]triazolo[1,5-a]pyrimidin-2-yl)-2-methoxy-4-(trifluoromethyl) pyridine-3-sulfonamide	610-007-6	422556-08-9	Opinion adapted	Skin Sens. 1, H317 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=100 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=100	Active substance in plant protection products
Pyridalyl (ISO); 2,6-dichloro-4-(3,3-dichloroallyloxy)phenyl 3-[5-(trifluoromethyl)-2-pyridyloxy]propyl ether	605-845-4	179101-81-6	Opinion development	Skin Sens. 1, H317 Repr. 2, H361d Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=1000 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-	Active substance in plant protection products

Substance name	**EC / List no**	**CAS no**	**CLH status/status under REACH**	**Classification adopted or proposed**	**Regulatory Program**
				factor=100	
Picolinafen (ISO); N-(4-fluorophenyl)-6-[3-(trifluoromethyl)phenoxy]pyridine-2-carboxamide; 4′-fluoro-6-[(α,α,α-trifluoro-m-tolyl)oxy]picolinanilide	604-030-0	137641-05-5	Submitted	STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=1000 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=100	Active substance in plant protection products
Penthiopyrad (ISO); (RS)-N-[2-(1,3-dimethylbutyl)-3-thienyl]-1-methyl-3-(trifluoromethyl)pyrazole-4-carboxamide	606-001-8	183675-82-3	Adopted	Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=1 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=1	Active substance in plant protection products
Fluopyram (ISO); N-(](2-[3-chloro-5-(trifluoromethyl)pyridin-2-yl]ethyl)[)-2-(trifluoromethyl)benzamide;	619-797-7	658066-35-4	Adopted	Aquatic Chronic 2, H411	Active substance in plant protection products
Flonicamid (ISO); N-(cyanomethyl)-4-(trifluoromethyl)pyridine-3-carboxamide;	605-127-0	158062-67-0	Adopted	Acute Tox. 4, H302	Active substance in plant protection products
Flutolanil (ISO); N-[3-(propan-2-yloxy)phenyl]-2-(trifluoromethyl)benzamide; α,α,α-trifluoro-3′-isopropoxy-o-toluanilide	613-921-3	66332-96-5	Intention	Aquatic Acute 1, M-factor=1 Aquatic Chronic 1, M-factor=10	Active substance in plant protection products

Substance name	**EC / List no**	**CAS no**	**CLH status/status under REACH**	**Classification adopted or proposed**	**Regulatory Program**
Flutianil (ISO); (2Z)-(]([2-fluoro-5-(trifluoromethyl)phenyl]thio)[)[3-(2-methoxyphenyl)-1,3-thiazolidin-2-ylidene]acetonitrile	812-888-4	958647-10-4	Adopted	Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=100	Active substance in plant protection products
Flurochloridone (ISO); 3-chloro-4-(chloromethyl)-1-[3-(trifluoromethyl)phenyl]pyrrolidin-2-one	262-661-3	61213-25-0	Adopted	Acute Tox. 4, H302 Skin Sens. 1, H317 Repr. 1B, H360Df Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Active substance in plant protection products
Fluopicolide (ISO); 2,6-dichloro-N-[3-chloro-5-(trifluoromethyl)-2-pyridylmethyl]benzamide	607-285-6	239110-15-7	Adopted		Active substance in plant protection products
Flazasulfuron (ISO); 1-(4,6-dimethoxypyrimidin-2-yl)-3-(3-trifluoromethyl-2-pyridylsulfonyl)urea	600-514-0	104040-78-0	Intention	Aquatic Acute 1, M-factor=1 000 Aquatic Chronic 1, M-factor=100	Active substance in plant protection products
Diflufenican (ISO); N-(2,4-difluorophenyl)-2-[3-(trifluoromethyl)phenoxy]-3-pyridinecarboxamide	617-446-2	83164-33-4	Adopted	Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=1000 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=100	Active substance in plant protection products
Cyflumetofen (ISO); 2-methoxyethyl (RS)-2-(4-tert-butylphenyl)-2-cyano-3-oxo-3-(α,α,α-trifluoro-o-tolyl)propionate	642-974-5	400882-07-7	Adopted	Skin Sens. 1A, H317 Carc. 2, H351	Active substance in plant protection products
Benfluralin	217-465-2	1861-40-1	Opinion development	Skin Irrit. 2, H315 Eye Irrit. 2, H319 Skin Sens. 1, H317 Carc. 2, H351 Repr. 2, H361d	Active substance in plant protection products

Substance name	**EC / List no**	**CAS no**	**CLH status/status under REACH**	**Classification adopted or proposed**	**Regulatory Program**
				Lact., H362 STOT SE 2, H371 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=10 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=10	
Sulfoxaflor (ISO); [methyl(oxo)(](1-[6-(trifluoromethyl)-3-pyridyl]ethyl)[)-λ6-sulfanylidene]cyanamide;	807-366-8	946578-00-3	Adopted	Acute Tox. 4, H302 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=1 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=1	Active substance in plant protection products
Fluazinam (ISO); 3-chloro-N-[3-chloro-2,6-dinitro-4-(trifluoromethyl)phenyl]-5-(trifluoromethyl)pyridin-2-amine;	616-712-5	79622-59-6	Adopted	Acute Tox. 4, H332 Skin Irrit. 2, H315 Eye Dam. 1, H318 Skin Sens. 1, H317 Repr. 2, H361 STOT SE 3, H335 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=10 Aquatic Chronic 1, H410	Active substance in plant protection products
Tembotrione (ISO); 2-(](2-chloro-4-(methylsulfonyl)-3-[(2,2,2-trifluoroethoxy)methyl]benzoyl)[)cyclohexane-1,3-dione;	608-879-8	335104-84-2	Adopted	Skin Sens. 1B, H317 STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=100 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=10	Active substance in plant protection products

Substance name	EC / List no	CAS no	CLH status/status under REACH	Classification adopted or proposed	Regulatory Program
Metaflumizone (ISO); 1-[[](Z)-[[]2-(4-cyanophenyl)-1-[[]3-(trifluoromethyl)phenyl]ethylidene]amino]-1-[[]4-(trifluoromethoxy)phenyl]urea	604-167-6	139968-49-3	Adopted	Repr. 2, H361d Lact., H362 STOT RE 2, H373	Active substance in plant protection products
Oxathiapiprolin (ISO); 1-(4-(](4-[[]5-(2,6-difluorophenyl)-4,5-dihydro-1,2-oxazol-3-yl]-1,3-thiazol-2-yl)[)piperidin-1-yl)-2-[[]5-methyl-3-(trifluoromethyl)-1H-pyrazol-1-yl]ethan-1-one	801-263-1	1003318-67-9	Adopted	Aquatic Chronic 1, H410	Active substance in plant protection products
Mefentrifluconazole; (2RS)-2-[4-(4-chlorophenoxy)-2-(trifluoromethyl)phenyl]-1-(1H-1,2,4-triazol-1-yl)propan-2-ol;	-	1417782-03-6	Adopted	Skin Sens. 1, H317 Aquatic Acute 1, H400 Aquatic Acute 1, M-factor=1 Aquatic Chronic 1, H410 Aquatic Chronic 1, M-factor=1	Active substance in plant protection products
Bifenthrin (ISO); (2-methylbiphenyl-3-yl)methyl rel-(1R,3R)-3-[(1Z)-2-chloro-3,3,3-trifluoroprop-1-en-1-yl]-2,2-dimethylcyclopropanecarboxylate;	617-373-6	82657-04-3	notified		Active substance in biocidal and plant protection products
Fipronil (ISO); (±)-5-amino-1-(2,6-dichloro-α,α,α-trifluoro-para-tolyl)-4-trifluoromethylsulfinyl-pyrazole-3-carbonitrile	424-610-5	120068-37-3	registered		Active substance in biocidal and plant protection products

Substance name	**EC / List no**	**CAS no**	**CLH status/status under REACH**	**Classification adopted or proposed**	**Regulatory Program**
Flufenoxuron; () 1-(4-(2-cloro-α,α,α-p-trifluorotolyloxy)-2-fluorophenyl)-3-(2,6-difluorobenzolyl)urea	417-680-3	101463-69-8	registered		Active substance in plant protection products
Picoxystrobin (ISO); methyl (2E)-3-methoxy-2-[2-(([([6-(trifluoromethyl)pyridin-2-yl]oxy)[)methyl)phenyl]acrylate	601-478-9	117428-22-5	registered		Active substance in plant protection products
Triflumizole (ISO); (1E)-N-[4-chloro-2-(trifluoromethyl)phenyl]-1-(1H-imidazol-1-yl)-2-propoxyethanimine; (ISO)	614-708-8	68694-11-1	notified		Active substance in plant protection products
Prosulfuron N-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)carbamoyl]-2-(3,3,3-trifluoropropyl)benzenesulfonamide or 1-(4-methoxy-6-methyl-1,3,5-triazin-2-yl)-3-[2-(3,3,3-trifluoropropyl)phenylsulfonyl]urea		94125-34-5	no CLH intention		Active substance in plant protection products
Haloxyfop-P (R)-2-([(4-[3-chloro-5-(trifluoromethyl)- 2-pyridyloxy]phenoxy)[)propanoic acid		95977-29-0	no CLH intention		Active substance in plant protection products

Substance name	EC / List no	CAS no	CLH status/status under REACH	Classification adopted or proposed	Regulatory Program
Gamma-Cyhalothrin; (S)-a-cyano-3-phenoxybenzyl (Z)-(1R,3R)-3-(2-chloro-3,3,3-trifluoropropenyl)-2,2-dimethylcyclopropanecarboxylate		76703-62-3	no CLH intention		Active substance in plant protection products
lambda-Cyhalothrin; [(R)-cyano-(3-phenoxyphenyl)methyl] (1S,3S)-3-[(Z)-2-chloro-3,3,3-trifluoroprop-1-enyl]-2,2-dimethylcyclopropane-1-carboxylate	-; 415-130-7	91465-08-6	no CLH intention		Active substance in biocidal and plant protection products
Tau-Fluvalinate; [cyano-(3-phenoxyphenyl)methyl] (2R)-2-[2-chloro-4-(trifluoromethyl)anilino]-3-methylbutanoate		102851-06-9	no CLH intention		Active substance in plant protection products
Tetraconazole; (+/-)-2-(2,4-Dichlorophenyl)-3-(1H-1,2,4-triazole-1-ylpropyl)-1,1,2,2-tetrafluorethyl ether		112281-77-3	no CLH intention		Active substance in plant protection products
Flufenacet; *N*-(4-Fluorophenyl)-*N*-(propan-2-yl)-2-(]([5-(trifluoromethyl)-1,3,4-thiadiazol-2-yl]oxy)[)acetamide		142459-58-3	no CLH intention		Active substance in plant protection products
Beflubutamid; N-benzyl-2-[4-fluoro-3-(trifluoromethyl)phenoxy]butanamide		113614-08-7	no CLH intention		Active substance in plant protection products

Substance name	EC / List no	CAS no	CLH status/status under REACH	Classification adopted or proposed	Regulatory Program
Penoxsulam; 2-(2,2-difluoroethoxy)-N-(5,8-dimethoxy-[1,2,4]triazolo[1,5-c]pyrimidin-2-yl)-6-(trifluoromethyl)benzenesulfonamide		219714-96-2	no CLH intention		Active substance in plant protection products
Cyflufenamid; N-[(Z)-N-(cyclopropylmethoxy)-C-[2,3-difluoro-6-(trifluoromethyl)phenyl]carbonimidoyl]-2-phenylacetamide		180409-60-3	no CLH intention		Active substance in plant protection products
Acrinathrin; (S)-Cyano(3-phenoxyphenyl)methyl (Z)-(1R,3S)-2,2-dimethyl[2-(2,2,2-trifluoro-1-trifluoromethylethoxycarbonyl)vinyl]-cyclopropanecarboxylate	600-147-6	101007-06-1	no CLH intention		Active substance in plant protection products
fluazifop-P; (2R)-2-(4-([5-(trifluoromethyl)pyridin-2-yl]oxy)phenoxy)propanoic acid	617-435-2	83066-88-0	no CLH intention		Active substance in plant protection products
Flubendiamide; 3-iodo-N'-(2-mesyl-1,1-dimethylethyl)-N-(](4-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]-o-tolyl)[)phthalamide	608-064-7	272451-65-7	no CLH intention		Active substance in plant protection products
Flumetralin; N-(2-chloro-6-fluorobenzyl)-N-ethyl-α,α,α-trifluoro-2,6-dinitro-p-toluidine; flumetralin (ISO)	613-108-3	62924-70-3	no CLH intention		Active substance in plant protection products

Substance name	EC / List no	CAS no	CLH status/status under REACH	Classification adopted or proposed	Regulatory Program
Fluometuron; 1,1-Dimethyl-3-[3-(trifluoromethyl)phenyl]urea	218-500-4	2164-17-2	no CLH intention		Active substance in plant protection products
Oxyfluorfen; 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene	255-983-0	42874-03-3	no CLH intention		Active substance in plant protection products

*The approval of these substances is pending.

Table A.109. Non- exhaustive list of EU approved biocidal active substances covered by the current PFAS definition.

Substance name	EC/List no.	CAS no.	BAS number	Product-type	Approval start date
Hexaflumuron; 1-(3,5-dichloro-4-(1,1,2,2-tetrafluoroethoxy)phenyl)-3-(2,6-difluorobenzoyl) urea	-; 401-400-1	86479-06-3	1314	PT18-Insecticides, acaricides and products to control other arthropods	01/04/2017
Chlorfenapyr; (ISO)4-bromo-2-(4-chlorophenyl)-1-ethoxy methyl-5-trifluoromethylpyrrole-3-carbonitrile	602-782-4	122453-73-0	66	PT08-Wood preservatives, PT18-Insecticides, acaricides and products to control other arthropods	01/05/2015
Bifenthrin	-	82657-04-3	8	PT08-Wood preservatives	01/02/2013
Fipronil	-; 424-610-5	120068-37-3	33	PT18-Insecticides, acaricides and products to control other arthropods	01/10/2013
Flocoumafen	-; 421-960-0	90035-08-8	34	PT14-Rodenticides	01/10/2011
lambda-Cyhalothrin; [(R)-cyano-(3-phenoxyphenyl) methyl] (1S,3S)-3-[(Z)-2-chloro-3,3,3-trifluoroprop-1-enyl]-2,2-dimethylcyclopropane-1-carboxylate	-; 415-130-7	91465-08-6	41	PT18-Insecticides, acaricides and products to control other arthropods	01/10/2013
Tralopyril	-	122454-29-9	1403	PT21-Antifouling products	01/04/2015

Table A.110. Non- exhaustive list of active pharmaceutical ingredients (APIs) following current PFAS definition, authorised as medicinal products.

		Type of registration							
API	**CASNR**	**CH**	**NH**	**CV**	**NV**	**A126a**	**WHO-EML**	**Orphan**	**ATC**
alpelisib	1217486-61-7	x							L01XX
apalutamide	956104-40-8	x							L02BB
aprepitant	170729-80-3	x					x		A04AD
bendroflumethiazide	73-48-3					x			C03AA C03AB C03EA
benfluorex	23602-78-0		x						A10BX
bicalutamide	90357-06-5		x			x	x		L02BB
cangrelor	163706-06-7	x							B01AC

		Type of registration							
API	**CASNR**	**CH**	**NH**	**CV**	**NV**	**A126a**	**WHO-EML**	**Orphan**	**ATC**
celecoxib	169590-42-5	x	x			x			C08CA L01XX M01AH
cinacalcet	226256-56-0	x							H05BX
desflurane	57041-67-5					x			N01AB
dexfenfluramine	3239-44-9		x						A08AA
doravirine	1338225-97-0	x							J05AG
dutasteride	164656-23-9		x						G04CA G04CB
efavirenz	154598-52-4	x	x				x		J05AG
elexacaftor	2216712-66-0	x							R07AX[a]
enzalutamide	915087-33-1	x							L02BB
fenfluramine	458-24-2		x						A08AA
flecainide	54143-55-4					x			C01BC
fluoxetine	54910-89-3		x	x		x	x		N06AB
flunixin	38677-85-9				x				QM01AG
fluphenazine	69-23-8					x	x		N05AB
fluvoxamine	54739-18-3		x			x			N06AB
fosaprepitant	172673-20-0		x						A04AD[b]
fosnetupitant	1703748-89-3	x							A04AD[b]
fulvestrant	129453-61-8		x			x			L02BA
gemcitabine	95058-81-4					x	x		L01BC
glecaprevir	1365970-03-1	x							J05AP
isoflurane	26675-46-7		x			x	x		N01AB
ivosidenib	1448347-49-6		x			x		x	L01XX
lansoprazole	103577-45-3		x			x			A02BC A02BD
ledipasvir	1256388-51-8	x							J05AP
leflunomide	75706-12-6	x	x						L04AA
letermovir	917389-32-3	x						x	J05AX
lomitapide	182431-12-5	x						x	C10AX
maraviroc	376348-65-1	x							J05AX
mefloquine	53230-10-7					x	x		P01BC P01BF
netupitant	290297-26-6	x							A04AD[b]
nilotinib	641571-10-0	x					x		L01XE
nilutamide	63612-50-0		x						L02BB
nitisinone	104206-65-7	x							A16AX
penfluridol	26864-56-2		x						N05AG
perflutren	76-19-7	x							V08DA
ponatinib	943319-70-8	x							L01XE
regorafenib	755037-03-7	x							L01XE
rolapitant	552292-08-7	x							A04AD
sevoflurane	28523-86-6			x		x			N01AB
silodosin	160970-54-7	x							G04CA
siponimod	1230487-00-9	x							L04AA
sitagliptin	486460-32-6	x							A10BH
sorafenib	284461-73-0	x							L01XE
tafluprost	209860-87-7		x						S01EE
telotristat	1033805-22-9	x							A16AX
teriflunomide	163451-81-8	x							L04AA

		Type of registration							
API	**CASNR**	**CH**	**NH**	**CV**	**NV**	**A126a**	**WHO-EML**	**Orphan**	**ATC**
tezacaftor	1152311-62-0	x							R07AX
tipranavir	174484-41-4	x							J05AE
travoprost	157283-68-6	x							S01EE
trifluoperazine	117-89-5	x							N05AB
upadacitinib	1310726-60-3	x							L04AA
vinflunine	162652-95-1	x							L01CA
voxilaprevir	1535212-07-7	x							J05AP

[a] No ATC code is available, based on similarity with tezacaftor and ivacaftor, the code R07AX was tentatively assigned.

[b] No ATC code available, based on similarity with aprepitant and rolapitant the code A04AD was tentatively assigned.

List of abbreviations:
CH=centralised authorisation for human health,
NH=decentralised registration for human health (mutual recognition),
CV=centralised authorisation for veterinary purposes,
NV=decentralised registration for veterinary purposes (mutual recognition),
A126a=registration in Article 126a.
WHO-EML=list of essential medicines of the World Health Organisation (WHO, 2019), ATC = Anatomical Therapeutic Chemical (ATC) Classification System up to the chemical-therapeutic-pharmacological subgroup (level 4)[46]. Number of potential alternatives is only reported for registered PFAS-medicinal products.
Orphans are medicinal products that have been developed to treat rare diseases and that have a market protection for 10 years (+potential 2 years extension)[47].

[46] https://www.whocc.no/atc_ddd_index/, date of access: 2022-12-16.
[47] https://ec.europa.eu/health/documents/community-register/html/index_en.htm, date of access: 2022-12-16.

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