Electronic Supplementary Material (ESI) for Environmental Science: Processes & Impacts.

An overview of the uses of per- and polyfluoroalkyl substances (PFAS) – Electronic supplementary information 1

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General explanations

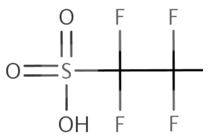
The document provides an overview of the applications of PFAS. The information was gathered from various sources, such as reports, journal articles, databases, patents, safety data sheets and websites. The information on the substances themselves can be divided into four categories/types: information that a substance has been used for a specific application, but no information on its current status [uses (U)]; information that a substance is currently used (current use means a use with public record(s) of use from the last 4 years, i.e. 2017 or later) [current uses (U*)]; information that a substance has been detected in a specific product [detection (D)], and information that a substance has been patented (and given a CAS number) for a specific application [patent (P)].

- Uses (U) and current uses (U*) were assigned based on, for example, data from the Chemical Data Reporting database under the Toxic Substances Control Act (TSCA) in the United States (US), data from the SPIN database of the Nordic countries, information from safety data sheets and information that a specific substance is sold for that particular use.
- Information on detected substances was mainly retrieved from scientific studies (e.g. journals articles, reports).
- Patents were retrieved via either SciFinder^{n} (CAS 2019) or Google patents (Google_patents 2019). The information in brackets [e.g. CAS 2019 (JP05033153, 1993)] provides the patent number and the year of the invention. More information on the literature sources is provided in the Methods section of the main article.
- The information in this document originates from public sources and we were not able to verify whether the information in the public sources is correct, whether the substances work as intended, and what their real benefits are. Therefore, we cannot guarantee the validity of the compiled information.

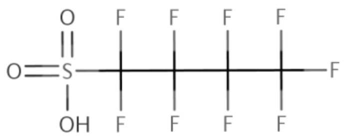
<u>Important information for the tables:</u>

a) **The chemical names in the tables are often generalized to a group of PFAS. However, this does not imply that substances with the same functional group, but different chain length, have the same properties. And most importantly, it does also not imply that all chain lengths of one generalized form are suitable for the same application.**

b) The structural formulae of some substances have been cut at one or both ends. The missing part of the carbon chain is not indicated. An example is displayed here:



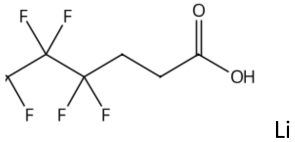
cut form



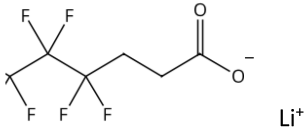
uncut form

Note that the complete molecular formulae are all provided in the tables.

c) Most of the anionic PFAS are displayed as neutral PFAS in the pictures in this document. Strictly speaking, this is not correct. The correct form is given in the tables under "molecular formula". However, editing the images (which were taken from SciFinder^n) would have been extremely time-consuming, so we decided to not correct them. An example of the incorrect and correct forms is shown here:



incorrect form



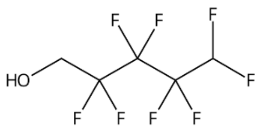
correct form

d) The graphics of the molecules do not intend to reflect any actual bond length ratios.

e) For polymers, only the monomers are shown.

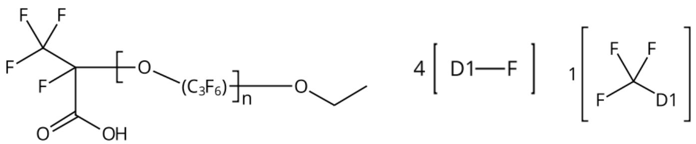
f) Labels provided in parentheses (e.g. ammonium perfluoroalkyl carboxylate[1a]) mean that the substance shown in the graphic below the label is another salt of the same anion (e.g. potassium perfluoroalkyl carboxylate and not ammonium perfluoroalkyl carboxylate).

g) The chemical names in the tables are often generalized to a group of PFAS (to cover more than one CAS No.), using "perfluoroalkyl", also it might be a "polyfluoroalkyl". An example is the PFAS group shown below. The general name should be "1-Alkanol, polyfluoro-" but in this document we write "1-Alkanol, perfluoro-". We have also not used the plural forms of the names, although they encompass often more than one substance.



h) The chemical names of the PFAS are either from Buck et al. (2011) or SciFinder^n (CAS 2019). In SciFinder^n, IUPAC names are used for normal registrations, whereas for manual registrations, only "descriptive" names are given (e.g. siloxanes and silicones, di-Me, Me 3-(1,1,2,2-tetrafluoroethoxy)propyl, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl).

i) The graphics from SciFinder^n may sometimes contain "D1" in the structure (see below for CAS No. 51798-33-5), and it is unknown where such "D1"s are connected to the main structure.



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List of abbreviations

ECTFE	Chlorotrifluoroethylene-ethylene copolymer (CAS No. 25101-45-5)
ETFE	Ethylene tetrafluoroethylene copolymer (CAS No. 25038-71-5)
D	detected analytically in products
DWR	durable water repllent
FEP	Fluorinated ethylene propylene (CAS No. 25067-11-2)
FTSAs	Fluorotelomer sulfonic acids
FTOHs	Fluorotelomer alcohols
HFE	Hydrofluoroethers (HFE-7000, HFE-7100, HFE-7200, and HFE-7500 are all commercial products)
HFP	Hexafluoropropylene polymer (CAS No. 25120-07-4)
MeFASEs	*N*-Methyl perfluoroalkane sulfonamidoethanols
No	number
P	patented
PCTFE	Polychlorotrifluoroethylene (CAS No. 9002-83-9)
PFA	Perfluoralkoxy polymer (CAS No. 26655-00-5)
PFCAs	Perfluoroalkyl carboxylic acids
PFHxS	Perfluorohexane sulfonic acid (CAS No. 355-46-4)
PFSAs	Perfluoroalkane sulfonic acids
PFOA	Perfluorooctanoic acid (CAS No. 335-67-1)
PFOS	Perfluorooctane sulfonic acid (CAS No. 1763-23-1)
PFPEs	Perfluoropolyethers
PTFE	Polytetrafluoroethylene (CAS No. 9002-84-0)
PVDF	Poly(vinylidene fluoride) (CAS No. 24937-79-9)
TSCA	Toxic Substances Control Act from 1976
U	used
U*	currently used (used after 2017)
US	United States
VDF	Vinylidenefluoride

1 Industry branches

1.1 Aerospace

Many applications in space are similar to those in terrestrial applications where a wide range of service temperatures, low friction, resistance to chemical attack, or dielectric properties are important. Therefore, fluoropolymers have found extensive application in space for bushing, lubricants, sleeves, tubing, seals, and as electrical insulation for wiring and in other forms for electronic packaging (B. A. Banks 1997). PFAS are also used in brake and hydraulic fluids and aircraft interior and exterior (FluoroIndustry 2019). The following sections provide more details on these specific applications.

1.1.1 Brake and hydraulic fluids in aircrafts

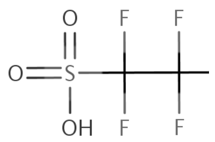
Hydraulic fluids actuate moving parts of the aircraft such as wing flaps, ailerons, the rudder and landing gear (POPRC 2019). There are three main types of hydraulic fluids: a) mineral-based fluids, b) polyalphaolefin-based fluids and c) phosphate ester-based fluids (Aeronautics_Guide 2019). Hydraulic fluids based on phosphate esters are used in most commercial aircrafts and are extremely fire-resistant (Aeronautics_Guide 2019). However, they can absorb water and the subsequently formed phosphoric acid can damage metallic parts of the hydraulic system. Fluorinated surfactants in phosphate ester-based hydraulic fluids inhibit the corrosion of mechanical parts of the hydraulic system by altering the electrical potential at the metal surface (POPRC 2019). The fluorinated surfactants prevent also fire and evaporation of the hydraulic fluid (KEMI Swedish Chemical Agency 2015b). Table 1 lists PFAS that have been or are still used as additives in phosphate ester-based brake and hydraulic fluids.

A hydraulic fluid based on polychlorotrifluoroethylene (PCTFE) oil – a PFAS – was developed in the early 1990s (R. E. Banks, Smart, and Tatlow 1994). However, it has been found that PCTFE produces severe corrosion of brass at temperatures above 135°C. As a result, it is believed that operation at very high temperatures is likely to cause unacceptable material removal from copper-based metals (ASTM 1997).

Table 1: PFAS historically or currently used, or patented, as additives to phosphate ester-based brake and hydraulic fluids. Patent number (date, legal status): WO2000024848 (2000, active). The types stand for U – use and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document. FC-98 is a commercial product.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkane sulfonic acids (PFSAs)[1a]	$C_nF_{2n+1}SO_3H$	n = 8	1763-23-1	U	(KEMI Swedish Chemical Agency 2015b)
Potassium perfluoroalkane sulfonate[1b]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	U	(POPRC 2019)
Alkene-1-sulfonic acid, perfluoro-, potassium salt (1:1)[1c]	$K^+ C_nF_{2n-1}SO_3^-$	n = 8	12751-11-0	P	(CAS 2019 (WO2000024848))
Cycloalkanesulfonic acid, perfluoro-, potassium salt (1:1)[1d]	K^+ c-$C_nF_{2n-1}SO_3^-$	n = 6 (part of FC-98)	3107-18-4	P	(CAS 2019 (WO2000024848); De Silva et al. 2011)
Cycloalkanesulfonic acid, decafluoro(trifluoromethyl)-, potassium salt (1:1)[1e]	K^+ c-$C_nF_{2n-1}SO_3^-$	n = 7 (part of FC-98)	68156-07-0	P	(CAS 2019 (WO2000024848); De Silva et al. 2011)

1a



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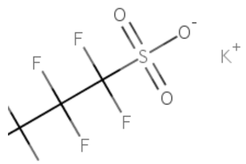

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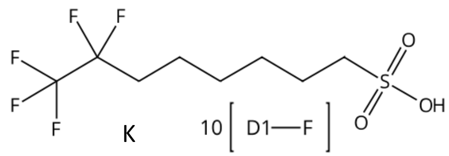

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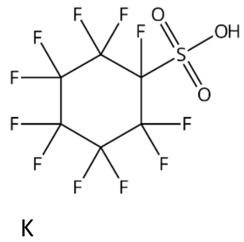

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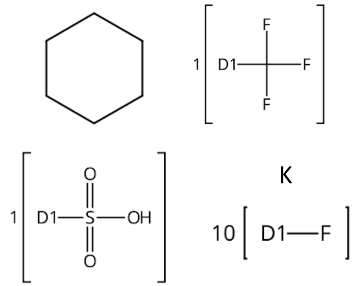
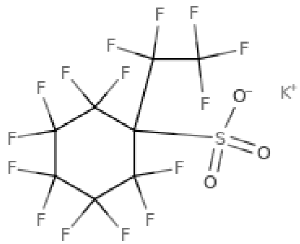


Cycloalkanesulfonic acid, decafluoro(pentafluoroethyl)-, potassium salt (1:1)[2a]	K^+ c-$C_nF_{2n-1}SO_3^-$	n = 8	67584-42-3	U	(POPRC 2019)
Cycloalkanesulfonic acid, perfluoro-4-(1,1,2,2,2-pentafluoroethyl)-, potassium salt (1:1)[2b]	K^+ c-$C_nF_{2n-1}SO_3^-$	n = 8 (part of FC-98)	335-24-0	P	(CAS 2019 (WO2000024848); De Silva et al. 2011)
Perfluoropolyethers (PFPEs)	-	-	-	U	(R. E. Banks, Smart, and Tatlow 1994)

2a



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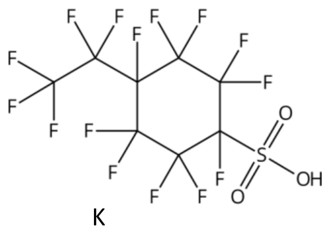


C_4-C_{12} PFCAs and C_4, C_6, C_8, and C_{10} PFSAs were detected in analyzed hydraulic fluids for aircraft applications (Zhu and Kannan 2020). However, it was not stated whether these hydraulic fluids were phosphate ester-based fluids or not.

1.1.2 Navigation

PCTFE oils are used as flotation fluids in gyroscopes. Navigational devices containing these oils have been used in many commercial and military aircraft, as well as missiles. Newer technologies such as fibre optics are now increasingly used, but the floated gyroscopes have showed high accuracy and long field life (R. E. Banks, Smart, and Tatlow 1994).

1.1.3 Wire and cables

Fluoropolymers are used in hoses, cable and wire insulations, and gaskets (POPRC 2016b). More information on this application is provided in Section 2.43 ‘Cable and wire`.

1.1.4 Thermal control and radiator surfaces

Thermal control and radiator surfaces have been the main uses of PFAS in aerospace applications (B. A. Banks 1997). Thermal control is required on a spacecraft because the materials undergo cycles of solar heating and radiative cooling with temperatures ranging between -80 and +150 °C. In a low earth orbit, such a cycle takes 90 minutes, which means that a spacecraft goes through 87660 thermal cycles in a 15 year mission. Thus, a spacecraft is required to reject waste heat and maintain acceptable temperatures within the spacecraft (B. A. Banks 1997). Typical characteristic of thermal control and radiator surfaces include long-term survival over a wide operating temperature range, low solar absorbance, high thermal emittance, and freedom from contamination by outgassing (B. A. Banks 1997). The most frequently used fluoropolymer for this applications have been fluorinated ethylene propylene copolymer (FEP, CAS No. 25067-11-2) with a second (unexposed) surface metalized with silver or aluminium (B. A. Banks 1997). Other similar forms of thermal control surfaces or blankets consisted of polytetrafluoroethylene (PTFE, CAS No. 9002-84-0) impregnated woven fiberglass (B. A. Banks 1997).

1.1.5 Fluoropolymer filled SiO_x atomic oxygen protective coatings

PTFE-filled SiO_x ($1.9<x<2.0$) has been used in space applications as high strain-to-fail coating to protect underlying polymers from atomic oxygen attack (B. A. Banks 1997).

1.1.6 Aerospace propellant systems

Aerospace propellant systems often utilize aggressive fuels and oxidizers which are incompatible with most available elastomers. Perfluoroelastomers can provide the oxidative stability needed and are compatible with both oxidizers and hydrazine-type fuels. Applications ranged from the Space Shuttle to ballistic missiles and rockets (B. A. Banks 1997).

1.1.7 Others

Perfluoropolyethers (PFPEs) have been used as lubricants in aerospace jet engines, high temperature turbine engines and satellite instrumentation because of their long-term retention of viscosity, low volatility in vacuum and their fluidity at extremely low temperatures (B. A. Banks 1997). An example of a commercial PFPE that has been used is Fomblin Z25 (B. A. Banks 1997). PCTFE oil has also been used in the oxygen-delivery system to the space shuttle oxidizer tanks (R. E. Banks, Smart, and Tatlow 1994). Perfluoroelastomers have been used as elastomeric seals in gas turbine engines in both commercial and military aircraft engines (Marshall 1997).

1.2 Biotechnology

1.2.1 Supply of oxygen and other gases to cells in culture

Perfluorocarbons such as perfluorodecalin (CAS No. 306-94-5) and perfluoromethyldecalin (CAS No. 306-92-3) have a significantly greater capacity to dissolve gases than water. Therefore, they have been used to increase yields in biological cell cultures requiring oxygen (R. E. Banks, Smart, and Tatlow 1994; Costello, Flynn, and Owens 2000). The use of perfluorocarbons for oxygenation of fragile cell cultures can also reduce or eliminate mechanical damage caused by conventional aeration methods. Brominated perfluorocarbons (e.g. 1-bromoperfluooctane, CAS No. 423-55-2) and perfluorotrialkyl amines (CAS No. 338-83-0 and 311-89-7) have been used to supply gases, including CO_2, to microbial cells (R. E. Banks, Smart, and Tatlow 1994). An additional approach has been to grow animal cells at the interface between perfluorocarbon oil and aqueous culture media (R. E. Banks, Smart, and Tatlow 1994).

1.2.2 *Ultrafiltration and microporous membranes*

Polyvinylidene fluoride (PVDF, CAS No. 24937-79-9) has been used for ultrafiltration and microporous membranes in biotechnology applications (R. E. Banks, Smart, and Tatlow 1994). One example is PVDF membranes that have been used to remove viruses from protein products of human or animal cell fermentations (Dohany 2000).

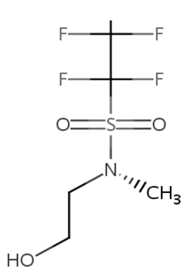
1.3 Building and Construction

PFAS have been used in the building and construction sector in a wide variety of applications. They have been used, for example, in cables, gaskets and hoses, in adhesives, sealants and caulks, in paints and coatings, in architectural membranes, and additives to cement. The SPIN database of the Nordic countries contains a variety of PFAS used in the building and construction industry (Norden 2020). They are shown in Table 2. Specific areas where PFAS have been used in building and construction are described in Subsections 0 to 1.3.5. PFAS in paints and coatings, and sealants and adhesives are discussed in Sections 2.8 and 2.35, respectively.

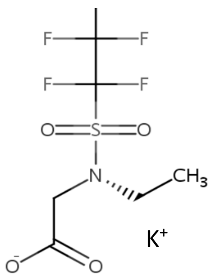
Table 2: PFAS listed in the SPIN database of the Nordic countries for building and construction. The types stand for U – use and U* – current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
N-Methyl perfluoroalkane sulfonamidoethanols (MeFASEs)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 8	24448-09-7	U	(Norden 2020)
Potassium *N*-ethyl perfluoroalkane sulfonamido acetates[1b]	$K^+ \ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 4 - 8	67584-51-4, 67584-52-5, 67584-53-6, 67584-62-7, 2991-51-7	U	(Norden 2020)
2-Propenoic acid, 2-[butyl[(perfluoroalkyl)sulfonyl] amino]ethyl esters[1c]	$C_nF_{2n+1}SO_2N(C_4H_9)CH_2CH_2OC(=O)CHCH_2$	n = 8	383-07-3	U	(Norden 2020)
Butanedioic acid, 2-sulfo-, 1,4-bis(perfluoroalkyl) ester, sodium salt (1:1)[1d]	$Na^+ \ C_nF_{2n+1}CH_2CH_2OC(O)CH_2CH(SO_3^-)C(O)OCH_2CH_2C_mF_{2m+1}$	n/m = 6	54950-05-9	U	(Norden 2020)

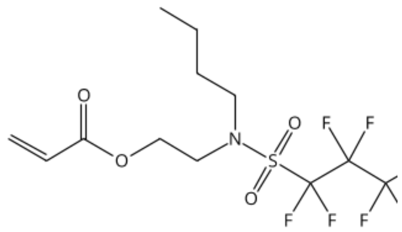
1a



1b



1c



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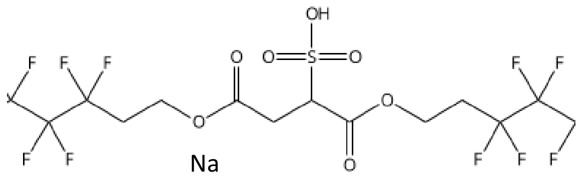
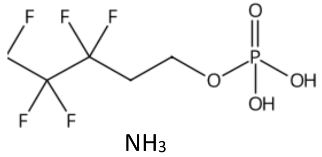


Ammonium (n:2) fluorotelomer phosphate monoester[2a]	$NH_4^+\ C_nF_{2n+1}CH_2CH_2OPO_3H^-$	undefined	65530-71-4	U*	(Norden 2020)
Diammonium (n:2) fluorotelomer phosphate monoester[(2a)]	$2\ NH_4^+\ C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	undefined	65530-72-5	U*	(Norden 2020)
Ethanol, 2,2′-iminobis-, compd. with α-fluoro-ω-[2-(phosphonooxy)ethyl]poly(difluoromethylene) (1:1)[2b]	$NH_2^+(CH_2CH_2OH)_2\ C_nF_{2n+1}CH_2CH_2OPO_3H^-$	undefined	65530-74-7	U	(Norden 2020)
Ammonium (n:2) fluorotelomer phosphate diester[2c]	$NH_4^+\ OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	undefined	65530-70-3	U*	(Norden 2020)
Perfluoroalkyltriethoxysilane[2d]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	U	(Norden 2020)

2a



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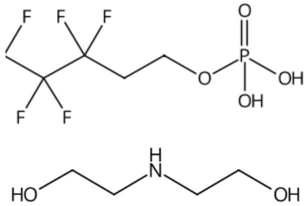

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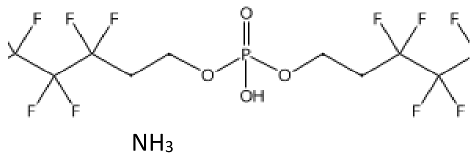
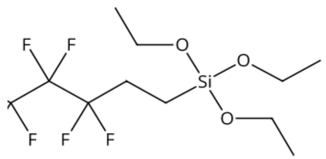
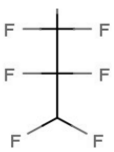


2d

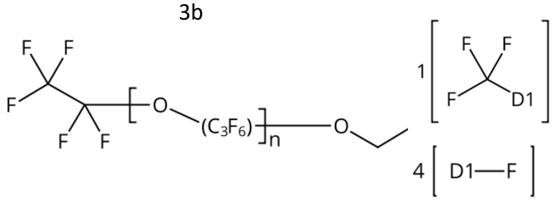


1H-Perfluoroalkane[3a]	$C_nF_{2n+1}CF_2H$	n = 1	354-33-6	U	(Norden 2020)
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], α-(1,1,2,2,2-pentafluoroethyl)-ω-[tetrafluoro(trifluoro methyl)ethoxy]-[3b]	$4\ \text{-F}\ \text{-}CF_3\ CF_3CF_2[O(C_3F_6O)]_nOCC$	-	60164-51-4	U	(Norden 2020)
Polytetrafluoroethylene (PTFE)[3c]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Perfluoro(propyl vinyl ether)-tetrafluoro ethylene copolymer (PFA)[3d]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-$	polymer	26655-00-5	U	(Norden 2020)

3a



3b



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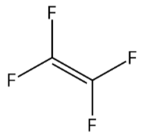
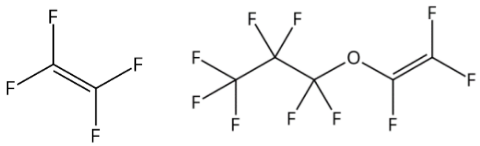
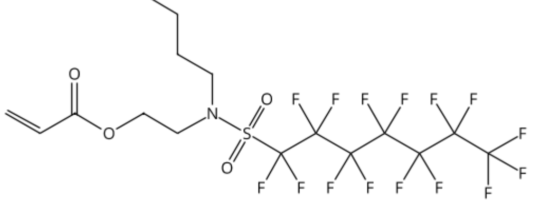


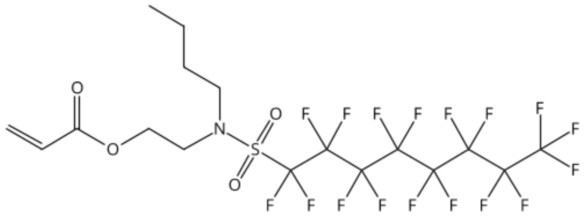
3d

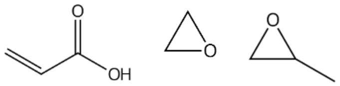


2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-hepta decafluorooctyl)sulfonyl]amino]ethyl ester, telomer with 2-[butyl[(1,1,2,2,3,3, 4,4,5,5,6,6,7,7,7-pentadecafluoroheptyl) sulfonyl]amino]ethyl 2-prope noate, 2-methyloxirane polymer with oxirane di-2-propenoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[4a]	$-[(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O-C_2H_4O)_m-(C_3H_6O-C_2H_4O)_w-2C_3H_4O_2-C_3H_4O_2]_u-C_8H_{18}S-$	polymer	68298-62-4	U	(Norden 2020)

4a

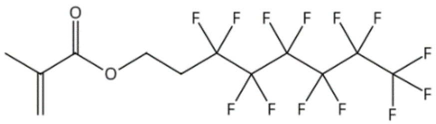


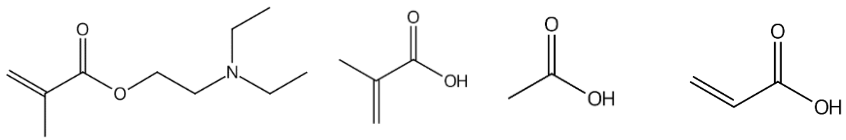




2-Propenoic acid, 2-methyl-, polymer with 2-(diethyl amino)ethyl 2-methyl-2-propenoate, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, acetate[5a]	-$(C_{12}H_9F_{13}O_2)_x(C_{10}H_{19}NO_2)_y$-$(C_4H_6O_2)_m$-$C_3H_4O_2)_w$-$xC_2H_4O_2$-	polymer	1071022-26-8	U*	(Norden 2020)

5a





Siloxanes and Silicones, di-Me, Me 3-(1,1,2,2-tetra fluoroethoxy)propyl, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl	-	-	104780-70-3	U*	(Norden 2020)
Polysiloxanes, di-Me, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl	-	-	115340-95-9	U*	(Norden 2020)
Siloxanes and Silicones, (3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether	-	-	143372-54-7	U	(Norden 2020)
Alcohols, C_{8-14}, perfluoro, reaction products with di-Me, Me hydrogen siloxanes and polyethylene glycol mono-Me ether	-	-	162567-79-5	U	(Norden 2020)

1.3.1 Architectural membranes

Architectural membranes have been used in the construction of large roofs, for example, above stadiums (FluoroIndustry 2019). A patent from the US describes the use of FEP as a roofing material (CAS 2019 (US7641964, 2008)). Other fluoropolymers that have been used are ethylene tetrafluoro-ethylene (ETFE, CAS No. 25038-71-5) (Daikin 2019), PVDF (BDIR 2016), and PTFE (BDIR 2016).

1.3.2 Greenhouses

ETFE and PTFE films have been used as windows in greenhouses and conservatories due to their high transparency to both UV and visible light and excellent resistance to weathering (R. E. Banks, Smart, and Tatlow 1994; Janousek, Lebertz, and Knepper 2019). Janousek, Lebertz, and Knepper (2019) analysed different low molecular weight PFAS in ETFE and PTFE foil used for facades or glass substituents and found C_4 to C_{14} perfluoroalkyl carboxylic acids (PFCAs), 6:2 fluorotelomer sulfonic acid (FTSA), and 6:2, 8:2, and 10:2 fluorotelomer alcohols (FTOHs). A patent describes a fogging resistant soft vinyl chloride polymer that contains fluorinated surfactants, has excellent antifungal property and thermal stability and is usefurl for greenhouses (CAS 2019 (JP61026644, 1986)). The patented substancers are poly(oxy-1,2-ethanediyl), α-[2-hydroxy-3-[(nonadecafluorononyl)sulfonyl]propyl]-ω-hydroxy- (CAS No. 103728-33-2) and poly(oxy-1,2-ethanediyl), α-(4,4,5,5,6,6,7,7,8,8,9,9,10,10, 11,11,12,12,12-nonadecafluoro-2-hydroxydodecyl)-ω-methoxy- (CAS No. 85643-63-6).

1.3.3 Cement additive

A Japanese patent from 1984 (JP59128240, 1984) discloses that fluorinated surfactants can reduce the shrinkage of cement (Kissa 2001). Fluorinated surfactants may have also been used in cement tiles pigmented with carbon black (Kissa 2001, CAS 2019 (GB1506464, 1978)) and they may have been used to improve primers used for cement mortar (Kissa 2001, CAS 2019 (JP57131263, 1982)). A PFAS that has been patented as primer for cement mortar is poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoroalkyl)sulfonyl] amino]ethyl]-ω-hydroxy- (CAS No. 29117-08-6) (CAS 2019 (JP57131263, 1982)).

1.3.4 Cable and wire

Fluoropolymers have been used in hoses, cable and wire insulations, and gaskets (POPRC 2016b). More information on this applications is provided in Section 2.43 ‘Wire and Cable`.

1.3.5 Others

Fluoropolymers, such as PTFE and PVDF, have been used as surface coatings for various building materials including metals, galvanized steel, tiles and glass material (KEMI Swedish Chemical Agency 2015b; R. E. Banks, Smart, and Tatlow 1994). More information on coatings is provided in Section 2.8 ‘Coatings, paints and varnishes`. PFAS have also been used in other products in the building and contruction sector; Table 3 lists some products where PFCAs and perfluoroalkane sulfonic acids (PFSAs) have been detected.

Table 3: List of building materials where PFCAs and PFSAs have been detected.

Category	Sub-categories	References
OSB and wood	Formica, oriented strand board, wooden board, chipboard	Bečanová et al. (2016)
Insulation material	Insulation glass fibre, insulation hemp rope, blow cellulose insulation, insulation Hardsil NT, wooden fibre insulation, pipe insulation, phenolic foam insulation, insulation Canabest panel, Tetrapak flexibuild, insulation aluminium foil, insulation foamglas Perinsul, Sound insulation, cotton insulation, paper insulation	Bečanová et al. (2016)

Mountain and sealing foam	sealant foam, asphalt	Bečanová et al. (2016)
Facade materials	window finishing bead, water-resisting paint, glass fibre net, window corner bead, outdoor paint, drywall, plaster	Bečanová et al. (2016)
Polystyrene	polystyrene	Bečanová et al. (2016)
Air conditioning	inside foil, cellophane foil, glass fibre foam, aluminium foil	Bečanová et al. (2016)

The Chemical Data Reporting database under the TSCA lists that 1-propene, 1,1,2,3,3,3-hexafluoro-, dimer (CAS No. 13429-24-8) was produced or imported above 11.3 t at at least one site in the US between 2012 and 2015 and was used as a processing aid in construction (USEPA 2016).

1.4 Chemical industry

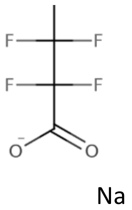
1.4.1 Processing aids for the polymerization of fluoropolymers

Fluorinated surfactants have been used as emulsifiers in the emulsion polymerization of many fluoropolymers. The fluorinated surfactants improve the physical properties of the polymer and increase the rate of polymerization (Kissa 2001). The process chemical (the surface-active fluorinated substance) is removed when the water containing the fluoropolymer emulsion is dried at high temperatures. However, at low hardening temperatures residues of the process chemical can be found in the finished polymer product (KEMI Swedish Chemical Agency 2015b). Historically, the most widely used surfactants for emulsion polymerization were the ammonium salt of perfluorooctanoic acid (CAS No. 3825-26-1) and of perfluorononanoic acid (CAS No. 4149-60-4) (Buck, Murphy, and Pabon 2012). However, the companies Arkema, Asahi, BASF Corporation, Clariant, Daikin, 3M/Dyneon, DuPont and Solvay Solexis agreed under the US EPA 2010/15 Stewardship program to manufacture fluoropolymers without using perfluorooctanoic acid (PFOA, CAS No. 335-67-1) as a processing aid by the end of 2015 (POPRC 2018a). Therefore, there has been a shift to alternatives such as per- and polyfluoroalkylether carboxylic acids. Some exemplary PFAS that have been used or are used as processing aids are listed in Table 4. In addition, many more PFAS have been patented as fluoropolymer processing aids. We have included some patents in Table 4. Other patents are e.g CN102504063 (2012, active), WO9618665 (1996, expired), US5285002 (1994, expired), US20080015304 (2008, discontinued), US20090124755 (2009, active), US2559749 (1951, expired), WO9702300 (1997, expired), or US20070015864 (2007, active). The patented molecules are listed in the ESI-2, but not here in Table 4.

Table 4: PFAS historically or currently used or patented as processing aids for PTFE, PVDF, FEP, perfluoralkoxy polymer (PFA) and/or some fluoroelastomers. Patent number (date, legal status): WO200504259 (2005, discontinued), EP2217652 (2009, not active), WO2010113950 (2010, active), DE1940293 (1970, expired), US4038230 (1977, expired), DE2213135 (1975, expired), JP47051233 (1972, expired), US4360652 (1982, expired), JP49043386 (1974, expired), US20070015864 (2007, active). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Sodium perfluoroalkyl carboxylates[1a]	$Na^+ C_nF_{2n+1}COO^-$	n = 7	335-95-5	U	(Z. Wang et al. 2013)
Lithium perfluoroalkyl carboxylates[(1a)]	$Li^+ C_nF_{2n+1}COO^-$	n = 6 - 9	60871-90-1, 17125-58-5, 60871-92-3	U	(Kissa 2001)
Ammonium perfluoroalkyl carboxylates[(1a)]	$NH_4^+ C_nF_{2n+1}COO^-$	n = 6 - 8	6130-43-4, 3825-26-1, 4149-60-4	U, P	(Z. Wang et al. 2013; CAS 2019 (WO2005042593); Kissa 2001)

Alkanoic acid, perfluoro-*n*-(trifluoromethyl)-, ammonium salt (1:1)[1b]	NH_4^+ $CF_3CF(CF_3)C_nF_{2n}COO^-$	n = 5, 7	3658-62-6, 3658-63-7	P	(CAS 2019 (US4360652))
Ammonium ω-hydroperfluoroalkanoates [1c]	NH_4^+ $CF_2HC_nF_{2n}COO^-$	n = 5	376-34-1	P	(CAS 2019 (WO2005042593))
Perfluoroalkyl phosphonic acids[1d]	$C_nF_{2n+1}PO_3H_2$	n = 4, 6	52299-24-8, 40143-76-8	P	(CAS 2019 (EP2217652))
Perfluoroalkyl phosphinic acids[1e]	$C_nF_{2n+1}P(C_mF_{2m+1})(OH)=O$	n = 4/4, 6/6	52299-25-9, 40143-77-9	P	(CAS 2019 (EP2217652))
(n:2) Fluorotelomer carboxylic acid[1f]	$C_nF_{2n+1}CH_2COOH$	n = 6	53826-12-3	-	(Z. Wang et al. 2013)

1a

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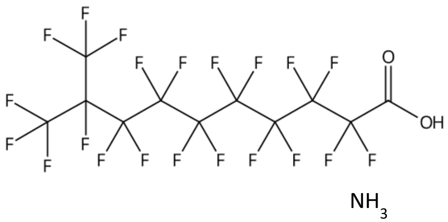
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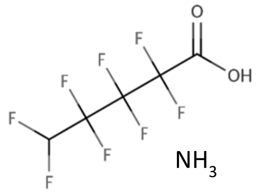
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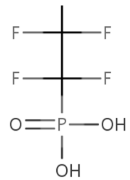
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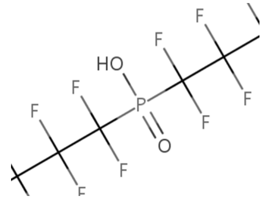
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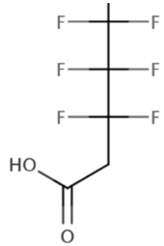
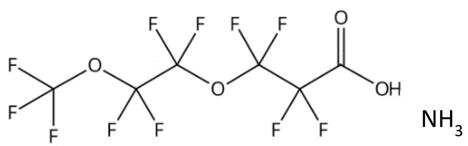


Propanoic acid, 2,2,3,3-tetrafluoro-3-[1,1,2,2-tetra fluoro-2-(trifluoromethoxy)ethoxy]-, ammonium salt[3a] (1:1)[2a]	NH_4^+ $CF_3OCF_2CF_2OCF_2CF_2COO^-$	-	1173788-87-8	P	(CAS 2019 (WO2010113950))
Propanoic acid, 2,2,3-trifluoro-3-[1,1,2,2,3,3-hexa fluoro-3-(trifluoromethoxy)propoxy]-, ammonium salt (1:1) (ADONA)[2b]	NH_4^+ $CF_3OC_3F_6OCHFCF_2COO^-$	-	958445-44-8	U*	(EFSA 2014)
Propane, 1,1,1,2,2,3,3-heptafluoro-3-(1,2,2,2-tetrafluoroethoxy)- (E1)[2c]	$CF_3CF_2CF_2OCFHCF_3$	-	3330-15-2	U*, D	(RIVM 2016; Expertisecentrum 2018)
Acetic acid, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-(1,1,2,2,2-pentafluoroethoxy)ethoxy]-, ammonium salt (1:1) (EEA-NH4)[2d]	NH_4^+ $CF_3CF_2OCF_2CF_2OCF_2COO^-$	-	908020-52-0	U	(Z. Wang et al. 2013)

2a

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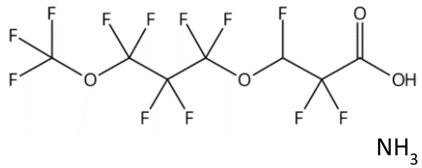
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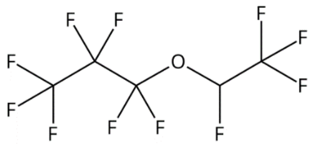
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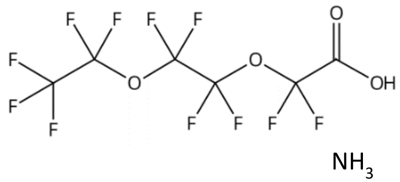
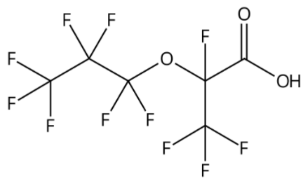


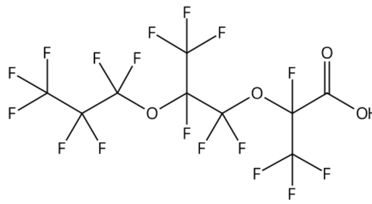
Hexafluoropropylene oxide dimer acid (HPFO-DA)[3a]	$C_3F_7OCF(CF_3)COOH$	-	13252-13-6	U*, D	(Lindstrom et al. 2017; RIVM 2016; Expertisecentrum 2018)

Propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-, ammonium salt (1:1) (NH_4-HFPO-DA)[(3a)]	NH_4^+ $C_3F_7OCF(CF_3)COO^-$	-	62037-80-3	U*	(RIVM 2016; Expertisecentrum 2018)
Hexafluoropropylene oxide trimer acid (HFPO-TA)[3b]	$CF_3CF_2(CF_2OCF(CF_3))_2COOH$	-	13252-14-7	U*	(Pan et al. 2017)
Propanoic acid, 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexa fluoro-2-(trifluoromethoxy)propoxy]-, ammonium salt (1:1)[3c]	NH_4^+ $CF_3OCF(CF_3)CF_2OCF(CF_3)$ COO^-	-	510774-77-3	U	(Hintzer and Schwertfeger 2014)
Hexafluoropropylene oxide tetramer acid (HFPO-TeA)[3d]	$C_2F_5(CF_2OCF(CF_3))_3COOH$	-	65294-16-8	U*	(Y. Wang et al. 2019)

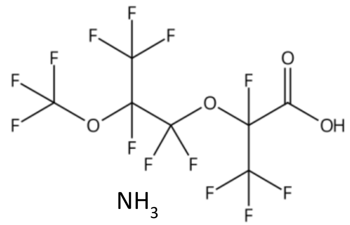
3a



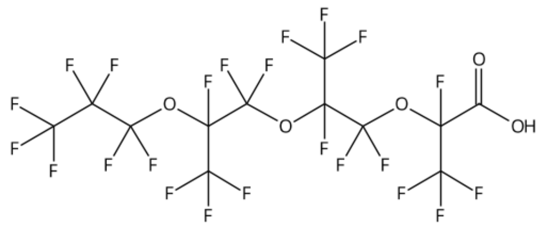
3b



3c

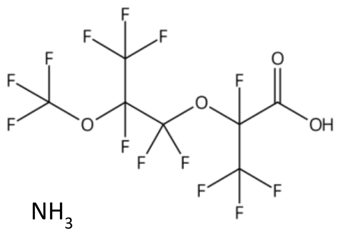


3d

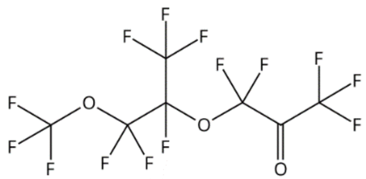


1-Propene, 1,1,2,3,3,3-hexafluoro-, telomer with chlorotrifluoroethene, oxidized, reduced, hydrolyzed	$ClC_3F_6O[CF_2CF(CF_3)O]_n[CF(CF_3)O]_m$ CF_2COOH, n = 1–4, m = 0–2	-	329238-24-6	U*	(Z. Wang et al. 2013)
Propanoic acid, 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(trifluoromethoxy)propoxy]-, ammonium salt (1:1)[4a]	NH_4^+ $CF_3OCF(CF_3)CF_2OCF(CF_3)$ COO^-	-	510774-77-3	P	(CAS 2019 (WO2010113950))
2-Propanone, 1-[1-[difluoro(trifluoromethoxy)methyl]-1,2,2,2-tetrafluoroethoxy]-1,1,3,3,3-pentafluoro-[4b]	$CF_3OCF_2CF(CF_3)OCF_2C(=O)CF_3$	-	18992-61-5	P	(CAS 2019 (DE1940293))
2-Propanone, 1-[2-[1-[difluoro(trifluoromethoxy) methyl]-1,2,2,2-tetrafluoroethoxy]-1,2,2-trifluoro-1-(trifluoromethyl)ethoxy]-1,1,3,3,3-pentafluoro-[4c]	$CF_3(OCF_2CF(CF_3))_2OCF_2C(=O)CF_3$	-	18934-99-1	P	(CAS 2019 (DE1940293))
Perfluorocyclobutane[4d]	c-C_nF_{2n}	n = 4	115-25-3	P	(CAS 2019 (US4038230))

4a



4b



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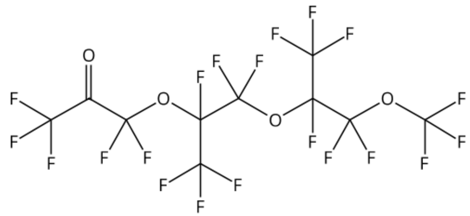

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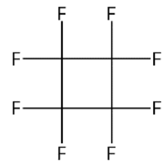
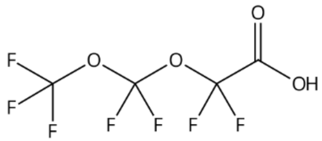


Perfluoro(*n*-oxaalkanoic) acid[5a]	$CF_3(OCF_2)_nCOOH$	n = 2, 3, 4	39492-88-1, 39492-89-2, 39492-90-5	U*, P	(Sheng et al. 2018; CAS 2019 (US20070015864))
Acetic acid, 2,2-difluoro-2-[[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy]-, ammonium salt (1:1) (cC604)[5b]	NH_4^+ $CF_3OC_3F_4O_3CF_2COO^-$	-	1190931-27-1	U*	(ECHA 2020)
-	$CF_3O(CF_2CF(CF_3)O)(CF_2OO)(C(CF_3)FO)COO^-$		-	U	(FOEN 2015)
- [5c]	$CH_3CH_2SO_4^-$ $C_3F_7(OCF(CF_3)CF_2)_nC(O)NHCH_2CH_2CH_2N^+(CH_3)(CH_3)C_2H_5$ n = 4 to 30		-	U	(Buck, Murphy, and Pabon 2012)

5a



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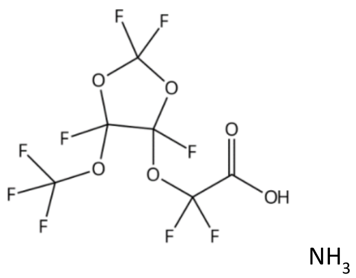

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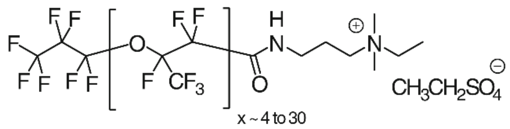


1.4.2 Production and processing of other plastics than fluoropolymers

PFAS have also been used during the production and processing of other plastics than fluoropolymers. This is described in more detail in Section 1.17 under "Processing aids for processing of polymers other than fluoropolymers".

1.4.3 Production of chlorine and sodium hydroxide

Chlorine and sodium/potassium hydroxide are among the most produced chemicals in the world (Gardiner 2015). Historically, chlorine and caustic soda (sodium hydroxide) were prepared with brine in either asbestos diaphragm cells or mercury electrode cells. PVDF and other fluoropolymers were used here as binder for the asbestos-fibre-based diaphragms (R. E. Banks, Smart, and Tatlow 1994). Nowadays, chlorine and caustic soda are produced with fluorinated membranes (R. E. Banks, Smart, and Tatlow 1994). The membrane divides the cell into anode and cathode chambers. Chlorine is generated at the anode, while sodium hydroxide and hydrogen are generated at the cathode. Oxidation at the anode occurs simultaneously with reduction at the cathode. The membrane permits only the passage of sodium ions from the anode chamber to the cathode chamber and prevents the migration of hydroxide ions to the anode chamber (R. E. Banks, Smart, and Tatlow 1994). Examples for such ion-exchange membranes are Chemour's Nafion® membranes (CAS No. 66796-30-3), AGCs (formerly Asahi Glass) Flemion® membranes and Asahi Kasei's Aciplex™ membranes. All these membranes are relatively stable under strongly oxidizing conditions and high temperatures (Cousins et al. 2019). The first Nafion® membranes were developed in the 1960s (Chemours 2019c) and have been continuously improved ever since. The initial Nafion® 400 series was composed of plain sulfonic acid membranes, which gave too low current efficiencies. Later membranes were developed with two sulfonic-acid-type polymers having different ion-exchange capacities. The latest Nafion® and also the Flemion® membranes have been designed to be carboxylate-sulfonate two-layer membranes with unique reinforcement (R. E. Banks, Smart, and Tatlow 1994; Kashiwada, Hirano, and Nakayama 2006). Reinfocements can be made by embedding a porous substrate (e.g. PTFE) in the membrane (Kashiwada, Hirano, and Nakayama 2006).

1.4.4 Production of other chemicals

PFAS have been used as inert reaction media, particularly when one of the reactants is gaseous (Costello, Flynn, and Owens 2000). Fluorotelomer alcohols have been used for the synthesis and separation of organic molecules in reaction mixtures (Poulsen, Jensen, and Wallström 2005). Nafion (CAS No. 31175-20-9) is used as a superacid and as a membrane in the production of fine chemicals (Chemours 2020). CTFE telomers have been used as a cutting or drawing oil in tantalum, molybdenum, and niobium processing (R. E. Banks, Smart, and Tatlow 1994). Perfluorosulfonic fluoride resins (for example, ethanesulfonyl fluoride, 1,1,2,2-tetrafluoro-2-[(1,2,2-trifluoroethenyl)oxy]-, polymer with 1,1,2,2-tetrafluoroethene, CAS No. 69462-70-0) have been used for fabricating reactive components in chemical applications, such as pure-polymer acid catalysts (Esposito 2016). PFAS are also used as solvents (see Section 1.4.8).

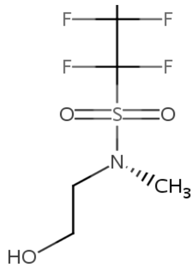
The SPIN database of the Nordic countries contains some additional PFAS that have been used or are used to manufacture chemicals and chemical products (Norden 2020). They are listed in Table 5. Some of the compounds listed in Table 5 may have been used as building blocks for producing other PFAS, e.g. MeFASEs.

Table 5: PFAS listed in the SPIN database of the Nordic countries for the manufacture of chemicals and chemical products. Some of the compounds listed may have been as building blocks for producing other PFAS, e.g. MeFASEs. The types stand for U – use and U* – current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
N-Methyl perfluoroalkane sulfonamidoethanols (MeFASEs)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 8	24448-09-7	U	(Norden 2020)
1-Alkanesulfonamide, *N*-[3-(dimethyloxidoamino) propyl]-perfluoro-[1b]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N(O)(CH_3)_2$	n = 6	80475-32-7	U	(Norden 2020)

(n:2) Fluorotelomer sulfonamide betaine (FTAB)[1c]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 6	34455-29-3	U	(Norden 2020)
Ammonium (n:2) fluorotelomer phosphate diester[1d]	$NH_4^+ OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	undefined	65530-70-3	U	(Norden 2020)

1a



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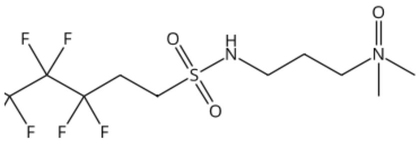

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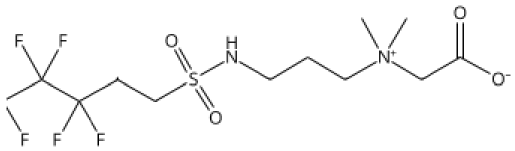
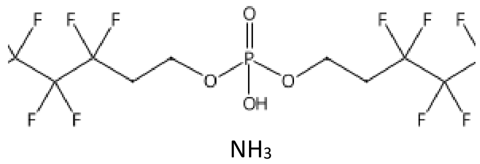
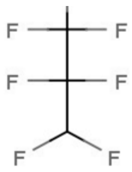


1d



1H-Perfluoroalkane[2a]	$C_nF_{2n+1}CF_2H$	n = 1	354-33-6	U	(Norden 2020)
Methyl perfluorobutyl ether[2b]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	U	(Norden 2020)
Methyl perfluoroisobutyl ether[2c]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(Norden 2020)
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethane diyl]], α-(1-carboxy-1,2,2,2-tetrafluoroethyl)-ω-[tetrafluoro(trifluoro methyl)ethoxy]-[2d]	4 -F $-CF_3$ $CF_3CF(COOH)[O(C_3F_6)]_nOCC$	-	51798-33-5	U*	(Norden 2020)
Polytetrafluoroethylene (PTFE)[2e]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Poly(vinylidene fluoride) (PVDF)[2f]	$-(CF_2CH_2)_x-$	polymer	24937-79-9	U	(Norden 2020)
Siloxanes and Silicones, di-Me, Me 3-(1,1,2,2-tetrafluoroethoxy) propyl, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl	-	-	104780-70-3	U	(Norden 2020)
Siloxanes and Silicones, (3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-hepta decafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether	-	-	143372-54-7	U	(Norden 2020)
1-Propanesulfonic acid, 2-methyl-, 2-[[1-oxo-3-[(γ-ω-perfluoro-C_{4-16}-alkyl)thio]propyl]amino] derivs., sodium salts	-	-	68187-47-3	U	(Norden 2020)

2a



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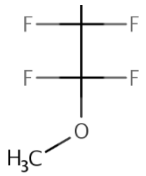

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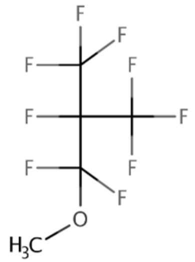

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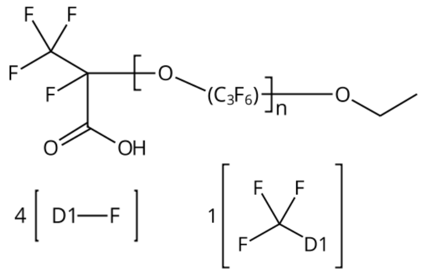
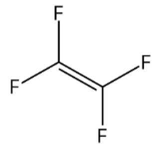


2e



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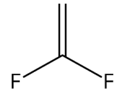


1.4.5 Polymer curing

Resins, elastomers, and adhesives have been cross-linked by vapour (similar to vapour-phase soldering) or even liquid immersion techniques using PFPEs as medium (R. E. Banks, Smart, and Tatlow 1994). Perfluoro-1,2-dimethylcycloalkane (CAS No. 306-98-9) and perfluoro-1,3-dimethylcycloalkane (CAS No. 335-27-3) are offered as fluids for curing low temperature cure resin systems (F2_Chemicals 2019a).

1.4.6 Ionic liquids

Bis(perfluorobutane-sulfonyl)imide (CAS No. 39847-39-7) has been marketed as a raw material for ionic liquids (Z. Wang et al. 2013). Examples for applications of ionic liquids are electrolytes for supercapacitors or lithium ion batteries (Section 2.12.2) and ultra hydrophobic solvents for the single drop microextraction (Section 2.19.1).

1.4.7 Technical equipment

PTFE has been used in reactor vessels, storage tanks, valves, pump fittings and seals, tubings and coatings because of its outstanding chemical resistance and thermal properties which are even better than those of stainless steel, glass, ceramic or other polymer plastics (Gardiner 2015). FEP has been used for lining chemical piping, fittings, and specialist storage tanks due to its impact strength (Gardiner 2015). ECTFE (ethylene tetrafluoroethylene copolymer, CAS No. 25038-71-5) hasd been used for tanks storing nitric and hydrochloric acid (Gardiner 2015). Other applications of ECTFE in the chemical process industry include seal glands, pipe plugs, fasteners, and pump parts (R. E. Banks, Smart, and Tatlow 1994). Similar, also PCTFE (polychlorotrifluoroethylene, CAS No. 9002-83-9) has been used in chemical process equipment and cryogenic applications, including seals, gaskets, pump parts, tubes, linings, and electrical insulators (R. E. Banks, Smart, and Tatlow 1994).

The pulp and paper industry has been using ECTFE for lining scrubbers and pipes for bleaching agents (Gardiner 2015). Hose-linings, tubing, and industrial gloves for chemical service constitute examples of the varied end-uses of fluorinated elastomers (R. E. Banks, Smart, and Tatlow 1994).

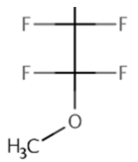
1.4.8 Solvents

Several perfluoro-ω-methylalkanes (CAS No. 212957-52-3, 212957-55-6, 212957-45-4, 212957-49-8) were patented as biocompatible solvents, in particular for perfluorocarbons and hydrocarbons (CAS 2019 (DE19719280, 1998)). Hydrofluoroethers such as the commercial mixtures HFE-7100 and HFE-7200 have been marketed as specialty solvents, dispersion media and reaction media (see Table 6) (3M 2009a, 2009b).

Table 6: Hydrofluoroethers used as solvents. The types stand for U – use and U* – current use. HFE-7100 and HFE-7200 are commercial products. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Methyl perfluorobutyl ether[1a]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	U	(3M 2009a; Norden 2020)
Methyl perfluoroisobutyl ether[1b]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(3M 2009a; Norden 2020)
Ethyl perfluorobutyl ether[1c]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	U	(3M 2009b; Norden 2020)
Ethyl perfluoroisobutyl ether[1d]	$CF_3CF(CF_3)CF_2OCH_2CH_3$	(part of HFE-7200)	163702-06-5	U	(Norden 2020)

1a



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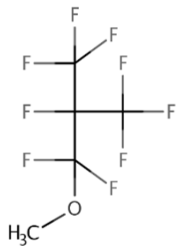

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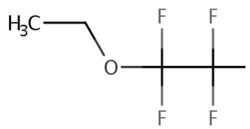

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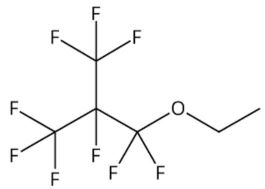


1.5 Electroless plating

Fluorinated surfactants may be used in electroless plating of copper, brass and nickel to promote the formation of a hydrophobic coating on the metal (Kissa 2001; CAS 2019 (JP05033153, 1993)). The fluorinated surfactants can promote the formation by dispersing the pitch fluoride in the plating solution. A patented substance for this function is 1-Propanaminium, 3-[[(1,1,2,2,3,3,4,4,5, 5,6,6,7,7,8,8,9,9,9-heptadecafluoro octyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1) (CAS No. 38006-74-5) (CAS 2019 (JP05033153, 1993)).

1.6 Electroplating (metal plating)

1.6.1 Chrome plating

Fluorinated surfactants are used in chrome plating baths to prevent the evaporation of chromium (VI) vapor (Kissa 2001). During chrome plating, a significant amount of gas is generated at the electrodes and released from the process tank (Buck, Murphy, and Pabon 2012). This causes bubbles and mist to be ejected from the plating bath causing aerosols, consisting of process liquids, to be dispersed into outdoor ambient air unless controlled (POPRC 2019). Fluorinated surfactants reduce the size of the gas bubbles by lowering the surface tension of the electrolyte solution (Kissa 2001). The smaller bubbles rise more slowly to the surface and have lower kinetic energy so that when the bubbles burst at the surface, mist is less likely to be emitted into the air (POPRC 2019). Fluorinated surfactants also form a barrier over the bath, thereby directly inhibiting the release of chromium (VI) vapour (POPRC 2016a).

Fluorinated surfactants have been used previously for both decorative chrome plating and hard chrome plating processes, but new technology using chromium (III) instead of chromium (VI) for decorative chrome plating has made fluorinated surfactants in decorative chrome plating obsolete (POPRC 2016a). The difference between hard and decorative metal plating is the thickness, hardness and deposition of the chrome layer on the plated object. The main function of hard metal plating is to provide resistance against corrosion and abrasion. Examples of hard metal plated parts include, hydraulic cylinders and rods, railroad wheel bearings and couplers, moulds for the plastic and rubber industry, tool and die parts (POPRC 2019). For decorative metal plating, the main function is primarily a decorative surface finish. Examples of decorative chrome plated parts include, car and truck pumpers, motorcycle parts, kitchen appliances, smart phones and tablets (POPRC 2019).

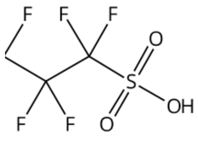
A list with fluorinated surfactants that have been or are used in chrome plating is shown in Table 7. Perfluorooctane sulfonic acid (PFOS, CAS No. 1763-23-1) related substances are still used in some countries because other wetting agents degrade more or less rapidly under the prevailing, strongly acidic and oxidizing conditions (POPRC 2016a; Hauser, Füglister, and Scheffelmaier 2020). This is also true for the fluorotelomer-based surfactants that are used as alternatives to PFOS and PFOS-related substances in chrome plating in Europe (Buck, Murphy, and Pabon 2012; POPRC 2012).

Table 7: PFAS historically or currently used in or patented for decorative and hard chrome plating. Patent number (date, legal status): JP54076443 (1979, expired), CN104611733 (2015, not yet ative), DE102006025847 (2007, not active), JP63208561 (1988, expired). The types stand for U – use, U* - current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl acids (PFAAs)					
Perfluoroalkane sulfonic acids (PFSA)[1a] *(Probably not the acids but the salts were used)*	$C_nF_{2n+1}SO_3H$	n = 8	1763-23-1	U*	(Hauser, Füglister, and Scheffelmaier 2020)
Ammonium perfluoroalkane sulfonate[(1a)]	$NH_4^+ C_nF_{2n+1}SO_3^-$	n = 8, 9	29081-56-9, 17202-41-4	U	(Buck, Murphy, and Pabon 2012)
Potassium perfluoroalkane sulfonate[(1a)]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	U	(CAS 2019 (JP54076443))
Lithium perfluoroalkane sulfonate[(1a)]	$Li^+ C_nF_{2n+1}SO_3^-$	n = 8	29457-72-5	U	(Kissa 2001)

Triethylammonium perfluoroalkane sulfonate[(1a)]	$N^+(C_2H_5)_3\ C_nF_{2n+1}SO_3^-$	n = 8	54439-46-2	P	(CAS 2019 (JP54076443))
Tetraethylammonium perfluoroalkane sulfonate[1b]	$N(C_2H_5)_4^+\ C_nF_{2n+1}SO_3^-$	n = 8	56773-42-3	U	(POPRC 2016a)
Diethanolamine perfluoroalkane sulfonate[1c]	$N^+H_2(C_2H_4OH)_2\ C_nF_{2n+1}SO_3^-$	n = 8	70225-14-8	U	(POPRC 2016a)
Perfluoroalkyl phosphinic acids[1d]	$C_nF_{2n+1}P(C_mF_{2m+1})(OH){=}O$	n/m = 3/3, 4/4, 6/6	1481-60-3, 52299-25-9, 40143-77-9	P	(CAS 2019 (DE102006025847))
Ammonium perfluoroalkyl carboxylate[1e]	$NH_4^+C_nF_{2n+1}COO^-$	n = 7, 8	3825-26-1, 4149-60-4	U	(Buck, Murphy, and Pabon 2012)
<u>Fluorotelomer-based substances</u>					
(n:2) Fluorotelomer sulfonic acids (FTSAs)[(1f)] *(Probably not the acids but the salts were used)*	$C_nF_{2n+1}\ H_2CH_2SO_3H$	n = 6	27619-97-2	U*	(Z. Wang et al. 2013)
Potassium (n:2) fluorotelomer sulfonate[1f]	$K^+\ C_nF_{2n+1}CH_2CH_2SO_3^-$	n = 6	59587-38-1	U	(Buck, Murphy, and Pabon 2012)

1a



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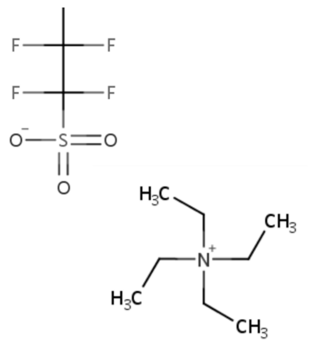

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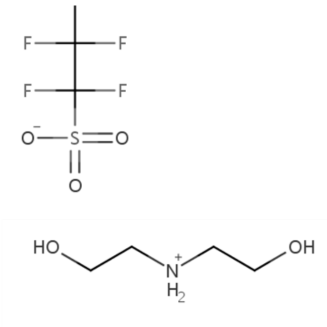

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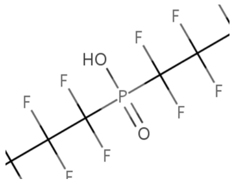

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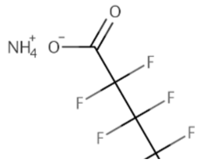

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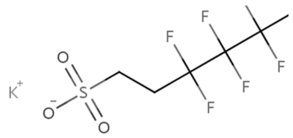
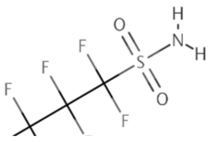


<u>Perfluoroalkane sulfonyl fluoride (PASF)-based substances</u>					
Perfluoroalkane sulfonamides[2a]	$C_nF_{2n+1}SO_2NH_2$	n = 6, 8	41997-13-1, 754-91-6	P	(CAS 2019 (JP63208561))
N-Alkyl perfluoroalkane sulfonamides	$C_nF_{2n+1}SO_2NH(R)$, $R = C_mH_{2m+1}$	n = 4, m = 1, 2, 4	-	U	(KEMI Swedish Chemical Agency 2015b)
1-Alkanesulfonamide, *N*,*N*′-[phosphinicobis(oxy-2,1-ethanediyl)]bis[perfluoro-*N*-methyl-[2b]	$[C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2O]_2P(O)OH$	n = 4	120945-47-3	U	(Norwegian Environment Agency 2017)
1-Alkanesulfonamide, *N*,*N*-bis(2,3-dihydroxy propyl)-perfluoro-[2c]	$C_nF_{2n+1}SO_2N[CH_2CH(OH)CH_2OH]_2$	n = 6, 8	118675-71-1, 74064-42-9	P	(CAS 2019 (JP63208561))
<u>Perfluoroalkane carbonyl fluoride (PACF)-based substances</u>					
Alkanamide, perfluoro-[2d]		n = 6, 8	2358-22-7, 82854-34-0	P	(CAS 2019 (JP63208561))

Alkanamide, *N*,*N*-bis(2,3-dihydroxypropyl)-perfluoro-[2e]	$C_nF_{2n+1}C(O)N[CH_2CH(OH)CH_2OH]_2$	n = 6, 8	118675-72-2, 118675-73-3	P	(CAS 2019 (JP63208561))

2a



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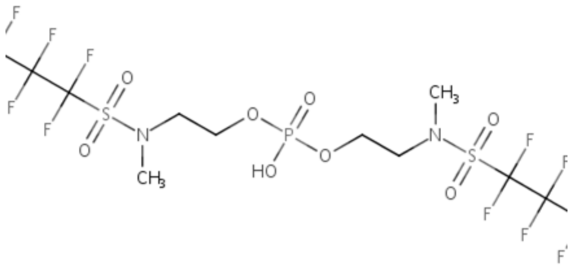

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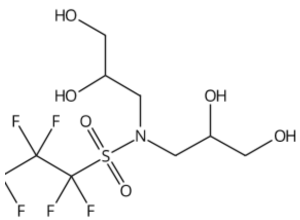

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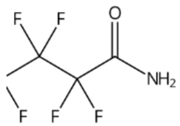

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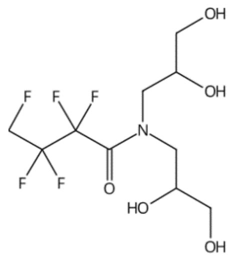
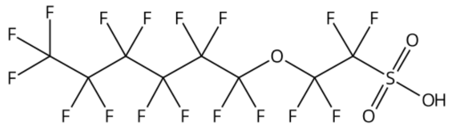


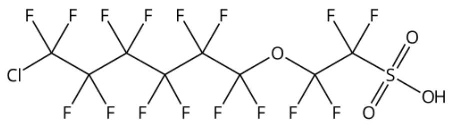
<u>Perfluoropolyether (PFPE) -based substances</u>					
Ethanesulfonic acid, 1,1,2,2-tetrafluoro-2-[(perfluoroalkyl)oxy]-, potassium salt (1:1)[3a]	$K^+ \ C_nF_{2n+1}OC_2F_4SO_3^-$	n = 6 (F-53)	68136-88-9	U	(Z. Wang et al. 2013)
Ethanesulfonic acid, 2-[(ω-chloro-perfluoroalkyl) oxy]-1,1,2,2-tetrafluoro-, potassium salt (1:1)[3b]	$K^+ \ ClC_nF_{2n}OC_2F_4SO_3^-$	n = 6 (F-53B), 8	73606-19-6, 83329-89-9	U*	(Pan et al. 2017; Z. Wang et al. 2013)

4a



K

4b



K

<u>Polymers</u>					
Fluorinated (meth)acrylate polymers	-		-	U	(KEMI Swedish Chemical Agency 2015b)

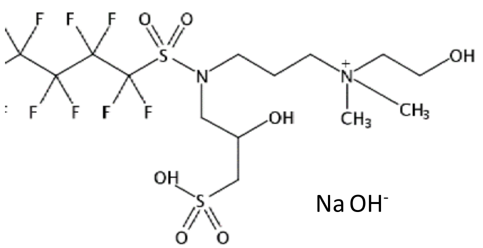
1.6.2 Plating with other substances

Fluorinated surfactants have also been used in metal plating applications which are not based on chromium. Fluorinated surfactants have been used in nickel-plating baths as non-foaming surfactant to reduce the surface tension and increase the strength of the nickel electroplate by eliminating pinholes, cracks, and peeling (Kissa 2001). Fluorinated surfactants have been used to prevent haze of plated copper by regulating foam and improving stability (Poulsen, Jensen, and Wallström 2005) and they have been added to tin-plating baths to produce a plating of uniform thickness (Kissa 2001). Fluorinated surfactant that have been patented for copper plating are shown in Table 8. Fluorinated surfactants have also been used for alkaline zinc and zinc alloy plating (POPRC 2016a). Furthermore, deposition of fluoropolymer particles (e.g. PTFE) onto steel for surface protection may be supported by fluorinated surfactants. Cationic and amphoteric fluorinated surfactants can impart a positive charge to fluoropolymer particles which facilitates the electroplating of the fluoropolymer (Kissa 2001).

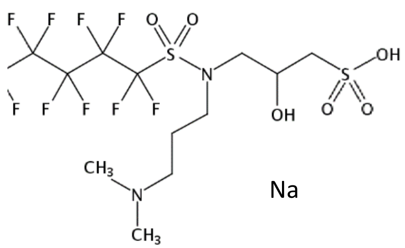
Table 8: PFAS patented for copper plating. Patent number (date, legal status): GB2077765 (1981, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Propanaminium, *N*-(2-hydroxyethyl)-3-[(2-hydro xy-3-sulfopropyl)[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl-, hydroxide, sodium salt (1:1:1)[1a]	$Na^+ OH^- C_nF_{2n+1}SO_2N(CH_2CH(OH)CH_2SO_3^-) CH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 6	81190-38-7	P	(CAS 2019 (GB2077765))
1-Propanesulfonic acid, 3-[[3-(dimethylamino)propyl][(1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluorohexyl) sulfonyl]amino]-2-hydroxy-, sodium salt (1:1)[1b]	$Na^+ C_nF_{2n+1}SO_2N(CH_2CH(OH)CH_2SO_3^-) CH_2CH_2CH_2N(CH_3)_2$	n = 6	73772-32-4	P	(CAS 2019 (GB2077765))
1-Propanaminium, 3-[(carboxymethyl)[(perfluoro alkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, hydroxide, sodium salt (1:1:1)[1c]	$OH^- Na^+ C_nF_{2n+1}SO_2N(CH_2COO^-)CH_2CH_2CH_2 N^+(CH_3)_3$	n = 6	81190-39-8	P	(CAS 2019 (GB2077765))
1-Propanaminium, *N*-(2-carboxyethyl)-3-[(2-carboxyethyl) [(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl-, inner salt, sodium salt (1:1)[1d]	$Na^+ C_nF_{2n+1}SO_2N(CH_2CH_2COO^-)CH_2CH_2CH_2 N^+(CH_3)_2CH_2CH_2COO^-$	n = 6	81190-42-3	P	(CAS 2019 (GB2077765))

1a



1b



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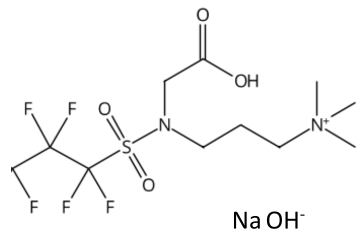
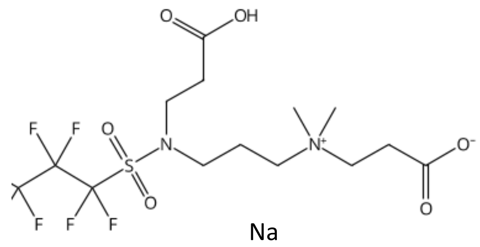


1d



1.7 Electronics industry

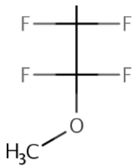
PFAS have been used in the electronics industry because they are water-repellent, have a low surface tension and high dielectric and breakdown strength (R. E. Banks, Smart, and Tatlow 1994). They have been used in the production of printed circuit boards, loud speakers, transductors, digital cameras, cell phones, printers, scanners, satellite communication systems, radar systems, and many other products (KEMI Swedish Chemical Agency 2015b; POPRC 2019). This is also confirmed by studies in which these articles were tested in the laboratory and various PFAS were found in the tested material. For example, tested circuit boards contained 6:2 fluorotelomer sulfonic acid (CAS No. 27619-97-2), perfluorooctane sulfonamide (CAS No. 754-91-6), PFOS (CAS No. 1763-23-1) and perfluorobutanoic acid (CAS No. 375-22-4) (Herzke, Olsson, and Posner 2012). The following subsections focus on PFAS in the manufacturing process in the electronics industry. Section 2.12 focuses on PFAS in the electronic devices themselves.

The Chemical Data Reporting database under the TSCA lists nine PFAS that were used as functional fluids in computer and electronic product manufacturing in the US between 2012 and 2015 (USEPA 2016). It also lists PFAS that were used in electric equipment, appliance, and component manufacturing and as surface active agents. The compounds are all shown in Table 9. Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-(trifluoromethyl)- (CAS No. 132182-92-4) was used in computer and electronic product manufacturing in the US between 2012 and 2015, but the specific function was declared confidential business information (USEPA 2016). The SPIN database of the Nordic countries lists additional PFAS that have been used either in the manufacturing of computer, electronic and optical products or in the manufacturing of radio, television and communication equipment (Norden 2020). These PFAS are also listed in Table 9 under 'Electric equipment, appliance, and component manufacturing'.

Table 9: PFAS that have been used or are still used in the US or the Nordic countries in the electronics industry. The types stand for U – use and U* – current use. HFE-7100 and HFE-7200 are commercial products. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Functional fluid (closed system)					
Methyl perfluoroalkyl ether[1a]	$C_nF_{2n+1}OCH_3$	n = 3, 4 (part of HFE-7100)	375-03-1, 163702-07-6	U	(USEPA 2016)
Methyl perfluoroisobutyl ether[1b]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(USEPA 2016)
Ethyl perfluorobutyl ether[1c]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	U	(USEPA 2016)
Ethyl perfluoroisobutyl ether[1d]	$CF_3CF(CF_3)CF_2OCH_2CH_3$	(part of HFE-7200)	163702-06-5	U	(USEPA 2016)
3-Ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoro methyl)hexane[1e]	$C_3F_7CF(OCH_2CH_3)CF(CF_3)CF_3$	-	297730-93-9	U	(USEPA 2016)
Perfluoro compounds, C_{5-18}	-	-	86508-42-1	U	(USEPA 2016)
Perfluoro-2-methyl-3-pentanone[1f]	$CF_3CF_2C(O)CF(CF_3)_2$	-	756-13-8	U	(USEPA 2016)

1a



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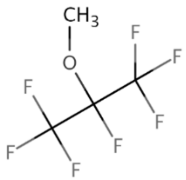

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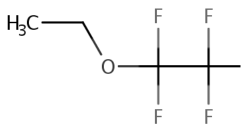
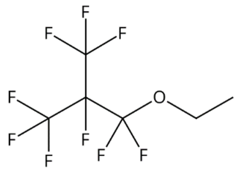
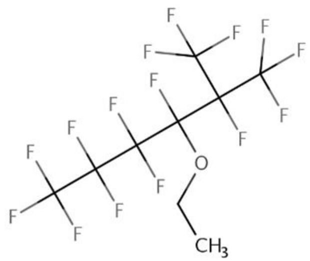


1d



1e



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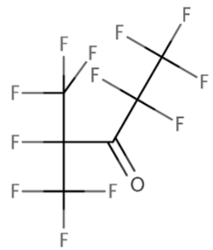
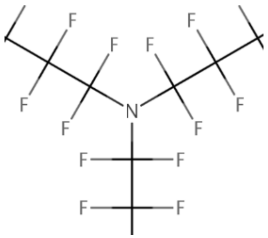


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluorotrialkyl amine[2a]	$N(C_nF_{2n+1})_3$	n = 4	311-89-7	U	(USEPA 2016)
Morpholine, 2,2,3,3,5,5,6,6-octafluoro-4-(trifluoromethyl)-[2b]	c-$C_5F_{11}NO$	-	382-28-5	U	(USEPA 2016)
Electric equipment, appliance, and component manufacturing					
Potassium perfluoroalkane sulfonate[2c]	$K^+\ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	U	(Norden 2020)
Diethanolammonium perfluoroalkane sulfonate[2d]	$N^+H_2(CH_2CH_2OH)_2\ C_nF_{2n+1}SO_3^-$	n = 8	70225-14-8	U	(Norden 2020)

(n:2) Fluorotelomer sulfonic acid (FTSA)[2e]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	U*	(Norden 2020)
1H-Perfluoroalkane[2f]	$C_nF_{2n+1}CF_2H$	n = 1	354-33-6	U	(USEPA 2016)

2a



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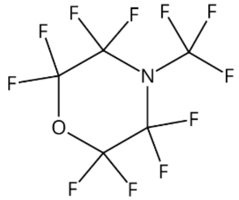

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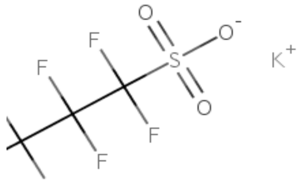
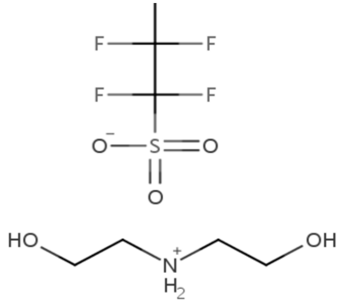


2d



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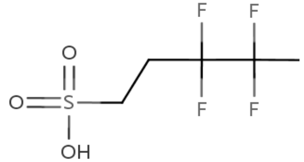

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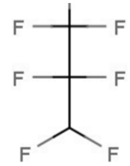
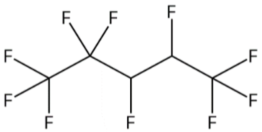


Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[3a]	$C_2F_5(CFH)_2CF_3$	-	138495-42-8	U	(Norden 2020)
Methyl perfluorobutyl ether[1a]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	U	(Norden 2020)
Methyl perfluoroisobutyl ether[1b]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(Norden 2020)
Polytetrafluoroethylene (PTFE)[3b]	$(CF_2CF_2)_x$	polymer	9002-84-0	U	(Norden 2020)
<u>Surface active agents</u>					
Ammonium perfluoroalkane sulfonamidoethanol[3c]	$NH_4^+\ C_nF_{2n+1}SO_2NHCH_2CH_2O^-$	n = 4	484024-67-1	U	(USEPA 2016)
<u>Plating agent and surface treatment agent</u>					
Linear perfluoroalkanes[3d]	C_nF_{2n+2}	n = 2	76-16-4	U	(USEPA 2016)

3a



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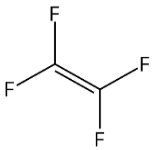

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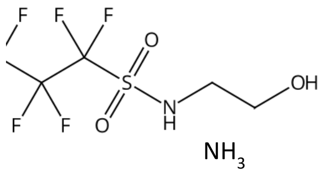

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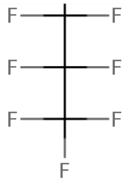


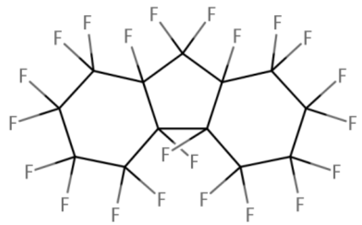
1.7.1 *Testing of electronic devices and equipment*

Perfluorocarbons and hydrofluoroethers are used as inert fluids for electronics testing (F2_Chemicals 2019a). Testing applications include liquid burn-in testing, reliability testing, dielectric testing, thermal shock testing, gross and fine leak testing, and electrical environmental testing. Table 10 lists a range of PFAS that are marketed for testing in these applications.

Table 10: PFAS marketed for testing of electronic devices and equipment. HFE-7000 and HFE-7100 are commercial products. The types stand for U – use and U* – current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Liquid burn-in testing					
Perfluoroperhydrofluorene[1a]	$C_{13}F_{22}$	-	307-08-4	U	(F2_Chemicals 2019a)
PFPEs					(R. E. Banks, Smart, and Tatlow 1994)
Reliability testing					
Perfluoropropyl methyl ether[1b]	$C_3F_7OCH_3$	(HFE-7000)	375-03-1	U	(3M 2014)
Dielectric test media					
Methyl perfluorobutylether[1b]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	U	(3M 2009a)
Methyl perfluoroisobutyl ether[1c]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(3M 2009a)
Thermal shock testing					
Perfluoroisohexane[1d]	C_6F_{14}	-	355-04-4	U	(F2_Chemicals 2019a)
Perfluoro-1,3-dimethylcycloalkane[1e]	C_nF_{2n}	n = 8	355-27-3	U	(F2_Chemicals 2019a)
Perfluoromethyldecalin[1f]	$C_{11}F_{20}$	-	306-92-3	U	(F2_Chemicals 2019a)

1a



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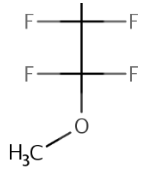

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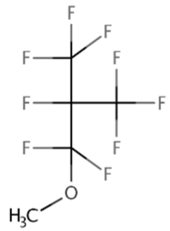

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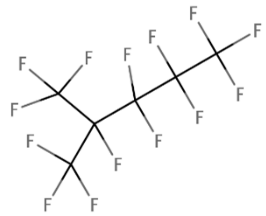

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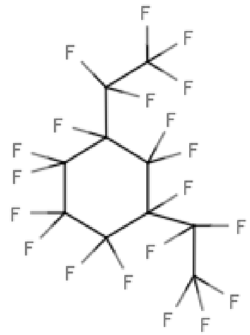

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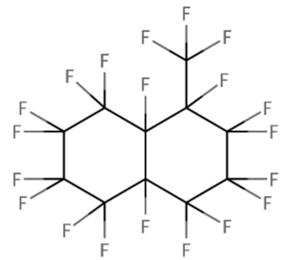
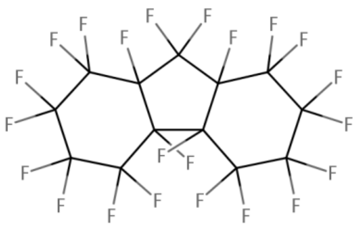


Perfluoroperhydrofluorene[2a]	$C_{13}F_{22}$	-	307-08-4	U	(F2_Chemicals 2019a)
Perfluorotetradecahydrophenanthrene[2b]	$C_{14}F_{24}$	-	306-91-2	U	(F2_Chemicals 2019a)
PFPEs	-	-	-	U	(R. E. Banks, Smart, and Tatlow 1994)
<u>Gross and fine leak testing</u>					
PFPEs	-	-	-	U	(R. E. Banks, Smart, and Tatlow 1994)
<u>Electrical environmental testing</u>					
Perfluorinated fluids	-	-	-	U	(Costello, Flynn, and Owens 2000)
<u>Use for testing in general</u>					
Perfluoromethylcycloalkane[2c]	C_nF_{2n}	n = 7	355-02-2	U	(F2_Chemicals 2019a)
Perfluoro-1,2-dimethylcycloalkane [2d]	C_nF_{2n}	n = 8	306-98-9	U	(F2_Chemicals 2019a)
Perfluoroperhydrofluoranthene[2e]	$C_{16}F_{26}$	-	662-28-2	U	(F2_Chemicals 2019a)

2a



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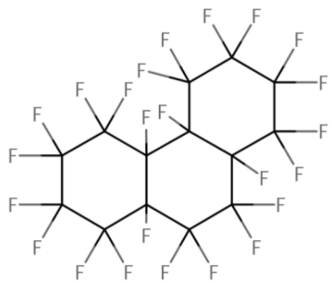
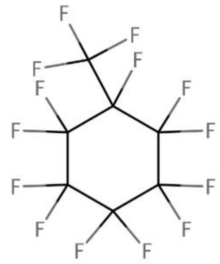


3a



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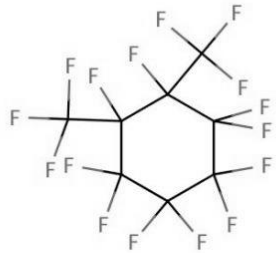

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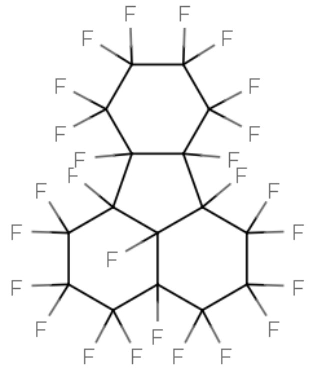
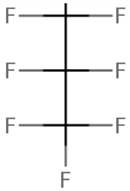
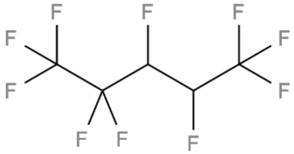
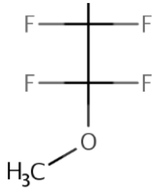
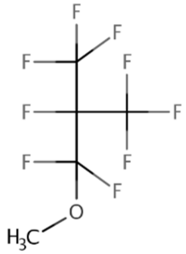
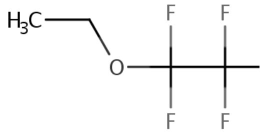
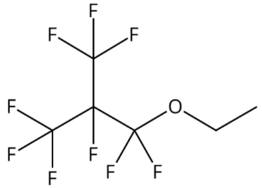


1.7.2 Heat transfer fluids (cooling of electric equipment)

Perfluorinated liquids can be used in evaporative cooling, brine cooling, direct contact cooling and total immersion cooling. Table 11 lists a range of PFAS that have been marketed for these applications. Power supplies, memory boards, logic circuits, and main processors of supercomputers, sensitive military electronics, and high voltage transformers have often been cooled by total immersion cooling (Costello, Flynn, and Owens 2000). Some of the perfluorocarbons (Flutec PP1, PP2, PP7, PP80, PP90, PP3, PP6, PP9, PP11, PP24, PP25) are also marketed for direct cooling of lasers, where the light pulse passes directly through the perfluorocarbon liquid (F2_Chemicals 2019a).

Table 11: PFAS marketed for cooling of electronic devices and equipment. HFE-7100, HFE-7200 and all Flutec brands are commercial products. The types stand for U – use and U* – current use. Additional explanations to the tables are provided on Page 2 and 3 of this document.

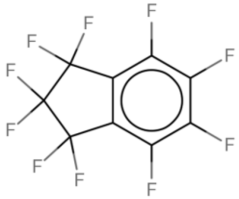
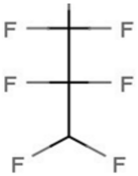
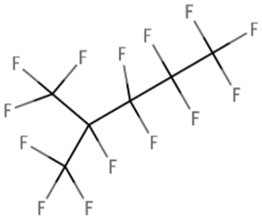
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Evaporative cooling – the fluid is enclosed in a heat cycle system and cools parts with high temperature due to evaporation					
Linear perfluoroalkanes[1a]	C_nF_{2n+2}	n = 3	76-19-7	U*	(F2_Chemicals 2019a; Norden 2020)
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[1b]	$CF_3CF_2(CFH)_2CF_3$		138495-42-8	U	(Chemours 2019e)
Brine cooling – the fluid is in contact with another fluid, effectively cooling the other fluid					
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[1b]	$CF_3CF_2(CFH)_2CF_3$		138495-42-8	U	(Chemours 2019e)
Methyl perfluorobutyll ether[1c]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	U	(3M 2009a)
Methyl perfluoroisobutyl ether[1d]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(3M 2009a)
Ethyl perfluorobutyl ether[1e]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	U	(3M 2009b)
Ethyl perfluoroisobutyl ether[1f]	$CF_3CF(CF_3)CF_2OCH_2CH_3$	(part of HFE-7200)	163702-06-5	U	(3M 2009b)

1a  1b  1c  1d  1e  1f 

Perfluoroindane[2a]	C_9F_{10}		374-80-1	U	(F2_Chemicals 2019a)

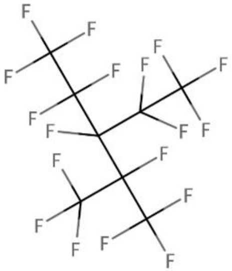
<u>Direct contact cooling – the fluid is in direct contact with the hot component</u>

Linear perfluoroalkanes[1a]	C_nF_{2n+2}	n = 7 (Flutec PP7)	335-57-9	U	(F2_Chemicals 2019a)
1H-Perfluoroalkane[2b]	$C_nF_{2n+1}CF_2H$	n = 1	354-33-6	U*	(Norden 2020)
Perfluoroisohexane[2c]	C_6F_{14}	(Flutec PP1)	355-04-4	U	(F2_Chemicals 2019a)

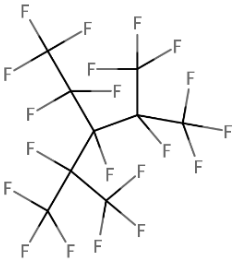
2a  2b  2c 

Perfluoro-2-methyl-3-ethylpentane[3a]	C_7F_{16}	(Flutec PP80)	354-97-2	U	(F2_Chemicals 2019a)
Perfluoro-2,4-dimethyl-3-ethylpentane[3b]	C_9F_{20}	(Flutec PP90)	50285-18-2	U	(F2_Chemicals 2019a)
Perfluoromethylcycloalkane[3c]	C_nF_{2n+2}	n = 6, n = 7 (Flutec PP2)	1805-22-7, 355-02-2	U	(F2_Chemicals 2019a; R. E. Banks, Smart, and Tatlow 1994)
Perfluoro-1,2-dimethylcycloalkane[3d]	C_nF_{2n}	n = 8	306-98-9	U	(F2_Chemicals 2019a)
Perfluoro-1,3-dimethylcycloalkane[3e]	C_nF_{2n}	n = 8 (Flutec PP3)	335-27-3	U	(F2_Chemicals 2019a)
Perfluorodecalin[3f]	$C_{10}F_{18}$	(Flutec PP6)	306-94-5	U	(F2_Chemicals 2019a)

3a



3b



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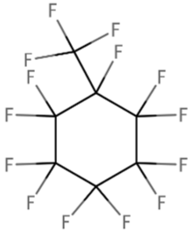

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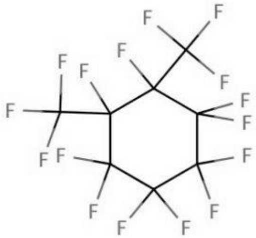

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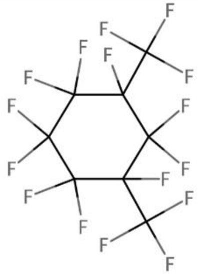

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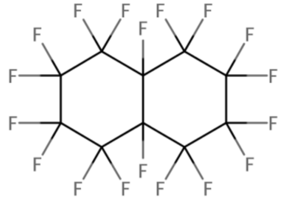
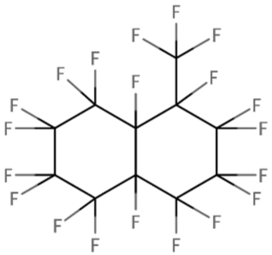
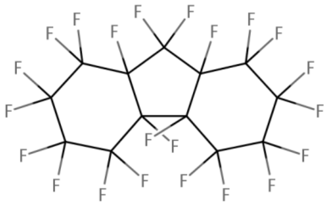


Perfluoromethyldecalin[4a]	$C_{11}F_{20}$	(Flutec PP9)	306-92-3	U	(F2_Chemicals 2019a)
Perfluoroperhydrofluorene[4b]	$C_{13}F_{22}$	(Flutec TG PPF)	307-08-4	U	(F2_Chemicals 2019a)
Perfluorotetradecahydrophenanthrene[4c]	$C_{14}F_{24}$	(Flutec PP11)	306-91-2	U	(F2_Chemicals 2019a)
Perfluoroperhydrofluoranthene[4d]	$C_{16}F_{26}$	(Flutec PP24)	662-28-2	U	(F2_Chemicals 2019a)
Perfluoroperhydrobenzyltetralin[4e]	$C_{17}F_{30}$	(Flutec PP25)	116265-66-8	U	(F2_Chemicals 2019a)

4a



4b



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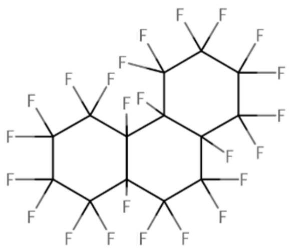
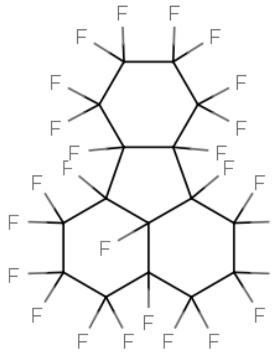
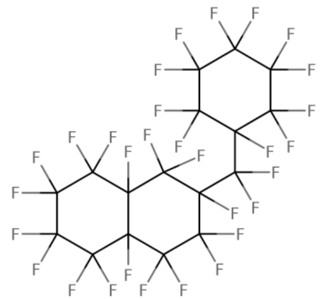


4d



4e



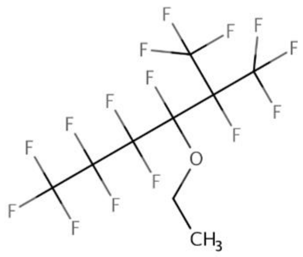
<u>Total immersion cooling – the hot components are immersed in a cooling rack filled with the fluid</u>

Methyl perfluoroalkyl ether[1c]	$C_nF_{2n+1}OCH_3$	n = 3 (HFE-7000)	375-03-1	U	(3M 2014)
Ethyl perfluoroisoalkyl ether[5a]	$C_3F_7CF(OCH_2CH_3)CF(CF_3)_2$	(HFE-7500)	297730-93-9	U	(3M 2008)

<u>Heat transfer in general</u>

1H-Perfluoroalkane[2a]	$C_nF_{2n+1}CF_2H$	n = 1	354-33-6	U*	(Norden 2020)
Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd., reduced, decarboxylated	-	polymer	161075-02-1	U	(USITC 2006)

5a



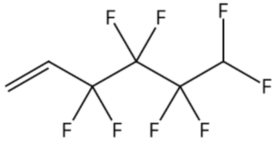
1.7.3 *Solvent systems and cleaning*

Perfluorocarbons can be used in conjunction with solvents such as alcohol to form the basis of cleaning solutions in which the perfluorocarbon acts as a heat-transfer agent, forms a nonflammable vapor blanket, reduces the flash point of the solvent, and finally rinses off solvent residues. Those cleaning solutions have been used industrially for cleaning items like computer disk drives and printed circuit boards (R. E. Banks, Smart, and Tatlow 1994). One example of such a cleaning solution is an isopropanol foam where a fluorinated surfactant has been used to maintain the foam when a metallic surface from which greases and contaminants need to be removed is passed on top of the foam (Buck, Murphy, and Pabon 2012). Other fluorinated surfactants used or patented for cleaning compositions for electric and electronic components are listed in Table 12.

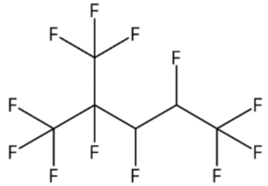
Table 12: Fluorinated surfactants used or patented for cleaning compositions for electric and electronic components. HFE-7100 and HFE-7200 are commercial products. Patent number (date, legal status): JP06179894 (1994, expired), JP06179896 (1994, expired), WO2008095881 (2008, active), JP10152452 (1998, expired). The types stand for U – use, U* - current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)s	CAS No.	Type	Reference
1-Hexene, 3,3,4,4,5,5,6,6-octafluoro-[1a]	$HCF_2CF_2CF_2CF_2CH{=}CH_2$	-	159148-08-0	P	(CAS 2019 (JP06179894))
Pentane, 1,1,1,2,3,4,5,5,5-nonafluoro-2-(trifluoromethyl)-[1b]	$CF_3CF(CF_3)CFHCFHCF_3$	-	85720-78-1	P	(CAS 2019 (JP06179896))
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[1c]	$C_2F_5(CFH)_2CF_3$	-	138495-42-8	U	(USEPA 2016)
Methyl perfluoroalkyl ether[1d]	$C_nF_{2n+1}OCH_3$	n = 2, 3, 4 (part of HFE-7100)	22410-44-2, 375-03-1, 163702-07-6	P	(CAS 2019 (JP10152452); USEPA 2016)
Methyl perfluoroisobutyl ether[1e]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(USEPA 2016)
Ethyl perfluorobutyl ether[1f]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	U	(USEPA 2016)

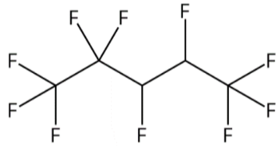
1a



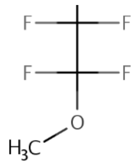
1b



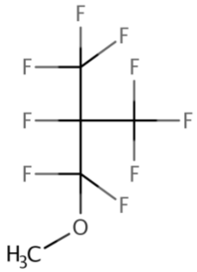
1c



1d



1e



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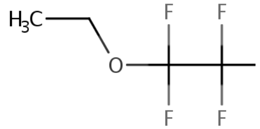
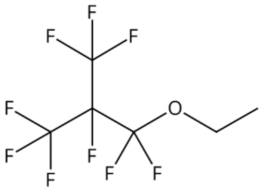
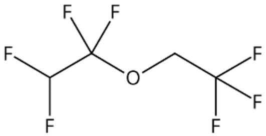


Ethyl perfluoroisobutyl ether[2a]	$CF_3CF(CF_3)CF_2OCH_2CH_3$	(part of HFE-7200)	163702-06-5	U	(USEPA 2016)
Ethane, 1,1,2,2-tetrafluoro-1-(2,2,2-trifluoroethoxy)-[2b]	$CF_2HCF_2OCH_2CF_3$	-	406-78-0	U	(USEPA 2016)
Linear perfluoroalkanes[2c]	C_nF_{2n+2}	n = 3	76-19-7	U	(USEPA 2016)

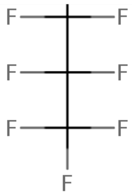
2a



2b



2c



1.7.4 Carrier fluid/lubricant deposition

Perfluorocarbons (e.g. perfluoroisohexane, CAS No. 355-04-4) and hydrofluorocarbons (e.g. pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-, CAS No. 138495-42-8) are used to dissolve and deposit lubricants on a range of substrates during the manufacturing of hard disk drives (Chemours 2019e; F2_Chemicals 2019a).

1.7.5 Others

PFOS (CAS No. 1763-23-1) was used in the past in the etching process of piezoelectric ceramic filters. These filters are used as band pass filters at intermediate frequency in two-way radios for police radios, FM radios, TVs, and RKEs (Remote Keyless Entry for Cars) (Japan 2008). PFOA was used in the past (in at least one company) in pulsed plasma nano-coating to manufacture smartphones (POPRC 2017). PCTFE films have been used for packaging air and moisture-sensitive materials, such as electronic equipment (R. E. Banks, Smart, and Tatlow 1994).

1.8 Energy sector

1.8.1 Energy production

Solar collectors and photovoltaic cells

Fluoropolymers, for example PVDF, FEP or ETFE have been used as front and back sheet films in flat-plate solar collectors and photovoltaic cells (R. E. Banks, Smart, and Tatlow 1994; Janousek, Lebertz, and Knepper 2019; Ameduri 2018). White pigmented films have been used for the bottom surface of the photovoltaic cells and transparent films have been used as cover for both, solar collectors and photovoltaic cells (S. Ebnesajjad and Snow 2000). The fluoropolymer can provide a strong vapor barrier, high transparency and great weatherability and it can also function as dirt-repellent coating (FluoroIndustry 2019; R. E. Banks, Smart, and Tatlow 1994; KEMI Swedish Chemical Agency 2015b). Fluorinated adhesives can be used in photovoltaic cells to hold the mesh cathode in place (Google_patents 2019 (EP1606846B1, 2005)).

Wind mills

Fluoropolymers have been used as coatings for wind mill blades (Ameduri 2018).

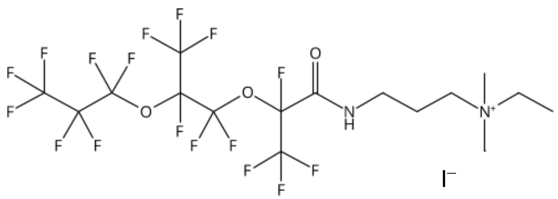
Coal-based power plants

Filters coated with fluorpolymers have been used in coal-based power plants to remove fly ash from the hot smokey discharge (Gardiner 2015). Fluoropolymers are also used in coal-based power plants for pressure tubing in flue gas heat exchangers for the desulfurisation of the emissions (Gardiner 2015; AGC 2018). A patent discloses the use of PFAS in the continuous separation of carbon dioxide in flue gases (CAS 2019 (CN106914122, 2017)). The patented fluorinated surfactants are shown in Table 13.

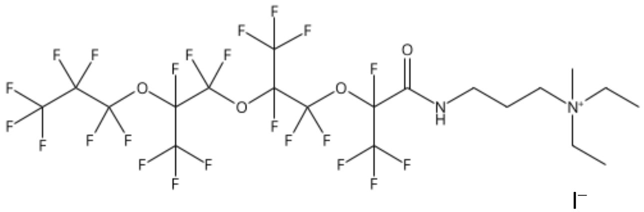
Table 13: Patented PFAS for the separation of carbon dioxide in flue gases. Patent number (date, legal status): CN106914122 (2017, active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Propanaminium, *N*,*N*-diethyl-*N*-methyl-3-[[2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(1,1,2,2,3,3,3-heptafluoro propoxy)propoxy]-1-oxopropyl]amino]-, iodide (1:1)[1a]	$I^- C_3F_7OCF(CF_3)CF_2OCF(CF_3)C(O)NH CH_2CH_2CH_2N^+(CH_3)(C_2H_5)_2$	-	84166-38-1	P	(CAS 2019 (CN106914122))
7,10,13-Trioxa-4-azahexadecan-1-aminium, *N*,*N*-diethyl-6,8,8,9,11,11,12,14,14,15,15,16,16,16-tetradecafluoro-*N*-methyl-5-oxo-6,9,12-tris(trifluoromethyl)-, iodide (1:1)[1b]	$I^- C_3F_7[OCF(CF_3)CF_2]_2OCF(CF_3)C(O)NH CH_2CH_2CH_2N^+(CH_3)(C_2H_5)_2$	-	84166-37-0	P	(CAS 2019 (CN106914122))
Ethanesulfonic acid, 2-[(ω-chloro-perfluoroalkyl)oxy]-1,1,2,2-tetrafluoro-, potassium salt (1:1)[1c]	$K^+ ClC_nF_{2n}OC_2F_4SO_3^-$	n = 6 (F-53B)	73606-19-6	P	(CAS 2019 (CN106914122))

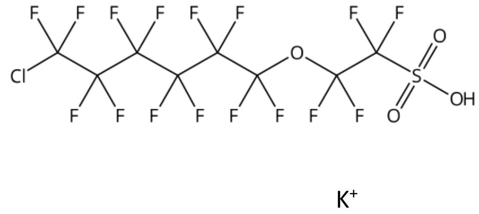
1a



1b



1c

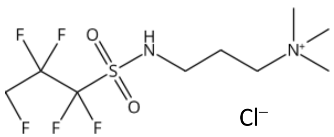


1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[2a]

$Cl^- \ C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$ n = 8

38006-74-5 P (CAS 2019 (CN106914122))

2a



1.8.2 Energy storage

Lithium-ion batteries

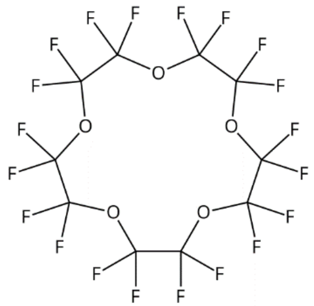
Lithium-ion batteries are currently the most advanced power sources for portable electronic applications (Gardiner 2015). PVDF and FEP are used as binders for both the negative (anode) and positive (cathode) electrodes in nearly all commercial lithium batteries. There function as binder is to join the active material and conductive additives together without reacting with the electrodes and electrolyte (Lee 2019). Fluorocarbon resins and fluoropolymers have been used in lithium batteries to prevent a thermal runaway reaction and combustion of the battery (Kountz, Hoover, and Pruce 2015). Patent WO2010058587 discloses, for example, the use of a fluorocarbon resin as heat absorbing layer in the inside of the case of the battery pack, and PTFE as a heat conductive layer at the outside of the case of the battery pack (Kountz, Hoover, and Pruce 2015). Patent US20090176148 discloses the immersion of the lithium batteries into a container filled with a heat transfer fluid. The fluid could be a perfluorocarbon, perfluoropolyether, perfluoroamine, perfluoroether or hydrofluoroether (Kountz, Hoover, and Pruce 2015). For possible specific substances, see Section 1.7.2 'Heat transfer fluids`. A tested lithium battery from a Sony Ericsson cell phone contained perfluorononanoic acid (CAS No. 375-95-1), 6:2 fluorotelomer sulfonic acid (CAS No. 27619-97-2), and *n*-methyl and *n*-ethyl perfluorooctane sulfonamidoethanols (CAS No. 24448-09-7 and 1691-99-2, respectively) (Herzke, Posner, and Olsson 2009). Additionally, a PFAS additive (Oxirane, 2-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)oxy]methyl]-, CAS No. 122193-68-4) improved the oxygen transport of lithium-air batteries (Wan et al. 2017).

Gel polymer electrolytes for lithium ion batteries that contain a polymer matrix made out of vinylidenfluorid-hexafluorpropylen copolymer (CAS No. 9011-17-0) or PVDF have also been investigated (Stepniak et al. 2014). Fluorinated surfactants that have been patented as electrolyte solvents for lithium-sulfur batteries are shown in Table 14 (CAS 2019 (DE102015225286, 2017)).

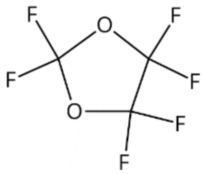
Table 14: Patented PFAS as electrolyte solvents for lithium-sulfur batteries. Patent number (date, legal status): DE102015225286 (2017, not yet active).

Chemical name	Molecular formula	CAS No.	Reference
1,4,7,10,13-Pentaoxacyclopentadecane, 2,2,3,3,5,5,6,6,8,8,9,9,11,11,12,12,14,14,15,15-eicosafluoro-[1a]	c-$(CF_2CF_2O)_5$	97571-69-2	(CAS 2019 (DE102015225286))
1,3-Dioxolane, 2,2,4,4,5,5-hexafluoro-[1b]	c-$CF_2OCF_2CF_2O$	21297-65-4	(CAS 2019 (DE102015225286))
Furan, 2,2,3,3,4,4,5,5-octafluorotetrahydro-[1c]	c-$OCF_2CF_2CF_2CF_2$	773-14-8	(CAS 2019 (DE102015225286))
2,5,8,11,14-Pentaoxapentadecane, 1,1,1,3,3,4,4,6,6,7,7,9,9,10,10,12,12,13,13,15,15,15-docosafluoro-[1d]	$CF_3O(CF_2CF_2O)_4CF_3$	64028-06-4	(CAS 2019 (DE102015225286))
Ethane, 1,1′-oxybis[1,1,2,2-tetrafluoro-2-(trifluoromethoxy)]-[1e]	$CF_3O(CF_2CF_2O)_2CF_3$	40891-99-4	(CAS 2019 (DE102015225286))

1a



1b



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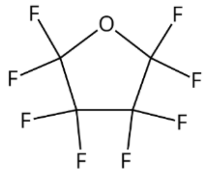

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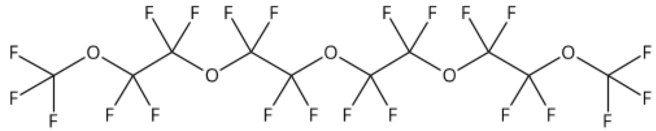
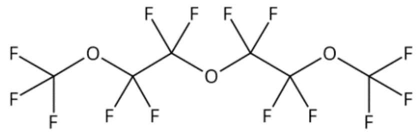


1e



Vanadium redox batteries

Fluorinated ion exchange membranes have been used in vanadium redox batteries. The ion exchange membrane may be made out of PTFE, perfluorosulfonic acid ionomer or perfluorosulfonic acid ionomer/PTFE copolymer (M. Liu and Lee 2014). The membranes are resistance to acidic environments and highly oxidizing species (Lloyd and Unlu 2015). A commercially available membrane is Nafion™ perfluorosulfonic acid polymer dispersion (Chemours 2019c).

Zinc batteries

Fluorinated surfactants have been added to zinc battery electrolytes to prevent the formation of dendrites (Kissa 2001). The fluorinated surfactant poly(oxy-1,2-ethanediyl), α-(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-ω-hydroxy- (Forafac 1110, CAS No. 52550-44-4) has been shown to change a coarse-grained deposit on the zincate electrode into a fine-grained surface and thus, is able to inhibit the formation of entangeld whiskers on the zinc counterelectrode (Kissa 2001). Fluorinated sufactants, such as Forafac 1110 have also been shown to inhibit the hydrogen evolution and electrode corrosion in alkaline and zinc-carbon batteries (Kissa 2001). Dendrite growth and/or hydrogen evolution have been prevented due to the adsorption of the fluorinated surfactants onto the electrode surface (Schaefer and Merrill 2020). Polymers such as PTFE or PVDF that have been utilized as binder for the electrodes can also decrease the formation of zinc dendrites by decreasing the number fo formation sites (Lu et al. 2018).

Alkaline manganese batteries

Alkaline manganese batteries have been made with MnO_2 cathodes containing carbon black treated with a fluorinated surfactant (e.g. potassium perfluoroalkylcarboxylate) (Kissa 2001).

Solid polymer electrolyte cells

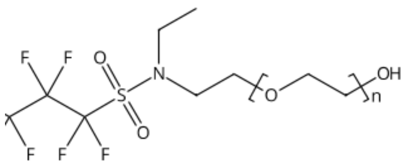
Perfluorosulfonic acid membranes have been widely used for solid polymer electrolyte cells (Buck, Murphy, and Pabon 2012). CTFE-based membranes have also been used in solid alkaline fuel cells which use hydroxide ions instead of protons as migrating species (Gardiner 2015). Fluoroplastics are aslo used as electrode coatings and gas diffusion layers in fuel cells (AGC 2018)

Hydrophobic polymeric materials such as PTFE can be made hydrophilic for use as microporous cell separators by treating them with fluorinated surfactants (CAS 2019 (FR2477162, 1981)). It is stated that Fluorad FC 170 is especially desirable because of its miscibility in either water, isopropanol or in alcohol-water mixtures. However, the patent mentions also that other fluorinated surfactants such as the commercial products Fluorad FC 134, FC 128, and FC 430 are also possible. Detailed information on these chemicals is shown in Table 15.

Table 15: PFAS patented as wetting agents for making hydrophobic polymeric separators for brine electrolytic cells hydrophilic. Fluorad FC 170, FC 134, FC 128, and FC430 are commercial products. Patent number (date, legal status): FR2477162 (1981, expired). Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Reference
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]amino]ethyl]-ω-hydroxy-[1a]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_nOH$	n = 8 (Fluorad FC 170)	138226-35-4	(CAS 2019 (FR2477162))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[1b]	I^- $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8 (Fluorad FC 134)	1652-63-7	(CAS 2019 (FR2477162))
Potassium *N*-ethyl perfluoroalkane sulfonamidoacetate[1c]	K^+ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8 (Fluorad FC 128)	2991-51-7	(CAS 2019 (FR2477162))
An acrylate-perfluoroalkyl copolymer surfactant	unspecified	(Fluorad FC 430)	11114-17-3	(CAS 2019 (FR2477162))

1a



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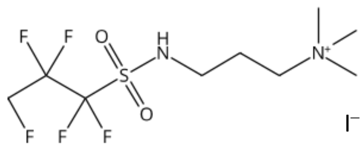

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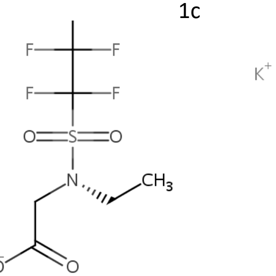


Fluorinated surfactants can also improve surface wetting during the screen printing of carbon black inks onto polymer electrolyte membrane fuel cell electrodes (Kissa 2001).

1.8.3 Energy distribution

It is stated that perfluorocarbons (C_8F_{18}, unclear if aliphatic or cyclic or both) have been used as cooling liquid in power transformers (R. E. Banks, Smart, and Tatlow 1994; Miyagi, Horii, and Sugimoto 1995). They have either been used as perfluorocarbon liquid/SF_6 gas combination or as pure perfluorocarbon liquid (R. E. Banks, Smart, and Tatlow 1994).

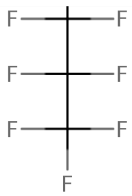
1.8.4 Conversion of heat to mechanical energy

Perfluorocarbons are also used as heat transfer fluids in organic Rankine engines (F2_Chemicals 2019a). The Rankine cycle is a way to convert heat to mechanical energy. It was originally devised for water and steam, but any liquid can potentially be used. Since the use of water can lead to corrosion of the turbine blades, perfluorocarbons are preferred (F2_Chemicals 2019a). Table 16 lists some perfluorocarbons which are marketed for the use in organic Rankine engines.

Table 16: PFAS marketed for the use in organic Rankine engines. The Flutec brands are commercial products. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Linear perfluoropentane[1a]	C_5F_{12}	(Flutec PP50)	678-26-2	U	F2_Chemicals2019b
Perfluoro-2-methylpentane[1b]	C_6F_{14}	(Flutec PP1)	355-04-4	U	F2_Chemicals2019b
Perfluoromethylcyclohexane[1c]	C_7F_{14}	(Flutec PP2)	355-02-2	U	F2_Chemicals2019b
Perfluoro-1,3-dimethylcyclohexane[1d]	C_8F_{16}	(Flutec PP3)	355-27-3	U	F2_Chemicals2019b
Perfluorodecalin[1e]	$C_{10}F_{18}$	(Flutec PP6)	306-94-5	U	F2_Chemicals2019b
Perfluoromethyldecalin[1f]	$C_{11}F_{20}$	(Flutec PP9)	306-92-3	U	F2_Chemicals2019b

1a



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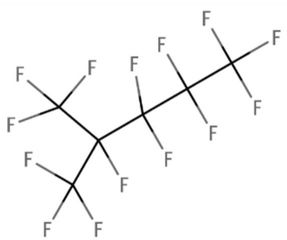

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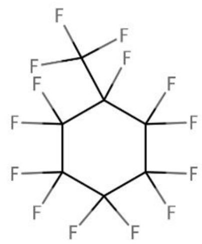

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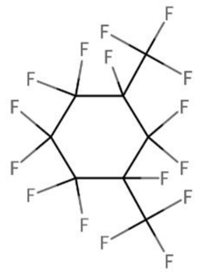

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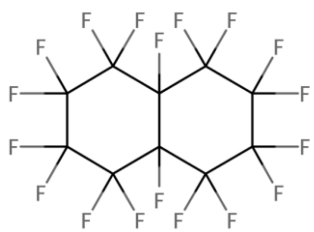

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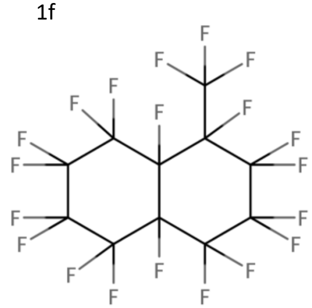


1.9 Food production industry

Wineries and dairies have used PVDF- and PTFE-based microporous filters (Dohany 2000; POPRC 2018a). The wineries have used these filters for the final filtration before bottling (Gardiner 2015). The SPIN database of the Nordic countries discloses additionally that 1H-pentafluoroethane (CAS No. 354-33-6) has been used to manufacture food products and beverages (Norden 2020). However, the intended use was not specified. Food packaging is also most often done at the food production site. However, we assigned food packaging to paper and packaging (see Section 2.26.1), because there are also non-food contact materials and they are listed together.

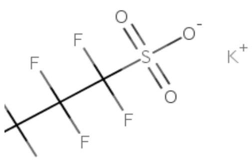
1.10 Machinery and equipment

There is not much information about the use of PFAS in machinery and equipment. It is known that PFAS are used in wire and cable insulations (see Section 2.43) and in lubricants and greases (see Section 2.21). However, the SPIN database of the Nordic countries lists a few PFAS for (electrical) machinery and equipment in general without further specifications (Norden 2020) (Table 17). 1H-Pentafluoroethane (CAS No. 354-33-6) is listed in the Chemical Data Reporting database under the TSCA as functional fluid and refrigerant gas for machinery manufacturing (USEPA 2016). If at some point more is known about the uses in this use category, it might be possible to assign the specific uses also to other use categories.

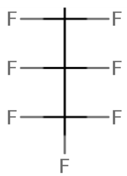
Table 17: PFAS historically or currently used in (electrical) machinery and equipment. The types stand for U – use and U* - current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Potassium perfluoroalkane sulfonates[1a]	K^+ $C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	U	(Norden 2020)
Linear perfluoroalkanes[1b]	C_nF_{2n+2}	n = 3	76-19-7	U	(Norden 2020)
1H-Perfluoroalkanes[1c]	$C_nF_{2n+1}CF_2H$	n = 1	354-33-6	U*	(Norden 2020)
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], α-(1,1, 2,2,2-pentafluoroethyl)-ω-[tetrafluoro(trifluoromethyl)ethoxy]-[1d]	4 -F -CF_3 $CF_3CF_2[O(C_3F_6O)]_nOCC$	-	60164-51-4	U*	(Norden 2020)
Polytetrafluoroethylene (PTFE)[1e]	-$(CF_2CF_2)_x$-	polymer	9002-84-0	U*	(Norden 2020)

1a



1b



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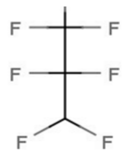
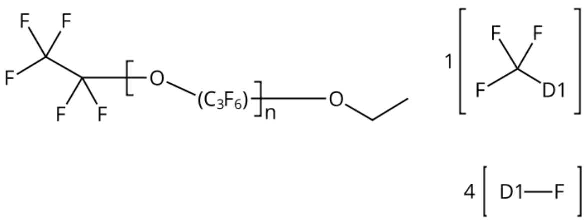


1d



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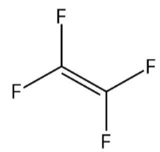
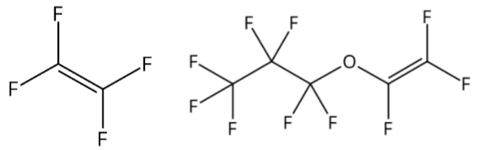


Perfluoro(propyl vinyl ether)-tetrafluoro ethylene copolymer (PFA)[2a]	-$(CF_2CF_2)_x$-$[CF_2CF(OC_3F_7)]_y$-	polymer	26655-00-5	U	(Norden 2020)

Polyperfluoromethylisopropyl ether[2b]	$-CF_3O[CF(CF_3)CF_2O]_x-(CF_2O)_y-CF_3-$	polymer	69991-67-9	U	(Norden 2020)
Polysiloxanes, di-Me, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl	-	-	115340-95-9	U	(Norden 2020)

2a



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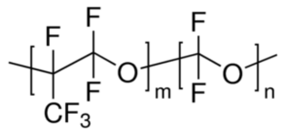


1.11 Manufacture of metal products

1.11.1 Manufacture of basic metals

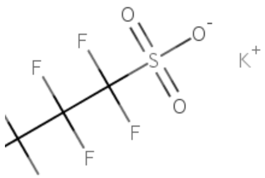
The SPIN database of the Nordic countries discloses that potassium perfluorooctane sulfonate (CAS No. 2795-39-3) was used for the manufacture of basic metals between 2002 and 2004 (Norden 2020). However, it's function in the manufacture of basic metals is unclear. Perfluoro-2-methyl-3-pentanone (CAS No. 756-13-8) has been used as functional fluid in primary metal manufacturing (USEPA 2016).

A patent discloses that fluorinated surfactants can be used to substantially inhibited or eliminated the formation of acid mist or spray over metal electrowinning tanks e.g. for the electrowinning of copper (CAS 2019 (WO9530783, 1995)). Elemental metals such as copper or nickel are recovered from ores and processing liquids by solvent extraction-electrowinning. During the electrowinning step, elemental metal can be plated out at the electrowinning cathode and oxygen evolves at the anode. The evolution of oxygen gas forms bubbles which entrain strong acid electrolyte, carrying it into the air above the electrowinning tank in the form of a fine mist or spray when the bubbles break. This mist or spray then spreads throughout the electrowinning tankhouse and can cause extreme discomfort to the skin, eyes, and respiratory systems of tankhouse workers (CAS 2019 (WO9530783, 1995)). Fluorinated surfactants that have been patented as mist suppression agents for solvent extraction metal electrowinning are shown in Table 18.

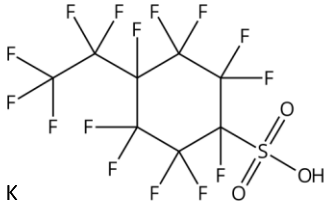
Table 18: PFAS patented as mist suppression agents for solvent extraction metal electrowinning. Patent number (date, legal status): WO9530783 (1995, expired). Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Potassium perfluoroalkane sulfonates[1a]	$K^+ C_nF_{2n+1}SO_3^-$	n = 6	3871-99-6	P	(CAS 2019 (WO9530783))
Cycloalkanesulfonic acid, perfluoro-, potassium salt (1:1)[1b]	K^+ c-$C_nF_{2n-1}SO_3^-$	n = 6	3107-18-4	P	(CAS 2019 (WO9530783))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[1c]	$Cl^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 4	53518-00-6	P	(CAS 2019 (WO9530783))
1-Propanaminium, *N*-ethyl-3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*-dimethyl-, ethyl sulfate (1:1)[1d]	$SO_4C_2H_5^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2C_2H_5$	n = 4	172616-08-9	P	(CAS 2019 (WO9530783))

1a



1b



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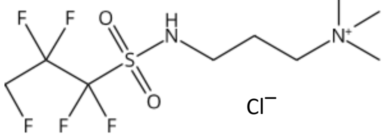

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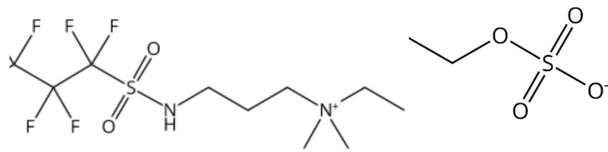
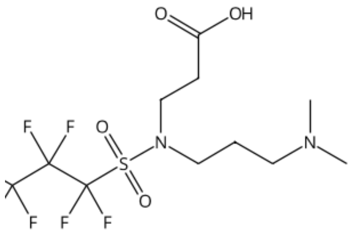


N-[3-(Dimethylamino)propyl]-*N*-[(perfluoroalkyl)sulfonyl]-β-alanine[2a]	$C_nF_{2n+1}SO_2N(CH_2CH_2COO^-)CH_2CH_2CH_2NH^+(CH_3)_2$	n = 4	172616-04-5	P	(CAS 2019 (WO9530783))
Cyclohexanecarboxamide, *N*-[3-(dimethyl amino)propyl]-1,2,2,3,3,4,4,5,5,6,6-undecafluoro-[2b]	$c\text{-}C_6F_{11}C(O)NHCH_2CH_2CH_2N(CH_3)_2$	-	37678-16-3	P	(CAS 2019 (WO9530783))
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[2c]	$c\text{-}C_6F_{11}C(O)NHCH_2CH_2CH_2N+(CH_3)_2CH_2CH_2COO^-$	-	172616-05-6	P	(CAS 2019 (WO9530783))

2a



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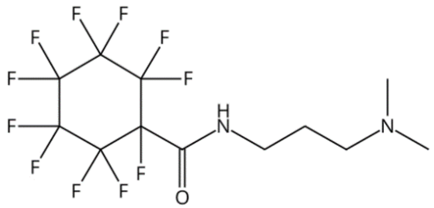

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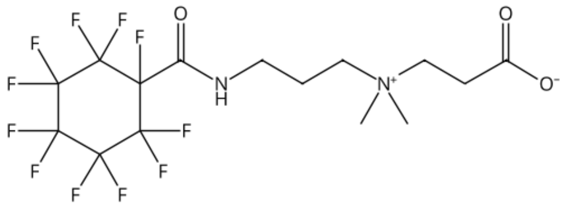
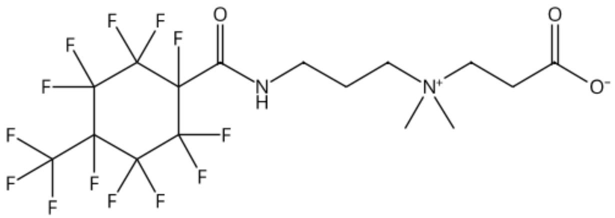


1-Propanaminium, *N-(*2-carboxyethyl)-3-[[[1,2,2,3,3,4,5,5,6,6-decafluoro-4-(trifluoromethyl)cyclohexyl]carbonyl] amino]-*N*,*N*-dimethyl-, inner salt[3a]	$c\text{-}C_6F_{10}(CF_3)(C(O)NHCH_2CH_2CH_2N+(CH_3)_2CH_2CH_2COO^-)$	-	172616-06-7	P	(CAS 2019 (WO9530783))
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoroalkyl) sulfonyl]amino]ethyl]-ω-hydroxy-[3b]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_mOH$	n = 4, m = unknown	68298-79-3	P	(CAS 2019 (WO9530783))

3a



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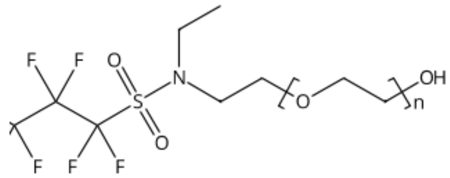


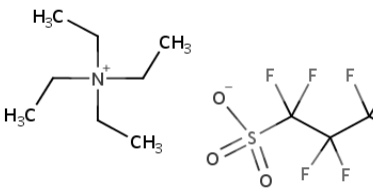
1.11.2 Manufacture of fabricated metal products, except machinery and equipment

The SPIN database of the Nordic countries lists also PFAS that have been used for the manufacture of fabricated metal products. Again, the function is not clear, but it is not the surface treatment and coating of metals, for which the SPIN database has a separate code. The PFAS from the SPIN database for the manufacture of fabricated metal products are shown in Table 19.

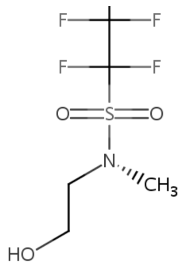
Table 19: PFAS historically or currently used for the manufacture of fabricated metal products. The types stand for U – use and U* - current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Tetraethylammonium perfluoroalkane sulfonates[1a]	$N(C_2H_5)_4^+\ C_nF_{2n+1}SO_3^-$	n = 8	56773-42-3	U	(Norden 2020)
N-Methyl perfluoroalkane sulfonamidoethanols (MeFASEs)[1b]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 8	24448-09-7	U	(Norden 2020)
(n:2) Fluorotelomer sulfonic acids (FTSAs)[1c]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	U*	(Norden 2020)
Polytetrafluoroethylene (PTFE)[1d]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Poly(vinylidene fluoride) (PVDF)[1e]	$-(CH_2CF_2)_x-$	polymer	24937-79-9	U	(Norden 2020)

1a



1b



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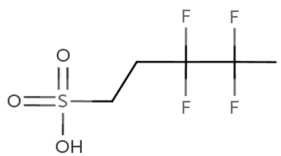

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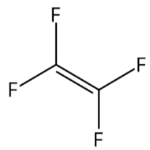
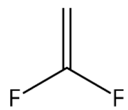
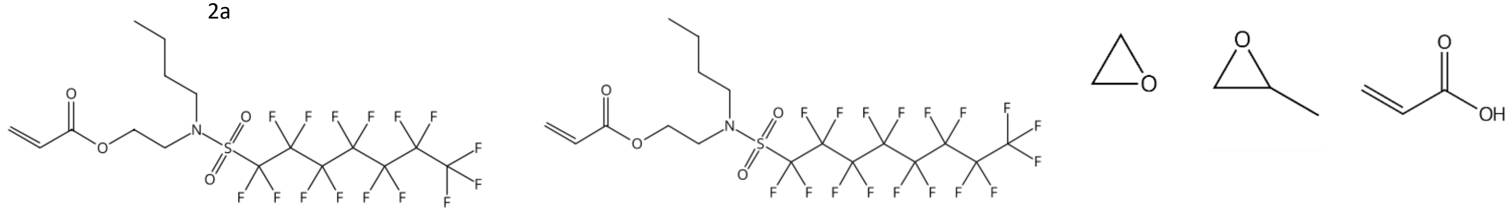


1e



2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6, 6,7,7,8,8,8-heptadeca fluorooctyl)sulfonyl]amino] ethyl ester, telomer with 2-[butyl[(1,1,2,2,3,3, 4,4,5,5,6,6,7,7,7-pentadecafluoroheptyl)sulfonyl]amino]ethyl 2-propenoate, 2-methyloxirane polymer with oxirane di-2-propenoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[2a]	$-[(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O-C_2H_4O)_m-(C_3H_6O-C_2H_4O)_w-2C_3H_4O_2-C_3H_4O_2]_u-C_8H_{18}S-$	polymer	68298-62-4	U	(Norden 2020)

2a



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		-	104780-70-3	U	(Norden 2020)
Polysiloxanes, di-Me, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-trideca fluorooctyl		-	115340-95-9	U*	(Norden 2020)
Siloxanes and Silicones, (3,3,4,4,5,5,6,6,7,7,8,8, 9,9,10, 10,10-heptadecafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether		-	143372-54-7	U	(Norden 2020)

A Japanese patent describes the use of poly(oxy-1,2-ethanediyl), α-(4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-nonadecafluoro-2-hydroxydodecyl)-ω-methoxy- (CAS No. 85643-63-6) as part of an acid-pickling promoter for the continuous pickling of steel wires (CAS 2019 (JP57198273, 1982)).

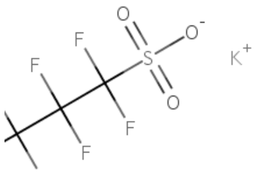
1.11.3 Treatment and coating of metals

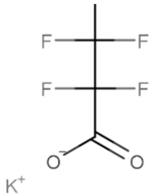
Fluorinated surfactants can promote the flow of metal coatings and prevent cracks in the coating during drying (Kissa 2001). Some fluorinated surfactants can also function as corrosion inhibitor on steel (Kissa 2001). The SPIN database of the Nordic countries lists PFAS that have been used in the treatment and coating of metals (Norden 2020). These PFAS include non-polymers and polymers (Table 20). Additional non-polymeric and polymeric PFAS described in patents for coatings on steel are also included in Table 20.

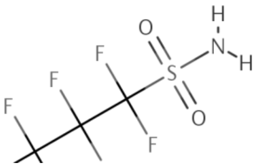
Table 20: PFAS used or patented for coatings on metal, including steel. Patent number (date, legal status): JP58213057 (1983, expired), US20050080210 (2005, active), CN1867623B(2006, discontinued). The types stand for U – use, U* - current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

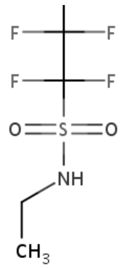
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Potassium perfluoroalkane sulfonates[1a]	$K^+ C_nF_{2n+1}SO_3^-$	n = 6, 8	3871-99-6, 2795-39-3	P	(CAS 2019 (JP58213057))

Tetraethylammonium perfluoroalkane sulfonates(1a)	$N(C_2H_5)_4^+\ C_nF_{2n+1}SO_3^-$	n = 8	56773-42-3	U	(Norden 2020)
Potassium perfluoroalkyl carboxylates1b	$K^+\ C_nF_{2n+1}COO^-$	n = 7	2395-00-8	P	(CAS 2019 (JP58213057))
Perfluoroalkyl sulfonamides (FASAs)1c	$C_nF_{2n+1}SO_2NH_2$	n = 6, 8	41997-13-1, 754-91-6	P	(CAS 2019 (JP58213057))
N-Ethyl perfluoroalkane sulfonamides (EtFASAs)1d	$C_nF_{2n+1}SO_2NHC_2H_5$	n = 8	4151-50-2	P	(CAS 2019 (JP58213057))
1-Alkanesulfonamide, *N*-butyl-perfluoro-1e	$C_nF_{2n+1}SO_2NHC_4H_9$	n = 8	31506-34-0	P	(CAS 2019 (JP58213057))
1-Alkanesulfonamide, *N*-hexyl-perfluoro-1f	$C_nF_{2n+1}SO_2NHC_6H_{13}$	n = 8	89932-70-7	P	(CAS 2019 (JP58213057))

1a


1b


1c


1d


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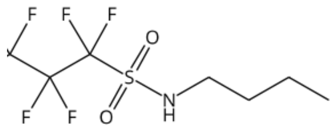

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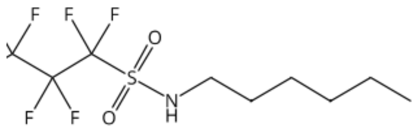
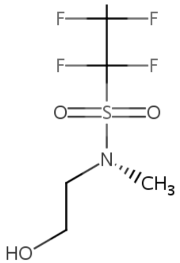
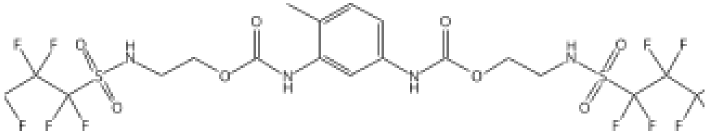
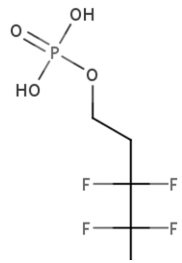


N-Methyl perfluoroalkane sulfonamidoethanols (MeFASEs)2a	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 6, 8	68555-75-9, 24448-09-7	P, U	(CAS 2019 (JP58213057); Norden 2020)
Carbamic acid, (4-methyl-1,3-phenylene)bis-, bis[2-[[(perfluroroalkyl)sulfonyl]amino]ethyl] ester2b	$C_6H_3(CH_3)[NHC(O)OCH_2CH_2NHSO_2C_nF_{2n+1}]_2$	n = 8	89946-29-2	P	(CAS 2019 (JP58213057))
(n:2) Fluorotelomer phosphat monoester (monoPAPs)2c	$C_nF_{2n+1}CH_2CH_2OP(=O)(OH)_2$	n = 8	57678-03-2	P	(CAS 2019 (JP58213057))
Alkanamide, perfluoro-*N*-methyl-2d	$C_nF_{2n+1}C(O)NHCH_3$	n = 6	89932-74-1	P	(CAS 2019 (JP58213057))

2a


2b


2c


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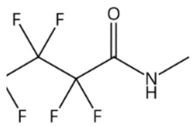
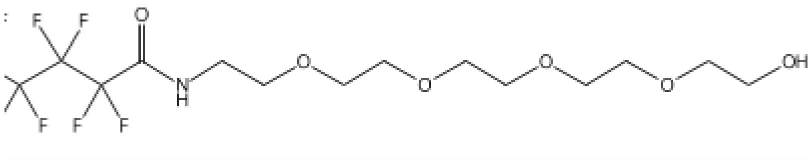


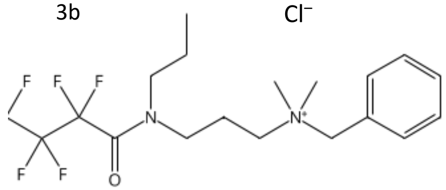
Alkanamide, perfluoro-*N*-(14-hydroxy-3,6,9,12-tetra oxatetradec-1-yl)-3a	$C_nF_{2n+1}C(O)NHCH_2CH_2(OCH_2CH_2)_4OH$	n = 7	89932-71-8	P	(CAS 2019 (JP58213057))

Benzenemethanaminium, *N*-[3-[(perfluoro-1-oxoalkyl) propylamino]propyl]-*N*,*N*-dimethyl-, chloride (1:1)[3b]	$Cl^- C_nF_{2n+1}C(O)N(C_3H_7)CH_2CH_2CH_2N^+(CH_3)_2CH_2C_6H_5$	n = 8	89932-72-9	P	(CAS 2019 (JP58213057))
Piperazinium, 1-(2-hydroxyethyl)-1-methyl-4-(perfluoro-1-oxoalkyl)-, chloride (1:1)[3c]	$Cl^- C_nF_{2n+1}C(O)NC_4H_8N^+(CH_3)CH_2CH_2OH$	n = 6	89932-73-0	P	(CAS 2019 (JP58213057))

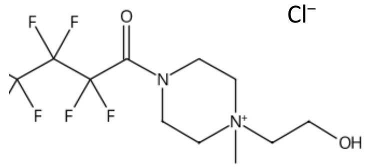
3a



3b

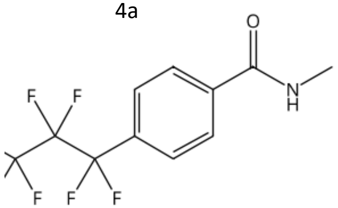


3c

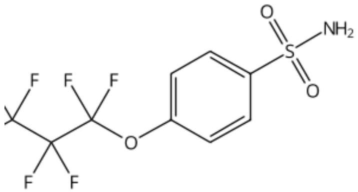


Benzamide, 4-(perfluoroalkyl)-*N*-methyl-[4a]	$C_nF_{2n+1}C_6H_4C(O)NHCH_3$	n = 8	89932-69-4	P	(CAS 2019 (JP58213057))
Benzenesulfonamide, 4-[(perfluoroalkyl)oxy]-[4b]	$C_nF_{2n+1}OC_6H_4SO_2NH_2$	n = 8	89932-76-3	P	(CAS 2019 (JP58213057))
1-Propanaminium, *N*-(carboxymethyl)-3-[[[4-[(per fluoroalkyl)oxy]phenyl]sulfonyl]amino]-*N*,*N*-dimethyl-, inner salt[4c]	$C_nF_{2n+1}OC_6H_4SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 8	89932-75-2	P	(CAS 2019 (JP58213057))
Benzoic acid, 4-[(perfluoroalkyl)oxy]-, potassium salt (1:1)[4d]	$K^+ C_nF_{2n+1}OC_6H_4COO^-$	n = 8	89932-68-3	P	(CAS 2019 (JP58213057))

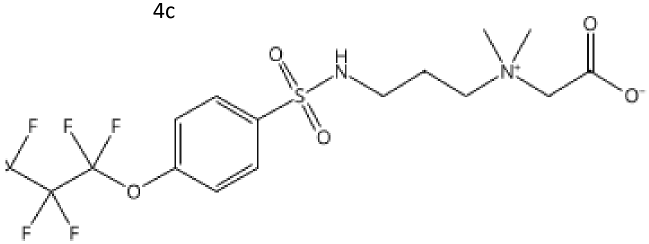
4a



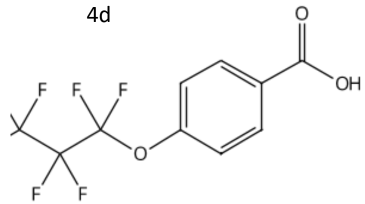
4b



4c

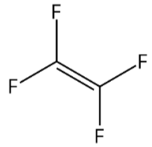
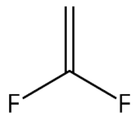
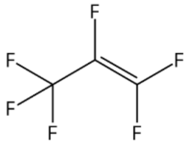
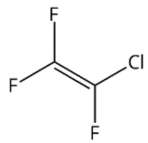
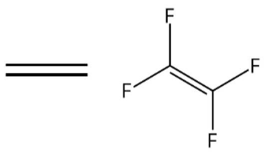
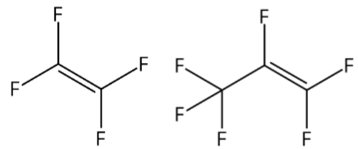


4d

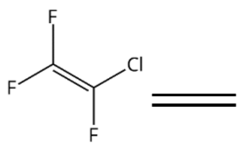
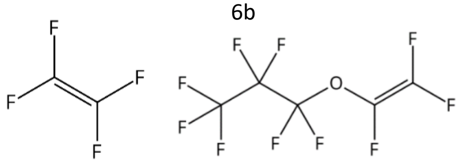
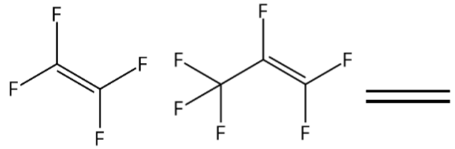
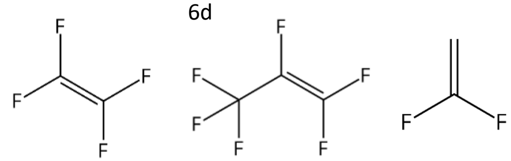


K

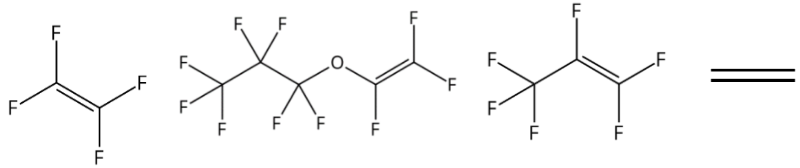
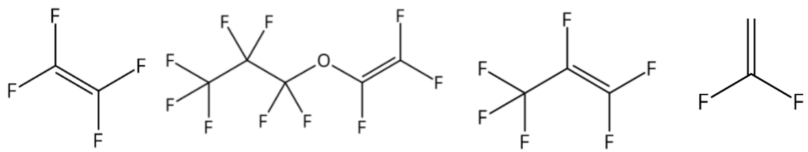
Polytetrafluoroethylene (PTFE)[5a]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Poly(vinylidene fluoride) (PVDF)[5b]	$-(CH_2CF_2)_x-$	polymer	24937-79-9	U	(Norden 2020)
Hexafluoropropylene polymer (HFP)[5c]	$-[CF_2CF(CF_3)]_x-$	polymer	25120-07-4	P	(Google_patents 2019 (CN1867623B))
Polychlorotrifluoroethylene (PCTFE)[5d]	$-(CF_2CFCl)_x-$	polymer	9002-83-9	P	(Google_patents 2019 (CN1867623B))
Ethylene tetrafluoroethylene copolymer (ETFE)[5e]	$-(CH_2CH_2)_x-(CF_2CF_2)_y-$	polymer	25038-71-5	P	(CAS 2019 (US20050080210)
Fluorinated ethylene propylene (FEP)[5f]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-$	polymer	25067-11-2	P	(CAS 2019 (US20050080210)

5a  5b  5c  5d  5e  5f 

Chlorotrifluoroethylene-ethylene copolymer (ECTFE)[6a]	$-(CF_2CFCl)_x-(CH_2CH_2)_y-$	polymer	25101-45-5	P	(CAS 2019 (US20050080210))
Perfluoralkoxy polymer (PFA)[6b]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-$	polymer	26655-00-5	P	(CAS 2019 (US20050080210)
Ethylene-tetrafluoroethylene-hexafluoro propylene copolymer[6c]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-(CH_2CH_2)_m-$	polymer	35560-16-8	P	(CAS 2019 (US20050080210))
Hexafluoropropylene-tetrafluoroethylene-vinylidene fluoride copolymer (THV)[6d]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-(CF_2CH_2)_m-$	polymer	25190-89-0	P	(CAS 2019 (US20050080210))

6a  6b  6c  6d 

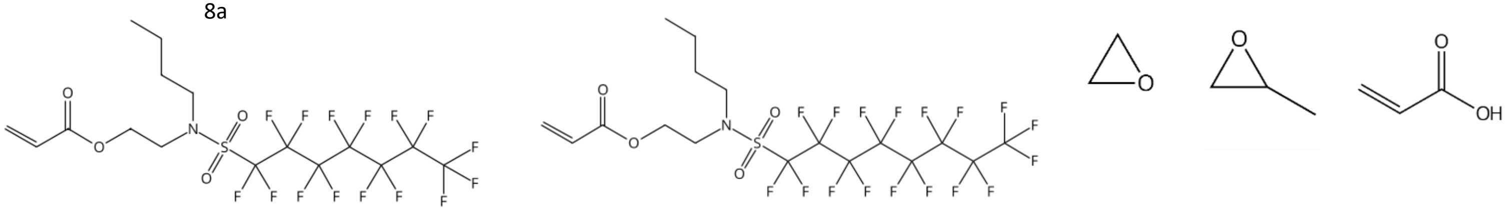
Ethylene-hexafluoropropylene-perfluoropropyl vinyl ether-tetrafluoroethylene copolymer[7a]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-[CF_2CF(CF_3)]_m-(CH_2CH_2)_w-$	polymer	74499-71-1	P	(CAS 2019 (US20050080210))
Hexafluoropropylene-perfluoropropyl vinyl ether-tetra fluoroethylene-vinylidene fluoride copolymer[7b]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-[CF_2CF(CF_3)]_m-(CF_2CH_2)_w-$	polymer	68182-34-3	P	(CAS 2019 (US20050080210))

7a  7b 

2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]amino] ethyl ester, telomer with 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,7-pentadecafluoroheptyl) sulfonyl] amino]ethyl 2-propenoate, 2-methyloxirane polymer	$-[(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O-C_2H_4O)_m-(C_3H_6O-C_2H_4O)_w-2C_3H_4O_2-C_3H_4O_2]_u-C_8H_{18}S-$	polymer	68298-62-4	U	(Norden 2020)

with oxirane di-2-propenoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[8a]

8a



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	-	104780-70-3	U	(Norden 2020)
Polysiloxanes, di-Me, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-trideca fluorooctyl	-	115340-95-9	U*	(Norden 2020)
Siloxanes and Silicones, (3,3,4,4,5,5,6,6,7,7,8,8, 9,9,10, 10,10-heptadecafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether	-	143372-54-7	U	(Norden 2020)

1.11.4 Processing of aluminum

Aluminum can be etched in alkali baths. Fluorinated surfactants can improve the efficient life of these baths (Kissa 2001). Fluorinated surfactants are also used in the phosphate process for aluminum. The fluoride-containing phosphating solutions help to dissolve the oxide layer of aluminum (GWP 2019; Kissa 2001).

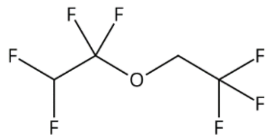
1.11.5 Cleaning of metal surfaces

Metal surfaces can be cleaned by pickling with molten-salt baths (Kissa 2001). Fluorinated surfactants used in those baths disperse scum, speed runoff of acid when metal is removed from the bath, and increase the bath life. The Chemical Data Reporting database under the TSCA lists three PFAS that were used above 11.3 t as solvents for cleaning and degreasing in fabricated metal product manufacturing in the US between 2012 and 2015 (USEPA 2016). The listed PFAS are shown in Table 21.

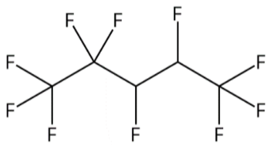
Table 21: PFAS that were used above 11.3 t as solvents for cleaning and degreasing in fabricated metal product manufacturing in the US between 2012 and 2015. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Ethane, 1,1,2,2-tetrafluoro-1-(2,2,2-trifluoro ethoxy)-[1a]	$CF_2HCF_2OCH_2CF_3$	-	406-78-0	U	(USEPA 2016)
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[1b]	$C_2F_5(CFH)_2CF_3$	-	138495-42-8	U	(USEPA 2016)
Cyclopentane, 1,1,2,2,3,3,4-heptafluoro-[1c]	$c\text{-}C_5H_3F_7$	-	15290-77-4	U	(USEPA 2016)

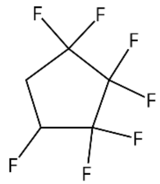
1a



1b



1c



1.11.6 Water removal from processed parts

Solvent displacement drying is a common and widely accepted method of water removal prior to plating, coating, and other surface treatments of plastics, metals, mirrors, lenses, crystals, and ceramics (Chemours 2019d). One PFAS for this use is pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro- (CAS No. 138495-42-8) (Chemours 2019d).

1.12 Mining

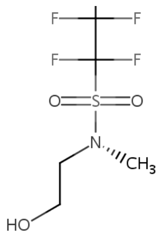
1.12.1 Ore flotation

Fluorinated surfactants have been used in copper and gold mines to increase wetting of the sulfuric acid or cyanide used to leach ore, enhancing the amount of metal recovery (3M 1999). A fluorinated surfactant that has been patented for this use is 1-propanaminium, 3-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,9-heptadecafluoro octyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1) (CAS No. 38006-74-5) (CAS 2019 (US5207996, 1993)). Tetraethylammonium perfluorooctane sulfonate (CAS No. 56773-42-3) and potassium perfluorooctane sulfonate (CAS No. 2795-39-3) have been used as acid mist suppressing agents (POPRC 2016a). Furthermore, fluorinated surfactants have also been used in ore floating to create stable aqueous foams to separate the metal salts from soil (Buck, Murphy, and Pabon 2012). Compounds that have been described as effective floating agents are potassium perfluoroalkyl carboxylates (CAS No. 2966-54-3, 3109-94-2, 2395-00-8, 51604-85-4, 24448-09-7) (Kissa 2001). Some other PFAS that can be used to recover metal salts from aqueous solutions are listed in Table 22.

Table 22: PFAS patented for the recovering of metal salts from aqueous solutions. Patent number (date, legal status): DE3231403 (1983, expired, not all patented molecuels shown). Type "P" stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
N-Methyl perfluoroalkane sulfonamido ethanols (MeFASEs)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 8	24448-09-7	P	(CAS 2019 (DE3231403))
1-Alkanesulfonamide, perfluoro-*N*-propyl-[1b]	$C_nF_{2n+1}SO_2NHC_3H_7$	n = 8	2266-83-3	P	(CAS 2019 (DE3231403))
1-Alkanesulfonamide, perfluoro-*N*-[3-(methylamino) propyl]-[1c]	$C_nF_{2n+1}SO_2NHC_3H_6NHCH_3$	n = 6	85520-91-8	P	(CAS 2019 (DE3231403))
Acetamide, *N*-methyl-*N*-[3-[[(perfluoroalkyl)sulfonyl] amino] propyl]-[1d]	$C_nF_{2n+1}SO_2NHC_3H_6N(CH_3)C(O)CH_3$	n = 6	85520-95-2	P	(CAS 2019 (DE3231403))

1a



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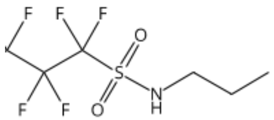

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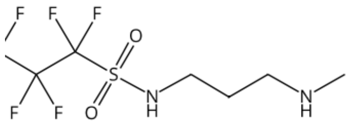

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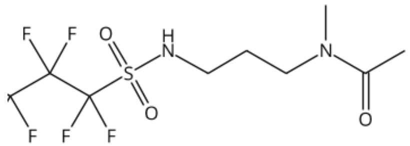


1.12.2 Nitrogen flotation

Fluorinated surfactants such as (n:2) fluorotelomer phosphate esters (CAS No. 67479-86-1, Zonyl FSP) can improve the separation of uranium contained in sodium carbonate and /or sodium bicarbonate solutions. The separation is carried out by nitrogen flotation (Kissa 2001).

1.12.3 Others

Vanadium compounds, such as NH_4VO_3 can be concentrated using a perfluorinated surfactant (unknown identidy). At ≤ 300 mg/L vanadium, 100% sorption has been achieved (Kissa 2001).

1.13 Nuclear industry

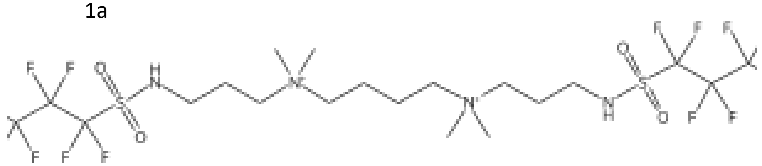
A range of fluoroplastics have been used in the nuclear industry to handle highly corrosive liquids and reactive uranium derivatives (Gardiner 2015). Perfluoropolyethers have been used in lubricating valves and ultracentrifuge bearings in UF_6 enrichment plants, as they are also stable to aggressive gases (Banks, Smart, and Tatlow 1994). Perfluorocarbons have also been used in the nuclear industry. They have a better thermal and chemical stability compared to aliphatic hydrocarbons at temperature of around 450°C (F2_Chemicals 2019).

1.14 Oil and gas industry

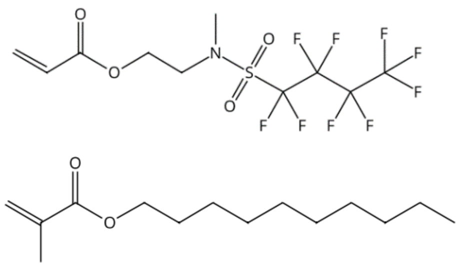
1.14.1 Drilling

Fluorinated surfactants can be used as hydrocarbon foaming agents in drilling fluids (CAS 2019 (WO2008089391, 2008)). Foamed drilling fluids have several advantages over non-foamed fluids. The volume of liquid in a foamed fluid is smaller than in non-foamed fluids, thus, less fluid gets lost in permeable subterranean formations. Foams also have lower densities than non-foamed drilling fluids, and the use of foams lowers potential formation damage when drilling in underbalanced conditions (i.e., when the pressure in the drilling fluid is lower than the pore pressure in the surrounding rock) (CAS 2019 (WO2008089391, 2008)). In the past, drilling fluids with long-chain perfluoroalkyl groups were used, for example, perfluorooctane sulfonamido groups. However, there has been a trend moving away from using perfluorooctyl-based fluorinated surfactants (at least in developed countries). For example, a patent from 2008 (WO2008089391) discloses some nonionic perfluorobutyl-based side-chain fluorinated polymers as hydrocarbon foaming agent in drilling fluids (see Table 23).

Table 23: PFAS patented for drilling fluids. Patent number (date, legal status): CN106634894 (2017, active), WO2008089391 (2008, active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1,4-Butanediaminium, *N*1,*N*1,*N*4,*N*4-tetramethyl-*N*1,*N*4-bis[3-[[(perfluoro)sulfonyl]amino]propyl]-, bromide (1:2)[1a]	2 Br^- $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2C_4H_8N^+(CH_3)_2CH_2CH_2CH_2NHSO_2CnF_{2n+1}$	n = 5, 7, 9	2098179-94-1, 2098179-96-3, 2098179-98-5	P	(CAS 2019 (CN106634894))
1a 	2 Br^-				
2-Propenoic acid, 2-methyl-, decyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate[2a]	$-(C_{14}H_{26}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	1040208-92-1	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, dodecyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate	$-(C_{16}H_{30}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	425664-43-3	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl ester, polymer with octadecyl 2-propenoate	$-(C_{21}H_{40}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	425664-29-5	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, octadecyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate	$-(C_{22}H_{42}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	425664-41-1	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, docosyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate	$-(C_{26}H_{50}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	1040208-71-6	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, docosyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate and octadecyl 2-methyl-2-propenoate	$-(C_{26}H_{50}O_2)_x-(C_{22}H_{42}O_2)_y-(C_{10}H_{10}F_9NO_4S)_m-$	polymer	1040209-02-6	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluoro butyl)sulfonyl]amino]ethyl ester, polymer with octadecyl 2-methyl-2-propenoate[2b]	$-(C_{22}H_{42}O_2)_x-(C_{11}H_{12}F_9NO_4S)_y-$	polymer	819069-72-2	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, docosyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-methyl-2-propenoate	$-(C_{26}H_{50}O_2)_x-(C_{11}H_{12}F_9NO_4S)_y-$	polymer	1040208-85-2	P	(CAS 2019 (WO2008089391))

2a



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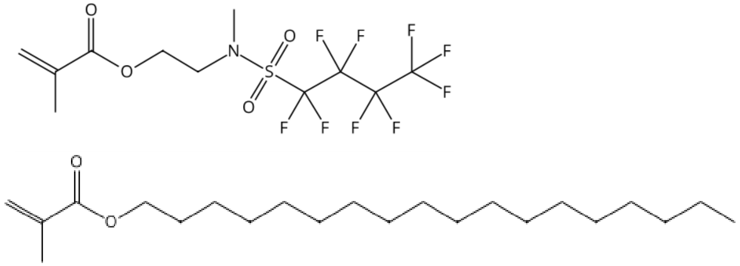
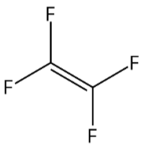


Another application for polymeric PFAS in drilling is the cable insulation for communication cables (CAS 2019 (WO2012019066, 2012)). With deep drilling, temperatures of at least 280°C are not uncommon at or near the bottom of the well. Communications cables are inserted into these downhole wells for passing signals between control units at the earth's surface and downhole tools, such as logging sensors, or to electrically power downhole operations, such as drilling (CAS 2019 (WO2012019066, 2012)). Cable insulations made out of PFA, FEP or ETFE (TEFZEL) can withstand the extremely high temperatures near the bottom of the well (CAS 2019 (WO2012019066, 2012)). For more information on the specific fluoropolymers see Table 24.

Table 24: Fluoropolymers patented for cable insulations for communications cables in deep drilling. Patent number (date, legal status): WO2012019066 (2012, active), US5894104A (1997, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Polytetrafluoroethylene (PTFE)[1a]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	P	(CAS 2019 (WO2012019066))
Perfluoralkoxy polymer (PFA)[1b]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-$	polymer	26655-00-5	P	(Google_patents 2019 (US5894104A))
Fluorinated ethylene propylene (FEP)[1c]	$-(CF_2CF_2)_x-[CF_2CF(CF_3))_y-$	polymer	25067-11-2	P	(CAS 2019 (WO2012019066))
Ethylene tetrafluoro-ethylene (ETFE)[1d]	$-(CH_2CH_2)_x-(CF_2CF_2)_y-$	polymer	25038-71-5	P	(CAS 2019 (WO2012019066))

1a



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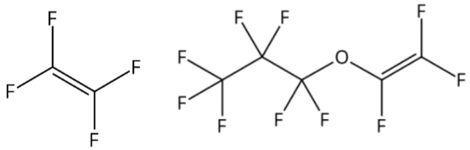

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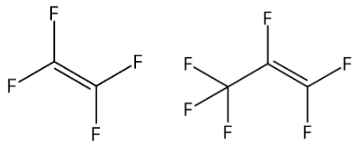

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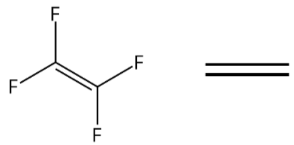

The Chemical Data Reporting database under the TSCA lists poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly(difluoromethylene) (1:1) (CAS No. 65545-80-4) that was used above 11.3 t as a surface active agent in oil and gas drilling, extraction and support activities in the US between 2012 and 2015 (USEPA 2016).

1.14.2 Chemical driven oil production

Fluorinated surfactants can be used in oil-well stimulation during water flooding and in nonaqeous stimulation fluids for foaming hydrocarbon liquids (Kissa 2001). During water flooding, water is injected into the reservoir to drive the crude oil to the boreholes (CAS 2019 (DE2922928)). Fluorinated surfactants can increase the effective permeability of the formation by modifying the interfacial tension between the reservoir surface and the aqueous liquid phases in contact therewith (CAS 2019 (US2765851, 1956)). In chemical flooding, fluorinated surfactant can be used to render the surfaces of the oil bearing reservoirs hydrophobic and oleophobic. This supports the displacement of the oil from the underground sand and rock formations (CAS 2019 (US2765851, 1956)). Different fluorinated surfactant have been patented for these applications, depending on the type of the formation (CAS 2019 (US20130269932, 2013), CAS 2019 (WO2012125219, 2012)) (see Table 25).

Fluorinated surfactants can also be used in fracturing subterranean formations penetrated by a wellbore. The fluorinated surfactants can act here as a foaming agent that initiates and extents the fractures in the formation (CAS 2019 (GB2018863, 1979)). Table 25 lists some fluorinated surfactants that have been patented for this use. Fluorinated surfactants have also been patented as foaming agents in liquid CO_2 fracturing fluid systems (CAS 2019 (WO2000036272, 2000)). The viscous foam reduces the viscosity of the fluid systems and makes it easier to remove the fracturing liquid from the oil or gas reservoir. Fluorinated surfactants that have been patented for this application are also listed in Table 25.

The SPIN database of the Nordic countries lists additional PFAS that have been used in the extraction of crude petroleum and natural gas (Norden 2020). These PFAS are also listed in Table 25 under 'no use specified'.

Table 25: PFAS historically or currently used or patented for use in enhanced oil recovery. HFE-7100 and HFE-7200 are commercial products. Patent number (date, legal status): US2765851 (1956, expired), WO2012125219 (2012, active), US20130269932 (2013, not yet active), WO2008089391 (2008, active), GB2018863 (1979, expired), DE3306593 (1983, expired), WO2000036272 (2000, active). The types stand for U – use, U* - current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
<u>Render the surfaces of the oil bearing reservoirs oleophobic</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 7	335-67-1	P	(CAS 2019 (US2765851))
<u>Treating siliciclastic hydrocarbon-bearing formations</u>					
1-Alkanesulfonamide, *N*,*N*′-1,2-ethanediylbis[*N*-[3-(dimethyloxidoamino)propyl]-perfluoro-[1b]	$C_nF_{2n+1}SO_2N(CH_2CH_2CH_2N(=O)(CH_3)_2)CH_2CH_2N(CH_2CH_2CH_2N(=O)(CH_3)_2)SO_2C_nF_{2n+1}$	n = 4	927673-93-6	P	CAS 2019 (WO2012125219))
Perfluoroalkane sulfonamido amine oxide (PFASNO)[1c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N(=O)(CH_3)_2$	n = 4	178094-76-3	P	CAS 2019 (WO2012125219))

Treating carbonate hydrocarbon-bearing formations

Perfluoroalkane sulfonamido amine oxide (PFASNO)[1c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N(=O)(CH_3)_2$	n = 4	178094-76-3	P	CAS 2019 (US20130269932))
Propanamide, *N*-[3-(dimethyloxidoamino)propyl]-2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy) propoxy]-[1d]	$CF_3OCF_2CF_2CF_2OCFHCF_2C(O)NHCH_2CH_2CH_2N(=O)(CH_3)_2$		1204951-03-0	P	CAS 2019 (US20130269932))
Acetamide, *N*-[3-(dimethyloxidoamino)propyl]-2,2-difluoro-2-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy) propoxy][1e]	$CF_3OCF_2CF_2CF_2OCF_2C(O)NHCH_2CH_2CH_2N(=O)(CH_3)_2$		1204950-97-9	P	CAS 2019 (US20130269932))

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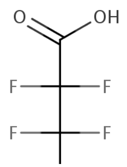

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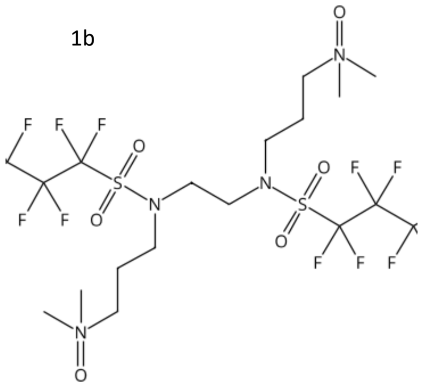

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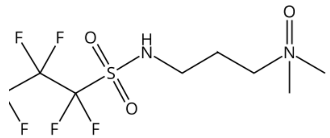

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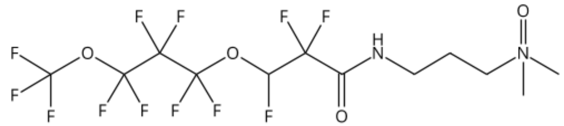

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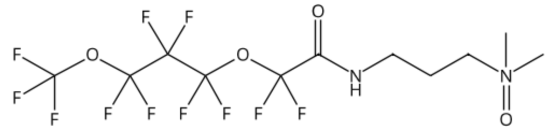
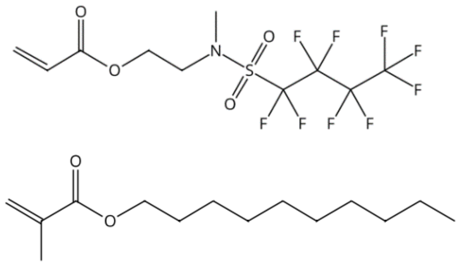


Hydrocarbon foaming agent

2-Propenoic acid, 2-methyl-, decyl ester, polymer with 2-[methyl[(1,1, 2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate[2a]	$-(C_{14}H_{26}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	1040208-92-1	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, dodecyl ester, polymer with 2-[methyl[(1,1, 2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate	$-(C_{16}H_{30}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	425664-43-3	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl) sulfonyl]amino]ethyl ester, polymer with octadecyl 2-propenoate	$-(C_{21}H_{40}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	425664-29-5	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, octadecyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate	$-(C_{22}H_{42}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	425664-41-1	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, docosyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate	$-(C_{26}H_{50}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-$	polymer	1040208-71-6	P	(CAS 2019 (WO2008089391))

2-Propenoic acid, 2-methyl-, docosyl ester, polymer with 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate and octadecyl 2-methyl-2-propenoate	$-(C_{26}H_{50}O_2)_x-(C_{22}H_{42}O_2)_y-(C_{10}H_{10}F_9NO_4S)_m-$	polymer	1040209-02-6	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, 2-[methyl[(1,1,2,2,3,3,4,4,4-nonafluoro butyl)sulfonyl]amino]ethyl ester, polymer with octadecyl 2-methyl-2-propenoate[2b]	$-(C_{22}H_{42}O_2)_x-(C_{11}H_{12}F_9NO_4S)_y-$	polymer	819069-72-2	P	(CAS 2019 (WO2008089391))
2-Propenoic acid, 2-methyl-, docosyl ester, polymer with 2-[methyl[(1,1, 2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-methyl-2-propenoate	$-(C_{26}H_{50}O_2)_x-(C_{11}H_{12}F_9NO_4S)_y-$	polymer	1040208-85-2	P	(CAS 2019 (WO2008089391))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, bromide (1:1)[2c]	$Br^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	73149-44-7	P	(CAS 2019 (GB2018863))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, fluoride (1:1)[(2c)]	$F^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	73149-43-6	P	(CAS 2019 (GB2018863))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1) [(2c)]	$Cl^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (GB2018863))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-N,N,N-trimethyl-, iodide (1:1) [(2c)]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	P	(CAS 2019 (GB2018863))

2a



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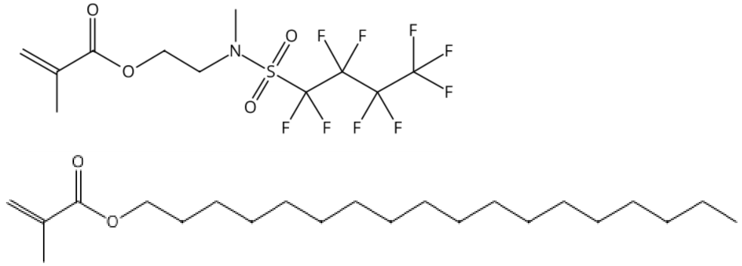

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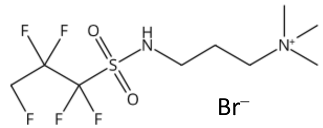
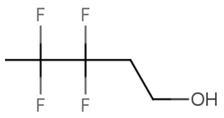
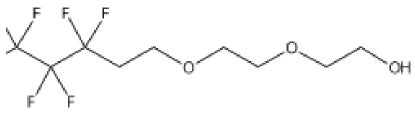


(n:2) Fluorotelomer alcohols (FTOHs)[3a]	$C_nF_{2n+1}CH_2CH_2OH$	n = 8	678-39-7	P	(CAS 2019 (DE3306593))
Ethanol, 2-[2-[(perfluoroalkyl)oxy]ethoxy]-[3b]	$C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_2OH$	n = 8	56900-98-2	P	(CAS 2019 (DE3306593))
3,6,9,12-Tetraoxaalkan-1-ol, perfluoro-	$C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_4OH$	n = 8	55427-54-8	P	(CAS 2019 (DE3306593))
3,6,9,12,15,18-Hexaoxaalkan-1-ol, perfluoro-	$C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_6OH$	n = 8	88247-39-6	P	(CAS 2019 (DE3306593))
3,6,9,12,15,18,21,24-Octaoxaalkan-1-ol, perfluoro-	$C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_8OH$	n = 8	88247-40-9	P	(CAS 2019 (DE3306593))
Propanol, [2-[(perfluoroalkyl)oxy]methylethoxy]-[3c]	2 $-CH_2$ $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_2OH$	n = 8	88243-13-4	P	(CAS 2019 (DE3306593))
3,6,9-Trioxaalkan-1-ol, perfluorodimethyl-	2 $-CH_2$ $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_3OH$	n = 8	88243-12-3	P	(CAS 2019 (DE3306593))
3,6,9,12-Tetraoxaalkan-1-ol, perfluorodimethyl-[3d]	2 $-CH_2$ $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_4OH$	n = 8	88271-22-1	P	(CAS 2019 (DE3306593))

3a



3b



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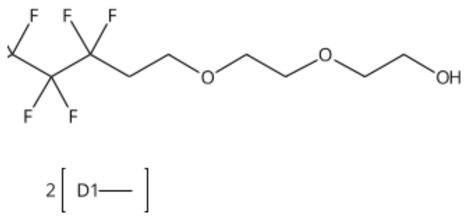
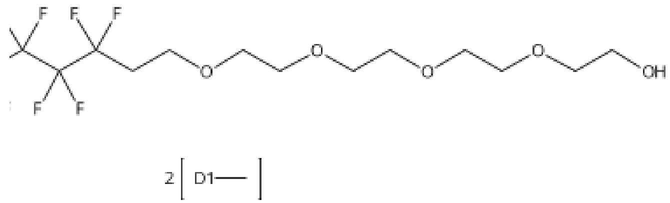
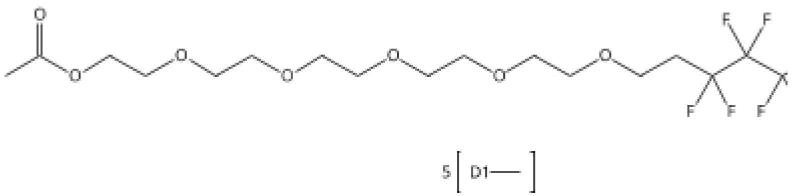


3d

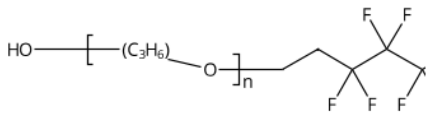


3,6,9,12-Tetraoxaalkan-1-ol, perfluorotetramethyl-	4 -CH_2 $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_4OH$	n = 8	88243-14-5	P	(CAS 2019 (DE3306593))
3,6,9,12,15-Pentaoxaalkan-1-ol, perfluoropentamethyl-	5 -CH_2 $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_5OH$	n = 8	88243-15-6	P	(CAS 2019 (DE3306593))
3,6,9,12,15,18-Hexaoxaalkan-1-ol, perfluoropentamethyl-	5 -CH_2 $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_6OH$	n = 8	88243-11-2	P	(CAS 2019 (DE3306593))
3,6,9,12,15,18-Hexaoxaalkan-1-ol, perfluorohexamethyl-	6 -CH_2 $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_6OH$	n = 8	88243-16-7	P	(CAS 2019 (DE3306593))
3,6,9,12,15,18,21-Heptaoxaalkan-1-ol, perfluoropentamethyl-	5 -CH_2 $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_7OH$	n = 8	88243-10-1	P	(CAS 2019 (DE3306593))
3,6,9,12,15,18,21,24-Octaoxaalkan-1-ol, perfluorooctamethyl-	8 -CH_2 $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_8OH$	n = 8	88243-17-8	P	(CAS 2019 (DE3306593))
3,6,9,12,15-Pentaoxapentacosan-1-ol, perfluoropentamethyl-, acetate[4a]	5 -CH_2 $C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_5OC(=O)CH_3$	n = 8	88243-09-8	P	(CAS 2019 (DE3306593))
Poly[oxy(methyl-1,2-ethanediyl)], α-(perfluoroalkyl)-ω-hydroxy-[4b]	$C_nF_{2n+1}C(OH)(CH_3)CH_2(OCH_2CH_2)_nOH$	n = 8	58285-35-1	P	(CAS 2019 (DE3306593))

4a



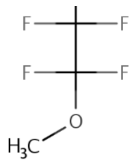
4b



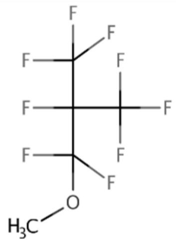
<u>Foam former for liquid CO_2 for fracturing</u>					
Methyl perfluorobutyl ether[5a]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	P	(CAS 2019 (WO2000036272))
Methyl perfluoroisobutyl ether[5b]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	P	(CAS 2019 (WO2000036272))
Ethyl perfluorobutyl ether[5c]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	P	(CAS 2019 (WO2000036272))
<u>No use specified</u>					
1-Alkaneamine, perfluoro-*N*,*N*-dimethyl-, *N*-oxide[5d]	$C_nF_{2n+1}CH_2CH_2N(CH_3)_2O$	n = 6, 8, 9	-	U	(Buck, Murphy, and Pabon 2012)

1-Alkanesulfonamide, *N*-[3-(dimethyloxidoamino)propyl]-perfluoro-N-methyl-[5e]	$C_nF_{2n+1}CH_2CH_2SO_2N(CH_3)CH_2CH_2CH_2N(O)(CH_3)_2$	n = 6	80475-32-7	U	(Norden 2020)

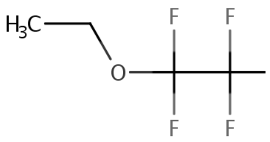
5a



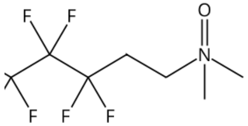
5b



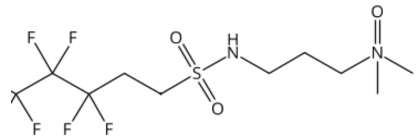
5c



5d

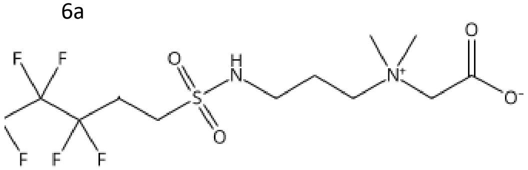


5e

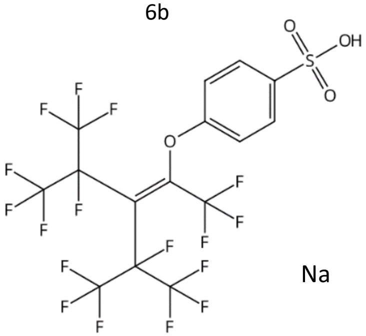


(n:2) Fluorotelomer sulfonamide betaine (FTAB)[6a]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 6	34455-29-3	U*	(Norden 2020)
Benzenesulfonic acid, 4-[[3,4,4,4-tetrafluoro-2-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]-1,3-bis(trifluoromethyl)-1-buten-1-yl]oxy]-, sodium salt (1:1)[6b]	$Na^+\ CF_3CF(CF_3)C[CF(CF_3)_2]=C(CF_3)OC_6H_4SO_3^-$	-	70829-87-7	U*	(Bao et al. 2017)
Polytetrafluoroethylene (PTFE)[6c]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Polymers of *N*-alkane perfluorooctane sulfonamido ethyl acrylates	-	polymer	-	U	(Savu 2000)
1-Propanesulfonic acid, 2-methyl-, 2-[[1-oxo-3-[(γ-ω-perfluoro-C_{4-16}-alkyl)thio]propyl]amino] derivs., sodium salts	-	-	68187-47-3	U*	(Norden 2020)
Thiols, C_{8-20}, γ-ω-perfluoro, telomers with acrylamide	-	-	70969-47-0	U*	(Norden 2020)

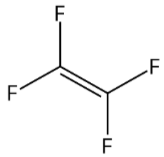
6a



6b



6c



A Chinese patent describes additionally the use of tetraethylammonium perfluorooctanesulfonate (CAS No. 56773-42-3), potassium perfluorobutane sulfonate (CAS No. 29420-49-3), *N*-ethyl perfluorooctane sulfonamidoethanol (CAS No. 1691-99-2), and perfluorooctane sulfonamide (CAS No. 754-91-6) as heavy crude oil well polymer blocking remover (CAS 2019 (CN106634915)).

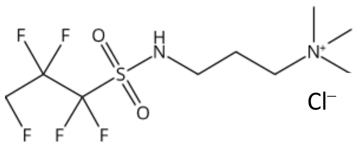
1.14.3 Chemical driven gas production

Fluorinated surfactants can be used to change low-permeability sandstone gas reservoirs from strongly hydrophilic to weakly hydrophilic. They can also eliminate reservoir capillary forces, dissolve partial solids, disassemble clogging, increase efficiency of displacing water with gas, and reduce damage to solid phase, thereby greatly increasing recovery rate and permeability rate of rock core (CAS 2019 (CN103351856, 2013)). Fluorinated surfactants that have been patented for this application are shown in Table 26.

Table 26: PFAS patented for use in chemical driven gas production. Patent number (date, legal status): CN103351856 (2013, active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[1a]	$Cl^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (CN103351856))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[1a]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	P	(CAS 2019 (CN103351856))

1a



1.14.4 Oil & gas transport

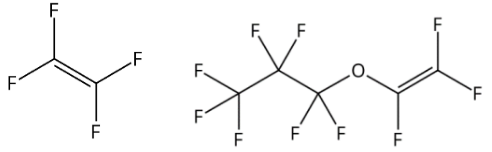
Pipes used in the production and transportation of oil are generally large and for reasons of economy are manufactured from carbon steel rather than more expensive corrosion resistant alloys (CAS 2019 (WO2006058270, 2006)). However, water, sulfur, sulfur dioxide, and carbon dioxide, present in the oil typically make the oil acidic causing corrosion of the interior surface of the pipe. Lining the interior surface of oil well pipes with fluorocarbons can prevent this corrosion. Due to the non-stick properties of the fluoropolymers, however, it is difficult to attach the fluoropolymers to the pipeline wall. For this reason, a primer is usually used (CAS 2019 (WO2006058271, 2006)). The presence of a perfluoropolymer in the primer layer enables the overcoat to melt bond to the primer layer when they are heated. The substances used in the primer layer and in the overcoat are melt-flowable fluoropolymers. Examples of such melt-flowable fluoropolymers include copolymers of tetrafluoroethylene (TFE) and at least one fluorinated copolymerizable monomer present in the polymer in sufficient amount to reduce the melting point of the copolymer substantially below that of TFE homopolymer, PTFE, e.g., to a melting temperature no greater than 315° (CAS 2019 (WO2006058271, 2006)). However, melt-flowable PTFE, commonly referred to as PTFE micropowder, can also be present in the primer layer or the overcoat along with the melt-fabricable copolymers, as such micropowder have similar melt flow rate as the copolymers (CAS 2019 (WO2006058271, 2006)).

Lining the interior can also prevent plugging which occurs when organic materials soluble in the oil at high temperatures of the oil deposit become insoluble as the oil cools during the rise through a pipe to the earth's surface. Lining the exterior of offshore pipes can protect them from corrosion through sea water (CAS 2019 (WO2006058270, 2006)). Fluoropolymers that can be used or ar used as linings of pipes used in oil pipelines are shown in Table 27.

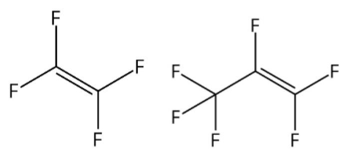
Table 27: Fluoropolymers used or patented for linings of pipes used in oil pipelines. Patent number (date, legal status): WO2006058270 (2006, active), US20050016610 (2005, discontinued). The types stand for U – use, U* - current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoralkoxy polymer (PFA)[1a]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-$	polymer	26655-00-5	P	(CAS 2019 (WO2006058270))
Fluorinated ethylene propylene (FEP)[1b]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-$	polymer	25067-11-2	P	(CAS 2019 (WO2006058270))
Perfluoro(ethyl vinyl ether)-perfluoro(propyl vinyl ether)-tetrafluoro ethylene copolymer[1c]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-[CF_2CF(OC_2F_5)]_m-$	polymer	546114-40-3	P	(CAS 2019 (WO2006058270))

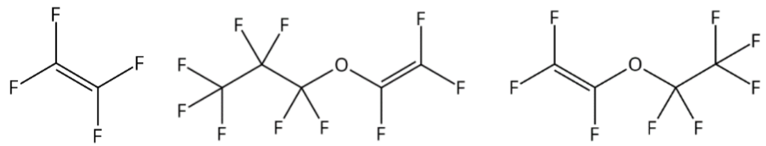
1a



1b

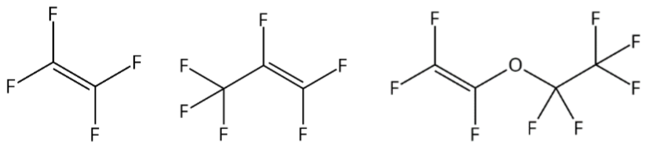


1c

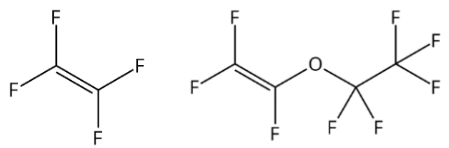


Hexafluoropropylene-perfluoro(ethyl vinyl ether)-tetrafluoroethylene copolymer[2a]	$-(CF_2CF_2)_x-[CF_2CF(OC_2F_5)]_y-[CF_2CF(CF_3)]_m-$	polymer	63654-40-0	P	(CAS 2019 (WO2006058270))
Perfluoro(ethyl vinyl ether)-tetrafluoroethylene copolymer[2b]	$-(CF_2CF_2)_x[CF_2CF(OC_2F_5)]_y-$	polymer	31784-04-0	P	(CAS 2019 (US20050016610))
Polytetrafluoroethylene (PTFE)[2c]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U	(Norden 2020)

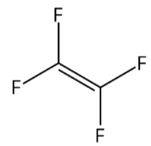
2a



2b



2c



Fluorinated surfactants have also been patented to aid reducing the viscosity of crude oil for pumping from the borehole. Viscosity frequently limits the rate crude oil can be produced from a well. Fluorinated surfactants can form crude oil-in-water emulsions that have lower viscosity than the unemulsified crude and can be pumped more easily (CAS 2019 (EP292427, 1988)). Two fluorinated surfactants that have been patented for this applications are 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]-, magnesium salt (2:1) (CAS No. 68005-63-0) and octene-1-sulfonic acid, pentadecafluoro-, potassium salt (1:1) (CAS No. 12751-11-0) (CAS 2019 (EP292427, 1988)).

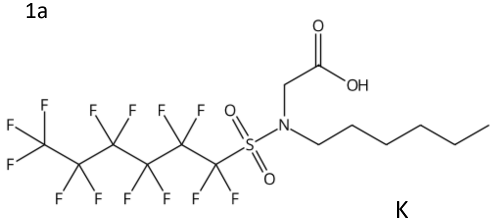
1.14.5 Oil & gas storage

Evaporation of liquid fuels (e.g., gasoline) can be prevented by an aqueous surface film containing anionic surfactants (CAS 2019 (JP55145780, 1980)). Possible fluorinated surfactants are shown in Table 28. Evaporation losses can also be reduced by covering the liquid surface of petroleum storage tanks with a floating layer of cereal (e.g. corn, wheat, or perlite) treated with a fluorinated surfactant (Kissa 2001; CAS 2019 (US4035149, 1977)).

Table 28: Fluorinated surfactants patented to prevent evaporative losses of liquid fuels. Patent number (date, legal status): JP55145780 (1980, expired), BE870812 (1979, expired). 'P' under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Glycine, *N*-hexyl-*N*-[(perfluoroalkyl)sulfonyl]-, potassium salt[1a]	$K^+ C_nF_{2n+1}SO_2N(C_6H_{13})CH_2COO^-$	n = 6	76843-36-2	P	(CAS 2019 (JP55145780))
1-Propanaminium, *N*-(carboxymethyl)-3-[hexyl[(perfluoroalkyll) sulfonyl]amino]-*N*,*N*-dimethyl-, inner salt[1b]	$C_nF_{2n+1}SO_2N(C_6H_{13})CH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 6	83409-36-3	P	(CAS 2019 (JP55145780))
Benzenesulfonic acid, 4-[[4,4,5,5,5-pentafluoro-3-(1,1,2,2,2-penta fluoro ethyl)-1,2,3-tris(trifluoromethyl)-1-penten-1-yl]oxy]-, sodium salt (1:1)[1c]	$Na^+ CF_3CF_2C(CF_3)(C_2F_5)C(CF_3){=}C(CF_3)OC_6H_4SO_3^-$	-	52584-45-9	P	(CAS 2019 (BE870812))

1a



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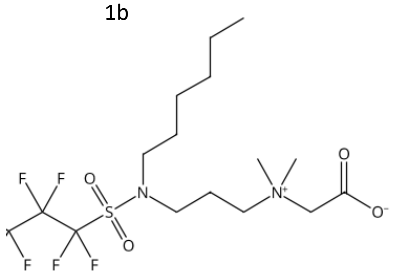

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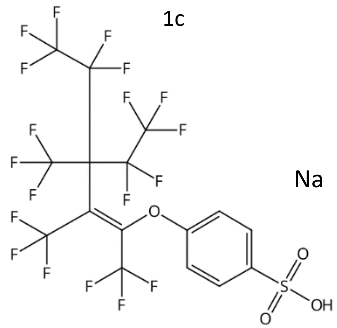


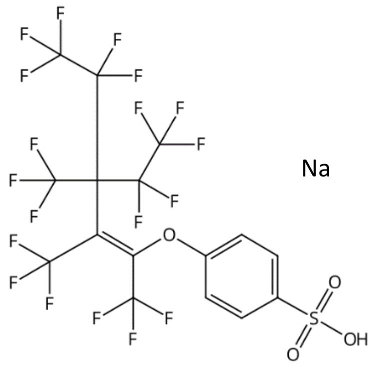
1.14.6 Oil Containment

Oil spills on water can be contained and prevented from spreading by a chemical barrier containing a fluorinated surfactant (CAS 2019 (GB1545401, 1979)). Table 29 lists fluorinated surfactants that have been patented for this application. It is also claimed that perlite or vermiculite, treated with a cationic fluorinated surfactant is hydrophobic and effective in cleaning oil spills (Kissa 2001; CAS 2019 (FR2333564, 1977)). However, the patent discloses no specification of the chemicals.

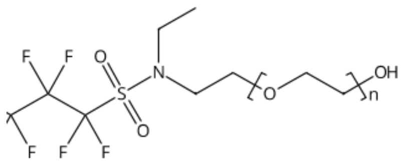
Table 29: PFAS patented for oil containment. Patent number (date, legal status): GB1545401 (1979, expired), JP50022783 (1975, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Benzenesulfonic acid, 4-[[4,4,5,5,5-pentafluoro-3-(1,1,2,2,2-pentafluoro ethyl)-1,2,3-tris(trifluoromethyl)-1-penten-1-yl]oxy]-, sodium salt (1:1)[1a]	$Na^+ CF_3CF(CF_3)C[CF(CF_3)_2]{=}C(CF_3)O\ C_6H_4SO_3^-$	-	52584-45-9	P	(.CAS 2019 (GB1545401))
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoroalkyl)sulfonyl] amino]ethyl]-ω-hydroxy-[1b]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_nOH$	n = 8	29117-08-6	P	(CAS 2019 (GB1545401))
Potassium *N*-ethyl perfluoroalkane sulfonamidoacetate[1c]	$K^+ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	P	(CAS 2019 (GB1545401))
Glycine, *N*-[(perfluoroalkyl)sulfonyl]-*N*-propyl-, potassium salt (1:1)[1d]	$K^+ C_nF_{2n+1}SO_2N(CH_2CH_2CH_3)CH_2COO^-$	n = 8	55910-10-6	P	(CAS 2019 (JP50022783))

1a



1b



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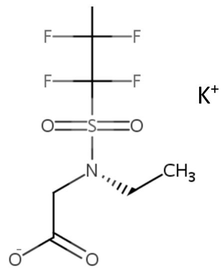
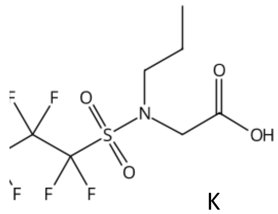


1d



1.14.7 Others

Fluoropolymers are used as filter material for oil and fuel filtration (POPRC 2018a). PFAS have also been used in the manufacture of coke and refined petroleum products. The four PFAS that are listed in the SPIN database of the Nordic countries for this application are 1-octanesulfonamide, *N*-[3-(dimethyloxidoamino)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-

tridecafluoro- (CAS No. 80475-32-7); 6:2 fluorotelomer sulfonamide betaine (CAS No. 34455-29-3); thiols, C_{8-20}, γ-ω-perfluoro, telomers with acrylamide (CAS No. 70969-47-0); and 1-propanesulfonic acid, 2-methyl-, 2-[[1-oxo-3-[(γ-ω-perfluoro-C_{4-16}-alkyl)thio]propyl]amino] derivs., sodium salts (CAS No. 68187-47-3) (Norden 2020). The last three are current uses.

1.15 Pharmaceutical industry

Fluoropolymers such as PTFE, PFA, FEP and ETFE have been used in reaction vessels, stirrers, and other components in place of traditional stainless steel or glass components (Gardiner 2015). PFAS have also been used in freeze dryers and VOC capturing in the pharmaceutical industry. Examples for PFAS in these applications are methyl perfluoropropyl ether (CAS No. 375-03-1) (3M 2014) and 3-ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl)hexane (CAS No. 297730-93-9) (3M 2008). PVDF has been used in filters for ultrapure water systems (Dohany 2000).

PCTFE films have been used for packaging air and moisture-sensitive pharmaceuticals (R. E. Banks, Smart, and Tatlow 1994; Gardiner 2015).

Furthermore, 1-bromoperfluorooctane (CAS No. 423-55-2) has been used as a processing aid in the manufacture of “microporous” particles for pharmaceutical applications (POPRC 2017). The “microporous” particles enable the combination of more than two active pharmaceutical ingredients into one pharmaceutical. They also enable targeted delivery in the lungs, for example in the treatment of chronic obstructive pulmonary disease or cystic fibrosis (POPRC 2017).

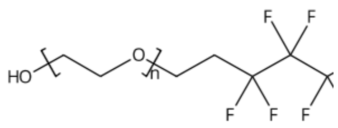
1.16 Photographic industry

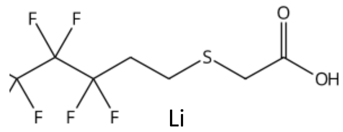
1.16.1 Use in processing solutions

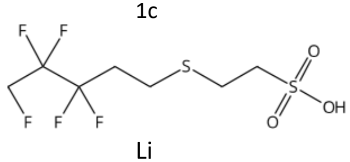
Fluorinated surfactants have been used as antifoaming agents in silver halide photographic processing solutions (CAS 2019 (JP2002196459, 2002)). Some specific molecules that have been patented for this applications are listed in Table 30. A fluorinated surfactant (glycine, *N*-ethyl-*N*-[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]-, potassium salt (1:1), CAS No. 2991-51-7) was used to lower the surface tension of the processing solution to eliminate air bubbles that can cause failure in image transfer (Kissa 2001; CAS 2019 (JP59037815, 1984)).

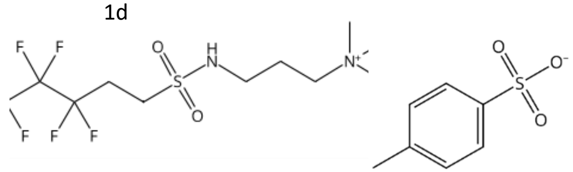
Table 30: PFAS patented as antifoaming agents in photographic processing solutions. Patent number (date, legal status): JP2002196459 (2002, not yet active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Poly(oxy-1,2-ethanediyl), α-(perfluoroalkyl)-ω-hydroxy-[1a]	$C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_nOH$	n = 6, 8	52550-44-4, 58228-15-2	P	(CAS 2019 (JP2002196459))
(n:2) Lithium fluorotelomer thioether acetic acid[1b]	Li^+ $C_nF_{2n+1}CH_2CH_2SCH_2COO^-$	n = 8	441765-12-4	P	(CAS 2019 (JP2002196459))
Ethanesulfonic acid, 2-[(perfluoroalkylthio]-, lithium salt (1:1)[1c]	Li^+ $C_nF_{2n+1}CH_2CH_2SCH_2CH_2SO_3^-$	n = 8	441765-14-6	P	(CAS 2019 (JP2002196459))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, 4-methylbenzenesulfonate (1:1)[1d]	$CH_3C_6H_4SO_3^-$ $C_nF_{2n+1}CH_2CH_2SO_2NH$ $CH_2CH_2CH_2N^+(CH_3)_3$	n = 8	438237-77-5	P	(CAS 2019 (JP2002196459))

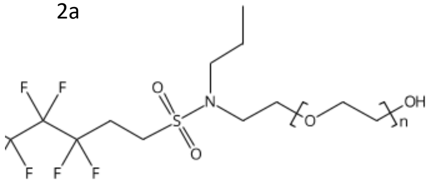
1a


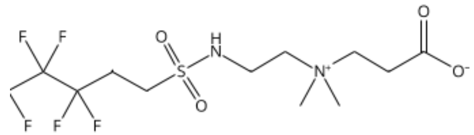
1b


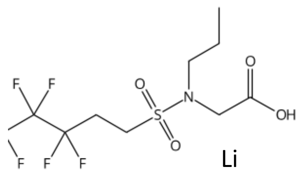
1c


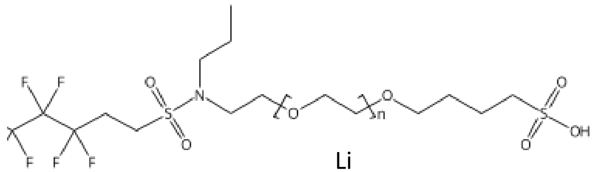
1d


Poly(oxy-1,2-ethanediyl), α-[2-[[(perfluoroalkyl)sulfonyl]propyl amino]ethyl]-ω-hydroxy-[2a]	$C_nF_{2n+1}CH_2CH_2SO_2N(C_3H_7)CH_2CH_2(OCH_2CH_2)_xOH$	n = 8	405226-47-3	P	(CAS 2019 (JP2002196459))
Ethanaminium, N-(2-carboxyethyl)-2-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*-dimethyl-, inner salt[2b]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 8	34695-29-9	P	(CAS 2019 (JP2002196459))
Glycine, N-[(perfluoroalkyl)sulfonyl]-N-propyl-, lithium salt[2c]	$Li^+ C_nF_{2n+1}CH_2CH_2SO_2N(C_3H_7)CH_2COO^-$	n = 8	441765-18-0	P	(CAS 2019 (JP2002196459))
Poly(oxy-1,2-ethanediyl), α-[2-[[(perfluoroalkyl)sulfonyl]propyl amino]ethyl]-ω-(4-sulfobutoxy)-, lithium salt[2d]	$Li^+ C_nF_{2n+1}CH_2CH_2SO_2N(C_3H_7)CH_2CH_2(OCH_2CH_2)_mOCH_2CH_2CH_2CH_2SO_3^-$	n = 8	441765-16-8	P	(CAS 2019 (JP2002196459))

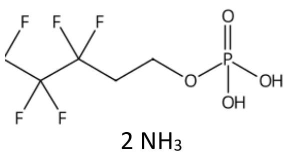
2a


2b


2c


2d


Diammonium (n:2) fluorotelomer phosphate monoester[3a]	$2\ NH_4^+ C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	n = 8	93857-44-4	P	(CAS 2019 (JP2002196459))
1-Alkanesulfonamide, perfluoro-*N*-[3-(phosphonooxy)propyl]-*N*-propyl-, sodium salt (1:2)[3b]	$2\ Na^+ C_nF_{2n+1}CH_2CH_2SO_2N(C_3H_7)CH_2CH_2CH_2OPO_3^{2-}$	n = 8	441765-20-4	P	(CAS 2019 (JP2002196459))

3a


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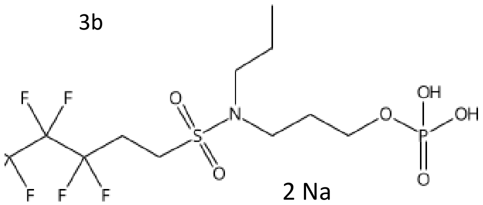


1.16.2 *Use in photo imaging devices itself*

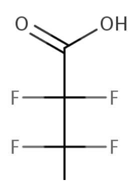
Fluorinated surfactants have been used in photo imaging devices such as films (including negative, colour reversal, cine, television and diagnostic X-ray), papers (colour reversal and positive) and reprographic plate (POPRC 2019). Fluorinated surfactants lack photo-activity and have the ability to provide critical functionality (such as controlling surface tension, electrostatic charge, friction, adhesion, and repelling dirt) (POPRC 2019). Thus, fluorinated surfactants have functioned as wetting agents, emulsion additives, stabilizers and antistatic agents (Kissa 2001). Lithium perfluorooctane sulfonate (CAS No. 29457-72-5) and PFOS were used as anti-reflective agents (POPRC 2019). Fluorinated surfactants can also be used to prevent spot formation and control edge uniformity in multilayer coatings (Kissa 2001) (for patented molecules see Table 31). Imaging materials that are very sensitive to light (e.g., high-speed films) benefit particularly from these properties (POPRC 2019).

In a diffusive-transfer photographic process, the photosensitive material and the image-accepting material have been layered in close contact to effect the diffusion transfer. When the photographic process was completed, the materials were peeled apart. Fluorinated surfactants in the timing layer of photographic diffusion-transfer materials provided a good contact when wet or dry, so that rupture or peeling of the emulsion layer was prevented (Kissa 2001).

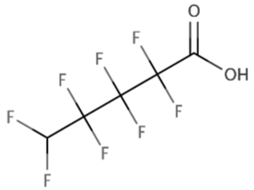
Table 31: PFAS patented for use in photographic material for controlling surface tension, electrostatic charge, friction, adhesion, and dirt repellence. Patent number (date, legal status): DE1961638 (1970, expired), DE2526970 (1976, expired), JP59206832 (1984, expired), EP643327 (1995, withdrawn), JP07077769 (1995, pending), IT966731 (1974, expired), DE3327464 (1984, expired), WO8300162 (1983, expired), EP15592 (1980, expired), JP10221812 (1998, pending). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl acids (PFAAs)					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3, 7	375-22-4, 335-67-1	U, P	(CAS 2019 (DE1961638), POPRC 2019)
Ammonium perfluoroalkyl carboxylates[(1a)]	$NH_4^+ \ C_nF_{2n+1}COO^-$	n = 7	3825-26-1	P	(CAS 2019 (DE1961638))
ω-Hydroperfluoroalkanoates[1b]	$CF_2HC_nF_{2n}COOH$	n = 5, 9	1546-95-8, 1765-48-6	P	(CAS 2019 (DE1961638))
Potassium perfluoroalkane sulfonates[1c]	$K^+ \ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (DE1961638))
Lithium perfluoroalkane sulfonates[(1c)]	$Li^+ \ C_nF_{2n+1}SO_3^-$	n = 8	29457-72-5	U	(POPRC 2019)
Tetraethylammonium perfluoroalkane sulfonates[1d]	$N(C_2H_5)_4^+ \ C_nF_{2n+1}SO_3^-$	n = 8	56773-42-3	U	(POPRC 2019)
1-Octanol, perfluoro-, dihydrogen phosphate, disodium salt[1e]	$2\ Na^+ \ HC_nF_{2n}OPO_3^{2-}$	n = 8	60131-28-4	P	(CAS 2019 (DE2526970))

1a



1b



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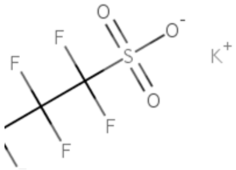
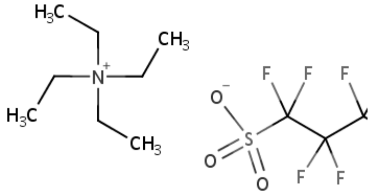
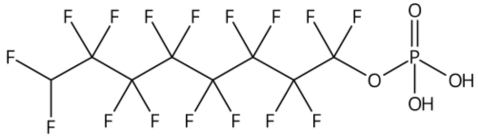


1d



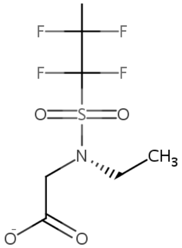
1e



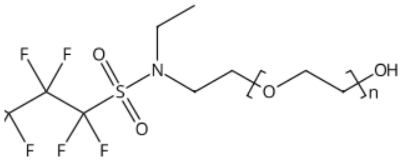
2 Na

Perfluoroalkane sulfonyl fluoride (PASF)-based substances					
Potassium *N*-ethyl perfluoroalkane sulfonamidoacetates[2a]	$K^+ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	P	(CAS 2019 (DE2337638))
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoroalkyl)sulfonyl]amino] ethyl]-ω-hydroxy-[2b]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_xOH$	n = 8 (x = undefined, 3, 5)	29117-08-6, 52137-93-6, 37338-48-0	P	(CAS 2019 (DE1961638), CAS 2019 (DE2337638), CAS 2019 (JP59206832))
Sodium *N*-ethyl perfluorooctane sulfonamidoacetates[2c]	$Na^+ C_nF_{2n+1}SO_2N(CH_2CH_2CH_3)CH_2COO^-$	n = 8	3871-50-9	P	(CAS 2019 (EP643327))
Glycine, *N*-[(perfluoroalkyl)sulfonyl]-*N*-ethyl-, potassium salt (1:1)[2d]	$K^+ C_nF_{2n+1}SO_2N(CH_2CH_3)CH_2COO^-$	n = 8	55910-10-6	P	(CAS 2019 (EP643327))

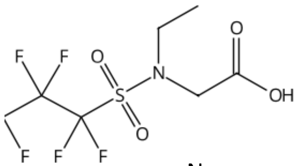
2a



2b

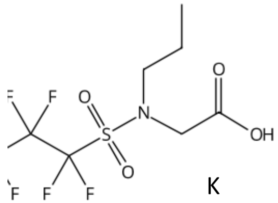


2c



Na

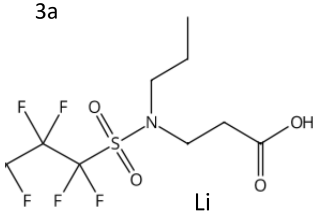
2d



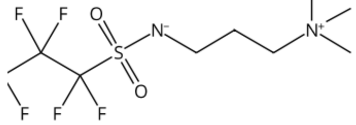
K

β-Alanine, *N*-[(perfluoroalkyl)sulfonyl]-*N*-propyl-, lithium salts[3a]	$Li^+ C_nF_{2n+1}SO_2N(CH_2CH_2CH_3)CH_2CH_2COO^-$	n = 8	163973-26-0	P	(CAS 2019 (JP07077769))
1-Alkanaminium, *N*,*N*,*N*-trimethyl-3-[[(perfluoro)sulfonyl]amino]-, inner salts[3b]	$C_nF_{2n+1}SO_2N^-CH_2CH_2CH_2N^+(CH_3)_3$	n = 6	38850-51-0	P	(CAS 2019 (DE2337638))
Methanaminium, 1-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, benzenesulfonate (1:1)[3c]	$C_6H_5SO_3^- C_nF_{2n+1}SO_2NHCH_2N^+(CH_3)_3$	n = 8	167162-25-6	P	(CAS 2019 (JP07077769))
Ethanaminium, 2-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodid (1:1)[3d]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2N^+(CH_3)_3$	n = 8	57765-32-9	P	(CAS 2019 (JP62173460))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-[3e]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	70225-25-1	P	(CAS 2019 (EP643327))

3a



3b



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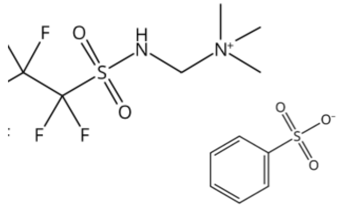
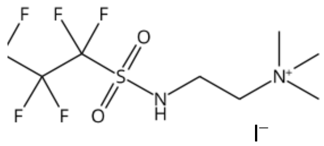


3d



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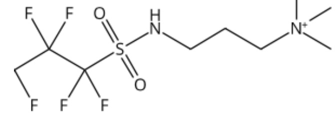
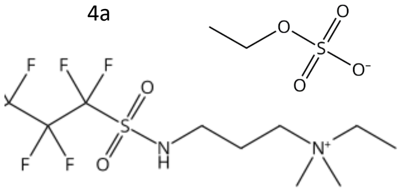
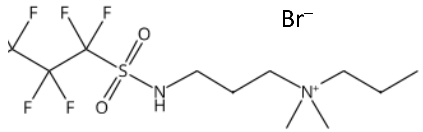


1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[(3e)]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	U	(POPRC 2019)
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[(3e)]	$Cl^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 4, 6, 8	53518-00-6, 52166-82-2, 38006-74-5	P	(CAS 2019 (IT966731), CAS 2019 (DE2337638)
1-Propanaminium, *N*-ethyl-3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl-, ethyl sulfate (1:1)[4a]	$SO_4C_2H_5^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2C_2H_5$	n = 8	53518-05-1	P	(CAS 2019 (IT966731))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl-*N*-propyl-, bromide (1:1)[4b]	$Br^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2CH_2$	n = 8	163973-44-2	P	(CAS 2019 (EP643327))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl-*N*-propyl-, 4-methylbenzenesulfonate (1:1)[4c]	$CH_3C_6H_4SO_3^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2CH_2$	n = 8	167162-27-8	P	(CAS 2019 (JP07077769))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-tris(2-methoxyethyl)-, iodide (1:1)[4d]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_2CH_2OCH_3)_3$	n = 8	91707-60-7	P	(CAS 2019 (DE3327464))

4a



4b



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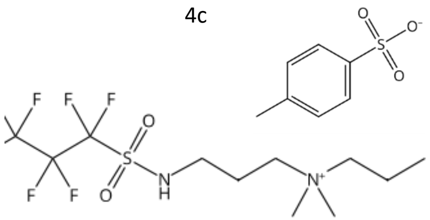
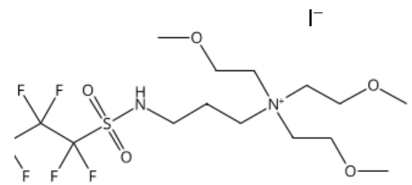
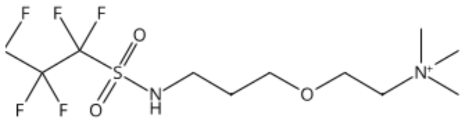


4d

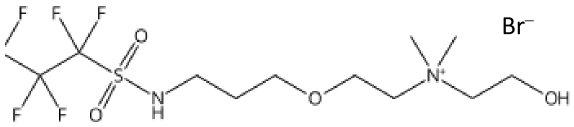


Ethanaminium, 2-[3-[[(perfluoroalkyl)sulfonyl]amino]propoxy]-*N*,*N*,*N*-trimethyl-[5a]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2OCH_2CH_2N^+(CH_3)_3$	n = 8	91707-62-9	P	(CAS 2019 (JP07319103))
Ethanaminium, *N*-[2-[3-[[(perfluoroalkyl)sulfonyl]amino]propoxy] ethyl]-2-hydroxy-*N*,*N*-dimethyl-, bromide (1:1)[5b]	$Br^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2OCH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 8	89447-44-9	P	(CAS 2019 (DE3327464))
1-Hexanaminium, *N*-[3-[[(perfluoroalkyl)sulfonyl]amino]propyl]-*N*,*N*-dimethyl-, bromide (1:1)[5c]	$Br^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2CH_2CH_2CH_2CH_3$	n = 8	53518-01-7	P	(CAS 2019 (IT966731))

5a



5b



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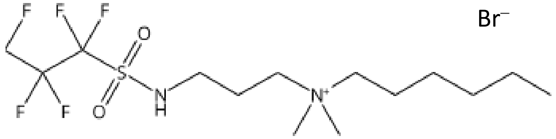
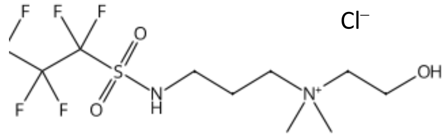
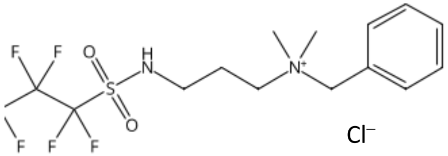


1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*-(2-hydroxy ethyl)-*N*,*N*-dimethyl-, chloride[6a]	$Cl^- \ C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 8	91322-74-6	P	(CAS 2019 (EP643327))
Benzenemethanaminium, *N*-[3-[[(perfluoroalkyl)sulfonyl]amino] propyl]-*N*,*N*-dimethyl-, chloride (1:1)[6b]	$Cl^- \ C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2C_6H_5$	n = 8	53517-99-0	P	(CAS 2019 (IT966731))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]methylamino]-*N*,*N*,*N*-trimethyl-[6c]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2CH_2N^+(CH_3)_3$	n = 8	153968-04-8	P	(CAS 2019 (EP643327))
1-Propanaminium, 3-[[(perfluoroalkyl]sulfonyl]propylamino]-*N*,*N*,*N*-trimethyl-[6d]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2CH_2N^+(CH_3)_3$	n = 8	16441-47-0	P	(CAS 2019 (EP643327))

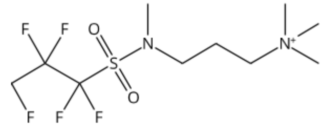
6a



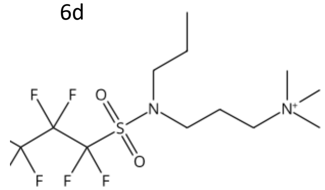
6b



6c

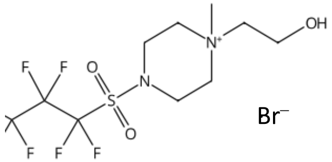


6d

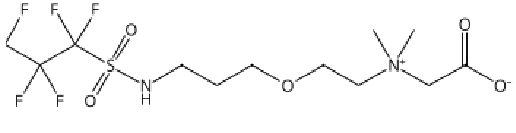


Piperazinium, 4-[(perfluoroalkyl)sulfonyl]-1-(2-hydroxyethyl)-1-methyl-, bromide (1:1)[7a]	$Br^- \ C_nF_{2n+1}SO_2NC_4H_8C^+(CH_3)CH_2CH_2OH$	n = 8	91707-64-1	P	(CAS 2019 (DE3327464))
Ethanaminium, *N*-(carboxymethyl)-2-[3-[[(perfluoroalkyl)sulfonyl] amino]propoxy]-*N*,*N*-dimethyl-, inner salt[7b]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2OCH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 8	110538-67-5	P	(CAS 2019 (JP62173460))
1-Propanaminium, 3-[(carboxymethyl)[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, inner salt[7c]	$C_nF_{2n+1}SO_2N(CH_2COO^-)CH_2CH_2CH_2N^+(CH_3)_3$	n = 6	38850-52-1	P	(CAS 2019 (DE2337638))
Poly(oxy-1,2-ethanediyl), α-(2-carboxyethyl)-ω-[2-[[(perfluoroalkyl) sulfonyl]propylamino]ethoxy]-, potassium salt[7d]	$K^+ \ C_nF_{2n+1}SO_2N(C_3H_7)(CH_2CH_2O)_nCH_2CH_2COO^-$	n = 8	167162-24-5	P	(CAS 2019 (JP07077769))

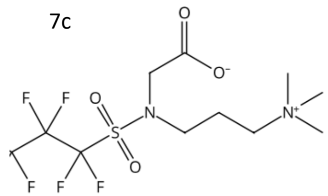
7a



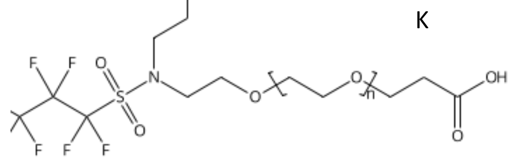
7b



7c

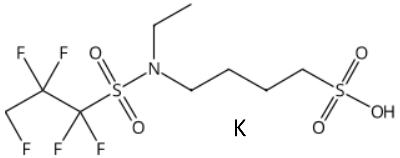


7d

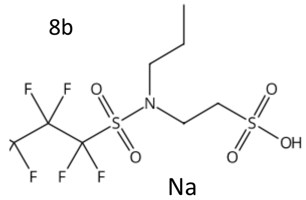


1-Butanesulfonic acid, 4-[ethyl[(perfluoroalkyl)sulfonyl]amino]-, potassium salt (1:1)[8a]	K^+ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2CH_2CH_2SO_3^-$	n = 8	60511-72-0	P	(CAS 2019 (JP59206832))
Ethanesulfonic acid, 2-[[(perfluoroalkyl)sulfonyl]propylamino]-, sodium salt (1:1)[8b]	Na^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2SO_3^-$	n = 8	63367-15-7	P	(CAS 2019 (DE2619248))
1-Propanesulfonic acid, 3-[[(perfluoroalkyl)sulfonyl]propylamino]-, sodium salt (1:1)[8c]	Na^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2CH_2SO_3^-$	n = 8	95470-07-8	P	(CAS 2019 (JP59206832))
4,7,10,13-Tetraoxa-17-thia-16-azapentacosanesulfonic acid, perfluoro-16-propyl-, 17,17-dioxide, sodium salt (1:1)[8d]	Na^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2(OCH_2CH_2)_4CH_2SO_3^-$	n = 8	166441-49-2	P	(CAS 2019 (EP643327))

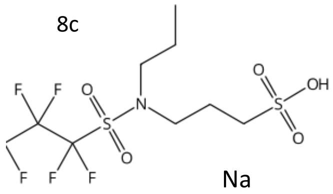
8a



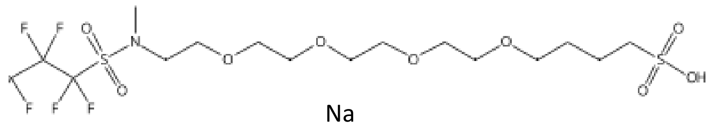
8b



8c

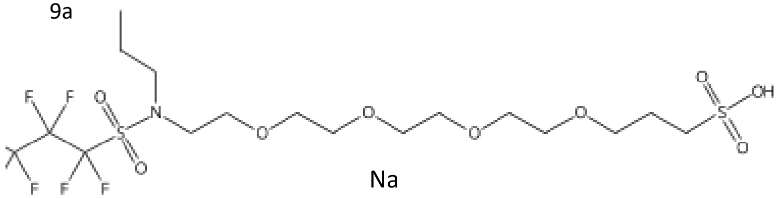


8d

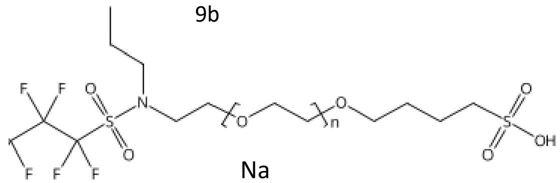


4,7,10,13-Tetraoxa-17-thia-16-azapentacosanesulfonic acid, perfluoro-16-propyl-, 17,17-dioxide, sodium salt (1:1)[9a]	Na^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2(OCH_2CH_2)_4CH_2SO_3^-$	n = 8	63367-16-8	P	(CAS 2019 (DE2619248))
Poly(oxy-1,2-ethanediyl), α-[2-[[(perfluoroalkyl)sulfonyl]propylamino]ethyl]-ω-(4-sulfobutoxy)-, sodium salt (1:1)[9b]	Na^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2(OCH_2CH_2)_nOCH_2CH_2CH_2CH_2SO_3^-$	n = 8	110494-69-4	P	(CAS 2019 (JP62173460))

9a

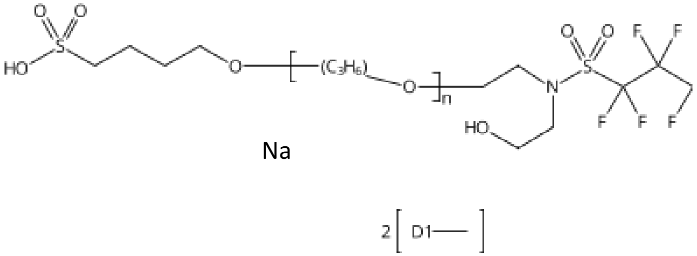


9b

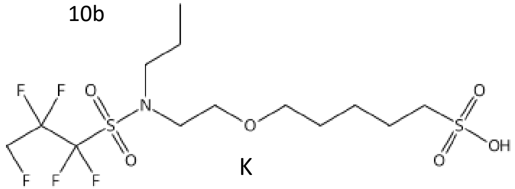


Poly[oxy(methyl-1,2-ethanediyl)], α-[2-[(2-hydroxymethylethyl)[(perfluoroalkyl)sulfonyl]amino]methylethyl]-ω-(4-sulfobutoxy)-, monosodium salt[10a]	Na^+ 2-CH_2 $C_nF_{2n+1}SO_2N(CH_2CH_2OH)CH_2CH_2(OCH_2CH_2CH_2)_nCH_2SO_3^-$	n = 7	167648-35-3	P	(CAS 2019 (JP07077769))
1-Pentanesulfonic acid, 5-[2-[[(perfluoroalkyl)sulfonyl]propylamino]ethoxy]-, potassium salt (1:1)[10b]	K^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2OCH_2CH_2CH_2CH_2CH_2SO_3^-$	n = 8	167162-23-4	P	(CAS 2019 (JP07077769))
Poly(oxy-1,2-ethanediyl), α-(4-sulfobutyl)-ω-[2-[[(perfluoroalkyl)sulfonyl]methylamino]ethoxy]-, sodium salt[10c]	Na^+ $C_nF_{2n+1}SO_2N(CH_3)(CH_2CH_2O)_nCH_2CH_2CH_2CH_2SO_3^-$	n = 8	153692-02-5	P	(CAS 2019 (JP07077769))

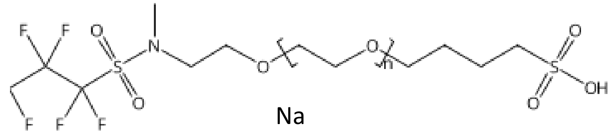
10a



10b



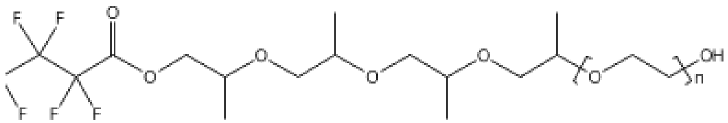
10c



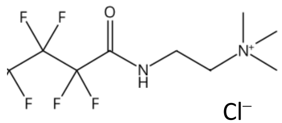
Perfluoroalkanoyl fluoride (PACF)-based substances

Poly(oxy-1,2-ethanediyl), α-(perfluoro-1,4,7,10-tetramethyl-13-oxo-3,6,9,12-tetraoxaeicos-1-yl)-ω-hydroxy-[11a]	$C_nF_{2n+1}C(O)\{[OCH_2CH(CH_3)]_4[OCH_2CH_2]_nOH\}$	n = 7	60015-08-9	P	(CAS 2019 (DE2526970))
Ethanaminium, *N*,*N*,*N*-trimethyl-2-[(perfluoro-1-oxoalkyl)amino]-, chloride (1:1)[11b]	$Cl^- C_nF_{2n+1}C(O)NHCH_2CH_2N^+(CH_3)_3$	n = 7	178766-44-4	P	(CAS 2019 (JP10221812))
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, chloride (1:1)[11c]	$Cl^- C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 7	53517-98-9	P	(CAS 2019 (IT966731))
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, iodide (1:1)[(11c)]	$I^- C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 2	53518-03-9	P	(CAS 2019 (IT966731))
1-Pentanaminium, *N*,*N*,*N*-trimethyl-5-[(perfluoro-1-oxoalkyl)amino]-, iodide (1:1)[11d]	$I^- C_nF_{2n+1}C(O)NHCH_2CH_2CH_2CH_2CH_2N^+(CH_3)_3$	n = 7	91707-61-8	P	(CAS 2019 (DE3327464))

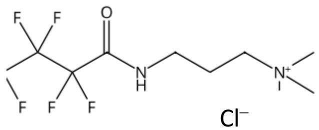
11a



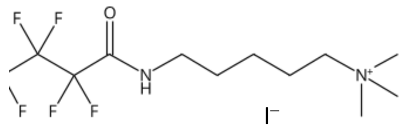
11b



11c

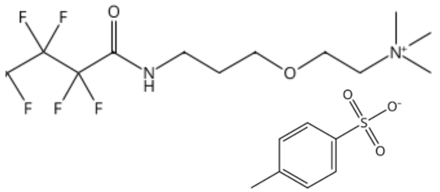


11d

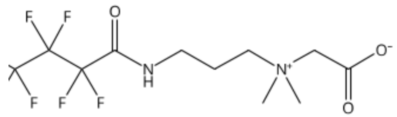


Ethanaminium, 2-[3-[(perfluoro-1-oxoalkyl)amino]propoxy]-*N*,*N*,*N*-trimethyl-, 4-methylbenzenesulfonate (1:1)[12a]	$CH_3C_6H_4SO_3^- C_nF_{2n+1}C(O)NHCH_2CH_2CH_2OCH_2CH_2N^+(CH_3)_3$	n = 8	85212-69-7	P	(CAS 2019 (DE3327464))
1-Propanaminium, *N*-(carboxymethyl)-*N*,*N*-dimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, inner salt[12b]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 10	77968-31-1	P	(CAS 2019 (DE3038818))
1-Propanaminium, *N*-(2-carboxyethyl)-3-[(perfluoro-1-oxoalkyl)amino]-*N*,*N*-dimethyl-, inner salt[12c]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 7	5158-52-1	P	(CAS 2019 (DE2337638))
Piperazinium, 1-(carboxymethyl)-1-(2-hydroxyethyl)-4-[3-[(perfluoro-1-oxoalkyl)amino]propyl]-, inner salt[12d]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2NC_4H_8N^+(CH_2CH_2OH)(CH_2COO^-)$	n = 9	77864-04-1	P	(CAS 2019 (JP55149938))

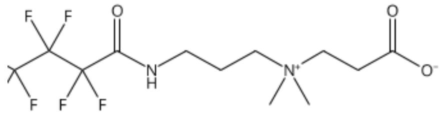
12a



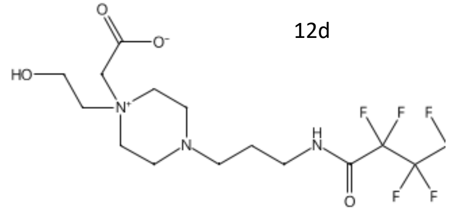
12b



12c

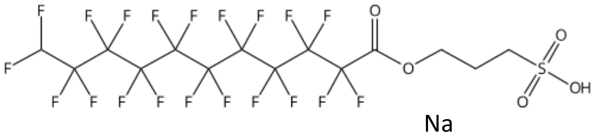


12d

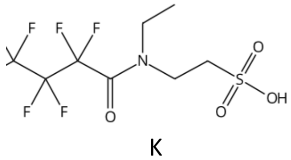


Undecanoic acid, perfluoro-, 3-sulfopropyl ester, sodium salt (1:1)[13a]	$Na^+\ CF_2HC_nF_{2n}C(O)OCH_2CH_2CH_2SO_3^-$	n = 9	29978-19-6	P	(CAS 2019 (DE1961638))
Ethanesulfonic acid, 2-[ethyl(perfluoroo-1-oxoalkyl)amino]-, potassium salt (1:1)[13b]	$K^+\ C_nF_{2n+1}C(O)N(C_2H_5)CH_2CH_2SO_3^-$	n = 7	57670-46-9	P	(CAS 2019 (DE2526970))
1-Naphthalenesulfonic acid, 3-hydroxy-4-[(perfluoro-1-oxodoalkyl) amino]-, sodium salt (1:1)[13c]	$Na^+\ C_nF_{2n+1}C(O)NHC_{10}H_5(OH)SO_3^-$	n = 11	63367-18-0	P	(CAS 2019 (DE2619248))
<u>n:1 & n:2 Fluorotelomer-based substances</u>					
1-Alkanol, perfluoro- [13d] (n:1)	$HC_nF_{2n}CH_2OH$	n = 6, 8	335-99-9, 376-18-1	P	(CAS 2019 (WO8300162))

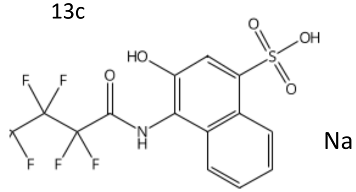
13a



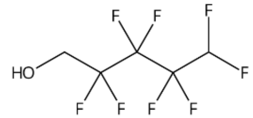
13b



13c

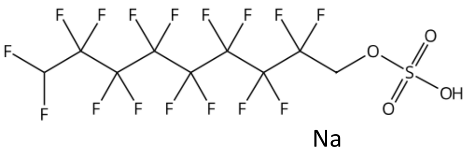


13d

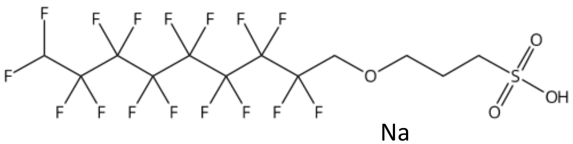


1-Alkanol, perfluoro-, 1-(hydrogen sulfate), sodium salt (1:1)[14a] (n:1)	$Na^+\ HC_nF_{2n}CH_2OSO_3^-$	n = 6, 8	29811-16-3, 29811-17-4	P	(CAS 2019 (DE1961638))
1-Propanesulfonic acid, 3-[(perfluoroalkyl)oxy]-, sodium salt (1:1)[14b] (n:1)	$Na^+\ HC_nF_{2n}CH_2OCH_2CH_2CH_2SO_3^-$	n = 8	29811-18-5	P	(CAS 2019 (DE1961638))
-[14c]	$Na^+\ C_nF_{2n+1}CH_2CH_2SCH_2CH_2C(O)NHC(CH_3)_2CH_2CH_2SO_3^-$	n = 6, 8, 10	-	U	(Buck, Murphy, and Pabon 2012)
Fluorotelomer-based products of various perfluoroalkyl chain length	-	-	-	U*	(SC 2017)

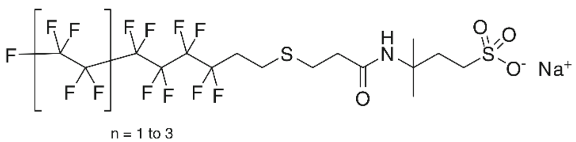
14a



14b

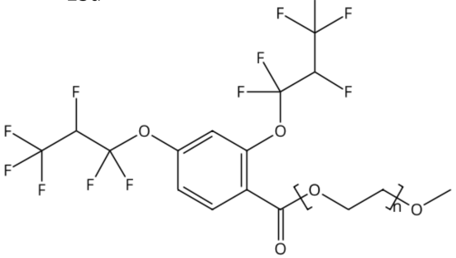


14c

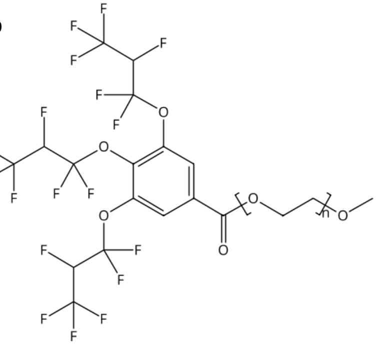


Side-chain fluorinated aromatics					
Poly(oxy-1,2-ethanediyl), α-[2,4-bis(1,1,2,3,3,3-hexafluoropropoxy) benzoyl]-ω-methoxy-[15a]	$C_6H_3(OCF_2CFHCF_3)_2[C(O)(OCH_2CH_2)_n OCH_3]$	-	75836-11-2	P	(CAS 2019 (EP15592))
Poly(oxy-1,2-ethanediyl), α-[3,4,5-tris(1,1,2,3,3,3-hexafluoropropoxy) benzoyl]-ω-methoxy-[15b]	$C_6H_3(OCF_2CFHCF_3)_2[C(O)(OCH_2CH_2)_n OCH_3]$	-	75836-10-1	P	(CAS 2019 (EP15592))
Poly(oxy-1,2-ethanediyl), α-[3,4,5-tris(1,1,2,3,3,3-hexafluoropropoxy) benzoyl]-ω-hydroxy-[15c]	$C_6H_3(OCF_2CFHCF_3)_2[C(O)(OCH_2CH_2)_n OH]$	n = unde-finded, 4, 9	75836-09-8, 75860-12-7, 75860-11-6	P	(CAS 2019 (EP15592))
Poly(oxy-1,2-ethanediyl), α-[2-[[3,4,5-tris(1,1,2,3,3,3-hexafluoro propoxy)benzoyl]amino]ethyl]-ω-hydroxy-[15d]	$C_6H_3(OCF_2CFHCF_3)_2[C(O)NHCH_2CH_2(OCH_2CH_2)_nOH]$	-	75836-08-7	P	(CAS 2019 (EP15592))

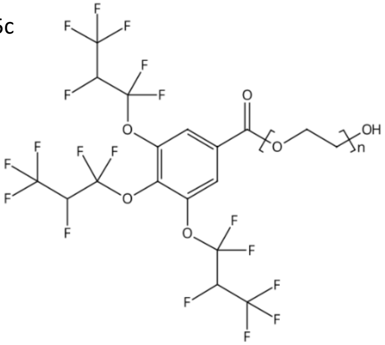
15a



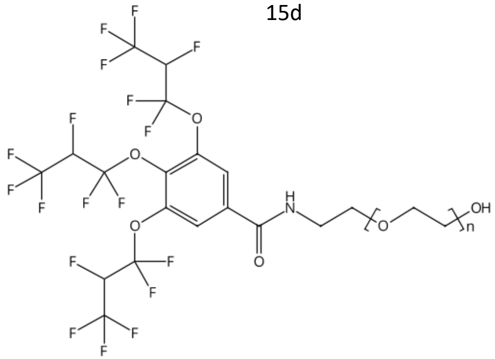
15b



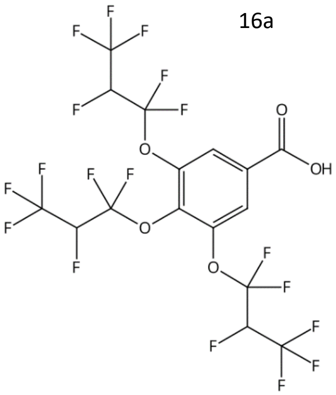
15c

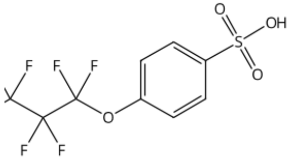


15d

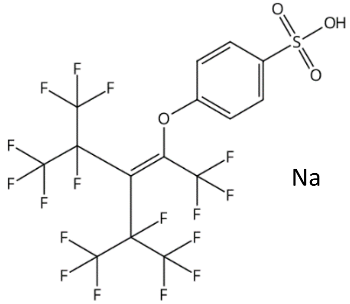


Benzoic acid, 3,4,5-tris(1,1,2,3,3,3-hexafluoropropoxy)-[16a]	$C_6H_2(OCF_2CFHCF_3)_3COOH$	-	75860-09-2	P	(CAS 2019 (EP15592))
Benzenesulfonic acid, 4-[(perfluoroalkyl)oxy]-, sodium salt (1:1)[16b]	$Na^+ C_nF_{2n+1}OC_6H_4SO_3^-$	n = 9	91998-13-9	P	(CAS 2019 (JP10221812))
Benzenesulfonic acid, 4-[[3,4,4,4-tetrafluoro-2-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]-1,3-bis(trifluoromethyl)-1-buten-1-yl]oxy]-, sodium salt (1:1) (OBS)[16c]	$Na^+ CF_3CF(CF_3)C[CF(CF_3)_2]=C(CF_3)O C_6H_4SO_3^-$	-	70829-87-7	U*	(Bao et al. 2017)
Benzenesulfonic acid, 4-[[4,4,5,5,5-pentafluoro-3-(1,1,2,2,2-pentafluoro ethyl)-1,2,3-tris(trifluoromethyl)-1-penten-1-yl]oxy]-, sodium salt (1:1)[16d]	$Na^+ CF_3CF_2C(CF_3)(C_2F_5)C(CF_3)=C(CF_3) OC_6H_4SO_3^-$	-	52584-45-9	P	(CAS 2019 (DE2619248))
Benzenesulfonic acid, 2,5-bis(1,1,2,3,3,3-hexafluoropropoxy)-, sodium salt (1:1)[16e]	$Na^+ C_6H_3(OCF_2CFHCF_3)_2SO_3^-$	-	75860-16-1	P	(CAS 2019 (EP15592))

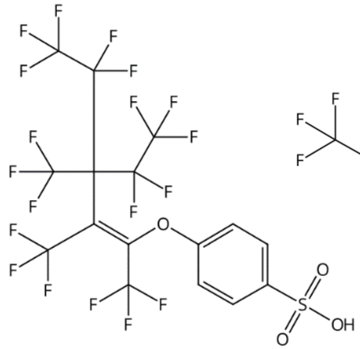
16a


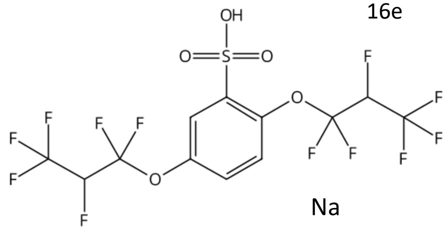
16b


Na

16c


Na

16d


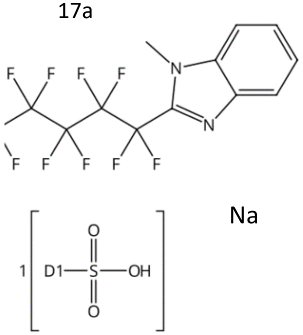
16e


Na

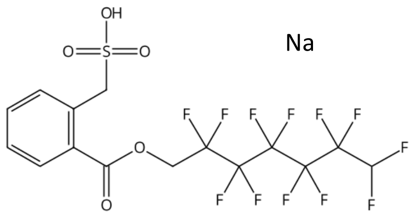
1H-Benzimidazolesulfonic acid, 1-methyl-2-(pentadecafluoroheptyl)-, sodium salt[17a]	$Na^+ C_nF_{2n+1}C_7N_2H_3(CH_3)\text{-}SO_3^-$	n = 7	63351-71-3	P	(CAS 2019 (DE2619248))

Other nonpolymers

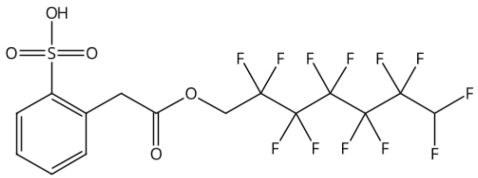
Benzoic acid, 2-(sulfomethyl)-, 1-(perfluoroalkyl) ester, sodium salt (1:1)[17b]	$Na^+ HC_nF_{2n}CH_2OC(O)C_6H_4CH_2SO_3^-$	n = 6	29817-88-7	P	(CAS 2019 (DE1961638))
Benzeneacetic acid, 2-sulfo-, 1-(perfluoroalkyl) ester, sodium salt (1:1)[17c]	$Na^+ HC_nF_{2n}CH_2OC(O)CH_2C_6H_4SO_3^-$	n = 6	29817-87-6	P	(CAS 2019 (DE1961638))
Benzoic acid, 2-sulfo-, 1-(perfluoroalkyl) ester, sodium salt (1:1)[17d]	$Na^+ HC_nF_{2n}CH_2OC(O)C_6H_4SO_3^-$	n = 6, 8	29811-19-6, 29811-20-9	P	(CAS 2019 (DE1961638))

17a


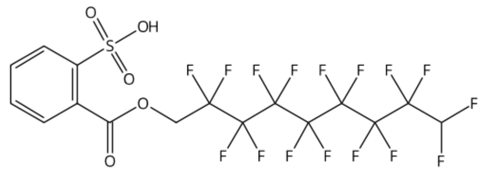
Na

17b


Na

17c


Na

17d


Na

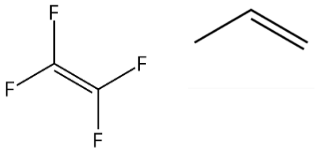
1.17 Production of plastic and rubber

PFAS have been used as mould release agents, foam blowing agents, in the etching of plastic, as antiblocking agents for rubber, and as curatives for fluoroelastomer formulations. The SPIN database of the Nordic countries lists a few PFAS that have been used to manufacture rubber and plastic products in general. Also, the Chemical Data Reporting database under the TSCA lists two fluoropolymers that were used above 11.3 t in the rubber product manufacturing in the US between 2012 and 2015 (USEPA 2016). The PFAS from both databases are shown in Table 32.

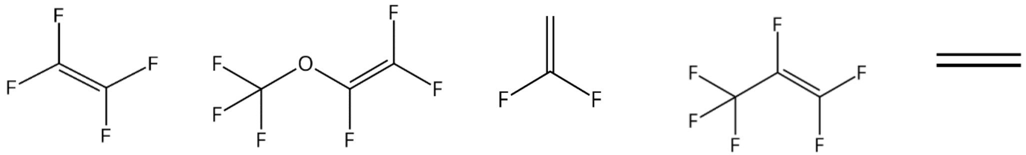
Table 32: PFAS that have either been listed in the SPIN database of the Nordic contries or in the Chemical Data Reporting database under the TSCA for the production of plastic and/or rubber. The types stand for U – use and U* – current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Production of rubber					
Propylene tetrafluorethylene copolymer[1a]	$-[(CH_3)CHCH_2]_x-(CF_2CF_2)_y-$	polymer	27029-05-6	U	(USEPA 2016)
1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoro ethene, ethene, 1,1,2,2-tetrafluoroethene and 1,1,2-trifluoro-2-(trifluoromethoxy)ethene[1b]	$-(C_3F_6O)_x-(C_3F_6)_y-(C_2H_4)_m-(C_2H_2F_2)_w-(C_2F_4)_u-$	polymer	149935-01-3	U	(USEPA 2016)

1a

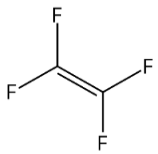


1b

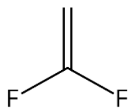


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Production of plastic and rubber products					
Polytetrafluoroethylene (PTFE)[2a]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Poly(vinylidene fluoride) (PVDF)[2b]	$-(CH_2CF_2)_x-$	polymer	24937-79-9	U*	(Norden 2020)
Perfluoro(propyl vinyl ether)-tetrafluoro ethylene copolymer (PFA)[2c]	$-(CF_2CF_2)_x-[CF_2CFO(C_3F_7)]_y-$	polymer	26655-00-5	U	(Norden 2020)
Hexafluoropropylene-tetrafluoroethylene-vinylidene fluoride copolymer (THV)[2d]	$-(CF_2CF_2)x-[CF_2CF(CF_3)]_y-(CF_2CH_2)_m-$	polymer	25190-89-0	U*	(Norden 2020)

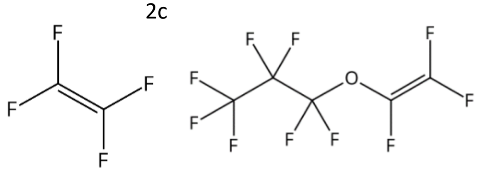
2a



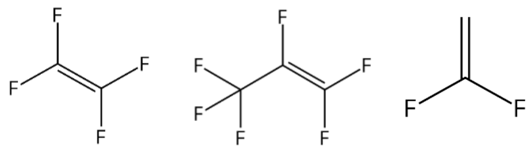
2b



2c



2d



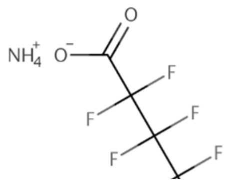
1.17.1 Mould release agent

Fluorinated surfactants are effective mould release agents due to their oleophobic and hydrophobic nature (Kissa 2001). Release agents are chemicals that aid in the separation of a mould from the material being moulded. Fluorinated surfactants have been used as release agents for thermoplastics, polypropylene, epoxy resins, and polyurethane elastomer foam mouldings (Kissa 2001). Besides their function in "de-moulding", they also reduce imperfections in the moulded surface (POPRC 2019). PFOS, its salts or POSF-based substances were previously used as mould release agents in rubber and plastics moulding applications (POPRC 2019). Perfluorobutane sulfonyl fluoride (PBSF)-derivatives or various C_4-perfluoroalkyl compounds are used currently as alternatives to PFOS in rubber moulding (POPRC 2019). Other fluorinated surfactants that have been patented as (mould) release agents are listed in Table 33.

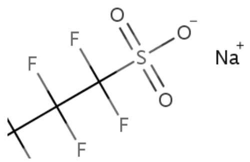
Table 33: PFAS patented as (mould) release agents. Patent number (date, legal status): DE2641898 (1977, expired), JP58217502 (1983, expired), JP54036342 (1979, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Ammonium perfluoroalkyl carboxylate[1a]	NH_4^+ $C_nF_{2n+1}COO^-$	n = 7	3825-26-1	P	(CAS 2019 (DE2641898))
Sodium perfluoroalkane sulfonate[1b]	Na^+ $C_nF_{2n+1}SO_3^-$	n = 8	4021-47-0	P	(CAS 2019 (JP58217502))
Poly(oxy-1,2-ethanediyl), α-[2-[[(perfluoroalkyl) sulfonyl]amino]ethyl]-ω-hydroxy-[1c]	$C_nF_{2n+1}SO_2NHCH_2CH_2(OCH_2CH_2)_mOH$	n = 8	63336-01-6	P	(CAS 2019 (DE2641898))
Poly(oxy-1,2-ethanediyl), α-[2-[[(perfluoroalkyl) sulfonyl]methylamino]ethyl]-ω-hydroxy-[1d]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2(OCH_2CH_2)_mOH$	n = 8	52701-06-1	P	(CAS 2019 (JP54036342))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[1e]	I^- $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	P	(CAS 2019 (JP58217502))

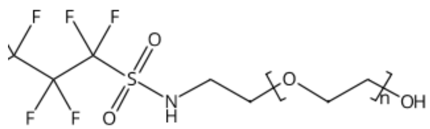
1a



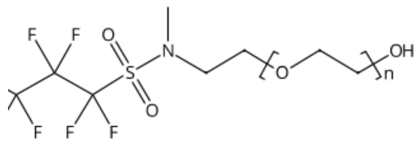
1b



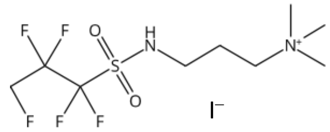
1c



1d

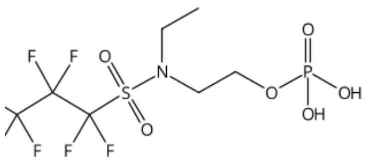


1e

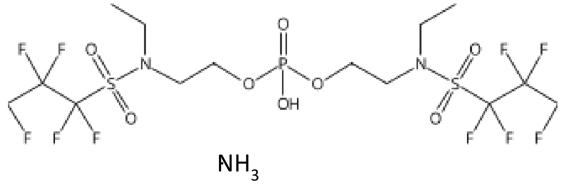


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Alkanesulfonamide, *N*-ethyl-perfluoro-*N*-[2-(phosphonooxy)ethyl]-[2a]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2OP(=O)(OH)_2$	n = 8	3820-83-5	P	(CAS 2019 (DE2641898))
1-Alkanesulfonamide, *N*,*N*′-[phosphinicobis(oxy-2,1-ethanediyl)]bis[N-ethyl-perfluoro-, ammonium salt (1:1)[2b]	NH_4^+ $[C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2O]_2PO_2^-$	n = 8	30381-98-7	P	(CAS 2019 (DE2641898))
1-Alkanol, perfluoro-ω-(trifluoromethyl)-[2c]	$CF_3CF(CF_3)C_nF_{2n}CH_2CH_2CH_2OH$	n = 6	31200-97-2	P	(CAS 2019 (DE2641898))
(n:2) Fluorotelomer phosphat monoester (monoPAPs)[2d]	$C_nF_{2n+1}CH_2CH_2OP(=O)(OH)_2$	n = 8	37013-72-2	P	(CAS 2019 (DE2641898))

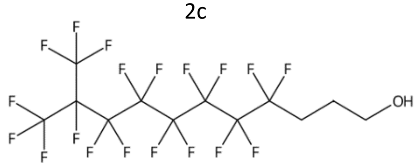
2a



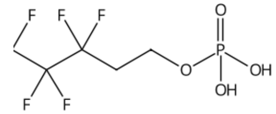
2b



2c

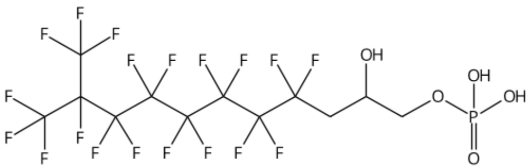


2d

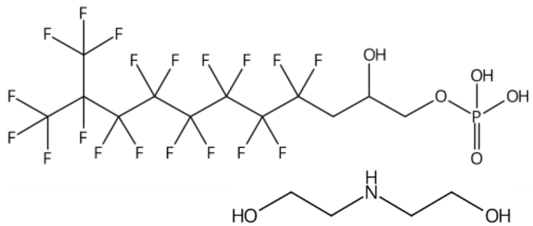


Diammonium (n:2) fluorotelomer phosphate monoester(2d)	2 NH_4^+ $C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	n = 7	63439-39-4	P	(CAS 2019 (DE2641898))
1,2-Alkanediol, perfluoro-ω-(trifluoromethyl)-, 1-(dihydrogen phosphate)[3a]	$CF_3CF(CF_3)C_nF_{2n}CH_2CH(OH)CH_2OP(=O)(OH)_2$	n = 6, 8, 10, 12	54009-73-3, 63295-27-2, 63295-28-3, 63295-29-4	P	(CAS 2019 (DE2641898))
1,2-Alkanediol, perfluoro-ω-(trifluoromethyl)-, 1-(dihydrogen phosphate), diammonium salt(3a)	2 NH_4^+ $CF_3CF(CF_3)C_nF_{2n}CH_2CH(OH)CH_2O$ PO_3^{2-}	n = 6	63295-18-1	P	(CAS 2019 (DE2641898))
1,2-Alkanediol, perfluoro-ω-(trifluoromethyl)-, 1-(dihydrogen phosphate) compd. with 2,2'-iminobis[ethanol] (1:2)[3b]	2 $NH_2^+(CH_2CH_2OH)_2$ $CF_3CF(CF_3)C_nF_{2n}CH_2CH$ $(OH)CH_2OPO_3^{2-}$	n = 6	63295-19-2	P	(CAS 2019 (DE2641898))
2-Alkanol, perfluoro-ω-(trifluoromethyl)-, dihydrogen phosphate, diammonium salt[3c]	2 NH_4^+ $CF_3CF(CF_3)C_nF_{2n+1}CH_2CH(CH_3)OPO_3^{2-}$	n = 6	63295-23-8	P	(CAS 2019 (DE2641898))

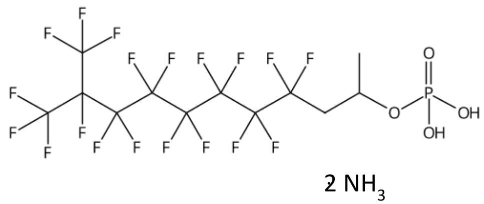
3a



3b

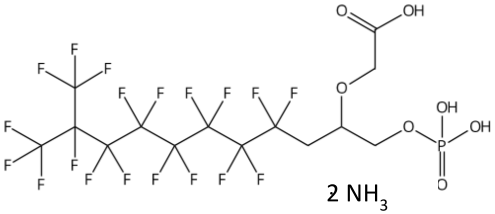


3c

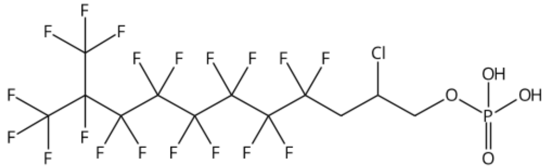


Acetic acid, 2-[[perfluoro-1-[(phosphonooxy)methyl]-ω-(trifluoromethyl)decyl]oxy]-, ammonium salt (1:2)[4a]	2 NH_4^+ $CF_3CF(CF_3)C_nF_{2n}CH_2CH(OCH_2COOH)$ $CH_2OPO_3^{2-}$	n = 6	63295-24-9	P	(CAS 2019 (DE2641898))
1-Alkanol, 2-chloro-perfluoro-hexadecafluoro-ω-(trifluoromethyl)-, dihydrogen phosphate[4b]	$CF_3CF(CF_3)C_nF_{2n}CH_2CH(Cl)CH_2OP(=O)(OH)_2$	n = 6	63295-22-7	P	(CAS 2019 (DE2641898))
(n:2) Fluorotelomer phosphat diester (diPAPs)[4c]	$OP(OH)(OCH_2CH_2C_nF_{2n+1})_2$	n = 7	63295-25-0	P	(CAS 2019 (DE2641898))

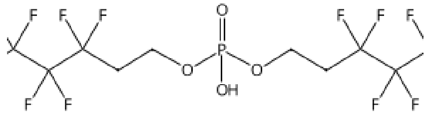
4a



4b

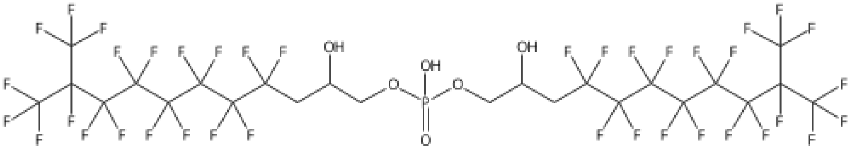


4c

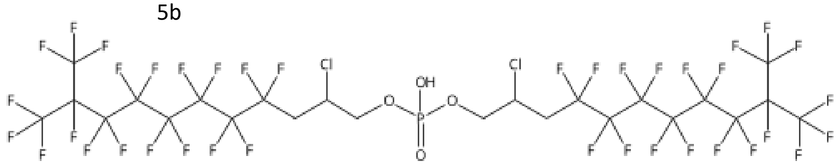


1,2-Alkanediol, perfluoro-ω-(trifluoromethyl)-, 1,1′-(hydrogen phosphate)[5a]	$OP(OH)[OCH_2CH(OH)CH_2C_nF_{2n}CF(CF_3)_2]_2$	n = 6	63295-20-5	P	(CAS 2019 (DE2641898))
1-Alkanol, 2-chloro-perfluoro-ω-(trifluoromethyl)-, hydrogen phosphate[5b]	$OP(OH)[OCH_2CH(Cl)CH_2C_nF_{2n}CF(CF_3)_2]_2$	n = 6	63295-26-1	P	(CAS 2019 (DE2641898))

5a

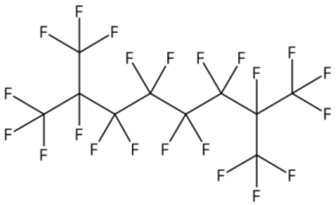


5b

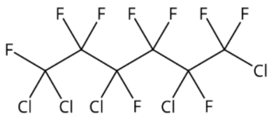


Perfluoro-2,7-dimethyloctane[6a]	$CF_3CF(CF_3)CF_2CF_2CF_2CF_2CF(CF_3)CF_3$	-	3021-63-4	P	(CAS 2019 (DE2641898))
Hexane, 1,1,3,5,6-pentachloro-1,2,2,3,4,4,5,6,6-nonafluoro-[6b]	$CFCl_2(CF_2CFCl)_2CF_2Cl$	-	307-26-6	P	(CAS 2019 (DE2641898))
Perfluorotrialkyl amine[6c]	$N(C_nF_{2n+1})_3$	n = 4	311-89-7	P	(CAS 2019 (DE2641898))
3,6,9,12-Tetraoxapentadecane, 1,1,1,2,4,4,5,7,7,8, 10,10,11,13, 13,14,14,15,15,15-eicosafluoro-5,8,11-tris(trifluoromethyl)-[6d]	$CF_3CFH(OCF_2CF(CF_3))_3OCF_2CF_2CF_3$	-	26738-51-2	P	(CAS 2019 (DE2641898))
Polytetrafluoroethylene (PTFE)[6e]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U	(Norden 2020)

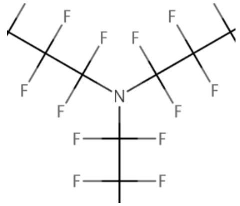
6a



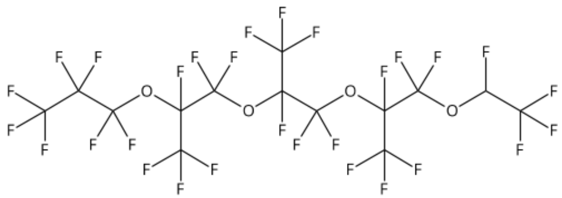
6b



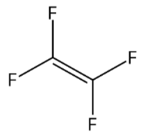
6c



6d

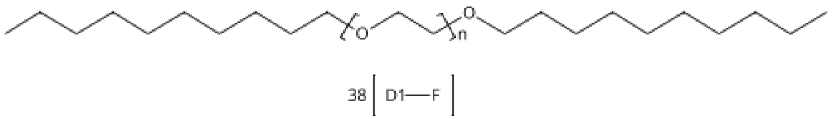


6e

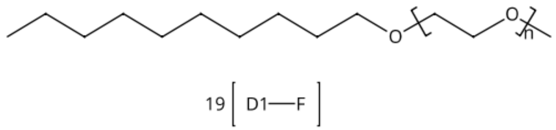


Poly(oxy-1,2-ethanediyl), α-(nonadecafluorodecenyl)-ω-[(nonadecafluorodecenyl)oxy]-[7a]	$-(C_2H_4O)_nC_{20}F_{38}O-$	polymer	37382-58-4	P	(CAS 2019 (DE2641898))
Poly(oxy-1,2-ethanediyl), α-methyl-ω-[(nonadecafluoro decenyl)oxy]-[7b]	$-(C_2H_4O)_nC_{11}H_3F_{19}O-$	polymer	37382-56-2	P	(CAS 2019 (DE2641898))

7a



7b



PFAS have been detected in artificial turf. Detected PFAS include 6:2 fluorotelomer sulfonic acid (CAS No. 27619-97-2) and PFOS (CAS No. 1763-23-1) (Lerner 2019). An interviewee of the article that revealed that PFAS are found in artificial turf suggested that PFAS in artificial turf originate from the production of the plastic sheets and the use of PFAS as mould release agents (Lerner 2019). However, a patent discloses that PTFE can be used in artificial turf to “lowering the friction coefficient” and other fluoropolymers such as PVDF or fluorelastomers might be used in as processing aids (CAS 2019 (EP1672020), 2006). So it is not entirely clear where the PFAS in artificial turf originate from, but mould release is one option.

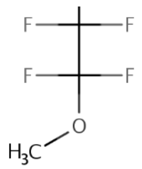
1.17.2 Foam blowing agents

PFAS have been used to aid foaming of plastics and polymers, such as polyolefins, polyurethanes, poly(diethylene glycol diacrylate), siloxanes, and foamable adhesives (Kissa 2001). Perfluorocarbons and hydrofluorocarbons have been used in recent years as foam blowing agents instead of chlorofluorocarbons (R. E. Banks, Smart, and Tatlow 1994; Tsay 2005). A few PFAS that have been used as foam blowing agents, or have been patented for this application, are listed in Table 34.

Table 34: PFAS historically or currently used or patented as blowing agent. Patent number (date, legal status): JP10152452 (1998, withdrawn). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Methyl perfluoroalkyl ether[1a]	$C_nF_{2n+1}OCH_3$	n = 2, 3	22410-44-2, 375-03-1	P, U	(CAS 2019 (JP10152452), Tsay 2005)
Perfluoro-2-methylpentane[1d]	$CF_3CF(CF_3)CF_2CF_2CF_3$		355-04-4	U	(F2_Chemicals 2019a)

1a



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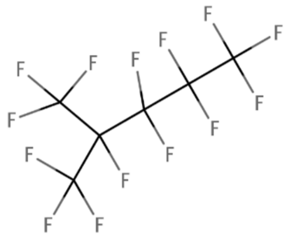


1.17.3 Foam regulator

A patent describes the use of fluorinated surfactants as foam regulators in the manufacture of foams from MDI-CR and PPG-Su-450 L (a polyol) (CAS 2019 (JP60199015)). One of the patented surfactants is poly(oxy-1,2-ethanediyl), α-(4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-nonadecafluoro-2-hydroxydodecyl)-ω-methoxy- (CAS No. 85643-63-6).

1.17.4 Processing aids for processing of polymers other than fluoropolymers

Polymer (plastic) processing aids based on fluoropolymers are used in polymers formulation to increase the processing efficiency and quality of polymeric compounds e.g. by eliminating melt fractures and other flow-induced imperfections (SpecialChem 2020). Besides the major use in linear low density polyethylene blown film, fluoropolymer-based processing aids are well suited for high density polyethylene, polyvinyl chloride, polystyrene, polyamide, polyolefins, and other standard and engineering polymers in various applications (SpecialChem 2020; Sina Ebnesajjad and Morgan 2012). Copolymers of vinylidenefluorid (VDF) and hexafluoropropylene (HFP, CAS No. 25120-07-4) are the most widely used fluoropolymers as processing aids for polyethylene, but also terpolymers of VDF, HFP and TFE have been used for polyethylene (Seiler et al. 2018). Copolymers with greater than 65 % (weght) VDF are commonly called PVDF copolymers. In addition to copolymers of VDF and HFP, it is also somewhat common to use PVDF homopolymer as a polymer processing aid for polyethylene (Seiler et al. 2018). A patent discloses that beside homo- and co-polymers of VDF and HFP, homo- and co-polymers of chlorotrifluoroethylene and perfluoroalkyl perfluorovinyl ethers can also be used as polymer processing aids (CAS 2019 (WO2011017021, 2011)).

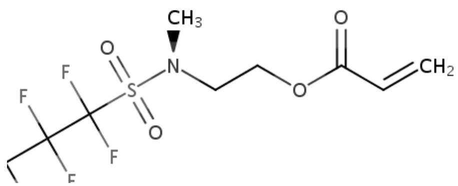
Some low molecular weight PFAS have also been used as processing aids for polymers (see Table 35).

Table 35: PFAS historically or currently used as processing aids for other chemicals. Patent number (date, legal status): DD159079 (1983, expired), DE2605203(1976, pending), DE2501239 (1975, expired), JP2014227421 (2014, active). The types stand for U – use, U* - current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

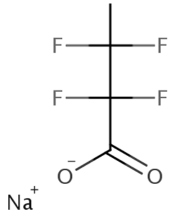
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
<u>For polymers based on C_4-acrylates</u>					

N-Methyl perfluoroalkane sulfonamidoethyl acrylates (MeFASEAC)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH=CH_2$	n = 4	67584-55-8	U	(Hodgkins 2018)
<u>For polyvinyl chloride (PVC)</u>					
Sodium perfluoroalkyl carboxylate[1b]	$Na^+ C_nF_{2n+1}COO^-$	n = 6, 12	20109-59-5, 60872-01-7	P	(CAS 2019 (DD159079))
Benzenesulfonic acid, 4-[[4,4,5,5,5-pentafluoro-3-(1,1,2,2,2-pentafluoroethyl)-1,2,3-tris(trifluoromethyl)-1-penten-1-yl]oxy]-, sodium salt (1:1)[1c]	$Na^+ CF_3CF_2C(CF_3)(C_2F_5)C(CF_3)=C(CF_3)OC_6H_4SO_3^-$	-	52584-45-9	P	(CAS 2019 (DE2605203))
<u>For polyethylene</u>					
n:2 Fluorotelomer carboxylic acid[1d]	$C_nF_{2n+1}CH_2COOH$	n = 6	53826-12-3	P	(CAS 2019 (DE2501239))
<u>For plastic material and resin manufacturing</u>					
n:2 Fluorotelomer sulfonic acid (FTSA)[1e]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	U	(USEPA 2016)

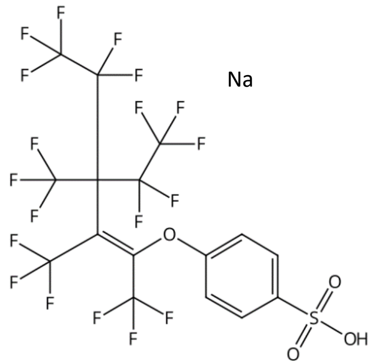
1a



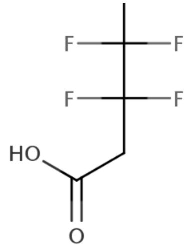
1b



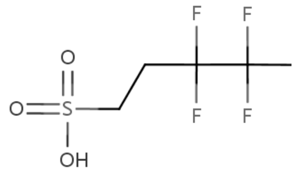
1c



1d



1e



Tetraethylammonium perfluoroalkane sulfonate	$N(C_2H_5)_4^+ C_nF_{2n+1}SO_3^-$	n = 8	56773-42-3	U	(USEPA 2016)

1.17.5 Etching of plastic

Fluorinated surfactants such as lithium perfluorooctanesulfonate (CAS No. 29457-72-5), potassium perfluoroalkanesulfonate, and an amine perfluoroalkanesulfonate have been effective wetting agents in etching solutions for plastics (Kissa 2001). An example for the etching of plastic is in plastic metallization (Hauser, Füglister, and Scheffelmaier 2020).

1.17.6 Antiblocking agents for rubber

Antiblocking agents for vulcanized or unvulcanized rubbers can be formulated with a nonionic fluorinated surfactant with unknown identity (Google_patents 2019 (JPS5647476A, 1981)).

1.17.7 Curatives for fluroelastomer formulations

PFBS-related substances may be used in curatives for fluoroelastomer fomulations. The curative reacts with the fluoroelastomer backbone to a three-dimensional network, and is thus fully incorporated into the polymer matrix. The curatives are deployed in industrial applications for the manufacturing of O-rings, seals, tubing inner linings, etc. (Norwegian Environment Agency 2017).

1.18 Semiconductor industry

Semiconductor manufacturing comprises up to 500 steps, involving four fundamental physical processes: a) implant; b) deposition; c) etch/polish; and d) photolithography (POPRC 2019). Photolithography is the process by which the circuits are produced on the semi-conductor wafers (Brooke, Footitt, and Nwaogu 2004). Generally, in these processes, a thin film of a photoresist (light-sensitive polymer) is first applied to a substrate material, such as silicon based wafers used to make integrated circuits. Then, light is used to transfer a geometric pattern from a photomask to the photoresist on the wafer. The photoresist is altered on exposure to light, making it either easier or more difficult to remove and so allowing structures to be built up on the wafer (Brooke, Footitt, and Nwaogu 2004). Positive photoresist, the most common type, becomes soluble in the developer when exposed to light. For negative photoresist, unexposed regions are soluble in the developer. Photoresists require the use of so called photo-acid generators to increase their sensitivity to allow etching images smaller than the wavelength of visible light (POPRC 2019). PFAS can either form part of the photoresist itself, act as the photo-acid generator or act as a photosensitizer in the chemical amplification of the effect of exposure.

PFAS can also be used to add a thin coating to the resist to reduce reflections, either to the top (top anti-reflective coatings, TARC) or bottom (bottom anti-reflective coatings, BARC) (Brooke, Footitt, and Nwaogu 2004). Additionally, PFAS may also be used as surfactants in the developers, or in ancillary products such as edge bead removers (Brooke, Footitt, and Nwaogu 2004).

1.18.1 PFAS in the photoresist

<u>PFAS as part of the photoresist itself</u>

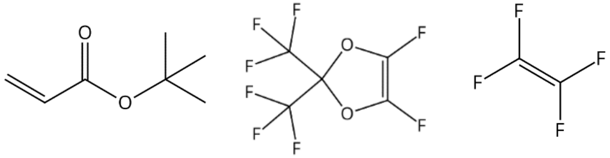
A photoresists is a layer on a silicon wafer that is needed to manufacture patterns on the wafer. Positive photoresist, the most common type, becomes soluble in the developer when exposed to light. For negative photoresist, unexposed regions are soluble in the developer. Two patented photoresists that include PFAS are shown in Table 36.

Table 36: PFAS patented as photoresist. Patent number (date, legal status): WO2005043239 (2005, active). Additional explanations to the table are provided on Page 2 and 3 of this document.

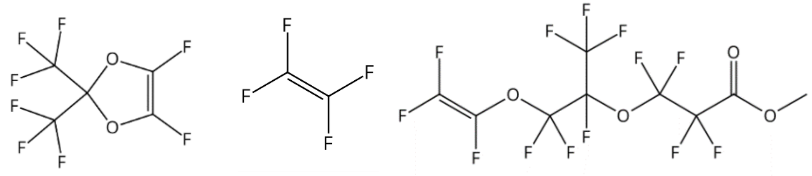
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
2-Propenoic acid, 1,1-dimethylethyl ester, polymer with 4,5-difluoro-2,2-bis(trifluoromethyl)-1,3-dioxole and tetrafluoro ethene[1a]	$-(C_7H_{12}O_2)_x-(C_5F_8O_2)_y-(C_2F_4)_m-$	polymer	851389-08-7	P	(CAS 2019 (WO2005043239))

Propanoic acid, 3-[1-[difluoro[(1,2,2-trifluoro ethenyl)oxy]methyl]-1,2,2,2-tetrafluoroethoxy]-2,2,3,3-tetrafluoro-, methyl ester, polymer with 4,5-difluoro-2,2-bis(trifluoromethyl)-1,3-dioxole and 1,1,2,2-tetrafluoroethene[1b]	$-(C_9H_3F_{13}O_4)_x-(C_5F_8O_2)_y-(C_2F_4)_m-$	polymer	86179-28-4	P	(CAS 2019 (WO2005043239))

1a



1b



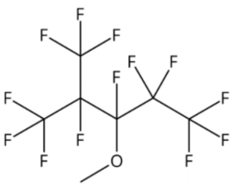
PFAS as photosensitizer in the photoresist

It has been stated that many conventional photoresist compositions include a photosensitizing additive, commonly referred to as a sensitizer or sensitizing dye, to increase the photosensitivity of the photoresist at a particular wavelength (CAS 2019 (US20140356789, 2014)). A few photosensitizer are listed in Table 37.

Table 37: PFAS patented as photosensitizer for photoresists. Patent number (date, legal status): US20140356789 (2014, discontinued). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-(trifluoromethyl)-[1a]	$CF_3CF(CF_3)CF(OCH_3)CF_2CF_3$	-	132182-92-4	P	(CAS 2019 (US20140356789))
Pentane, 1,1,1,2,3,3-hexafluoro-4-(1,1,2,3,3,3-hexafluoropropoxy)-[1b]	$CF_3CFHCF_2OCH(CH_3)CF_2CFHCF_3$	-	870778-34-0	P	(CAS 2019 (US20140356789))
1-Alkanone, 1-(9H-fluoren-2-yl)-perfluoro-, O-[(perfluoroalkyl) sulfonyl]oxime[1c]	$C_nF_{2n+1}SO_2ON(C_mF_{2m}H)C_{13}H_{10}$	n = 4	848352-66-9	P	(CAS 2019 (US20140356789))
(n:2) Fluorotelomer methacrylates (FTMACs)[1d]	$C_nF_{2n+1}CH_2CH_2OC(O)C(CH_3)=CH_2$	n = 6	2144-53-8	P	(CAS 2019 (US20140356789))

1a



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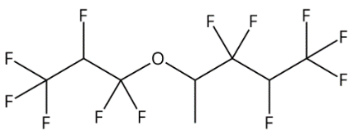

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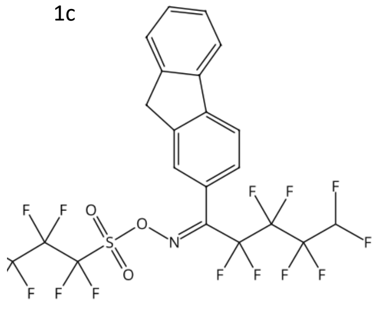

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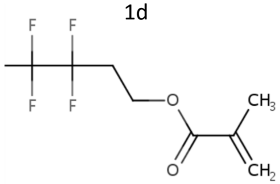


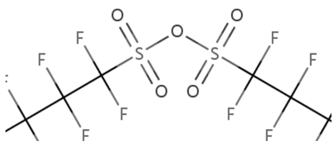
PFAS as photo-acid generator in the photoresist

Photo-acid generators (PAG) are components of photoresist formulation that are able to generate strong acids by light irradiation (Asakura, Yamato, and Ohwa 2006). Examples of described photo-acid generators are shown in Table 38.

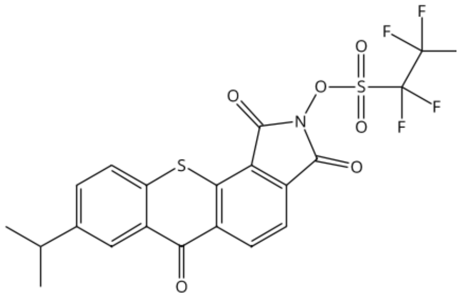
Table 38: PFAS historically or currently used as photo-acid generators. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkane sulfonic acids (PFSAs) *(these substances have probably not been used alone but as the anionic part of a PAG)*	$C_nF_{2n+1}SO_3H$	n = 4, 8	375-73-5, 1763-23-1	U	(Norwegian Environment Agency 2017; UNEP 2017)
Functionalized tetrafluoroethanesulfonates *(the substance has probably not been used alone but as the anionic part of a PAG)*	$R\text{-}C_2F_4SO_3H$	-	-	U	(Glodde, Liu, and Varanasi 2010)
Perfluoroalkane sulfonic anhydride[1a]	$C_nF_{2n+1}SO_2OSO_2C_nF_{2n+1}$	n = 4, 8	36913-91-4, 423-92-7	U	(Iwashima et al. 2003)
1-Alaknesulfonic acid, perfluoro-, 3,6-dihydro-8-(1-methylethyl)-1,3,6-trioxo[1]benzothiopyrano[2,3-e]isoindol-2-yl ester[1b]	$C_nF_{2n+1}SO_2ONC_{18}O_3SH_{12}$	n = 4	639827-06-8	U	(Shirai 2007)
1-Alkanesulfonic acid, perfluoro-, 3,6-dihydro-1,3,6-trioxo[1] benzothiopyrano[2,3-e]isoindol-2-yl ester[1c]	$C_nF_{2n+1}SO_2ONC_{15}O_3SH_6$	n = 4	639827-04-6	U	(Shirai 2007)
9H-Fluoren-9-one, O-[(perfluoroalkyl)sulfonyl]oxime[1d]	$C_nF_{2n+1}SO_2ONC_{13}H_8$	n = 4	639782-56-2	U	(Shirai 2007)
1-Alkanesulfonic acid, perfluoro-, 1,3-dioxo-1H-benz[de] isoquinolin-2(3H)-yl ester[1e]	$C_nF_{2n+1}SO_2ONC_{12}O_2H_6$	n = 1, 4, 8	85342-62-7, 171417-91-7, 639827-02-4	U	(Iwashima et al. 2003; Malval et al. 2008)

1a



1b



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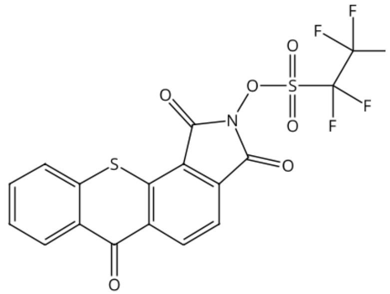

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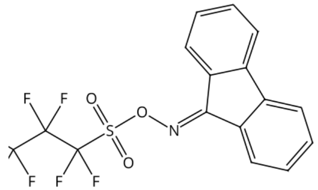

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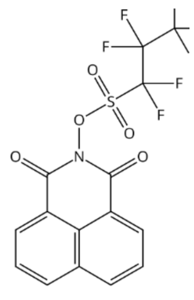
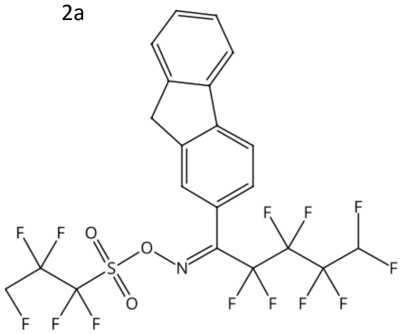
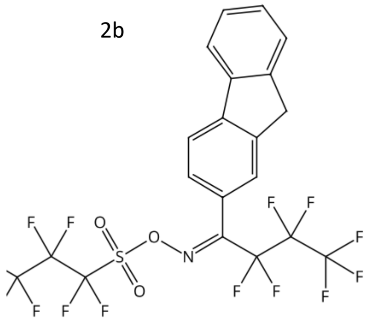


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Alkanone, 1-(9H-fluoren-2-yl)-perfluoro-, O-[(perfluoroalkyl) sulfonyl]oxime[2a]	$C_nF_{2n+1}SO_2ON(C_mF_{2m}H)C_{13}H_{10}$	n/m = 4/4, 4/6	848352-66-9, 691358-66-4	U	(Asakura, Yamato, and Ohwa 2006; Yamato, Asakura, and Ohwa 2006)
1-Alkanone, 1-(9H-fluoren-2-yl)-perfluoro-, O-[(perfluoroalkyl) sulfonyl]oxime[2b]	$C_nF_{2n+1}SO_2ON(C_mF_{2m})C_{13}H_{10}$	n = 4	749924-57-0	U	(Yamato, Asakura, and Ohwa 2006)

2a



2b



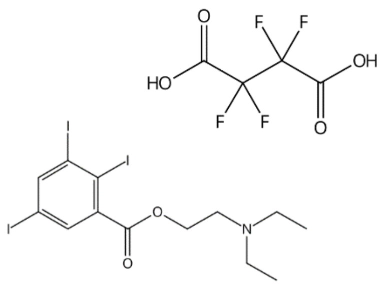
PFAS as quencher in the photoresist

Chemically amplified resist compositions comprising an acid generator and capable of generating an acid upon exposure to light or EB include chemically amplified positive resist compositions wherein deprotection reaction takes place under the action of acid and chemically amplified negative resist compositions wherein polarity switch or crosslinking reaction takes place under the action of acid. Quenchers are often added to these resist compositions for the purpose of controlling the diffusion of the acid to unexposed region to improve the contrast (CAS 2019 (US20200073237, 2020)). Some patented quencher that contain PFAS are shown in Table 39.

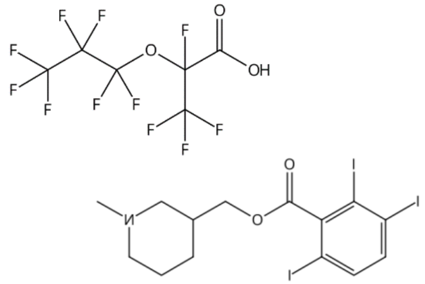
Table 39: PFAS patented as quencher in a photoresist. Patent number (date, legal status): US20200073237 (2020, assigned). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Butanedioic acid, 2,2,3,3-tetrafluoro-, compd. with 2-(diethylamino)ethyl 2,3,5-triiodobenzoate (1:2)[1a]	2 $C_{13}H_{16}I_3NO_2$ $C_4H_2F_4O_4$	-	2412106-73-9	P	(CAS 2019 (US20200073237))
Benzoic acid, 2,3,6-triiodo-, (1-methyl-3-piperidinyl)methyl ester, compd. with 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoro propoxy)propanoate (1:1)[1b]	$C_{14}H_{16}I_3NO_2$ $C_6HF_{11}O_3$	-	2412106-69-3	P	(CAS 2019 (US20200073237))
Benzoic acid, 2,3,5-triiodo-, 2-[(1,1-dimethylethyl)[2-[(2,3,6-triiodobenzoyl)oxy]ethyl]amino]ethyl ester, compd. with 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonamide (1:1)[1c]	$C_{22}H_{21}I_6NO_4$ $C_4H_2F_9NO_2S$	-	2412106-51-3	P	(CAS 2019 (US20200073237))

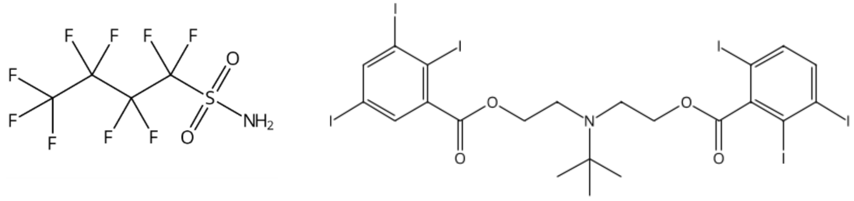
1a



1b



1c



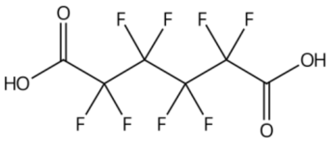
1.18.2 PFAS in the anti-reflective coating

Absorbing antireflective coatings and underlayers in photolithography are used to diminish back reflection of light from highly reflective substrates (CAS 2019 WO2009066169, 2009). The major disadvantages of back reflectivity are thin film interference effects and reflective notching. Thin film interferences occur when light waves reflected by the upper and lower boundaries of a thin film interfere with one another, either enhancing or reducing the reflected light. Reflective notching are caused by scattered light from the substrate (e.g. silicon wafer). An antireflective coating coated beneath a photoresist and above a reflective substrate provides significant improvement in lithographic performance of the photoresist. The antireflective coating is cured to prevent intermixing between the antireflective coating and the photoresist. The photoresist is exposed image-wise and developed. The antireflective coating in the exposed area is then typically dry etched using various etching gases, and the photoresist pattern is thus transferred to the substrate (CAS 2019 (WO2009066169, 2009)). PFAS that have been patented for use as or in anti-reflective coatings are listed in Table 40.

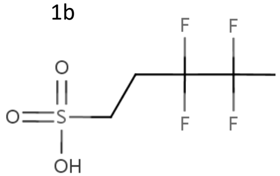
Table 40: PFAS patented for use as or in anti-reflective coating. Patent number (date, legal status): JP2009145658 (2009, active), US7544750 (2009, active), JP2000221689 (2000, withdrawn), JP2010102128 (2010, active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Top antireflective coating					
Alkanedioic acid, perfluoro-[1a]	$OHC(O)C_nF_{2n}COOH$	n = 4	336-08-3	P	(CAS 2019 (JP2009145658))
(n:2) Fluorotelomer sulfonic acid (FTSA)[1b]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 8	39108-34-4	P	(CAS 2019 (JP2009145658))
2-Propenoic acid, polymer with 2-ethenylnaphthalene and 4,4,5, 5,6,6,7,7,8,8,9,9,10,10,11,11,11-heptadecafluoro-2-hydroxyundecyl 2-propenoate[1c]	$-(C_{14}H_9F_{17}O_3)_x-(C_{12}H_{10})_y-(C_3H_4O_2)_m-$	polymer	934505-67-6	P	(CAS 2019 (US7544750))

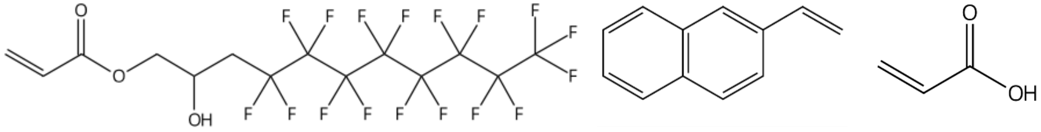
1a



1b



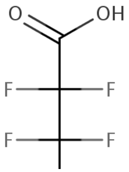
1c



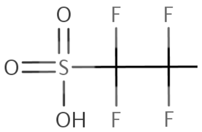
<u>Antireflective undercoat layer</u>

Perfluoroalkyl carboxylic acids (PFCAs)[2a]	$C_nF_{2n+1}COOH$	n = 4	2706-90-3	P	(CAS 2019 (JP2000221689))
Perfluoroalkane sulfonic acids (PFSAs)[2b]	$C_nF_{2n+1}SO_3H$	n = 4	375-73-5	P	(CAS 2019 (JP2000221689))
2-Propenoic acid, 4,4,5,5,6,6,7,7,7-nonafluoro-2-hydroxyheptyl ester, polymer with 2-propene-1-sulfonic acid[2c]	$-(C_{10}H_9F_9O_3)_x-(C_3H_6O_3S)_y-$	polymer	910114-99-7	P	(CAS 2019 (JP2010102128))

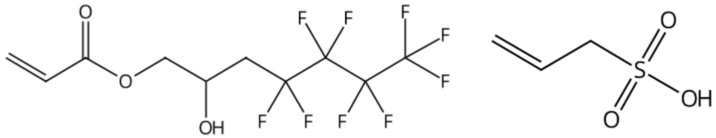
2a



2b

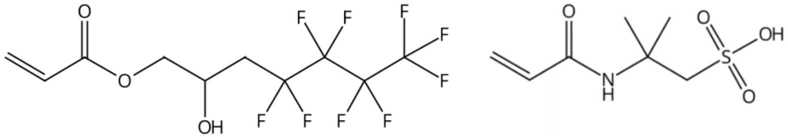


2c

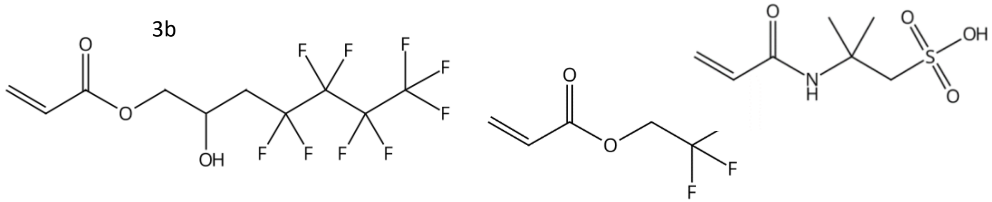


2-Propenoic acid, 4,4,5,5,6,6,7,7,7-nonafluoro-2-hydroxyheptyl ester, polymer with 2-methyl-2-[(1-oxo-2-propen-1-yl)amino]-1-propane sulfonic acid[3a]	$-(C_{10}H_9F_9O_3)_x-(C_7H_{13}NO_4S)_y-$	polymer	910114-98-6	P	(CAS 2019 (JP2010102128))
2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadeca fluorodecyl ester, polymer with 2-methyl-2-[(1-oxo-2-propen-1-yl)amino]-1-propane sulfonic acid and 2,2,2-trifluoroethyl 2-propenoate[3b]	$-(C_{13}H_7F_{17}O_2)_x-(C_7H_{13}NO_4S)_y-(C_5H_5F_3O_2)_m-$	polymer	172083-53-3	P	(CAS 2019 (JP2010102128))

3a



3b



1.18.3 PFAS in developers or edge bead removers

Photosensitive lithographic plates are processed by a developer. A cationic surfactant, e.g. 1-propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1), CAS No. 1652-63-7 in the developer can facilitate the control of the development process (Kissa 2001; CAS 2019 (JP63175858)).

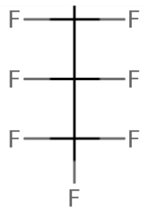
1.18.4 Rinsing solutions

The developed photoresist layer may be rinsed by immersing the wafer in a liquid that can contain PFAS (CAS 2019 (US20080299487)). Examples of those PFAS are shown in Table 41.

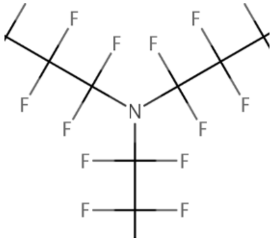
Table 41: PFAS patented as rinsing agents for manufacturing semiconductor devices. HFE-7100 and HFE-7200 are commercial products. Patent number (date, legal status): US20080299487 (2008, discontinued). Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Linear perfluoroalkanes[1a]	C_nF_{2n+2}	n = 6	355-42-0	P	(CAS 2019 (US20080299487))
Perfluorotrialkyl amine[1b]	$N(C_nF_{2n+1})_3$	n = 4, 5	311-89-7, 338-84-1	P	(CAS 2019 (US20080299487))
1-Butanamine, 1,1,2,2,3,3,4,4,4-nonafluoro-*N*-(1,1,2, 2,3,3,4,4,4-nonafluorobutyl)-*N*-(trifluoromethyl)-[1c]	$N(C_4F_9)_2(CF_3)$	-	514-03-4	P	(CAS 2019 (US20080299487))
Methyl perfluoroalkyl ether[1d]	$C_nF_{2n+1}OCH_3$	n = 3, 4 (part of HFE-7100)	375-03-1, 163702-07-6	P	(CAS 2019 (US20080299487))
Methyl perfluoroisobutyl ether[1e]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	P	(CAS 2019 (US20080299487))
Ethyl perfluorobutyl ether[1f]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	P	(CAS 2019 (US20080299487))
3-Ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl) hexane[2a]	$C_3F_7CF(OCH_2CH_3)CF(CF_3)CF_3$	-	297730-93-9	P	(CAS 2019 (US20080299487))

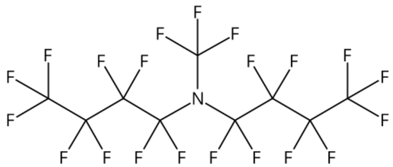
1a



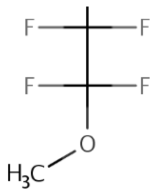
1b



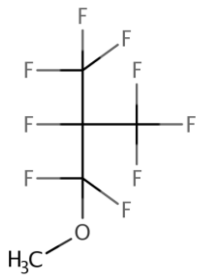
1c



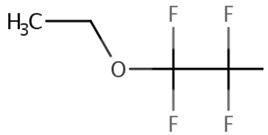
1d



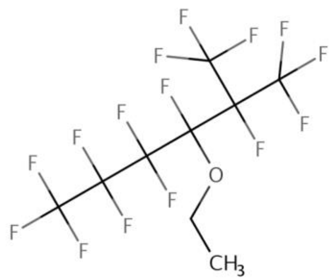
1e



1f



2a



1.18.5 PFAS used for etching the silicon dioxide coating of the semiconductor device

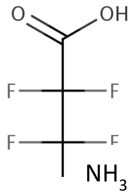
Circuits are produced on the semiconductor wafers by etching a fine pattern in the silicon dioxide coating of the semiconductor device. Inadequate wetting during acid etching may cause an entrapment of small air bubbles which mask the area to be etched. A fluorinated surfactant in the etching bath can facilitate the complete wetting of the entire area and can help to produce a sharp detail of the pattern (Kissa 2001). The fluorinated surfactant also reduces the reflection of the etching solution, which is important for achieving the accuracy and precision required to manufacture miniaturised high-performance semiconductor chips (POPRC 2019). Historically, PFOS was used in the etching solutions; however the Semiconductor Industry Association reported that the semiconductor industry globally has successfully completed the phase-out of PFOS (POPRC 2019). Other PFAS molecules that have been patented as wet etching agents are shown in Table 42. There is also a second etching method which uses a processing gas for etching (CAS 2019 (WO2016068004, 2016)). This method is called plasma etching or dry etching. PFAS in a plasma with oxygen generate a variety of reactive species that breakdown chemical deposits to make volatile products, which are readily removed under vacuum (F2_Chemicals 2019a). PFAS that have been used or have been patented for use in plasma etching are listed in Table 43.

Table 42: PFAS used or patented as wet etching agents for manufacturing semiconductor devices. Patent number (date, legal status): EP133584 (1985, expired), US4620934 (1986, expired), US20040089840 (2004, active), JP59056482 (1984, expired), WO2009021005 (2009, not yet active), US4620934 (1986, expired). The types stand for U – use, U* - current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

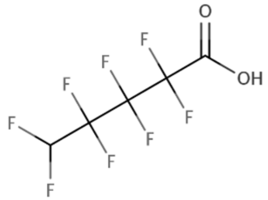
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl acids (PFAAs)					
Ammonium perfluoroalkyl carboxylate[1a]	$NH_4^+\ C_nF_{2n+1}COO^-$	n = 7	3825-26-1	P	(CAS 2019 (EP133584))
ω-Hydroperfluoroalkanoates[1b]	$HC_nF_{2n}COOH$	n = 6	1546-95-8	P	(CAS 2019 (EP133584))
Ammonium ω-hydroperfluoroalkanoate[(1b)]	$NH_4^+\ HC_nF_{2n}COO^-$	n = 6	376-34-1	P	(CAS 2019 (EP133584))
Alkanoic acid, perfluoro-n-(trifluoromethyl)-, ammonium salt (1:1)[1c]	$NH_4^+\ CF_3CF(CF_3)C_4F_8COO^-$	-	19742-57-5	P	(CAS 2019 (EP133584))
Potassium perfluoroalkane sulfonate[1d]	$K^+\ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (US4620934))

Cycloalkanesulfonic acid, perfluoro-, potassium salt (1:1)[1e]	K^+ c-$C_nF_{2n-1}SO_3^-$	n = 6	3107-18-4	P	(CAS 2019 (US4620934))
<u>Perfluoroalkane sulfonyl fluoride (PASF)-based substances</u>					
Perfluoroalkane sulfonamides (FASAs)[1e]	$C_nF_{2n+1}SO_2NH_2$	n = 4	30334-69-1	P	(CAS 2019 (US20040089840))

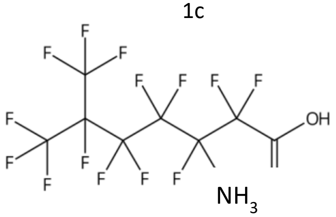
1a



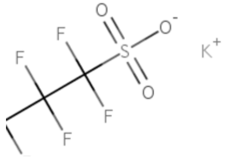
1b



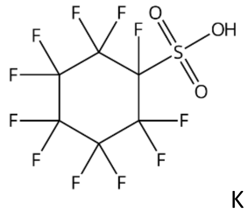
1c



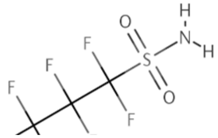
1d



1e

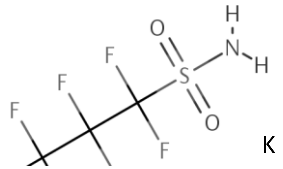


1f

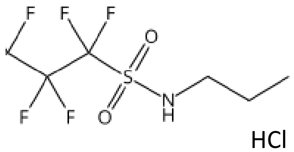


Potassium perfluoroalkane sulphonamides[3a]	K^+ $C_nF_{2n+1}SO_2NH_2$	n = 4	289042-19-9	P	(CAS 2019 (US20040089840))
1-Alkanesulfonamide, perfluoro-*N*-propyl-, hydrochloride (1:1)[3b]	HCl $C_nF_{2n+1}SO_2NHC_3H_7$	n = 13	94817-83-1	P	(CAS 2019 (JP59056482))
Ammonium perfluoroalkane sulfonamidoethanol[3c]	NH_4^+ $C_nF_{2n+1}SO_2NHCH_2CH_2O^-$	n = 4	484024-67-1	U	(Norwegian Environment Agency 2017)
Potassium perfluoroalkane sulfonamidoethanol[(3c)]	K^+ $C_nF_{2n+1}SO_2NHCH_2CH_2O^-$	n = 4	688738-73-0	P	(CAS 2019 (US20040089840))
Sodium perfluoroalkane sulfonamidoacetic acid[3d]	Na^+ $C_nF_{2n+1}SO_2NHCH_2COO^-$	n = 4	688738-74-1	P	(CAS 2019 (US20040089840))
Sodium potassium perfluoroalkane sulfonamidoacetic acid[(3d)]	Na^+ K^+ $C_nF_{2n+1}SO_2NHCH_2COO^-$	n = 4	688361-68-4	P	(CAS 2019 (US20040089840))
Perfluoroalkane sulfonamido amine oxide (PFASNO)[3e]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N(=O)(CH_3)_2$	n = 4	178094-76-3	P	(CAS 2019 (US20040089840))

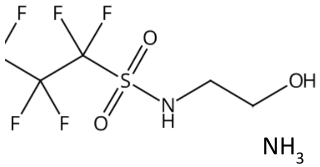
3a



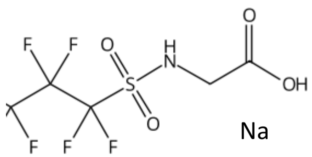
3b



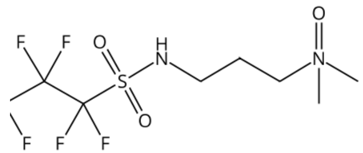
3c



3d



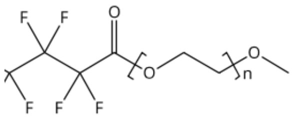
3e



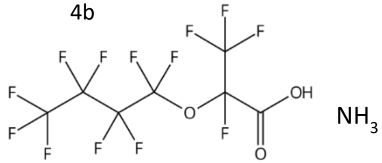
<u>Perfluoroalkanoyl fluoride (PACF)-based substances</u>					
Poly(oxy-1,2-ethanediyl), α-(perfluoro-1-oxoalkyl)-ω-methoxy-[4a]	$C_nF_{2n+1}C(O)[(OCH_2CH_2)_xOCH_3]$	n = 9	94797-81-6	P	(CAS 2019 (JP59056482))
<u>Perfluoropolyether (PFPE) - based substances</u>					
Propanoic acid, 2,3,3,3-tetrafluoro-2-(perfluoroalkoxy)-, ammonium salt (1:1)[4b]	NH_4^+ $C_4F_9OCF(CF_3)COO^-$	-	96513-97-2	P	(CAS 2019 (EP133584))

Fluorotelomer-based substances					
Poly(oxy-1,2-ethanediyl), α-(perfluoro-2-hydroxyalkyl)-ω-(3-hydroxypropoxy)-[4c]	$C_nF_{2n+1}CH_2CH(OH)CH_2(OCH_2CH_2)_xOCH_2CH_2CH_2OH$	n = 9	94817-10-4	P	(CAS 2019 (JP59056482))
Poly(oxy-1,2-ethanediyl), α-(perfluoro-2-hydroxyalkyl)-ω-methoxy-[4d]	$C_nF_{2n+1}CH_2CH(OH)CH_2(OCH_2CH_2)_xOCH_3$	n = 9	85643-63-6	P	(CAS 2019 (JP59056482))

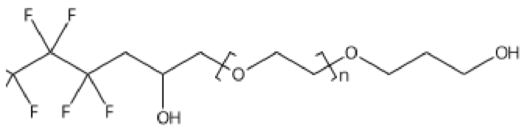
4a



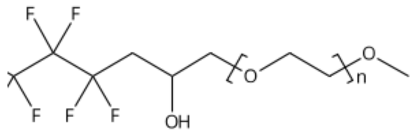
4b



4c

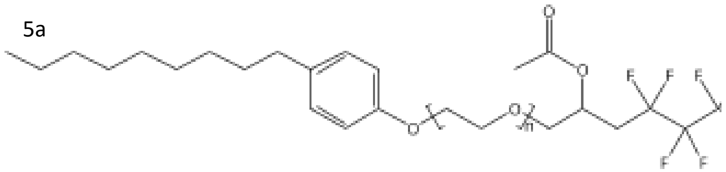


4d

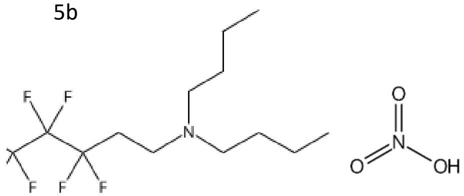


Poly(oxy-1,2-ethanediyl), α-[2-(acetyloxy)-perfluoroalkyl]-ω-(4-nonylphenoxy)-[5a]	$C_nF_{2n+1}CH_2CH[OC(=O)CH_3]CH_2(OCH_2CH_2)_xOC_6H_4C_9H_{19}$	n = 13	94797-96-3	P	(CAS 2019 (JP59056482))
1-Alkanamine, *N*,*N*-dibutyl-perfluoro-, nitrate (1:1)[5b]	NO_3H $C_nF_{2n+1}CH_2CH_2N(C_4H_9)_2$	n = 13	94817-82-0	P	(CAS 2019 (JP59056482))
2-Alkanol, perfluoro-1-[(1-methylpropyl)amino]-[5c]	$C_nF_{2n+1}CH(OH)CH_2NHCH(CH_3)CH_2CH_3$	n = 9	94817-79-5	P	(CAS 2019 (JP59056482))

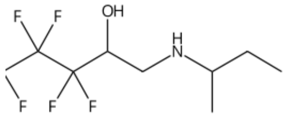
5a



5b

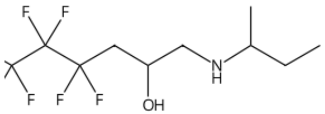


5c



2-Alkanol, perfluoro-1-[(1-methylpropyl)amino]- (2)[6a]	$C_nF_{2n+1}CH_2CH(OH)CH_2NHCH(CH_3)CH_2CH_3$	n = 9	94817-80-8	P	(CAS 2019 (JP59056482))
n:2 Fluorotelomer sulfonic acid (FTSA)[6b]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	P	(CAS 2019 (WO2009021005))
Ammonium n:2 fluorotelomer sulfonate[(6b)]	NH_4^+ $C_nF_{2n+1}CH_2CH_2SO_3^-$	n = 6	314057-01-7	P	(CAS 2019 (WO2009021005))

6a



6b

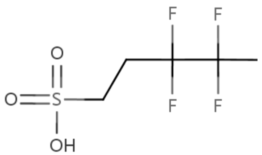
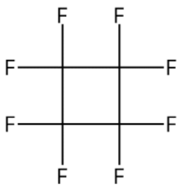


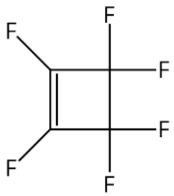
Table 43: PFAS patented as dry/plasma etching agents for manufacturing semiconductor devices. HFE-7000 and HFE-7500 are commercial products. Patent number (date, legal status): US6602434 (2003, discontinued), JP2018195678 (2018, active), WO9916110 (1999, active), US6183655 (2001, discontinued), WO2018212045 (2018, active), WO2016068004) (2016, pending). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluorocycloalkane[1a]	c-C_nF_{2n}	n = 4	115-25-3	U	Coburn 1982)
Perfluorocycloalkene[1b]	c-C_nF_{2n-2}	n = 4, 5	697-11-0, 559-40-0	P	(CAS 2019 (US6602434))
Linear perfluoroalkanes[1c]	C_nF_{2n+2}	n = 3, 4, 5, 9	76-19-7, 355-25-9, 678-26-2, 375-96-2	U, P	(F2_Chemicals 2019; Coburn 1982; CAS 2019 (JP2018195678))
1H-Polyfluoroalkane[1d]	$C_nF_{2n+1}CF_2H$	n = 2	2252-84-8	P	(CAS 2019 (US6183655))
2,5,8,11,14-Pentaoxapentadecane, 1,1,1,3,3,4,4,6,6,7,7, 9,9,10,10,12,12,13,13,15,15,15-docosafluoro-[1e]	$CF_3O(CF_2CF_2O)_4CF_3$	-	64028-06-4	P	(CAS 2019 (WO2018212045))

1a



1b



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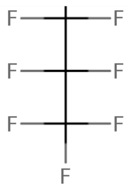
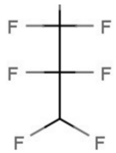
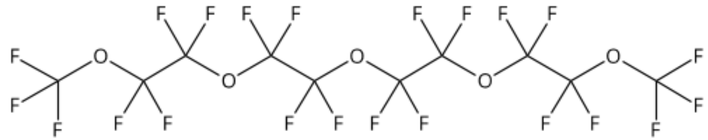


1d

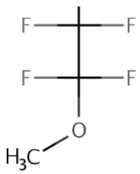


1e



Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Methyl perfluoroalkyl ether[2a]	$C_nF_{2n+1}OCH_3$	n = 3 (HFE-7000)	375-03-1	U	(3M 2014)
Ethyl perfluoroisobutyl ether[2b]	$C_3F_7CF(OCH_2CH_3)CF(CF_3)CF_3$	(HFE-7500)	297730-93-9	U	(3M 2008)
1,1,1,2-Tetrafluoro-2-(trifluoromethoxy)ethane[2c]	$CF_3OCFHCF_3$	-	2356-62-9	U	(Tsay 2005)

2a



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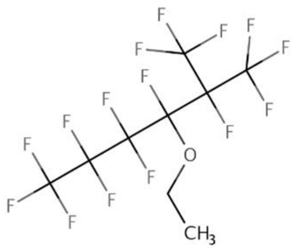

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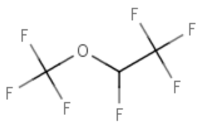
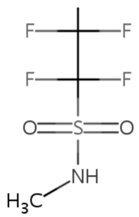


1.18.6 Cleaning compositions for silicon wafers

The most frequent processing steps in manufacturing semiconductors are wafer-cleaning steps, accounting for over 10% of the total processing steps (CAS 2019 (US20050197273, 2005)). These cleaning steps are normally either oxidative and etch steps (or a combination of the two). During oxidative cleaning steps, oxidative compositions are used to oxidize the silicon or polysilicon surface, typically by contacting the wafer with aqueous peroxide or ozone solution. During etch cleaning steps, etching compositions are used to remove native and deposited silicon oxide films and organic contaminants from the silicon or polysilicon surface before gate oxidation or epitaxial deposition, typically by contacting the wafer with aqueous acid (CAS 2019 (US20050197273, 2005)). Historically, PFOS was used as part of the cleaning solutions (POPRC 2019). There are also other PFAS that have been patented for this application (see Table 44).

Table 44: PFAS patented for use in cleaning compositions for silicon wafers: Patent number (date, legal status): US20050197273 (2005, active), JP05275407 (1993, expired), JP2012211949 (2012, withdrawn). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
<u>Perfluoroalkane sulfonyl fluoride (PASF)-based substances</u>					
N-Methyl perfluoroalkane sulfonamides (MeFASAs)[1a]	$C_nF_{2n+1}SO_2NHCH_3$	n = 4	68298-12-4	P	(CAS 2019 (US20050197273))
N-Ethyl perfluoroalkane sulfonamides (EtFASAs)[1b]	$C_nF_{2n+1}SO_2NHC_2H_5$	n = 4	40630-67-9	P	(CAS 2019 (US20050197273))
1-Alkanesulfonamide, *N*-butyl-perfluoro-[1c]	$C_nF_{2n+1}SO_2NHC_4H_9$	n = 4	864069-33-0	P	(CAS 2019 (US20050197273))
1-Alkanesulfonamide, perfluoro-*N*-(2-methoxyethyl)-[1d]	$C_nF_{2n+1}SO_2NHCH_2CH_2OCH_3$	n = 4	40630-68-0	P	(CAS 2019 (US20050197273))
1-Alkanesulfonamide, *N*-hexyl-perfluoro-[1e]	$C_nF_{2n+1}SO_2NHC_6H_{13}$	n = 4	606966-46-5	P	(CAS 2019 (US20050197273))
Perfluoroalkane sulfonamidoethanols (FASEs)[1f]	$C_nF_{2n+1}SO_2NHCH_2CH_2OH$	n = 4	34454-99-4	P	(CAS 2019 (US20050197273))

1a

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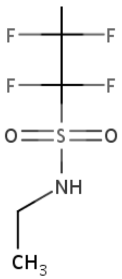
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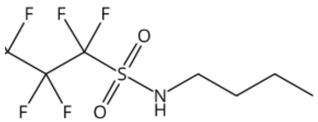
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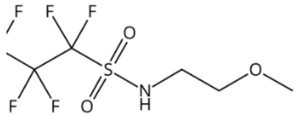
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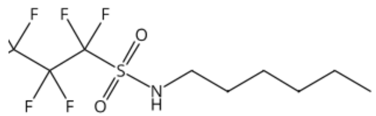
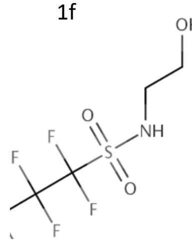
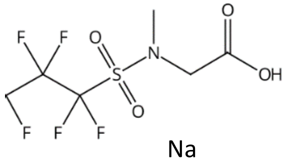

1f


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Sodium *N*-methyl perfluorobutane sulfonamidoacetate[2a]	$Na^+ C_nF_{2n+1}SO_2N(CH_3)CH_2COO^-$	n = 4	864069-37-4	P	(CAS 2019 (US20050197273))
Sodium *N*-ethyl perfluorobutane sulfonamidoacetate[2b]	$Na^+ C_nF_{2n+1}SO_2N(CH_2CH_3)CH_2COO^-$	n = 4	68555-68-0	P	(CAS 2019 (US20050197273))
Glycine, *N*-[(perfluoroalkyl)sulfonyl]-*N*-propyl-[2c]	$C_nF_{2n+1}SO_2N(CH_2CH_2CH_3)CH_2COOH$	n = 4	864069-46-5	P	(CAS 2019 (US20050197273))
Glycine, *N*-[(perfluoroalkyl)sulfonyl]-*N*-propyl-, sodium salt (1:1)[(2c)]	$Na^+ C_nF_{2n+1}SO_2N(CH_2CH_2CH_3)CH_2 COO^-$	n = 4	864069-35-2	P	(CAS 2019 (US20050197273))

Butanoic acid, 4-[[(perfluoroalkyl)sulfonyl]propylamino]-, potassium salt (1:1)[2d]	K^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2CH_2$ COO^-	n = 4	864069-32-9	P	(CAS 2019 (US20050197273))
Hexanoic acid, 6-[[(perfluoroalkyl)sulfonyl]propylamino]-, potassium salt (1:1)[2e]	K^+ $C_nF_{2n+1}SO_2N(C_3H_7)[(C_5H_{10})COO^-$	n = 4	864069-34-1	P	(CAS 2019 (US20050197273))

2a



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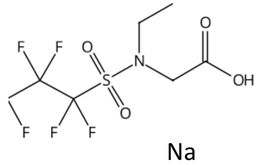

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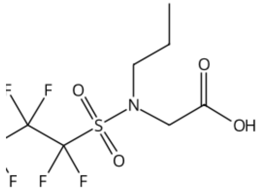
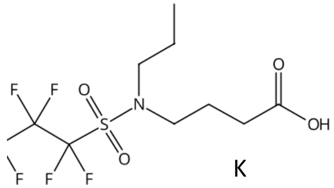


2d



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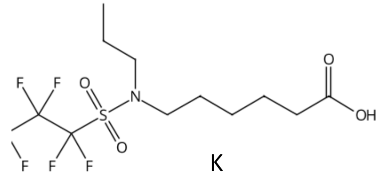
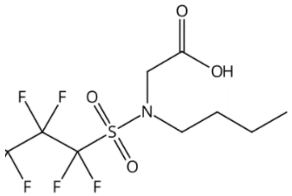
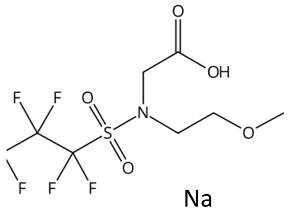


Glycine, *N*-butyl-*N*-[(perfluoroalkyl)sulfonyl]-[3a]	$C_nF_{2n+1}SO_2N(C_4H_9)CH_2COOH$	n = 4	864069-45-4	P	(CAS 2019 (US20050197273))
Glycine, *N-(*2-methoxyethyl)-*N*-[(perfluoroalkyl)sulfonyl]-, sodium salt[3b]	Na^+ $C_nF_{2n+1}SO_2N(CH_2CH_2OCH_3)CH_2$ COO^-	n = 4	864069-36-3	P	(CAS 2019 (US20050197273))
Glycine, *N*-hexyl-*N*-[(perfluoroalkyl)sulfonyl]-, potassium salt[3c]	K^+ $C_nF_{2n+1}SO_2N(C_6H_{13})CH_2COO^-$	n = 4	864069-53-4	P	(CAS 2019 (US20050197273))
Ethanaminium, 2-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, sulfate (1:1)[3d]	SO_4H^- $C_nF_{2n+1}SO_2NHCH_2CH_2$ $N^+(CH_3)_3$	n = 8	153968-00-4	P	(CAS 2019 (JP05275407))

3a



3b



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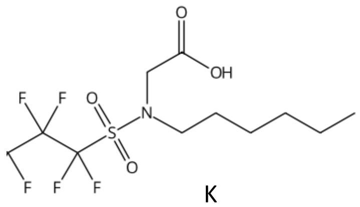
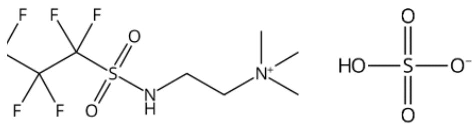
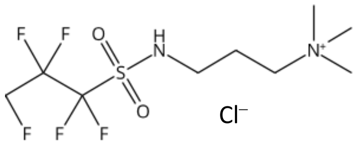


3d

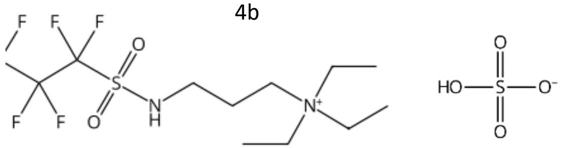


1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[4a]	Cl^- $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+$ $(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (JP05275407))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, sulfate (1:1)[(4a)]	SO_4H^- $C_nF_{2n+1}SO_2NHCH_2CH_2CH$ N^+ $(CH_3)_3$	n = 8	153968-01-5	P	(CAS 2019 (JP05275407))
1-Propanaminium, *N*,*N*,*N*-triethyl-3-[[(perfluoroalkyl)sulfonyl] amino]-, sulfate (1:1)[4b]	SO_4H^- $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+$ $(CH_2CH_3)_3$	n = 8	153968-03-7	P	(CAS 2019 (JP05275407))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]methylamino]-*N*,*N*,*N*-trimethyl-, sulfate (1:1)[4c]	SO_4H^- $C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2CH_2$ $N^+(CH_3)_3$	n = 8	153968-05-9	P	(CAS 2019 (JP05275407))

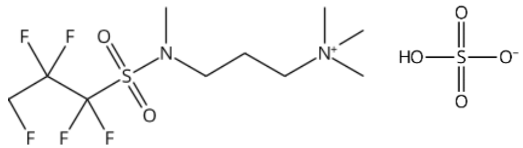
4a



4b



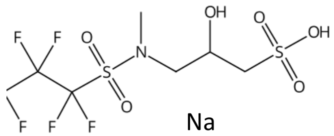
4c



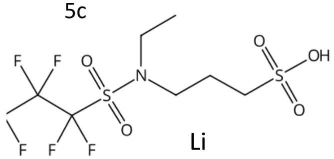
1-Propanesulfonic acid, 3-[methyl[(perfluoroalkyl)sulfonyl] amino]-, lithium salt (1:1)[5a]	Li^+ $C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2CH_2SO_3^-$	n = 4	864069-44-3	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 3-[methyl[(perfluoroalkyl)sulfonyl] amino]-, sodium salt (1:1)[5b]	Na^+ $C_nF_{2n+1}SO_2N(CH_3)CH_2CH(OH)CH_2SO_3^-$	n = 4	864069-38-5	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 3-[ethyl[(perfluoroalkyl)sulfonyl]amino]-, lithium salt (1:1)[5c]	Li^+ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2CH_2SO_3^-$	n = 4	864069-41-0	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 3-[ethyl[(perfluoroalkyl)sulfonyl]amino]-2-hydroxy-, sodium salt (1:1)[5d]	Na^+ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH(OH)CH_2SO_3^-$	n = 4	864069-39-6	P	(CAS 2019 (US20050197273))

5a

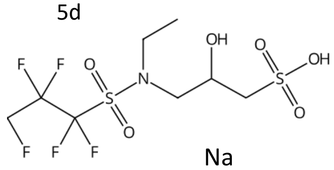
5b



5c

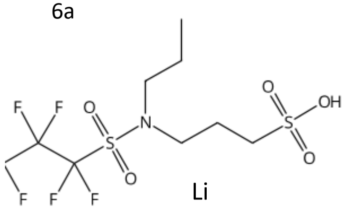


5d



1-Propanesulfonic acid, 3-[[(perfluoroalkyl)sulfonyl]propyl amino]-, lithium salt (1:1)[6a]	Li^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2CH_2SO_3^-$	n = 4	864069-42-1	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 2-hydroxy-3-[[(perfluoroalkyl)sulfonyl] propylamino]-, ammonium salt (1:1)[6b]	NH_4^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH(OH)CH_2SO_3^-$	n = 4	864069-49-8	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 2-hydroxy-3-[[(perfluoroalkyl)sulfonyl] propylamino]-, sodium salt (1:1)[(6b)]	Na^+ $C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH(OH)CH_2SO_3^-$	n = 4	864069-40-9	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 3-[butyl[(perfluoroalkyl)sulfonyl]amino]-, lithium salt (1:1)[6c]	Li^+ $C_nF_{2n+1}SO_2N(C_4H_9)CH_2CH_2CH_2SO_3^-$	n = 4	864069-43-2	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 3-[butyl[(perfluoroalkyl)sulfonyl]amino]-2-hydroxy-, ammonium salt (1:1)[6d]	NH_4^+ $C_nF_{2n+1}SO_2N(C_4H_9)CH_2CH(OH)CH_2SO_3^-$	n = 4	864069-48-7	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 3-[(2-hydroxyethyl)[(perfluoroalkyl) sulfonyl]amino]-, lithium salt (1:1)[6e]	Li^+ $C_nF_{2n+1}SO_2N(CH_2CH_2OH)CH_2CH_2CH_2SO_3^-$	n = 4	864069-50-1	P	(CAS 2019 (US20050197273))

6a



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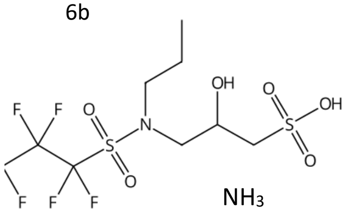

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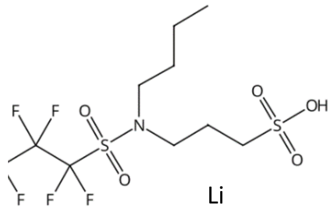

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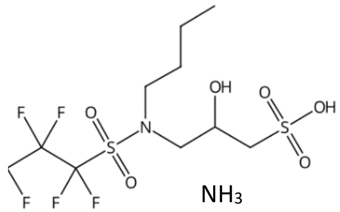

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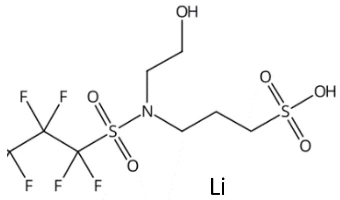
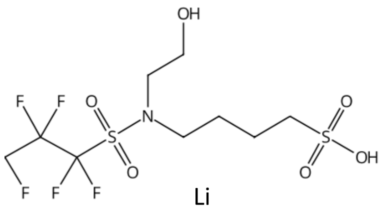
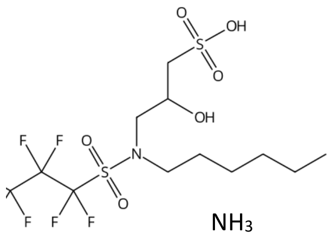


1-Butanesulfonic acid, 4-[(2-hydroxyethyl)[(perfluoroalkyl) sulfonyl]amino]-, lithium salt (1:1)[7a]	Li^+ $C_nF_{2n+1}SO_2N(CH_2CH_2OH)CH_2CH_2CH_2CH_2SO_3^-$	n = 4	864069-51-2	P	(CAS 2019 (US20050197273))
1-Propanesulfonic acid, 3-[hexyl[(perfluoroalkyl)sulfonyl] amino]-2-hydroxy-, ammonium salt (1:1)[7b]	NH_4^+ $C_nF_{2n+1}SO2N(C_6H_{13})CH_2CH(OH)CH_2SO_3^-$	n = 4	606967-06-0	P	(CAS 2019 (US20050197273))
1-Propanaminium, *N*,*N*-dimethyl-*N*-[3-[[(perfluoroalkyl)sulfonyl] amino]propyl]-3-sulfo-[7c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2CH_2SO_3H$	n = 4	864069-52-3	P	(CAS 2019 (US20050197273))
Propanoic acid, 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(trifluoromethoxy)propoxy]-, ammonium salt (1:1)[7d]	NH_4^+ $CF_3OCF(CF_3)CF_2OCF(CF_3)COO^-$	-	510774-77-3	P	(CAS 2019 (JP2012211949))

7a



7b



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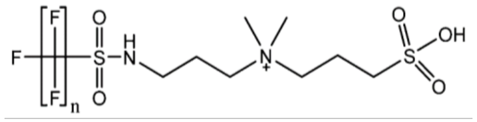

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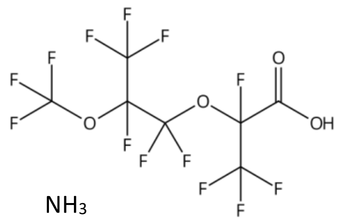

1.18.7 *Cleaning composition for integrated circuit modules*

Alcohols containing small amounts of fluorinated surfactants (e.g. potassium *N*-ethyl perfluoroalkane sulfonamidoacetate, CAS No. 2991-51-7) may be used to remove cured epoxy resins from integrated circuit modules (Kissa 2001; CAS 2019 (EP32179, 1981)).

1.18.8 *Chemical vapour deposition chamber cleaning*

Chemical vapour deposition chambers are cleaned to remove dielectric film build up (F2_Chemicals 2019a). One substance that has been used extensively for this application is perfluoropropane (CAS No. 76-19-7). In a plasma with oxygen, it generates a variety of reactive species that breakdown chemical deposits to make volatile products, which are readily removed under vacuum (F2_Chemicals 2019a).

1.18.9 *Wafer thinning*

The wafer thinning process often requires bonding a wafer that will undergo thinning to a carrier wafer that supports the first wafer during the thinning process (CAS 2019 (US20130201635, 2013)). Fluorinated silane coatings are patented for non-stick coatings of the carrier wafer.

Table 45: PFAS patented for coating carrier wafer during wafer thinning. Patent number (date, legal status): US20130201635 (2013, active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyltriethoxysilane[1a]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	P	(CAS 2019 (US20130201635))
Perfluoroalkyltrimethoxysilane[1b]	$C_nF_{2n+1}CH_2CH_2Si(OCH_3)_3$	n = 6, 8	85857-16-5, 83048-65-1	P	(CAS 2019 (US20130201635))
Silane, chlorodimethyl(perfluoroalkyl)-[1c]	$C_nF_{2n+1}CH_2CH_2Si(CH_3)_2Cl$	n = 6, 8	102488-47-1, 74612-30-9	P	(CAS 2019 (US20130201635))
Silane, dichloromethyl(perfluoroalkyl)-[1d]	$C_nF_{2n+1}CH_2CH_2Si(CH_3)Cl_2$	n = 6	73609-36-6	P	(CAS 2019 (US20130201635))
Silane, trichloro(perfluoroalkyl)-[1e]	$C_nF_{2n+1}CH_2CH_2SiCl_3$	n = 6, 8	78560-45-9, 78560-44-8	P	(CAS 2019 (US20130201635))
Silane, trichloro[3-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethoxy]propyl]-[1f]	$CF_3CF(CF_3)OCH_2CH_2CH_2SiCl_3$	-	15538-93-9	P	(CAS 2019 (US20130201635))

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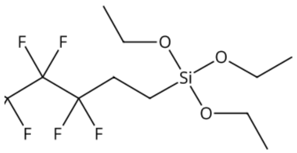

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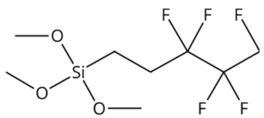

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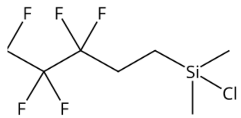

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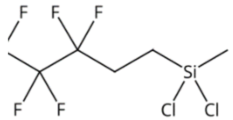

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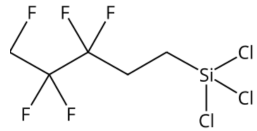

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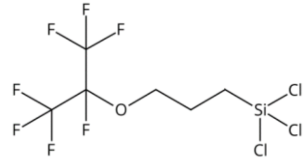


1.18.10 *Working fluid for pumps*

CTFE telomers and higher molecular weight perfluoropolyethers have been used as working fluid in vacuum pumps used in plasma etching (Costello, Flynn, and Owens 2000; R. E. Banks, Smart, and Tatlow 1994). An example for such a perfluoropolyether oil is Demnum® S, poly[oxy(1,1,2,2,3,3-hexafluoro-1,3-propanediyl)], α-(1,1,2,2,3,3,3-heptafluoro propyl)-ω-(1,1,2,2,2-pentafluoro-ethoxy)- (CAS No. 105060-59-1) (R. E. Banks, Smart, and Tatlow 1994).

1.18.11 *Technical equipment*

Fluoropolymers such as PTFE, PFA, FEP and ETFE have been used for high purity inert moulds and piping (Gardiner 2015). Perfluoroelastomers have been used in semiconductor processing equipment where the elastomers are in direct contact with dry process chemicals and reactive plasma such as O_2, C_2F_6/O_2, CF_4/O_2 and NF_3, and/or aggressive wet chemical environments (Marshall 1997). PVDF bottles have been used for shipping or storing high purity chemicals in the semiconductor industry (Dohany 2000).

1.18.12 Others

PTFE can be used in a bonding ply in a low loss mulitlayer printed circiut board (CAS 2019 (WO2003026371, 2003)). Wafer baskets made out of PFA have been used to handle corrosive liquids and gases in the semiconductor industry, where requirements for very pure materials have been paramount (R. E. Banks, Smart, and Tatlow 1994).

1.19 Textile production

PFAS that are used in the textile production are described in this Section, PFAS that are used in the produced materials themselves are either described in Section 2.5 'Apparel' or Section 2.40 'Textile and upholstery', respectively.

1.19.1 Dyeing and bleaching of textiles

PFAS have been used as wetting agents to enhance dyeing and as penetration aids for bleaches (Poulsen, Jensen, and Wallström 2005). PFOA-related compounds have been used as antifoaming agent in the dyeing process using sulfur dyes (POPRC 2016b). Poly(oxy-1,2-ethanediyl), α-[[ethyl[(heptadecafluorooctyl)sulfonyl]amino] acetyl]-ω-hydroxy- (CAS No. 109636-63-7) and poly[oxy(methyl-1,2-ethanediyl)oxy-1,2-ethanediyl], α-[[[(heptadecafluorooctyl)sulfonyl]methylamino]acetyl]-ω-hydroxy- (CAS No. 114672-54-7) are useful in a release agent for dye-transfer material (CAS 2019 (EP227092, 1987)).

The SPIN database of the Nordic countries discloses that PTFE and PVDF were used in dyestuff and pigments in the past (Norden 2020).

1.19.2 Other textile treatments

PFAS have been used as antifoaming agents in textile treatment baths and as emulsifying agents for fibre finishes (Poulsen, Jensen, and Wallström 2005). A quaternary ammonium compound - diethylmethyl(γ-ω-perfluoro-$C_{8\text{-}14}$-β-alkenyl), tetrafluoroborates (CAS No. 153325-45-2) - was used in the past in the manufacturing of textiles (Norden 2020).

1.20 Watchmaking industry

PFPEs have been used as lubricants in Rolex® watches (R. E. Banks, Smart, and Tatlow 1994). PFAS are also used as drying solutions after aqueous cleaning in the jewellery and watchmaking industries, e.g. pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro- (CAS No. 138495-42-8) (Chemours 2019e).

1.21 Wood processing

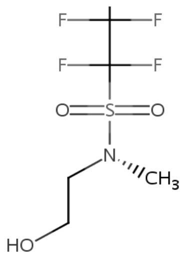
PFAS have been used for the manufacturing of wood and products of wood and cork (Norden 2020). The SPIN database of the Nordic countries lists a few PFAS that were used in this application in the past (Table 46).

Table 46: PFAS used in the past for the manufacturing of wood and products of wood and cork.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
N-Methyl perfluoroalkane sulfonamido ethanols (MeFASE)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 8	24448-09-7	U	(Norden 2020)

Butanedioic acid, 2-sulfo-, 1,4-bis(perfluoroalkyl) ester, sodium salt (1:1)[1b]	$Na^+ C_nF_{2n+1}CH_2CH_2OC(O)CH_2CH(SO_3^-)C(O)OCH_2CH_2C_mF_{2m+1}$	n = 6	54950-05-9	U	(Norden 2020)
Polytetrafluoroethylene (PTFE)[1c]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U	(Norden 2020)
Polysiloxanes, di-Me, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-trideca fluorooctyl	-	n = 6	115340-95-9	U	(Norden 2020)
Siloxanes and Silicones, (3,3,4,4,5,5,6,6,7,7,8,8,9,9,10, 10,10-heptadecafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether	-	n = 6	143372-54-7	U	(Norden 2020)

1a



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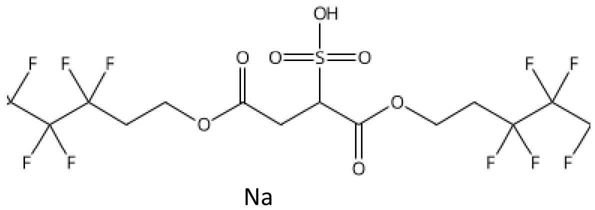

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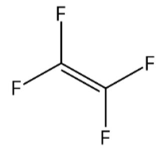


1.21.1 *Bleaching of wood*

PVDF, woven into coarse fabric, has been used widely for drum filtration during bleaching of wood pulp with chemicals (Dohany 2000).

1.21.2 *Coating for wood substrate*

A co-polymer of 65% vinylidene fluoride, 25% TFE, and 10% vinyl ester (e.g., vinyl butyrate) has been useful as weather-resistant, clear coating for wood substrates (R. E. Banks, Smart, and Tatlow 1994).

1.21.3 *Others*

Wood particle board bonded with urea–formaldehyde adhesive resins shows improved cold-water swelling and internal bond strength when treated with fluorinated surfactants (Buck, Murphy, and Pabon 2012). PFAS have also been detected in oriented strand boards, wooden boards, chipboards and Formica (see Table 47).

Table 47: PFAS detected by Bečanová et al. (2016) and Janousek, Lebertz, and Knepper (2019) in different wooden building materials.

Wooden building material	Chemical group name	Molecular formula	Specification of chemical(s)	CAS No.
Formica	Perfluoroalkyl carboxylic acids	$C_nF_{2n+1}COOH$	n = 4, 6	2706-90-3, 375-85-9
Oriented strand boards	Perfluoroalkyl carboxylic acids	$C_nF_{2n+1}COOH$	n = 3 - 6	375-22-4, 2706-90-3, 307-24-4, 375-85-9
Oriented strand boards	Perfluoroalkane sulfonic acids	$C_nF_{2n+1}SO_3H$	n = 10	335-77-3

Wooden boards	Perfluoroalkyl carboxylic acids	$C_nF_{2n+1}COOH$	n = 4 - 6	2706-90-3, 307-24-4, 375-85-9
Wooden boards	Perfluoroalkane sulfonic acids	$C_nF_{2n+1}SO_3H$	n = 7, 8	375-92-8, 1763-23-1
Chipboards	Perfluoroalkyl carboxylic acids	$C_nF_{2n+1}COOH$	n = 4 - 7	2706-90-3, 307-24-4, 375-85-9, 335-67-1
Chipboards	Perfluoroalkane sulfonic acids	$C_nF_{2n+1}SO_3H$	n = 6	355-46-4

2 Other use categories

2.1 Aerosol propellants

The SPIN database of the Nordic countries discloses that PTFE is currently used in or as aerosol propellants (Norden 2020).

2.2 Air conditioning

1H-pentafluoroethane (CAS No. 354-33-6) was used in 2016 and 2017 in the Nordic countries in the manufacture of non-domestic cooling and ventilation equipment (Norden 2020). 1H-pentafluoroethane was also used in the US between 2012 and 2015 in air conditioner/refrigeration (USEPA 2016).

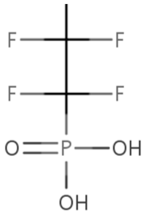
2.3 Antifoaming agent

PFAS have been used as antifoaming agents in various applications. One example is photographic processing solutions (see Section 1.16.1). Perfluoroalkyl phosphonic and phosphinic acids have also been patented as antifoaming agents for detergent solutions (CAS 2019 (DE2233941, 1974), Table 48). 6:2 Fluorotelomer-based siloxanes and silicones (CAS No. 115340-95-9) were used as antifoaming agent in the Nordic countries between 2014 and 2016 (Norden 2020).

Table 48: PFAS patented as antifoaming agent for detergent solutions. Patent number (date, legal status): DE2233941 (1974, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl phosphonic acids (PFPAs)[1a]	$C_nF_{2n+1}P(=O)(OH)_2$	n = 4, 6, 8, 10	52299-24-8, 40143-76-8, 40143-78-0, 52299-26-0	P	(CAS 2019 (DE2233941))
Perfluoroalkyl phosphinic acids (PFPiAs)[1b]	$C_nF_{2n+1}P(C_mF_{2m+1})(=O)OH$	n = 4/4, 6/6, 8/8, 10/10	52299-25-9, 40143-77-9, 40143-79-1, 52299-27-1	P	(CAS 2019 (DE2233941))

1a



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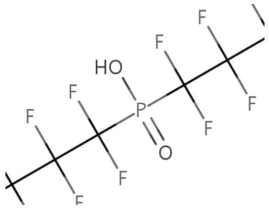


2.4 Ammunition

Fluoropolymers have been added to ammunition to make the final product rubbery. The fluoropolymers in ammunition reduce the likelihood of an unplanned explosion due to shock (CSWAB 2019).

2.5 Apparel

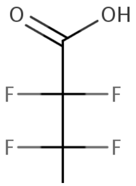
Fluoropolymers are used as breathable membranes and side-chain fluorinated polymers as long-lasting durable water repellent (DWR) finishes in apparel. DWRs provide water and oil repellency, stain and soiling resistance to outdoor- and sportswear, military clothing, and work wear for medical staff, pilots and firemen (UNEP 2017; FluoroIndustry 2019). Side-chain fluorinated polymers based on acrylic, methacrylic or polyurethane backbones and copolymerised with non-fluorinated monomers are the main technology used in DWR (Holmquist et al. 2016). Prior to the 3M phase out, perfluorooctane sulfonyl- and fluorotelomer-based substances were used. After the 3M phase out, side-chain fluorinated polymers were mostly based on a mixture of 8:2 and longer fluorotelomer-based side chains. 3M now manufactures side-chain fluorinated polymers containing perfluorobutane sulfonyl side chains, and the fluorotelomer manufacturers have transitioned from a mixture of 8:2 and longer to 6:2 fluorotelomer-based side chains. A list of PFAS that have been used, are still used, or have been detected in apparel is provided in Table 49.

Table 49: PFAS historically or currently used or detected in apparel. The types stand for U – use, U* – current use, and D - detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
<u>Membranes for apparel</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 11	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1	D	(X. Liu et al. 2014; Guo, Liu, and Krebs 2009)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 4, 6, 7, 8	375-73-5, 355-46-4, 375-92-8, 1763-23-1	D	(X. Liu et al. 2014)

PTFE (mostly expanded PTFE)	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(R. E. Banks, Smart, and Tatlow 1994)
Perfluoropolyethers as a pendant group or in a polymer backbone			-	U	(R. E. Banks, Smart, and Tatlow 1994)
<u>Sportswear/Sportssocks</u>					
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 8	1763-23-1	D	(UNEP 2017)
<u>Treated apparel (rain- and outerwear)</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(X. Liu et al. 2014; Guo, Liu, and Krebs 2009; Kotthoff et al. 2015)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 4, 6 , 8	375-73-5, 355-46-4, 1763-23-1	D	(X. Liu et al. 2014)
Perfluoroalkane sulfonamides (FASAs)[1c]	$C_nF_{2n+1}SO_2NH_2$	n = 8	754-91-6	D	(Schulze and Norin 2006)
N-Methyl perfluoroalkane sulfonamides (MeFASAs)[1d]	$C_nF_{2n+1}SO_2NHCH_3$	n = 8	31506-32-8	D	(Schulze and Norin 2006)
N-Methyl perfluoroalkane sulfonamido ethanols (MeFASE)[1e]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 8	24448-09-7	D	(Berger and Herzke 2006)
N-Ethyl perfluoroalkane sulfonamidoethanols (EtFASEs)[1f]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2OH$	n = 8	1691-99-2	D	(Schulze and Norin 2006)
(n:2) Fluorotelomer olefins[1g]	$C_nF_{2n+1}CH=CH_2$	n = 10	30389-25-4	D	(Schulze and Norin 2006)

1a



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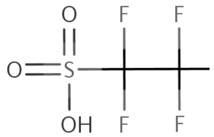

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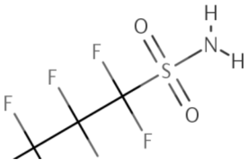

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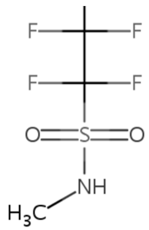

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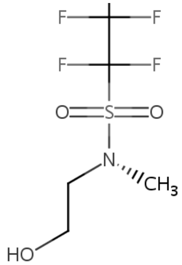

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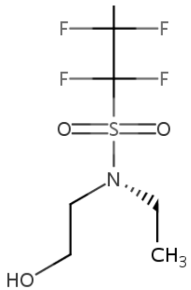

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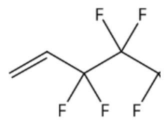
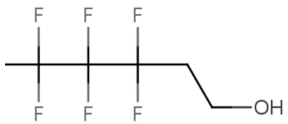


(n:2) Fluorotelomer alcohols (FTOHs)[2a]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8, 10	647-42-7, 678-39-7, 865-86-1	D	(Kotthoff et al. 2015; Borg and Ivarsson 2017)
(n:2) Fluorotelomer sulfonic acids (FTSAs)[2b]	$C_nF2_{n+1}CH_2CH_2SO_3H$	n = 6, 8	27619-97-2, 39108-34-4	D	(Schulze and Norin 2006)
Side-chain fluoirinated polymers based on fluorinated acrylates and methacrylates		polymer	-	U*	(Poulsen, Jensen, and Wallström 2005)

Side-chain fluorinated polymers with PFBS-related side chains		polymer	949581-65-1, 940891-99-6, 923298-12-8	U	(Norwegian Environment Agency 2017; Z. Wang et al. 2013)
<u>Military clothing</u>					
Side-chain fluorinated acrylate polymers		polymer	-	U*	(Case 2011)
Side-chain fluorinated polymers with PFBS-related side chains		polymer	949581-65-1, 940891-99-6, 923298-12-8	U	(Norwegian Environment Agency 2017; Z. Wang et al. 2013)
<u>Workwear for medical staff, pilots and firemen</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 11	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1	D	(KEMI Swedish Chemical Agency 2015b; Peaslee et al. 2020)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 4	375-73-5	D	(Peaslee et al. 2020)
(n:2) Fluorotelomer sulfonic acids (FTSAs)[2b]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6, 8	27619-97-2, 39108-34-4	D	(Peaslee et al. 2020)
Side-chain fluorinated polymers with PFBS-related side chains		polymer	949581- 65-1, 940891-99-6, 923298- 12-8	U*	(Norwegian Environment Agency 2017; Z. Wang et al. 2013)
<u>Cotton</u>					
Alkanamide, perfluoro-*N*-[3-(trimethoxy silyl)propyl]-[2c]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2Si(OCH_3)_3$	n = 5	154380-34-4	U	(Z. Wang et al. 2013)
<u>Surgical gown/non-woven medical garments</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 11	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1	D	(X. Liu et al. 2014; Guo, Liu, and Krebs 2009)
Polytetrafluoroethylene (PTFE)	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(POPRC 2018a)
Side-chain fluorinated polymers		polymer	-	U*	(POPRC 2019)

2a



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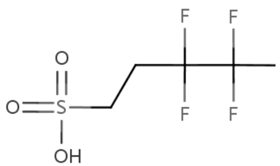

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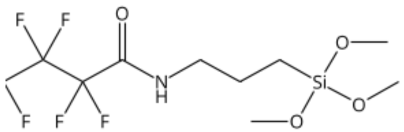


2.6 Automotive

PFAS have been and are used in various parts of automobiles. According to the FluoroCouncil (2019) and Dohany (2000), PFAS have been or are used in the car body, automobile engines, electronics, environmental systems, fuel systems, interiors, steering systems, suspension/brakes, and transmission (FluoroIndustry 2019; Dohany 2000). Many of these specific applications are covered in other sections of this report. Therefore, we only briefly list the components that contain PFAS here and refer readers to the specific sections for more information.

2.6.1 General use

In 2018, twelve PFAS were listed on the Global Automotive Declarable Substance List (GADSL) (POPRC 2018a). This list contains pure substances potentially used or may be found in automotive parts. The listed PFAS are shown in Table 50. The specific uses of these PFAS are not stated. Additionally, pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro- (CAS No 138495-42-8) is used as drying solution in the automotive tool manufacturing (Chemours 2019e).

Table 50: PFAS listed in the Global Automotive Declarable Substance List. The substances may be used or found in automotive parts. Additional explanations to the table are provided on Page 2 and 3 of this document.

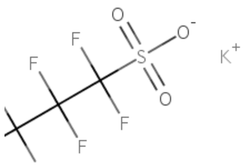
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Reference
Perfluoroalkyl carboxylic acids (PFCAs)	$C_nF_{2n+1}COOH$	n = 7	335-67-1	(POPRC 2018a)
Ammonium perfluoroalkyl carboxylate	$NH_4^+ C_nF_{2n+1}COO^-$	n = 7	3825-26-1	(POPRC 2018a)
Potassium perfluoroalkyl carboxylate	$K^+ C_nF_{2n+1}COO^-$	n = 7	2395-00-8	(POPRC 2018a)
Silver perfluoroalkyl carboxylate	$Ag^+ C_nF_{2n+1}COO^-$	n = 7	335-93-3	(POPRC 2018a)
Sodium perfluoroalkyl carboxylate	$Na^+ C_nF_{2n+1}COO^-$	n = 7	335-95-5	(POPRC 2018a)
Perfluoroalkane carbonyl fluoride (PACFs)	$C_nF_{2n+2}COF$	n = 7	335-66-0	(POPRC 2018a)
Poly(oxy-1,2-ethanediyl), α-(4,4,5,5,6,6,7,7,8,8,9,9, 10,10,11,11,11-hepta decafluoro-2-hydroxyundecyl)-ω-[(4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-heptadeca fluoro-2-hydroxyundecyl)oxy]	$C_nF_{2n+1}CH_2CH(OH)CH_2(OCH_2CH_2)_mOCH_2CH(OH)CH_2C_nF_{2n+1}$	n = 8	122402-79-3	(POPRC 2018a)
2-Propenoic acid, C_{16-18}-alkyl esters, polymers with 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10-heptadecafluorodecyl acrylate		n = 8	160336-09-4	(POPRC 2018a)
Cyclotetrasiloxane, 2-(4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-heptadecafluoroundecyl)-2,4,6,8-tetramethyl-, Si-[3-(oxiranylmethoxy)propyl] derivs.		n = 8	206886-57-9	(POPRC 2018a)
Trisiloxane, 3,3'-(3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-1,10-decanediyl)bis[3-[(dimethylsilyl)oxy]-1,1,5,5-tetramethyl-, reaction products with 4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-heptadecafluoro-1-undecene		n = 6 and 8	185701-89-7	(POPRC 2018a)

The SPIN Database of the Nordic countries lists additional substances that have been used in the maintenance and repair of motor vehicles (Norden 2020).

Table 51: PFAS listed in the SPIN Database of the Nordic countries for the maintenance and repair of motor vehicles. HFE-7100 is a commercial product. The types stand for U – use and U* – current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Potassium perfluoroalkane sulfonate[1a]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	U	(Norden 2020)
Potassium *N*-ethyl perfluoroalkane sulfonamido acetate[1b]	$K+ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 6, 8	67584-53-6, 2991-51-7	U	(Norden 2020)
(n:2) Fluorotelomer methacrylates (FTMACs)[1c]	$C_nF_{2n+1}CH_2CH_2OC(O)C(CH_3)=CH_2$	undefined	65530-66-7	U	(Norden 2020)
Lithium (n:2) fluorotelomer thioether propionate[1d]	$Li^+ C_nF_{2n+1}CH_2CH_2SCH_2CH_2COO^-$	undefined	65530-69-0	U	(Norden 2020)
Perfluoroalkyltriethoxysilane[1e]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	U	(Norden 2020)

1a



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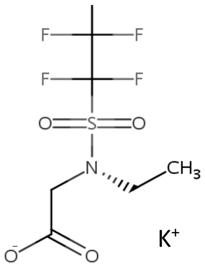

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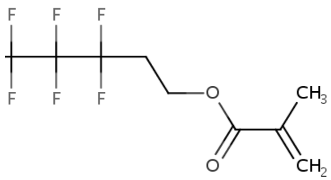

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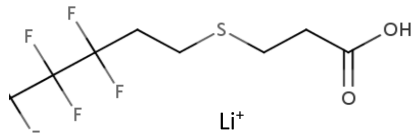

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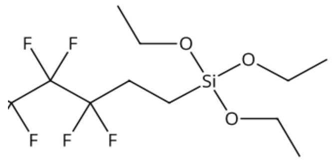
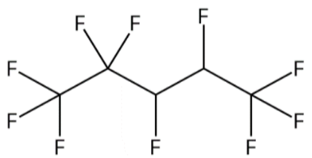


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[2a]	$C_2F_5(CFH)_2CF_3$	-	138495-42-8	U*	(Norden 2020)
Poly(difluoromethylene), α-(cyclohexylmethyl)-ω-hydro-[2b]	$HC_nF_{2n}CH_2C_6H_{11}$	undefined	65530-85-0	U*	(Norden 2020)
Methyl perfluorobutyl ether[2c]	$C_nF_{2n+1}OCH_3$	(part of HFE-7100)	163702-07-6	U	(Norden 2020)
Methyl perfluoroisobutyl ether[2d]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(Norden 2020)
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], α-(1,1,2,2,2-pentafluoroethyl)-ω-[tetrafluoro(trifluoromethyl)ethoxy]-[2e]	4 -F -CF_3 $CF_3CF_2[O(C_3F_6O)]_nOCC$		60164-51-4	U	(Norden 2020)
Polytetrafluoroethylene (PTFE)[2f]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)

2a



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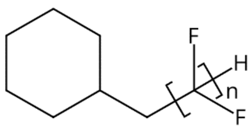

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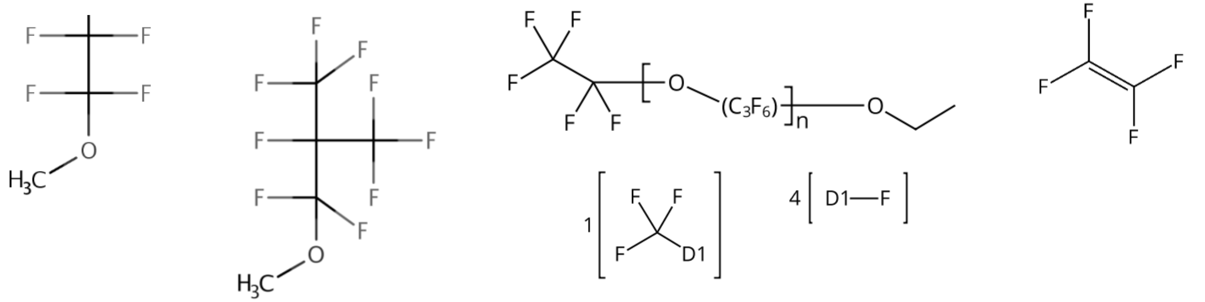
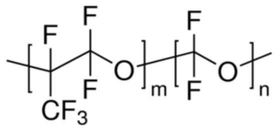


Polyperfluoromethylisopropyl ether[3a]	$-CF_3O[CF(CF_3)CF_2O]_x-(CF_2O)_yCF_3-$	polymer	69991-67-9	U*	(Norden 2020)
2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-hepta decafluorooctyl)sulfonyl]amino]ethyl ester, telomer with 2-[butyl[(1,1,2,2,3,3, 4,4,5,5,6,6,7,7,7-pentadecafluoroheptyl) sulfonyl]amino]ethyl 2-prope noate, 2-methyloxirane polymer with oxirane di-2-propenoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[3b]	$-[(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O)_m-(C_2H_4O)_w-(C_3H_4O_2)_u-(C_8H_{18}S)_v-$	polymer		U	(Norden 2020)

3a



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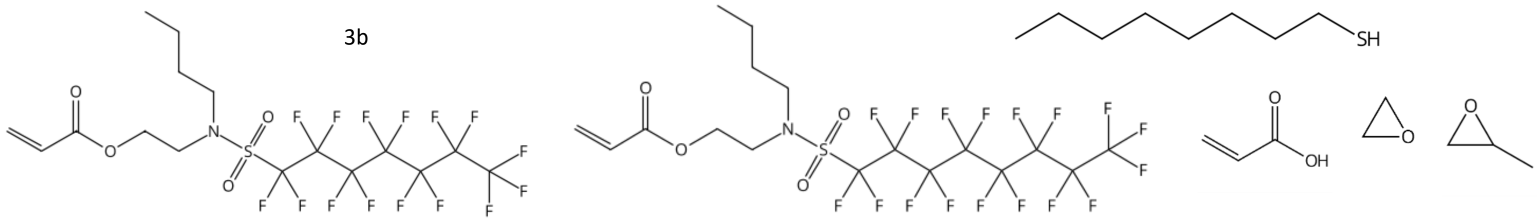


2.6.2 Car body

PVDF film has been used for body trim by the principal automobile manufacturers (Dohany 2000). A high weather resistance paint finish based on fluoroolefin-vinyl ether (FEVE) copolymers (Lumiflon) has been marketed for usage as no-wax brilliant top coat for automobiles (R. E. Banks, Smart, and Tatlow 1994).

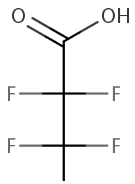
Fluorinated surfactants in windshield wiper fluids can prevent icing of the windshield (Kissa 2001). An analysed windshield fluid contained 4:2, 6:2, 8:2 and 10:2 FTOHs (CAS No. 2043-47-2, 647-42-7, 678-39-7, 865-86-1, respectively) (Dinglasan-Panlilio and Mabury 2006).

Fluorinated surfactants in automotive waxes aid spreading and improve the resistance of the polish to water and oil (Kissa 2001). Some PFAS that have been used, or have been detected in automotive waxes and polish are shown in Table 52.

Table 52: PFAS historically or currently used or detected in automotive waxes and polish. The types stand for U – use and U* – current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 5, 7	307-24-4, 335-67-1	D	(Blom and Hanssen 2015; Borg and Ivarsson 2017)
(n:2) Fluorotelomer alcohols (FTOHs)[1b]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8	647-42-7, 678-39-7	D	(Blom and Hanssen 2015)
Ammonium (n:2) fluorotelomer phosphate monoester[1c]	$NH_4^+ \; C_nF_{2n+1}CH_2CH_2OPO_3H^-$	undefined	65530-71-4	U	(Norden 2020)
Diammonium (n:2) fluorotelomer phosphate monoester[(1c)]	$2\; NH_4^+ \; C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	undefined	65530-72-5	U	(Norden 2020)
Ammonium (n:2) fluorotelomer phosphate diester[1d]	$NH_4^+ \; OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	undefined	65530-70-3	U	(Norden 2020)
Polytetrafluoroethylene (PTFE)[1e]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U	(Norden 2020)

1a



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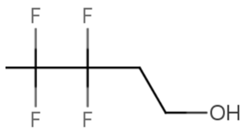

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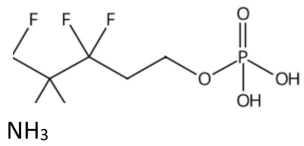

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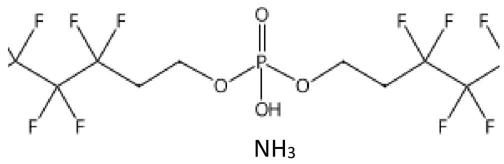

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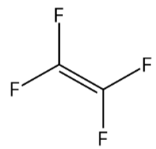


2.6.3 Engines

Fluoropolymers are used in crankshaft seals, front cover seals, cylinder head gaskets, O-rings, valve stem seals, camshaft seals, oil pan seals, EGR valve seals, water pump seals, bearings, back-up rings, valve packings, engine oil coolers, and gaskets (FluoroIndustry 2019). PFAS have also been used as motor oil additives (Herzke, Posner, and Olsson 2009). Cylinder head coatings and hoses made with PFAS increase the fuel efficiency and reduce the fugitive gasoline vapor emissions (FluoroIndustry 2019). PFOA-related compounds have been used in engine linings (POPRC 2018a). The use of PFAS in seals is described in more detail in Section 2.35 'Sealants and adhesives`.

2.6.4 Electronics

PFAS are also used in engine, transmission and under-hood wiring, and fiber optic cables (FluoroIndustry 2019). The use of PFAS in cable and wire insulation is described in more detail in Section 2.43 'Wire and cable`.

2.6.5 Environmental Systems

Fluoropolymers are also used in hood, door and trunk hinges, bearings, push/pull cables, power door lock seals, seat adjustment systems, and active headlight seals (FluoroIndustry 2019). Furthermore, PFOA-related compounds have been used in windshield washer arms (POPRC 2018a). The use of PFAS in seals is described in more detail in Section 2.35, and the use of PFAS in cables and wire insulations in Section 2.43.

2.6.6 Fuel Systems

PFAS are used in the fuel system in seals, oil coolers, valve bodies, liquid and vapor lines, the fuel tank, the filler neck, connectors and oxygen sensors (FluoroIndustry 2019).

2.6.7 Interior

PFAS are used in the interior of automobiles (FluoroIndustry 2019; Bečanová et al. 2016). Bečanová et al. (2016) analyzed interior materials from different automobiles and detected PFCAs and PFSAs in plastic materials, foams, textiles and carpets from the car interior. Pigmented PVDF and ABS laminates have been used in Europe for thermoformed automotive dash panels (Dohany 2000). More information on PFAS in plastic is provided in Section 2.32 'Plastic and rubber` and Section 1.17 'Production of plastic and rubber', more information on carpets is provided in Section 2.16.1 'Carpets`, and more information on PFAS in textiles in Section 2.40 'Textile and upholstery` and Section 1.19 'Textile production'.

2.6.8 Lubricants and greases

C_4-C_{12} PFCAs and C_4, C_6, C_8, and C_{10} PFSAs were detected in automotive greases (Zhu and Kannan 2020). More information on PFAS in lubricants and greases is provided in Section 2.21 'Lubricants and greases'.

2.6.9 Safety restraint systems

PFOA-related compounds have been used in vehicle safety restraint systems and air bag systems (POPRC 2018a).

2.6.10 Steering Systems

Fluoropolymers are used in the steering system in gear seals and mounts, earings, column adjustment, and pump and steering rack seals (FluoroIndustry 2019). More information on seals is provided in Section 2.35 'Sealants and adhesives`.

2.6.11 Suspension/Brakes

PFAS are used in strut and piston seals, shock absorbers, and brake pad additives (FluoroIndustry 2019). PVDF organosol dispersions have been used to coat steel hydraulic brake tubes for corrosion protection (Dohany 2000).

2.6.12 Transmissions

Fluoropolymers are also used in seals and bearings, piston, shaft and fluid transfer seals, gaskets, O-rings, and sensor modules (FluoroIndustry 2019; S. Ebnesajjad and Snow 2000).

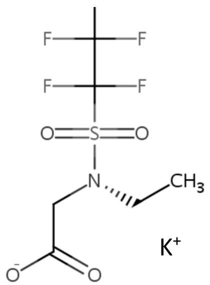
2.7 Cleaning compositions

Fluorinated surfactants lower the surface tension and improve wetting and rinse-off in a variety of industrial and household cleaning products (POPRC 2016a). Examples are dishwashing liquids, car wash products, floor cleaning products, carpet spot cleaner, and cleaning solutions for optical devices. They can also be used for surfaces such as wood and concrete (Buck, Murphy, and Pabon 2012; POPRC 2016a). Additionally, fluorinated surfactants can be used in cleaners containing strong acids or alkali due to their chemical stability (POPRC 2016a). An application where high acid resistance is required is in "strippers" for floor polish removal systems (Chemours 2019a). The performance depends on the ability of the stripper to completely wet and penetrate the layer(s) of old polish/wax, so that they can be separated from the substrate. The fluorinated surfactants aid wetting the old floor polish (Chemours 2019a). Additionally, PFAS can be used as solvents for dry cleaning. PFAS that have been used or patented for or have been detected in cleaning compositions in general are shown in Table 53. The use of PFAS for more specific applications is described in Subsections 2.7.1 to 2.7.6.

Table 53: PFAS historically or currently used or patented for or detected in cleaning compositions in general. Patent number (date, legal status): DE3236114 (1983, rejected), JP10152452 (1998, withdrawn). The types stand for U – use, U* – current use, P – patent, and D - detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Fluorinated surfactants					
Potassium *N*-ethyl perfluoroalkane sulfonamido acetate[1a]	$K^+ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 4 - 8	67584-51-4, 67584-52-5, 67584-53-6, 67 584-62-7, 2991-51-7	U, U*	(Norden 2020)
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl [(perfluoro alkyl)sulfonyl]amino]ethyl]-ω-hydroxy-[2b]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_nOH$	n = 8	29117-08-6	P	(CAS 2019 (DE3236114))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[2c]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 4, 6, 8	67939-95-1, 68957-58-4, 1652-63-7	U	(Buck, Murphy, and Pabon 2012)
(n:2) Fluorotelomer alcohols (FTOHs)[2d]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8, 10	647-42-7, 678-39-7, 865-86-1	D	(Kotthoff et al. 2015)

1a



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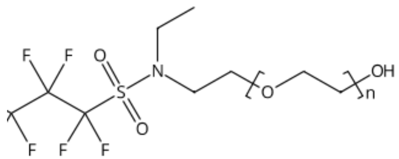

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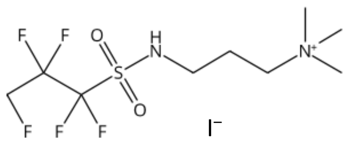

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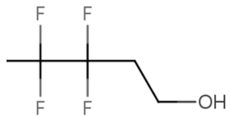
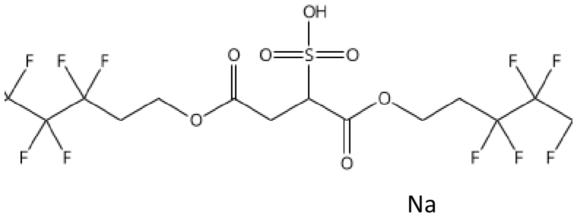


Butanedioic acid, 2-sulfo-, 1,4-bis(perfluoroalkyl) ester, sodium salt (1:1)[2a]	$Na^+ C_nF_{2n+1}CH_2CH_2OC(O)CH_2CH(SO_3^-)C(O)OCH_2CH_2C_mF_{2m+1}$	n = 6	54950-05-9	U	(Norden 2020)
(n:2) Fluorotelomer thioether propanoic acid[2b]	$C_nF_{2n+1}CH_2CH_2SCH_2CH_2COOH$	undefined	65530-83-8	U	(Norden 2020)
Lithium (n:2) fluorotelomer thioether propionate[(2b)]	$Li^+ C_nF_{2n+1}CH_2CH_2SCH_2CH_2COO^-$	undefined	65530-69-0	U*	(Norden 2020)
Ammonium (n:2) fluorotelomer phosphate monoester[2c]	$NH_4^+ C_nF_{2n+1}CH_2CH_2OPO_3H^-$	undefined	65530-71-4	U*	(Norden 2020)

Diammonium (n:2) fluorotelomer phosphate monoester[(2c)]	2 NH_4^+ $C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	undefined	65530-72-5	U*	(Norden 2020)

2a



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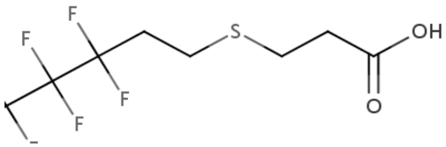

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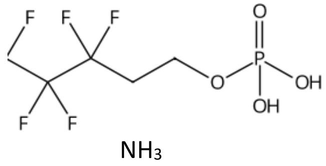
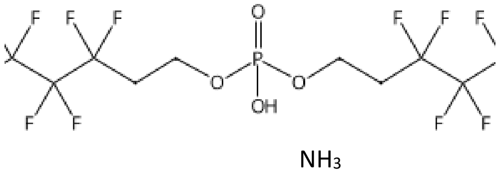


Ammonium (n:2) fluorotelomer phosphate diester[3a]	NH_4^+ $OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	undefined	65530-70-3	U*	(Norden 2020)
<u>Fluorinated solvents</u>					
1H-Perfluoroalkane[3b]	$C_nF_{2n+1}CF_2H$	n = 1	354-33-6	U	(Norden 2020)
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[3c]	$C_2F_5(CFH)_2CF_3$	-	138495-42-8	U*	(Norden 2020)
3,3-Dichloro-1,1,1,2,2-pentafluoropropane[3d]	$CF_3CF_2CHCl_2$	-	422-56-0	U*	(Norden 2020)
1,3-Dichloro-1,1,2,2,3-pentafluoropropane[3e]	CF_2ClCF_2CFHCl	-	507-55-1	U*	(Norden 2020)

3a



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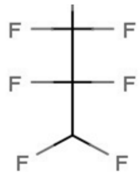

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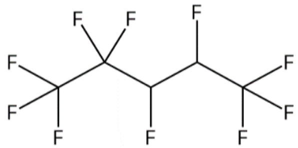
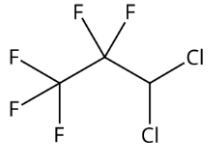
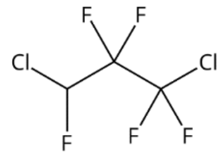


3d

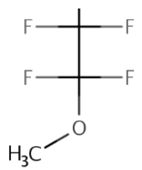


3e



Methyl perfluoroalkyl ether[4a]	$C_nF_{2n+1}OCH_3$	n = 2, 3, 4 (part of HFE-7100)	22410-44-2, 375-03-1, 163702-07-6	P, U*	(CAS 2019 (JP10152452), Norden 2020)
Methyl perfluoroisobutyl ether[4b]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U*	(Norden 2020)
Ethyl perfluorobutylether[4c]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	U*	(Norden 2020)
Ethyl perfluoroisobutyl ether[4d]	$CF_3CF(CF_3)CF_2OCH_2CH_3$	(part of HFE-7200)	163702-06-5	U*	(Norden 2020)
Cyclopentane, 1,1,2,2,3,3,4-heptafluoro-[4e]	c-$C_5H_3F_7$	-	15290-77-4	U*	(Norden 2020)
<u>Others</u>					

Polytetrafluoroethylene (PTFE)[4f]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)

4a


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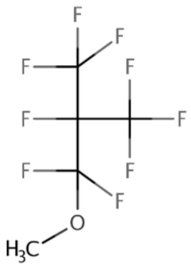

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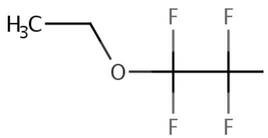

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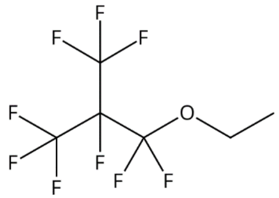

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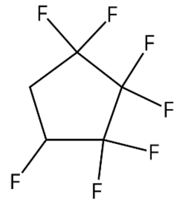
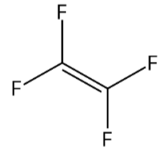
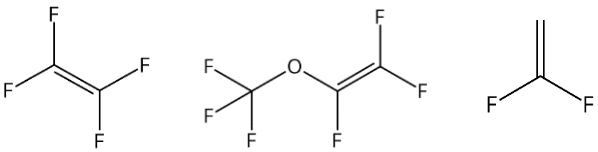


4f


Ethene, 1,1,2,2-tetrafluoro-, polymer with 1,1-difluoroethene and 1,1,2-trifluoro-2-(trifluoro methoxy)ethene[5a]	$-(C_3F_6O)_x-(C_2H_2F_2)_y-(C_2F_4)_m-$	polymer	56357-87-0	U*	(Norden 2020)
Phosphonic acid, perfluoro-C_{6-12}-alkyl derivs.	-	n = 6 - 12	68412-68-0	U	(Norden 2020)
Perfluoro compounds, C_{5-18}	-	n = 5 - 18	86508-42-1	U*	(Norden 2020)

5a


2.7.1 Cleaning compositions for hard surfaces

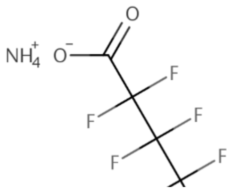
PFAS have been particularly useful for cleaning hard surfaces like wood, glass, countertops, and flooring (Buck, Murphy, and Pabon 2012). PFAS that have been used, are currently used, have been patented, or have been detected for these applications are shown in Table 54.

Table 54: PFAS that have been used, are currently used, have been patented, or have been detected for cleaning hard surfaces. Patent number (date, legal status): JP57119999 (1982, expired), BE861660 (1978, expired), US5750488 (1998, discontinued), DE2636993 (1978, withdrawn), US4511489 (1985, expired). The types stand for U – use, U* – current use, D – detected, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

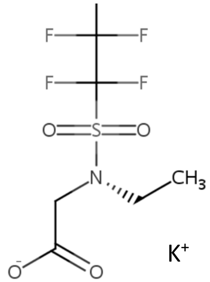
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Glass					

Ammonium perfluoroalkyl carboxylate[1a]	$NH_4^+ \ C_nF_{2n+1}COO^-$	n = 8	4149-60-4	P	(CAS 2019 (JP57119999))
Potassium *N*-ethyl perfluoroalkane sulfonamide acetate[1b]	$K^+ \ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 6, 8	67584-53-6, 2991-51-7	U	(Norden 2020)
Perfluoroalkane sulfonamido betaine[1c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 8	75046-16-1	P	(CAS 2019 (JP57119999))
Alkanoic acid, 6-[(perfluoro-1-oxoundecyl)amino]-, ammonium salt (1:1)[1d]	$NH_4^+ \ C_nF_{2n+1}C(O)NHC_5H_{10}COO^-$	n = 10	83952-11-8	P	(CAS 2019 (JP57119999))
Alkanoic acid, 6-[(perfluoro-1-oxoundecyl)amino]-, compd. with 2,2′-iminobis[ethanol] (1:1)[(1d)]	$NH_2^+(CH_2CH_2OH)_2 \ C_nF_{2n+1}C(O)NHC_5H_{10}COO^-$	n = 10	83952-09-4	P	(CAS 2019 (JP57119999))
Alkamide, perfluoro-*N*-(29-hydroxy-3,6,9,12,15,18,21,24,27-nonaoxanonacos-1-yl)-[too large to show]	$C_nF_{2n+1}C(O)NHCH_2CH_2(OCH_2CH_2)_9OH$	n = 8	83952-10-7	P	(CAS 2019 (JP57119999))
<u>Dishes and glasses</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[(1a)]	$C_nF_{2n+1}COOH$	n = 3, 7, 9	375-22-4, 335-67-1, 335-76-2	D	(Blom and Hanssen 2015; Borg and Ivarsson 2017)
(n:2) Fluorotelomer alcohols (FTOHs)[1e]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8	647-42-7, 678-39-7	D	(Blom and Hanssen 2015)

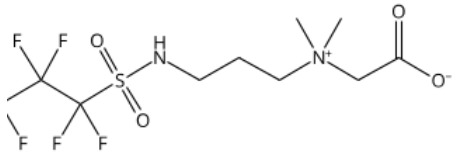
1a



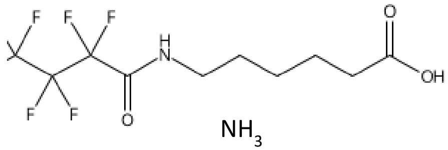
1b



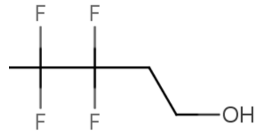
1c



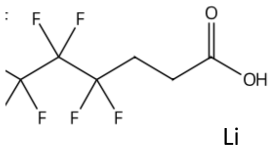
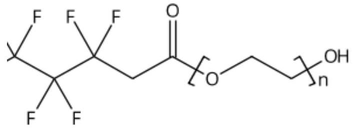
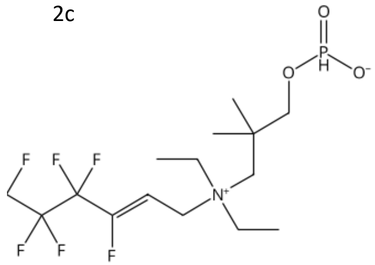
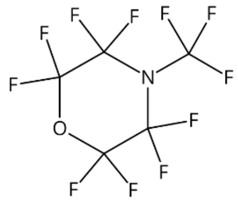
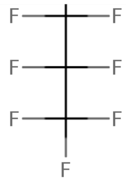
1d



1e

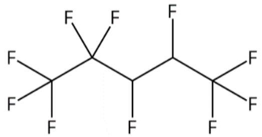


<u>Metal surfaces</u>					
Lithium (n:3) fluorotelomer unsaturated carboxylic acids[2a]	$Li^+ \ C_nF_{2n+1}CH_2CH_2COO^-$	n = 8	67304-23-8	P	(CAS 2019 (BE861660))
Poly(oxy-1,2-ethanediyl), α-(perfluoro-1-oxodecyl)-ω-hydroxy-[2b]	$C_nF_{2n+1}CH_2C(=O)(OCH_2CH_2)_nOH$	n = 6, 8	67296-32-6, 67296-33-7	P	(CAS 2019 (BE861660))
2-Alken-1-aminium, *N*,*N*-diethyl-perfluoro-*N*-[3-[(hydro xylphosphinyl)oxy]-2,2-dimethylpropyl]-, inner salt[2c]	$C_nF_{2n+1}CF=CHCH_2N^+(CH_2CH_3)_2CH_2C(CH_3)_2CH_2OPH(=O)O^-$	n = 7	67304-22-7	P	(CAS 2019 (BE861660))
Morpholine, 2,2,3,3,5,5,6,6-octafluoro-4-(trifluoro methyl)-[2d]	$c\text{-}C_5F_{11}NO$	-	382-28-5	P	(CAS 2019 (US5750488))
Linear perfluoroalkanes[2e]	C_nF_{2n+2}	n = 5	678-26-2	P	(CAS 2019 (US5750488))

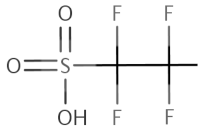
2a

2b

2c

2d

2e


Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[3a]	$C_2F_5(CFH)_2CF_3$	-	138495-42-8	P	(CAS 2019 (US5750488))
<u>Steel screws after Ni plating</u>					
Perfluoroalkane sulfonic acids (PFSAs)[3b]	$C_nF_{2n+1}SO_3H$	n = 8	1763-23-1	P	(CAS 2019 (DE2636993))
<u>Tile, tub and bowl</u>					
Perfluoroalkyl phosphonic acids (PFPAs)[3c]	$C_nF_{2n+1}P(=O)(OH)_2$	n = 6, 8, 10	40143-76-8, 40143-78-0, 52299-26-0	U	(Z. Wang et al. 2016)
Perfluoroalkyl phosphinic acids (PFPiAs)[3d]	$C_nF_{2n+1}P(C_mF_{2m+1})(=O)OH$	n/m = 6/6, 6/8, 6/10, 6/12, 8/8, 8/10	40143-77-9, 6108 00-34-5, 1240600-40-1, 1240600-41-2, 4014 3-79-1, 500776-81-8	U	(Z. Wang et al. 2016)
<u>Plastic surfaces</u>					
Ammonium perfluoroalkane sulfonate[3b]	NH_4^+ $C_nF_{2n+1}SO_3^-$	n = 10	67906-42-7	P	(CAS 2019 (US4511489))
Potassium *N*-ethyl perfluoroalkane sulfonamidoacetate[1b]	K^+ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	P	(CAS 2019 (US4511489))
Benzenesulfonic acid, 4-[[4,4,5,5,5-pentafluoro-3-(1,1,2,2,2-pentafluoroethyl)-1,2,3-tris(trifluoromethyl)-1-penten-1-yl]oxy]-, sodium salt (1:1)[3e]	Na^+ $CF_3CF_2C(CF_3)(C_2F_5)C(CF_3)=C(CF_3)OC_6H_4SO_3^-$	-	52584-45-9	P	(CAS 2019 (US4511489))

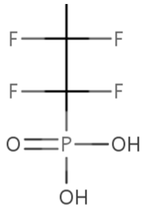
3a



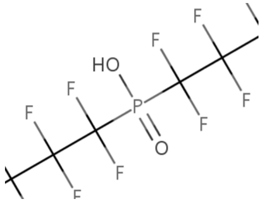
3b



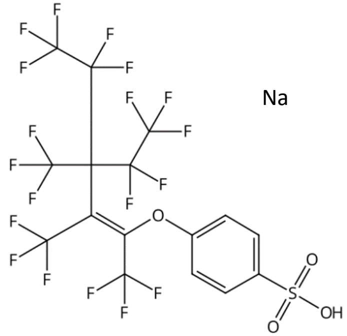
3c



3d



3e



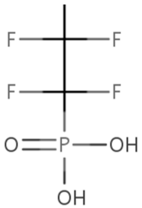
2.7.2 *Carpet and upholstery cleaners*

Fluorinated surfactants in carpet spot cleaners and upholstery cleaners provide stain resistance and repel soil. The principle of soil repellence is based on the reduction of the surface energy of the fibre by the fluoroalkyl chains of PFAS. These chains repel both water and oil so that soil particles cannot enter the carpet (RPA 2004). Table 55 shows two fluorinated surfactants that have been used in carpet and upholstery cleaners.

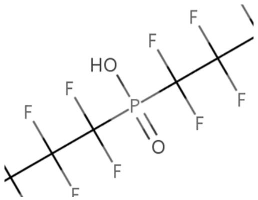
Table 55: PFAS used in carpet and upholstery cleaners. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl phosphonic acids (PFPAs)[1a]	$C_nF_{2n+1}P(=O)(OH)_2$	n = 6, 8, 10	40143-76-8, 40143-78-0, 52299-26-0	U	(Z. Wang et al. 2016)
Perfluoroalkyl phosphinic acids (PFPiAs)[1b]	$C_nF_{2n+1}P(C_mF_{2m+1})(=O)OH$	n/m = 6/6, 6/8, 6/10, 6/12, 8/8, 8/10	40143-77-9, 610800-34-5, 1240600-40-1, 1240600-41-2, 40143-79-1, 500776-81-8	U	(Z. Wang et al. 2016)

1a



1b



2.7.3 Cleaning compositions for adhesives

Fluorinated surfactants (e.g. glycine, *N*-[(perfluoroalkyl)sulfonyl]-*N*-propyl-, potassium salt (1:1), CAS No. 55910-10-6) in non-aqueous cleaning compositions aid the removal of adhesives (Kissa 2001; CAS 2019 (JP59071398, 1984)).

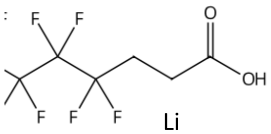
2.7.4 Dry cleaning fluids

PFAS can be used for dry cleaning of textiles, metals, glass, ceramics, and natural and synthetic polymers (CAS 2019 (WO2000065018, 2000), (BE861660, 1978)). The PFAS described in patent WO2000065018 can be used as stabilizer, the PFAS described in patent BE861660 to improve the removal of hydrophilic soil by the solvents. Table 56 lists some PFAS that have been used or patented as dry cleaning fluids.

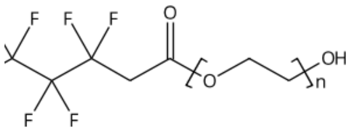
Table 56: PFAS used or patented as dry cleaning fluids. Patent number (date, legal status): WO2000065018 (2000, active), BE861660 (1978, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Dry cleaning of textiles					
Lithium n:3 fluorotelomer unsaturated carboxylic acids[1a]	Li^+ $C_nF_{2n+1}CH_2CH_2COO^-$	n = 8	67304-23-8	P	(CAS 2019 (BE861660))
Poly(oxy-1,2-ethanediyl), α-(perfluoro-1-oxodecyl)-ω-hydroxy-[1b]	$C_nF_{2n+1}CH_2C(=O)(OCH_2CH_2)_nOH$	n = 6, 8	67296-32-6, 67296-33-7	P	(CAS 2019 (BE861660))
2-Alken-1-aminium, *N*,*N*-diethyl-perfluoro-*N*-[3-[(hydroxyl phosphinyl)oxy]-2,2-dimethylpropyl]-, inner salt[1c]	$C_nF_{2n+1}CF{=}CHCH_2N^+(CH_2CH_3)_2CH_2C(CH_3)_2CH_2OPH(=O)O^-$	n = 7	67304-22-7	P	(CAS 2019 (BE861660))
Dry cleaning of metals, glass, ceramics, natural and synthetic polymers, and fabrics					
Methyl perfluoroalkyl ether[1d]	$C_nF_{2n+1}OCH_3$	n = 3, 4	375-03-1, 163702-07-6	P, U	(CAS 2019 (WO2000065018); 3M 2009a)
Ethyl perfluoroalkyl ether[1e]	$C_nF_{2n+1}OCH_2CH_3$	n = 4	163702-05-4	P, U	(CAS 2019 (WO2000065018); 3M 2009b)

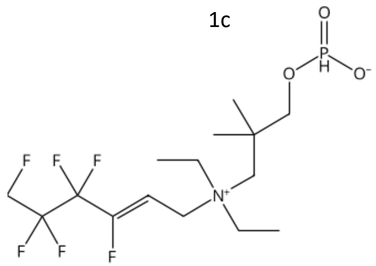
1a



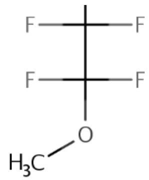
1b



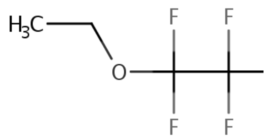
1c



1d



1e



2.7.5 Cleaning optical devices

Chemours promotes some of his Vertrel™ specialty fluids for the cleaning of optical devices. For example, pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro- (CAS No. 138495-42-8) is marketed for clean and spot-free optical assemblies and lenses (Chemours 2019e). Vertrel™ specialty fluids are also promoted for cleaning optical fibers to ensure that they are joined properly after being spliced, to prevent signal loss (Chemours 2019e). Additionally, Vertrel™ specialty fluids are marketed for cleaning flat screen panels for example for plasma TVs (Chemours 2019e).

2.7.6 Others

Calcium sulfate can be removed from reverse osmosis membranes by fluorinated surfactants (e.g. Zonyl FSN, Zonyl FSP or Zonyl FSA) (Kissa 2001). A cationic fluorinated surfactant (unknown idendity) can facilitate wetting and the removal of oily soil on concrete (Kissa 2001).

2.8 Coatings, paints, and varnishes

Fluorinated surfactants provide exceptional wetting, levelling and flow control for paints and coatings (Buck, Murphy, and Pabon 2012). They also provide various properties to paints and coatings including anti-crater, improved surface appearance, better flow and levelling, reduced foaming, decreased block, open-time extension, oil repellency, and dirt pickup resistance (Buck, Murphy, and Pabon 2012). Fluorinated surfactants can overcome wetting and dewetting problems caused by contaminants on the surface, such as film or hydrocarbon or silicone oil (Kissa 2001). An additional feature is that fluorinated surfactants are able to form a second coat on a first coat, which requires the surface tension of the second coat to be lower than that of the first coat (Kissa 2001).

2.8.1 Paints

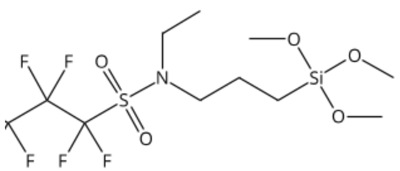
Fluorinated surfactants in paints can function as an emulsifier for the binder, as dispersant for the pigment, and as wetting agent. Additionally, they can also be used to impart oil- and water repellency to the paint or coating. However, in the dried film, the fluorinated surfactant acts as an external plasticizer, imparting softness and flexibility (Kissa 2001; Holmberg et al. 2002). One possibility to get around this problem are surfactants that are polymerizable after hydrolysis. Table 57 lists surfactants that are polymerizable after hydrolysis and can be useful for oil- and water repellent coatings or paints.

Table 57: Fluorinated surfactants patented for oil- and water-repellent coatings and paints having a hydrolysable group. Patent number (date, legal status): US5274159 (1993, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

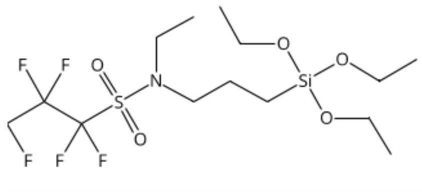
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Alkanesulfonamide, *N*-ethyl-perfluoroalkyl-*N*-[3-(tri methoxysilyl)propyl]-[1a]	$C_nF_{2n+1}SO_2N(CH_2CH_3)CH_2CH_2CH_2Si(OCH_3)_3$	n = 4, 8	154380-33-3, 61660-12-6	P	(CAS 2019 (US5274159))
1-Alkanesulfonamide, *N*-ethyl-perfluoroalkyl-*N*-[3-(tri ethoxysilyl)propyl]-[1b]	$C_nF_{2n+1}SO_2N(CH_2CH_3)CH_2CH_2CH_2Si(OCH_2CH_3)_3$	n = 8	127193-07-1	P	(CAS 2019 (US5274159))

Poly(oxy-1,2-ethanediyl), α-[dimethoxy[3-[(perfluoro-1-oxooctyl)amino]propyl]silyl]-ω-[[dimethoxy[3-[(perfluoro-1-oxooctyl)amino]propyl]silyl]oxy]-[1c]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2Si(OCH_3)_2(OCH_2CH_2)_xOSi(OCH_3)_2CH_2CH_2CH_2NHC(O)C_nF_{2n+1}$	n = 7	154380-30-0	P	(CAS 2019 (US5274159))

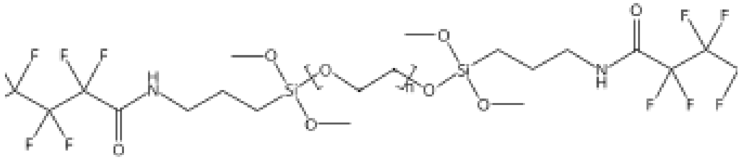
1a



1b

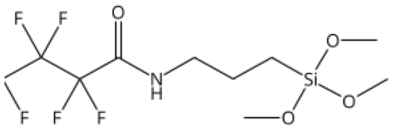


1c

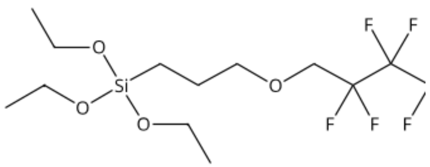


Alkanamide, perfluoro-*N*-[3-(trimethoxysilyl)propyl]-[2a]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2Si(OCH_3)_3$	n = 5, 7, 9	154380-34-4, 98046-76-5, 154380-29-7	P	(CAS 2019 (US5274159))
Silane, triethoxy[3-[(perfluoroalkyl)oxy]propyl]-[2b]	$C_nF_{2n+1}CH_2OCH_2CH_2CH_2Si(OCH_2CH_3)_3$	n = 7	19116-62-2	P	(CAS 2019 (US5274159))
Silane, trichloro[3-[(perfluoroalkyl)oxy]propyl]-[2c]	$C_nF_{2n+1}CH_2OCH_2CH_2CH_2SiCl_3$	n = 7	755-08-8	P	(CAS 2019 (US5274159))
2,5,8,10,13,16-Hexaoxa-9-silaheptadecane, 9-[2-(2-methoxyethoxy)ethoxy]-9-[3-[(perfluoroalkyl)oxy]propyl]-[2d]	$C_nF_{2n+1}CH_2OCH_2CH_2CH_2Si[(OCH_2CH_2)_2OCH_3]_3$	n = 7	154380-27-5	P	(CAS 2019 (US5274159))
2,5,8,11,13,16,19,22-Octaoxa-12-silatricosane, 12-[2-[2-(2-methoxyethoxy)ethoxy]ethoxy]-12-[3-[(perfluoroalkyl) oxy]propyl]-[not shown]	$C_nF_{2n+1}CH_2OCH_2CH_2CH_2Si[(OCH_2CH_2)_3OCH_3]_3$	n = 7	154380-28-6	P	(CAS 2019 (US5274159))

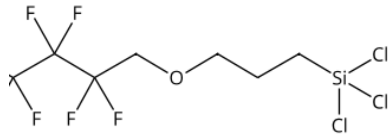
2a



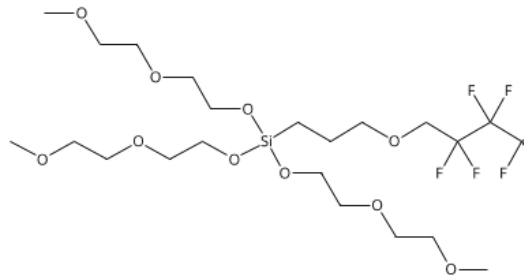
2b



2c

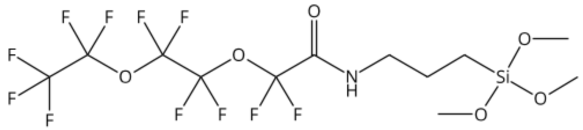


2d



Acetamide, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-(1,1,2,2,2-pentafluoroethoxy)ethoxy]-*N*-[3-(trimethoxysilyl)propyl]-[3a]	$CF_3CF_2OCF_2CF_2OCF_2C(O)NHCH_2CH_2CH_2Si(OCH_3)_3$	-	154380-35-5	P	(CAS 2019 (US5274159))

3a



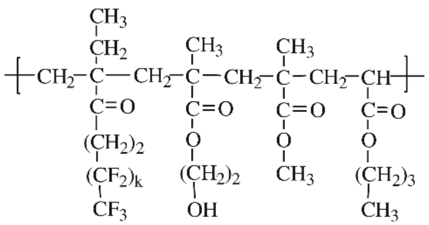
The second option is the use of a polymerizable surfactant that may either undergo homopolymerization or copolymerize with some other component of the system (Holmberg et al. 2002). A monolayer of surfactant may homopolymerize when adsorbed at an interface. The palisade layer may either form by adsorption from an aqueous solution or by migration through a film. Copolymerization may take place in a bulk phase (Holmberg et al. 2002). An example for a polymerizable surfactant is $C_8F_{17}SO_2N(C_2H_5)CH_2CH_2OC(=O)(C_nH_{2n+1})$, a graft copolymer with an acrylic main chain and a molecular weight of 2600 Da (Torstensson, Ranby, and Hult 1990).

PFAS such as perfluorinated urethanes, PTFE, and PVDF enhance the protective properties of anticorrosive paints (Norden 2020; Kissa 2001). PFAS are also used in antifouling paints on ships (see Table 58).

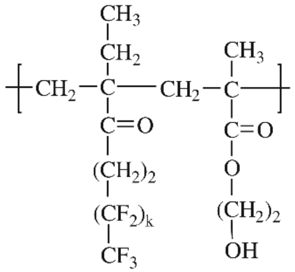
Table 58: PFAS used in antifouling paints on ships. The types stand for U – use and U* – current use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Fluorinated acrylate quadripolymer (QPFA)[1a]	see graphic	polymer	-	U	(Zhang et al. 2015)
Fluorinated acrylate bipolymer (BPFA)[1b]	see graphic	polymer	-	U	(Zhang et al. 2015)
Fluorinated acrylate homopolymer (HPFA)[1c]	see graphic	polymer	-	U	(Zhang et al. 2015)
Polytetrafluoroethylene (PTFE)[1d]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Ethanol, 2,2'-[oxybis(2,1-ethanediyloxy)]bis-, ethers with ethoxylated reduced Me esters of reduced polymd. oxidized tetrafluoroethylene	-	polymer	1260733-08-1	U	(Z. Wang et al. 2020)

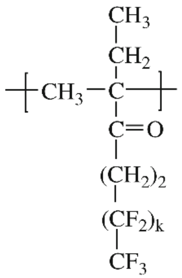
1a



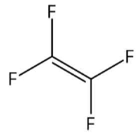
1b



1c



1d

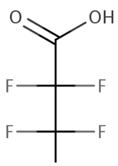


There is a variety of other PFAS that have been or are also used in paints in general. Table 59 lists some of them. As mentioned above, the substances may be used as an emulsifier for the binder, as dispersant for the pigment, as wetting agent, or to impart water- and oil repellency.

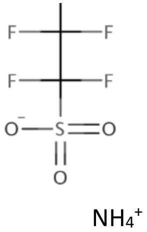
Table 59: Other PFAS historically or currently used or patented for use in paints in general. Patent number (date, legal status): US4208496 (1980, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 7	335-67-1	U	(KEMI Swedish Chemical Agency 2015b)
Ammonium perfluoroalkane sulfonate[1b]	NH_4^+ $C_nF_{2n+1}SO_3^-$	n = 10	67906-42-7	P	(CAS 2019 (US4208496))
N-Methyl perfluoroalkane sulfonamides (MeFASAs)[1c]	$C_nF_{2n+1}SO_2NHCH_3$	n = 4	68298-12-4	U	(Norwegian Environment Agency 2017)
N-Methyl perfluoroalkane sulfonamidoethanols (MeFASEs)[1d]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 4, 8	34454-97-2, 24448-09-7	U	(Norwegian Environment Agency 2017; Norden 2020)
N-Methyl perfluoroalkane sulfonamidoethyl acrylates (MeFASEACs)[1e]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH{=}CH_2$	n = 4	67584-55-8	U	(Norwegian Environment Agency 2017)
Potassium *N*-ethyl perfluoroalkane sulfonamid oacetate[1f]	K^+ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	U	(Norden 2020)

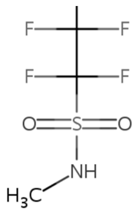
1a



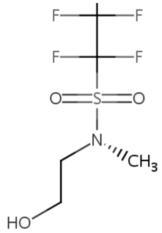
1b



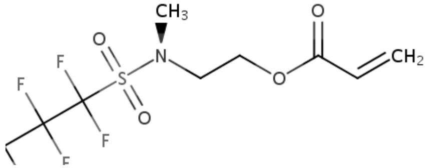
1c



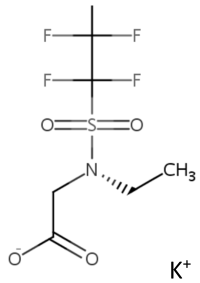
1d



1e

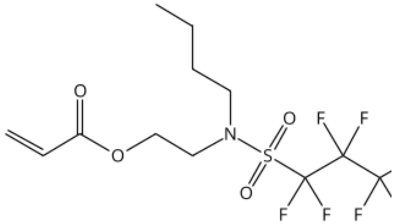


1f

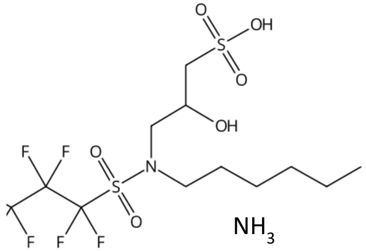


2-Propenoic acid, 2-[butyl[(perfluoroalkyl)sulfonyl] amino]ethyl ester[2a]	$C_nF_{2n+1}SO_2N(C_4H_9)CH_2CH_2OC(=O)CHCH_2$	n = 8	383-07-3	U	(Norden 2020)
1-Propanesulfonic acid, 3-[hexyl[(perfluoroalkyl)sulfonyl] amino]-2-hydroxy-, ammonium salt (1:1)[2b]	NH_4^+ $C_nF_{2n+1}SO_2N(C_6H_{13})CH_2CH(OH)CH_2SO_3^-$	n = 4	606967-06-0	U	(Norwegian Environment Agency 2017)
(n:2) Fluorotelomer alcohols (FTOHs)[2c]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6	647-42-7	U*	(Norden 2020)
Butanedioic acid, 2-sulfo-, 1,4-bis(perfluoroalkyl) ester, sodium salt (1:1)[2d]	Na^+ $C_nF_{2n+1}CH_2CH_2OC(O)CH_2CH(SO_3^-)C(O)OCH_2CH_2C_mF_{2m+1}$	n = 6	54950-05-9	U	(Norden 2020)

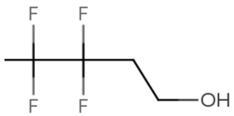
2a



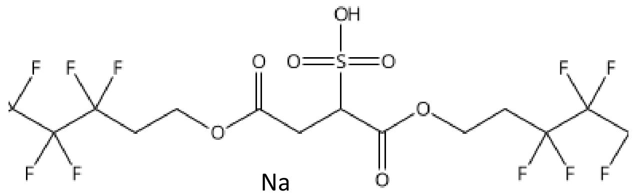
2b



2c



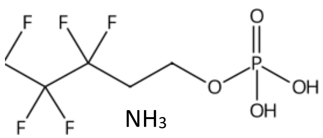
2d



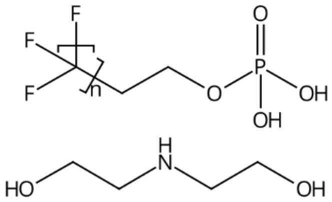
Ammonium (n:2) fluorotelomer phosphate monoester[3a]	NH_4^+ $C_nF_{2n+1}CH_2CH_2OPO_3H^-$	undefined	65530-71-4	U*	(Norden 2020)
Diammonium (n:2) fluorotelomer phosphate monoester[(3a)]	2 NH_4^+ $C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	undefined	65530-72-5	U*	(Norden 2020)
Ethanol, 2,2′-iminobis-, compd. with α-fluoro-ω-[2-(phos phonooxy)ethyl]poly(difluoromethylene) (1:1)[3b]	$NH_2^+(CH_2CH_2OH)_2$ $C_nF_{2n+1}CH_2CH_2OPO_3H^-$	undefined	65530-74-7	U	(Norden 2020)
Ethanol, 2,2′-iminobis-, compd. with α-fluoro-ω-[2-(phos phonooxy)ethyl]poly(difluoromethylene) (2:1)[(3b)]	$NH_2^+(CH_2CH_2OH)_2$ 1/2 $C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	undefined	65530-63-4	U	(Norden 2020)
Ammonium (n:2) fluorotelomer phosphate diester[3c]	NH_4^+ $OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	undefined	65530-70-3	U*	(Norden 2020)

Ethanol, 2,2′-iminobis-, compd. with α,α′-[phosphinicobis (oxy-2,1-ethanediyl)]bis[ω-fluoropoly(difluoromethylene)] (1:1)[3d]	$NH_2^+(CH_2CH_2OH)$ $(O)P(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	undefined	65530-64-5	U	(Norden 2020)

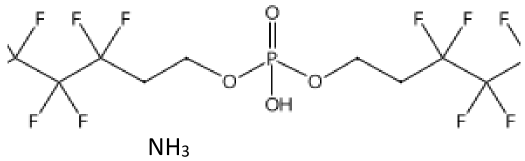
3a



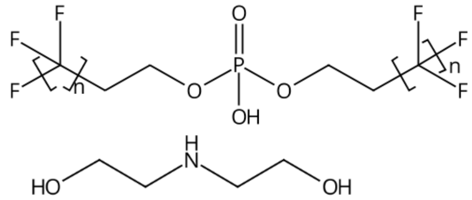
3b



3c

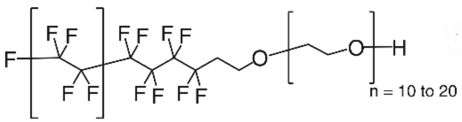


3d

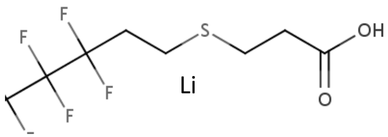


Poly(oxy-1,2-ethanediyl), α-(perfluoroalkyl)-ω-hydroxy-[4a]	$C_nF_{2n+1}CH_2CH_2O(CH_2CH_2O)_mH$ m = 10 to 20	n = 6, 8, 10	52550-44-4	U	(Buck, Murphy, and Pabon 2012)
Lithium n:2 fluorotelomer thioether propionate[4b]	Li^+ $C_nF_{2n+1}CH_2CH_2SCH_2CH_2COO^-$	n = 7	4956-89-1	P	(CAS 2019 (US4208496))
Polytetrafluoroethylene (PTFE)[4c]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
Poly(vinylidene fluoride) (PVDF)[4d]	$-(CH_2CF_2)_x-$	polymer	24937-79-9	U	(Norden 2020)
Terpolymer composed of $CH_2{=}CF_2$, C_2F_4, and C_3F_6	-	polymer	-	U	(R. E. Banks, Smart, and Tatlow 1994)

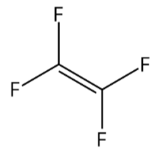
4a



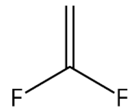
4b



4c

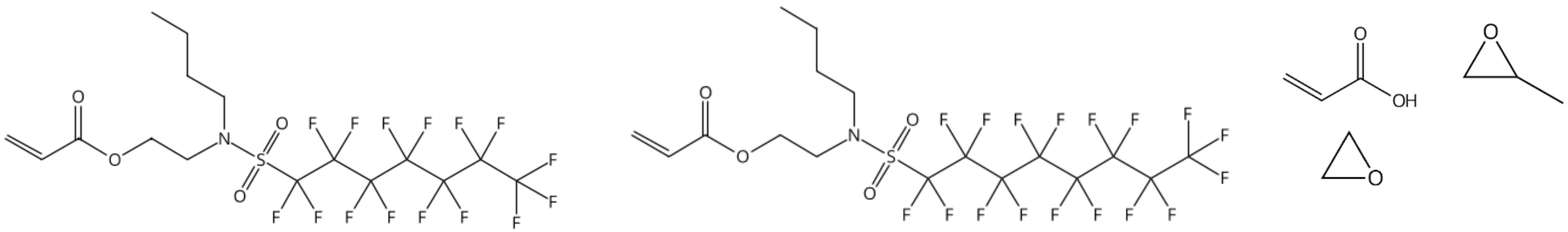


4d



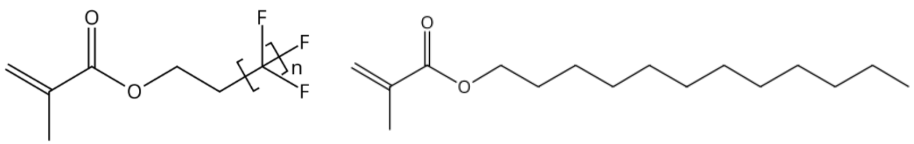
2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8, 8,8-heptadeca fluorooctyl)sulfonyl]amino]ethyl ester, telomer with 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,7-pentadecafluoroheptyl)sulfonyl]amino]ethyl 2-prope noate, 2-methyloxirane polymer with oxirane di-2-propenoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[5a]	$-[(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O-C_2H_4O)_m-(C_3H_6O-C_2H_4O)_w-2C_3H_4O_2-C_3H_4O_2]_u-C_8H_{18}S-$	polymer	68298-62-4	U	(Norden 2020)

5a

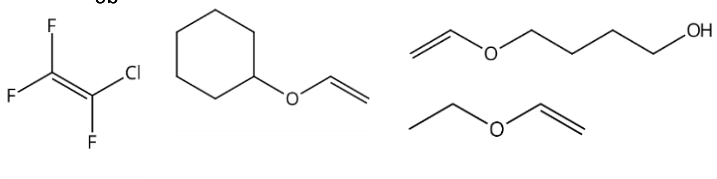


2-Propenoic acid, 2-methyl-, dodecyl ester, polymer with α-fluoro-ω-[2-[(2-methyl-1-oxo-2-propen-1-yl)oxy]ethyl] poly(difluoromethylene)[6a]	$-(C_{16}H_{30}O_2)_x-[(CF_2)_nC_6H_9FO_2]_y-$	polymer	65605-58-5	U	(Norden 2020)
1-Butanol, 4-(ethenyloxy)-, polymer with 1-chloro-1,2,2-tri fluoroethene, (ethenyloxy)cyclohexane and ethoxyethene[6b]	$-(C_8H_{14}O)_x-(C_6H_{12}O_2)_y-(C_4H_8O)_m-(C_2ClF_3)_w-$	polymer	88795-12-4	U	(Norden 2020)
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	-	polymer	104780-70-3	U*	(Norden 2020)
Polysiloxanes, di-Me, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-trideca fluorooctyl	-	polymer	115340-95-9	U*	(Norden 2020)
Siloxanes and Silicones, (3,3,4,4,5,5,6,6,7,7,8,8,9,9,10, 10,10-heptadecafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether	-	polymer	143372-54-7	U	(Norden 2020)
Alcohols, C_{8-14}, perfluoro, reaction products with di-Me, Me hydrogen siloxanes and polyethylene glycol mono-Me ether	-	polymer	162567-79-5	U	(Norden 2020)

6a



6b



A polymer developed by Asahi Glass is shown in Figure 1. The combination of several kinds of vinyl monomers provides the polymer with various properties necessary for a paint, such as solubility, compatibility with pigments, crosslinking reactivity and good adhesion, hardness, and flexibility of the final finish. The polymer can be used in paints on plastics, cements, metals, glass, etc. and its field of application includes skyscraper side walls and other architectural structures, bridges (top-layer protective paint), and automobiles (no-wax brilliant top coat) (R. E. Banks, Smart, and Tatlow 1994).

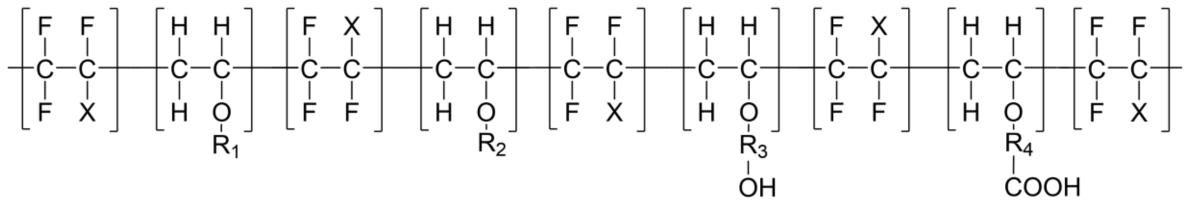


Figure 1: Fluoroolefin-vinyl ether copolymers (Lumiflon®) (adapted from Banks, Smart, and Tatlow (1994)).

2.8.2 Coatings in general

Coatings may be decorative, functional, or both. Additionally, a coating needs to have the same or a lower surface tension than the substrate to which it is applied. Water-borne systems are therefore more demanding with regard to wetting and adhesion than solvent-based systems because water has a very high surface tension (Poulsen, Jensen, and Wallström 2005). This is particularly the case for non-adsorbing substrates like metal and plastics which have also a low surface tension (Poulsen, Jensen, and Wallström 2005). PFAS are used in coatings, even though they are generally much more expensive than other surfactants because they can lower the surface tension of the coating (POPRC 2016a).

Fluoropolymers used for coatings are PTFE, PCTFE, HFP, or PVDF, for example as coatings on glass, ceramic, and metal. Coatings out of PTFE, FEP, or ETFE have mainly been used in antistick and anticorrosive applications (R. E. Banks, Smart, and Tatlow 1994). A heat resistant coating containing OBS (CAS No. 70829-87-7) has been patented (CAS 2019 (JP56152870, 1980)).

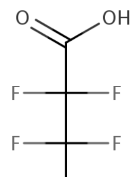
Other examples for coatings containing fluorinated surfactants are pigment dispersions used in automotive coatings (CAS 2019 (US3839254, 1974)). Table 60 lists some PFAS that have been used or detected in coatings. Coatings described specifically for metals (or steel) are not included in Table 60 as they are described in detail in Section 1.11.3 under 'Metal finishing'.

Table 60: PFAS historically or currently used, or detected in coatings. The types stand for U – use and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

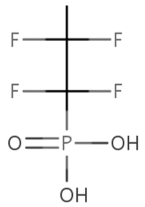
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Janousek, Lebertz, and Knepper 2019)
Ammonium perfluoroalkyl carboxylate[(1a)]	$NH_4^+ C_nF_{2n+1}COO^-$	n = 7	3825-26-1	D	(Poulsen, Jensen, and Wallström 2005)
Perfluoroalkyl phosphonic acids (PFPAs)[1b]	$C_nF_{2n+1}P(=O)(OH)_2$	n = 6, 8, 10	40143-76-8, 40143-78-0, 52299-26-0	U	(Z. Wang et al. 2016)

Perfluoroalkyl phosphinic acids (PFPiAs)[1c]	$C_nF_{2n+1}P(C_mF_{2m+1})(=O)OH$	n = 6/6, 6/8, 6/10, 6/12, 8/8, 8/10	40143-77-9, 610800-34-5, 1240600-40-1, 1240600-41-2, 40143-79-1, 500776-81-8	U	(Z. Wang et al. 2016)
(n:2) Fluorotelomer sulfonic acid (FTSA)[1d]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	D	(Janousek, Lebertz, and Knepper 2019)
(n:2) Fluorotelomer alcohols (FTOHs)[1e]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8, 10	647-42-7, 678-39-7, 865-86-1	D	(Janousek, Lebertz, and Knepper 2019)
Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly (difluoromethylene) (1:1)	-	-	65545-80-4	U	(USEPA 2016)
Phosphoric acid, mixed esters with poly ethylene glycol and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol, ammonium salts	-	-	1224429-82-6	U	(USEPA 2016)
-[1f]	$-F(C_3F_6O)_n-C_2F_4C(O)O(CH_2CH_2O)_mH-$ n = 2 to 200, m = 2 to 500	polymer	-	U	(Buck, Murphy, and Pabon 2012)

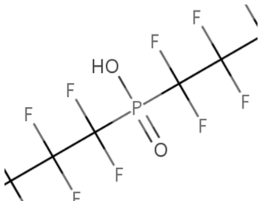
1a



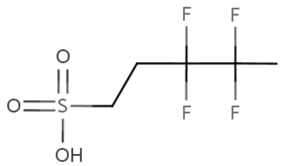
1b



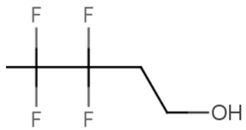
1c



1d



1e



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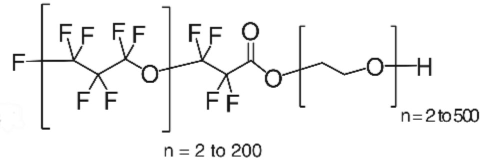
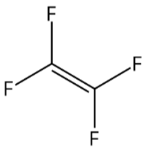
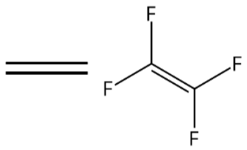


Polytetrafluoroethylene (PTFE)[2a]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U	(Banks, Smart, and Tatlow 1994)
Ethylene tetrafluoroethylene copolymer (ETFE)[2b]	$-(CH_2CH_2)_x-(CF_2CF_2)_y-$	polymer	25038-71-5	U	(Banks, Smart, and Tatlow 1994)
Fluorinated ethylene propylene (FEP)[2c]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-$	polymer	25067-11-2	U	(Banks, Smart, and Tatlow 1994)
Perfluoralkoxy polymer (PFA)[2d]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-$	polymer	26655-00-5	U	(Banks, Smart, and Tatlow 1994)

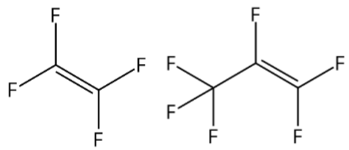
2a



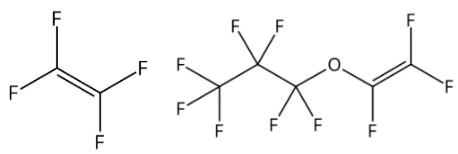
2b



2c

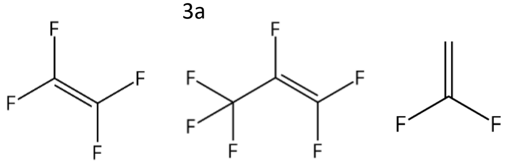


2d

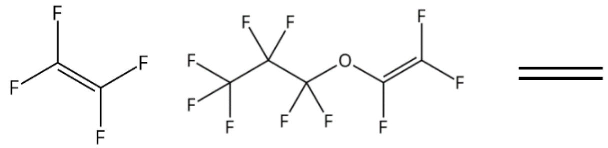


Hexafluoropropylene-tetrafluoroethylene-vinylidene fluoride copolymer (THV)[3a]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-(CF_2CH_2)_m-$	polymer	25190-89-0	U	(Gardiner 2015)
Propane, 1,1,1,2,2,3,3-heptafluoro-3-[(1,2,2-trifluoroethenyl)oxy]-, polymer with 1-chloro-1,2,2-trifluoroethene and ethene[3b]	$-(CF_2CFCl)_x-[CF_2CF(OC_3F_7)]_y-(CH_2CH_2)_m-$	polymer	35397-13-8	U	(USEPA 2016)

3a



3b



2.8.3 *Coatings for food contact materials others than paper*

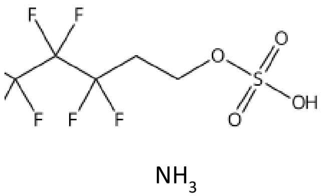
Food contact materials can be made out of many different materials. For applications where the packaging needs to be made oil and water repellent, PFAS are often used. The use of PFAS in paper and packaging as food contact materials is described in Section 2.26.1. Coatings of other materials are included here. Patent CN109370426 describes for example a coating composition for food contact materials and/or cookware (CAS 2019 (CN109370426, 2019)). Patent DE2549243 describes a coating for polyethylene (PE) film used e.g. for packaging toys and foodstuff (CAS 2019 (DE2549243, 1977)). The PE film with fluorinated coating is used as a primary packaging and prevents adhesion to a secondary film subsequently used for multiple packaging.

Table 61: PFAS that have been patented for use in food contact materials other than paper. Patent number (date, legal status): DE2549243 (1977, expired),CN109370426 (2019, not yet active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

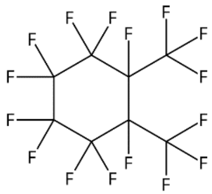
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Alkanol, perfluoro-, 1-(hydrogen sulfate), ammonium salt (1:1)[1a]	$NH_4^+\ C_nF_{2n+1}CH_2CH_2OSO_3^-$	n = 6, 8, 10, 12	63225-56-9, 63225-57-0, 63255-58-1, 63225-59-2	P	(CAS 2019 (DE2549243))
Perfluoro-1,2-dimethylcycloalkane[1b]	$c-C_nF_{2n}$	n = 8	306-98-9	P	(CAS 2019 (CN109370426))
Linear perfluoroalkanes[1c]	C_nF_{2n+2}	n = 5	678-26-2	P	(CAS 2019 (CN109370426))
Perfluoro-2,7-dimethyloctane[1d]	$CF_3CF(CF_3)CF_2CF_2CF_2CF_2CF(CF_3)CF_3$	-	3021-63-4	P	(CAS 2019 (CN109370426))

Perfluoro-3,4-dimethylhexane[1e]	$CF_3CF_2(CF(CF_3))_2CF_2CF_3$	-	1735-48-4	P	(CAS 2019 (CN109370426))
Hexane, 1,1,1,2,2,3,3,4,5,5,6,6,6-tridecafluoro-[1f]	$C_3F_7CFHCF_2CF_3$	-	1998-67-0	P	(CAS 2019 (CN109370426))

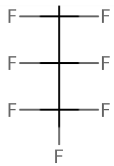
1a



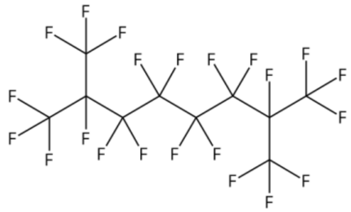
1b



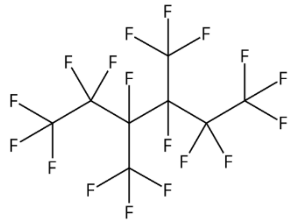
1c



1d



1e



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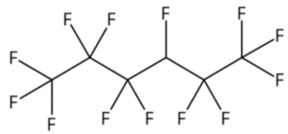
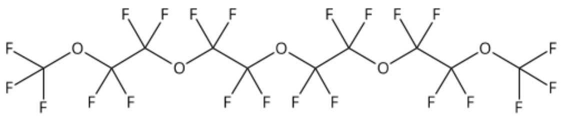
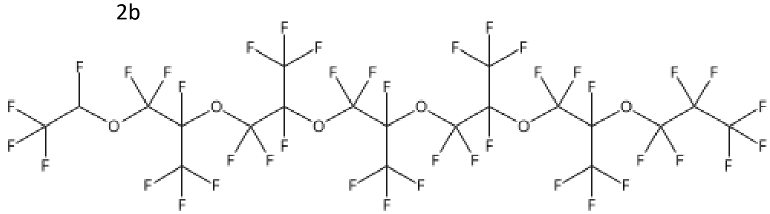


2,5,8,11,14-Pentaoxapentadecane, 1,1,1,3,3,4,4, 6,6,7,7,9,9,10,10,12,12,13,13,15,15,15-docosafluoro-[2a]	$CF_3O(CF_2CF_2O)_4CF_3$	-	64028-06-4	P	(CAS 2019 (CN109370426))
3,6,9,12,15,18-Hexaoxaheneicosane, 1,1,1,2,4, 4,5,7,7,8,10,10,11,13,13,14,16,16,17,19,19,20,20,21,21,21-hexacosafluoro-5,8,11,14,17-pentakis (trifluoromethyl)-[2b]	$CF_3CFH(OCF_2CF(CF_3)_5OCF_2CF_2CF_3$	-	55154-18-2	P	(CAS 2019 (CN109370426))

2a



2b



2.9 Conservation of books and manuscripts

Expanded PTFE (Gore-tex) has been used to preserve historical manuscripts (Gardiner 2015).

2.10 Cook- and baking ware

Polymeric PFAS can be used in the undercoat and overcoat of cookware such as frying pans, but also in large-scale commercial baking. The coating prevents the food from sticking to the pan and facilitates the cleaning of the cookware. The treated products are also abrasion and temperature resistant (KEMI Swedish Chemical Agency 2015b). The most common fluoropolymer for this application has been PTFE (CAS No. 9002-84-0), but FEP (CAS No. 25067-11-2) and PFA (CAS No. 26655-00-5) can also be used (CAS 2019 (WO2006066027, 2006)).

PFOA (CAS No. 335-67-1) and perfluorobutane sulfonic acid (PFBS, CAS No. 375-73-5) have been detected in reusable baking liner (Blom and Hanssen 2015). PFBS has also been detected in non-stick cupcake baking ware and 6:2 and 8:2 FTOH (CAS No. 647-42-7 and 678-39-7, respectively) have been detected in non-stick silicon baking ware, non-stick cupcake baking ware, and reusable baking liner (Blom and Hanssen 2015). The detection of PFBS did most probably not originate from the fluoropolymers itself but is rather a contamination of the sample.

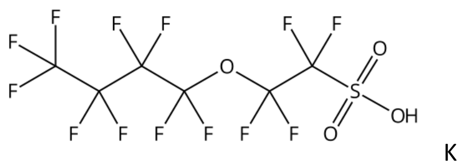
2.11 Dispersions

Fluorinated surfactants can be used to disperse various particles. For example, ferromagnetic metal oxide particles have been dispersed with potassium *N*-ethyl perfluorooctane sulfonamidoacetate (CAS No. 2991-50-6) to make magnetic fluids (Kissa 2001). Conductive carbon black particles have been dispersed with nonionic or cationic hydrocarbon-type or fluorinated surfactants for use in polymer blends of poly(vinyl chloride) pipes (Kissa 2001). Also, dispersions of cells in clinical laboratories can be prepared with potassium *N*-ethyl perfluorooctane sulfonamidoacetate (CAS No. 2991-50-6) to diagnose cell abnormalities (Kissa 2001; CAS 2019 (JP52105208, 1977)). Fluorinated surfactants can also be used to disperse lubricating greases (see Table 62) (CAS 2019 (EP95825, 1983)). The SPIN database of the Nordic countries discloses that PTFE has also been used as a dispersion agent (Norden 2020).

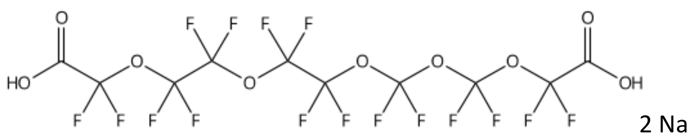
Table 62: Fluorinated surfactants patented as dispersants for lubricating greases. Patent number (date, legal status): EP95825 (1983, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Ethanesulfonic acid, 1,1,2,2-tetrafluoro-2-[(perfluoro alkyl)oxy]-, potassium salt (1:1)[1a]	$K^+ C_nF_{2n+1}OC_2F_4SO_3^-$	n = 4	88707-88-4	P	(CAS 2019 (EP95825))
3,5,7,10,13-Pentaoxapentadecanedioic acid, 2,2,4,4,6,6,8,8,9,9,11,11,12,12,14,14-hexadecafluoro-, sodium salt (1:2)[1b]	$2\ Na^+\ CO_2^-CF_2OCF_2CF_2OCF_2CF_2(OCF_2)_3COO^-$	-	88707-87-3	P	(CAS 2019 (EP95825))
Phosphine, tris[4-[4,4,6,7,7,9,10,10,12,13,13,15, 15,15-tetradeca fluoro-6,9,12-tris(trifluoromethyl)-2,5,8,11,14-pentaoxapentadec-1-yl]phenyl]-[(too large to show)]	$P[C_6H_4CH_2OCH_2(CF_2OCF(CF_3))_3CF_2OCF_3]_3$	-	88750-33-8	P	(CAS 2019 (EP95825))

1a



1b



2.12 Electronic devices

2.12.1 Printed circuit boards

Printed circuit boards, which are laminates of copper on a fibre-reinforced fluoropolymer layer, take advantage of the low dielectric constant provided by the fluoropolymer (R. E. Banks, Smart, and Tatlow 1994). Two fluoropolymers that have been disclosed in a patent for this application are PTFE (CAS No. 9002-84-0) and ethene, 1,1,2,2-tetrafluoro-, polymer with 1,1'-oxybis[ethene] (CAS No. 102646-47-9) (CAS 2019 (US20030203174, 2003)). 6:2 Fluorotelomer sulfonic acid (CAS No. 27619-97-2), perfluorooctane sulfonamide (CAS No. 754-91-6), PFOS (CAS No. 1763-23-1) and perfluorobutanoic acid (CAS No. 375-22-4) were detected in circuit board samples (Herzke, Olsson, and Posner 2012).

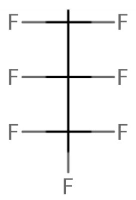
2.12.2 Capacitors

Perfluorocarbons and hydrofluorocarbons (e.g. pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-, CAS No. 138495-42-8) are used in applications requiring separation of high voltage components such as capacitors, because they have high dielectric breakdown strength and (unlike oil) are not flammable (F2_Chemicals 2019a; Chemours 2019e). PFAS that have been used as liquid impregnants for capacitors are shown in Table 63.

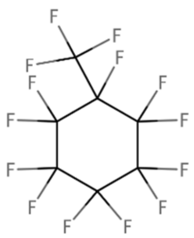
Table 63: PFAS used as liquid impregnants for capacitors. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Linear perfluoroalkanes[1a]	C_nF_{2n+2}	n = 6	355-42-0	U	(R. E. Banks, Smart, and Tatlow 1994)
Perfluoromethylcycloalkane[1b]	C_nF_{2n+2}	n = 6, 7	1805-22-7, 355-02-2	U	(R. E. Banks, Smart, and Tatlow 1994)
Perfluoro-1,3-dimethylcycloalkane[1c]	C_nF_{2n}	n = 8	335-27-3	U	(R. E. Banks, Smart, and Tatlow 1994)
Perfluorotrialkyl amine[1d]	$N(C_nF_{2n+1})_3$	n = 4	311-89-7	U	(R. E. Banks, Smart, and Tatlow 1994)
Perfluorinated cyclic ethers	-	-	-	U	(R. E. Banks, Smart, and Tatlow 1994)

1a



1b



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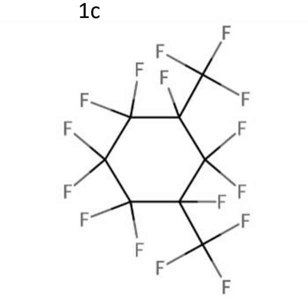
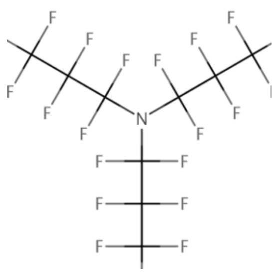


1d



Ionic liquid gel polymer electrolytes based on ionic liquid 1-ethyl-3-methylimidazolium tris(pentafluoroethyl) trifluorophosphate (CAS No. 123199-69-9) immobilized in vinylidenfluorid-hexafluorpropylen copolymer (CAS No. 9011-17-0) has been used to fabricate supercapacitors (Pandey and Hashmi 2013).

2.12.3 Acoustic equipment

Applications in the acoustic field depend mostly on the piezoelectric and pyroelectric properties of PVDF films (R. E. Banks, Smart, and Tatlow 1994). PVDF films in the β form can provide an electrical signal in response to mechanical or thermal signals or, inversely, mechanical motion or a change in heat content in response to an applied electrical field. Copolymers with trifluoroethylene are of particular interest due to their spontaneous crystallization in the β phase. Applications include speakers, transducers, hydrophones, and electromagnetic radiation detectors (R. E. Banks, Smart, and Tatlow 1994).

2.12.4 Liquid crystal displays (LCDs)

Liquid crystal displays are part of smartphones, PC monitors, flat-panel displays for TVs, tablet computers and notebooks (Kirsch and Bremer 2010). In most of these applications, the active matrix technology has been applied (Yamada et al. 2017). There are different driving modes in the active matrix technology, i.*e.* twisted nematic-mode, super-twisted nematic-mode and electrically controlled birefringence-mode (Yamada et al. 2017). The nematic liquid-crystalline materials that were developed in the early 1990s contained fluorine itself or short fluorinated functional groups as polar terminal groups (e.g. $-OC_2F_5$ or $-OCF_2CHFCF_3$) (Kirsch 2015). Their main function was to provide the liquid crystal with a dipole moment, which is essential for switching by an applied electrical field. More recently, many liquid crystals in practical use or under development contain fluorinated aliphatic bridges, linking the cyclic subunits of their mesogenic core structure (Kirsch and Bremer 2010). In particular, insertion of a $-CF_2CF_2-$ or a $-CF_2O-$ bridge leads to a dramatic increase of the nematic phase range and clearing temperature (Kirsch 2015). The $-CF_2O-$ bridge, moreover, causes a sharp reduction of the rotational viscosity (Kirsch 2015). Fluorine-containing organic molecules (e.g. tricyclic compounds with a 5,5,6,6-tetra-fluorocyclohexa-1,3-diene moiety in the mesogen) have also been applied in the electrically controlled birefringence-mode, which is current state of the art technology (Yamada et al. 2017). For more information, see Yamada *et al.* (2017) and Kirsch (2015). PCTFE is used in coatings to protect the moisture-sensitive LCD panels (Gardiner 2015).

2.12.5 Flat panel display

Flat panel displays which are backlight display devices use light management films to control the light intensity of the display. These light management films comprise a thermoplastic base layer, such as polycarbonate or polyethylene terephthalate, and a microstructure prismatic layer. Tetrabutylphosphonium perfluorobutane sulfonate (CAS No. 220689-12-3) has been patented for use in these light management films to reduce static electricity build-up and dust attraction during fabrication (CAS 2019 (WO2006031507, 2006)).

2.12.6 Household equipment

Teflon strips (PTFE) have been used on razors (Gardiner 2015). PFCAs and PFSAs were detected in switches (not clear what kind of switches), vacuum cleaners, coffee makers, keyboards, screens, and TVs (Bečanová et al. 2016). For more detailed information (which specific PFAAs were detected in which product), see Bečanová et al. (2016).

2.12.7 Others

PCTFE has been used for coating electroluminescent lamps in commercial signage and safety exit signs (Gardiner 2015).

2.13 Fingerprint development

HFE-7100 (CAS No. 219484-64-7) has been used as a replacement for chlorofluorocarbon solvents in fingerprint development (Hansen and Joullié 2005). HFE-7100 is a mixture composed out of methyl nonafluoroisobutyl ether (CAS No. 163702-08-7) and methyl nonafluorobutyl ether (CAS No. 16302-07-6).

2.14 Fire-fighting foams

Fire-fighting foams with fluorinated surfactants are used for extinguishing liquid fires (Class B fires) (UNEP 2017). Examples are fires in flammable liquids like oil, petrol, other non-water-soluble hydrocarbons, and flammable water-soluble liquids like alcohols and acetone (UNEP 2017). There are two major Class B foam subtypes: synthetic foams and protein foams. Examples for synthetic foams are aqueous film forming foams (AFFFs) and alcohol-resistant aqueous film-forming foams (AR-AFFFs), and examples for protein foams are fluoroprotein (FP) foams, film-forming fluoroprotein (FFFP) foams, alcohol-resistant fluoroprotein (AR-FP) foams, and alcohol-resistant film-forming fluoroprotein (AR-FFFP) foams.

All of these fire-fighting foams float on the flammable liquid and form a foam barrier which inhibits evaporation and reigniting (Kissa 2001). Various fluorinated surfactant have been added in the past (i) as film formers in AFFFs and FFFPs, (ii) as fuel repellents in FPs, and (iii) as foam stabilizers in FFFPs and AR-AFFFs (Z. Wang et al. 2013). The types of PFAS in fire-fighting foams vary by year of production and manufacturer (Dauchy et al. 2017).

AFFFs can be divided into three main types: legacy POSF-based AFFFs, legacy fluorotelomer-based AFFFs and modern fluorotelomer-based AFFFs (ITRC 2020). Legacy POSF-based AFFFs were manufactured in the US from the late 1960s until 2002 exclusively by 3M and sold under the brand name “Lightwater”. Legacy POSF-based AFFFs contain PFOS and various precursors that could potentially break down in the environment to PFOS and shorter chain PFSAs such as perfluorohexane sulfonic acid (PFHxS, CAS No. 355-46-4) (ITRC 2020). Legacy fluorotelomer-based AFFFs were manufactured and sold in the US from the 1970s until 2016 and encompass all other brands of AFFF besides 3M Lightwater (ITRC 2020). Legacy fluorotelomer-based AFFF foams have historically contained predominantly short-chain (C6) PFAS with formulations ranging from about 50–98% short-chains, but also contained some longer chain PFAS content. The longer chain PFAS content of these foams has the potential to break down in the environment to PFOA and other PFCAs (Weiner et al. 2013). Modern fluorotelomer-based AFFFs contain almost exclusively short-chain PFAS in response to the USEPA voluntary PFOA Stewardship Program. However, stockpiles of legacy perfluorinated fire-fighting foams still exist (POPRC 2018a) and as fire-fighting foams have a long shelf life (10 to 20 years), these legacy perfluorinated fire-fighting foams, which contain longer chain PFAS content, may still be used around the world in Class B fires (POPRC 2016a). It has also been noticed that many companies preferred to remain with their standard processes and mixture of shorter and longer chain PFAS content. One example is the use of C8-C20-γ- ω-perfluorotelomer thiols with acrylamide (CAS number 70969-47-0) (KEMI Swedish Chemical Agency 2015b).

There are also other – non foam based – fire protection fluids. 3M markets a perfluoroketone compound (perfluoro-2-methyl-3-pentanone, CAS No. 756-13-8) for use as fire protection fluid (Poulsen, Jensen, and Wallström 2005). Perfluoro-2-methyl-3-pentanone was used in the Nordic countries as fire extinguishing agent in 2016 and 2017 (Norden 2020) and in the US between 2012 and 2015 (USEPA 2016).

2.14.1 Fluoroprotein (FP) foams

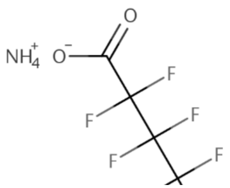
Protein foam concentrates are produced from products such as hoof and horn meal, chicken feathers, or fish meal (Kissa 2001). Fluorinated surfactants added to protein foams enhance the fire-extinguishing efficiency by repelling hydrocarbon fuel when the foam is covered with fuel (Kissa 2001). The fluoroprotein foam can e.g. be introduced to the base of a burning fuel tank, rises then through the fuel and extinguishes the fire. Also, the low surface tension allows fluoroprotein foams to move rapidly over a hydrocarbon fuel surface (Kissa 2001). Fluoroprotein foams have been used for hydrocarbon storage tank protection and marine applications (POPRC 2016a). Examples of fluorinated surfactants used in fluoroprotein foams are given in Table 64.

A Chinese patent discloses that gases like perfluoropropane (CAS No. 76-19-7), perfluorobutane (CAS No. 355-25-9), 1H-pentafluoroethane (CAS No. 354-33-6), and hexafluoroethane (CAS No. 76-16-4) are useful foaming agents for protein foams (CAS 2019 (CN101371944, 2009)).

Table 64: PFAS historically or currently used in, patented for use, or detected in FP, FFFP, and AR-FFFP. Patent number (date, legal status): US3475333 (1969, expired), JP55146172 (1980, expired), DE2240263 (1973, expired), JP60060865 (1985, expired). The types stand for U – use, U* – current use, P – patent, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	References
Fluoroprotein foam (FP)					
Ammonium perfluoroalkyl carboxylate[1a]	$NH_4^+ C_nF_{2n+1}COO^-$	n = 7	3825-26-1	P	(CAS 2019 (US3475333))
Potassium perfluoroalkyl carboxylate[(1a)]	$K^+ C_nF_{2n+1}COO^-$	n = 9	51604-85-4	P	(CAS 2019 (JP55146172))
(n:2) Fluorotelomer thioether acetamide derivative[1b]	$C_nF_{2n+1}CH_2CH_2S(CH_2CH_2(CONH_2))_mH$	m = 10 - 20, n = 6, 8, 10	-	U	(Buck, Murphy, and Pabon 2012)
Benzenesulfonic acid, [(heptadecafluorooctyl)oxy]-, sodium salt[1c]	$C_6H_6\ C_8F_{17}OSO_3H$	-	41674-07-1	P	(CAS 2019 (DE2240263))
1,3-Benzenedicarboxylic acid, [(heptadecafluoro octyl)oxy]-, calcium salt[1d]	x $Ca^{2+}\ C_6H_4(COO^-)_2C_8F_{17}O$	-	97746-87-7	P	(CAS 2019 (JP60060865))

1a



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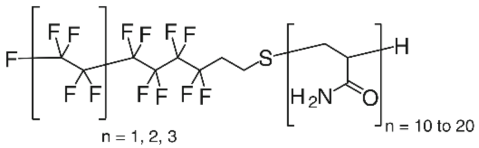

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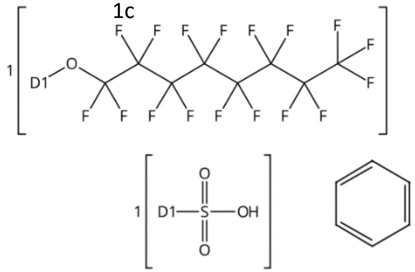

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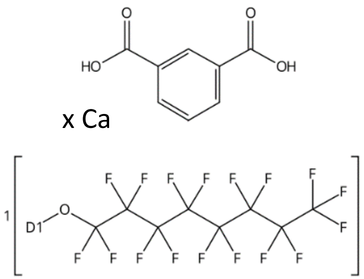
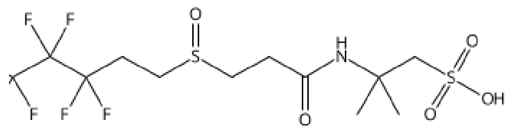


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	References
Film forming fluoroprotein (FFFP) foam					
1-Propanesulfonic acid, 2-[[3-[(perfluoro alkyl)sulfinyl]-1-oxopropyl]amino]-2-methyl-[2a]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 6, 8	1513864-10-2, 1513864-12-4	D	(Dauchy et al. 2017)
1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)sulfinyl][2b]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH(OH)CH_2N^+(CH_3)_3$	n = 6	1513864-03-3	D	(Dauchy et al. 2017)

(1-Propanesulfonic acid, 2-[[3-[(perfluoroalkyl) thio]-1-oxopropyl]amino]-2-methyl-[2c]	$C_nF_{2n+1}CH_2CH_2SCH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 6	62880-95-9	D	(Dauchy et al. 2017)

2a



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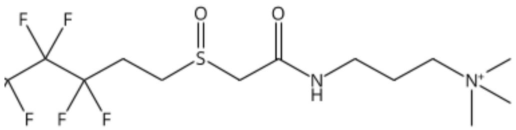

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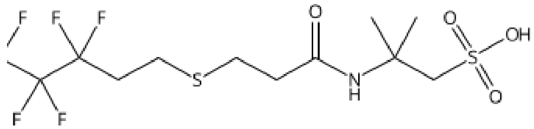
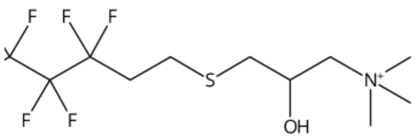


1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)thio]-[3a]	$C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2N^+(CH_3)_3$	n = 6	88992-46-5	D	(Dauchy et al. 2017)
Benzenesulfonic acid, 4-[[3,4,4,4-tetrafluoro-2-[1, 2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]-1,3-bis(trifluoromethyl)-1-buten-1-yl]oxy]-, sodium salt (1:1)[3b]	$Na^+ \ C_9F_{17}OC_6H_4SO_3^-$	-	70829-87-7	U*	(Bao et al. 2017)

3a



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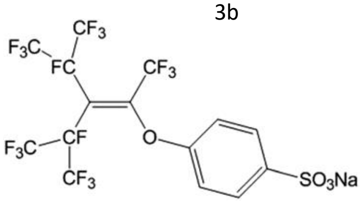
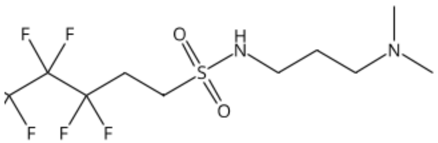


<u>Alcohol-resistant film forming fluoroprotein (AR-FFFP) foam</u>					
1-Alkanesulfonamide, *N*-[3-(dimethylamino) propyl]-perfluoro-[4a]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N(CH_3)_2$	n = 6	34455-22-6	D	(Dauchy et al. 2017)
(n:2) Fluorotelomer sulfonamide betaine (FTAB)[4b]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 6	34455-29-3	D	(Dauchy et al. 2017)
(n:2) Fluorotelomer sulfonic acid (FTSA)[4c]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	D	(Dauchy et al. 2017)
1-Propanesulfonic acid, 2-[[3-[(perfluoroalkyl) sulfinyl]-1-oxopropyl]amino]-2-methyl-[2a]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 6	1513864-10-2	D	(Dauchy et al. 2017)
1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)sulfinyl][2b]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH(OH)CH_2N^+(CH_3)_3$	n = 6	1513864-18-0	D	(Dauchy et al. 2017)
(1-Propanesulfonic acid, 2-[[3-[(perfluoroalkyl) thio]-1-oxopropyl]amino]-2-methyl-[2c]	$C_nF_{2n+1}CH_2CH_2SCH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 4, 6	1333933-57-5, 62880-95-9	D	(Dauchy et al. 2017)
(n:2) Fluorotelomer thioether acetic acid[4d]	$C_nF_{2n+1}CH_2CH_2SCH_2COOH$	n = 6	-	D	(Dauchy et al. 2017)

1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)thio]- [3a]	$C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2N^+(CH_3)_3$	n = 4, 6, 8, 10	1513864-16-8, 88992-46-5, 727351-53-3, 1513864-17-9	D	(Dauchy et al. 2017)

4a



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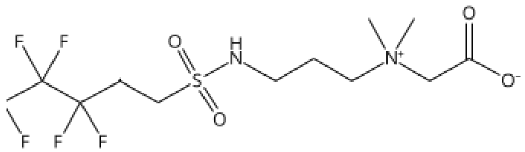

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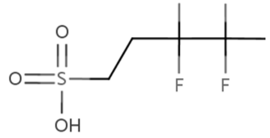

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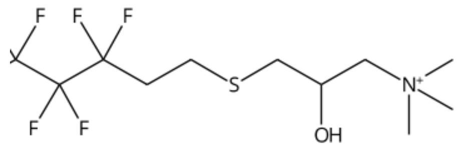
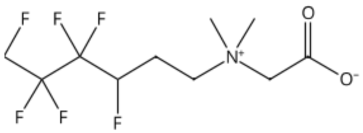


(n:1:2) Fluorotelomer betaine[5a]	$C_nF_{2n+1}CFHCH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 7	171184-03-5	D	(Dauchy et al. 2017)
(n:3) Fluorotelomer betaine[5b]	$C_nF_{2n+1}CH_2CH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 7	171184-15-9	D	(Dauchy et al. 2017)
Perfluoroalkane sulfonamido amine[5c]	$C_nF_{2n+1}SO_2NCH_2CH_2CH_2N^+H(CH_3)_2$	n = 8	13417-01-1	D	(Dauchy et al. 2017)

5a



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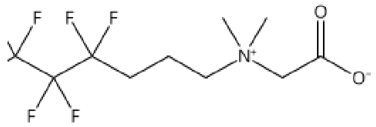

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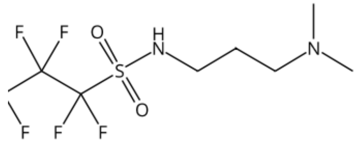


2.14.2 Film-forming fluoroprotein (FFFP) foam

FFFP foams are based on natural proteins as foaming agents. They have been used for aviation and shallow spill fires (POPRC 2016b). The fluorinated surfactants in FFFP act as foam stabilizer and film former (Cousins et al. 2016). Examples of PFAS which have been or are still used in FFFP are provided in Table 64.

2.14.3 Alcohol-resistant film forming fluoroprotein (AR-FFFP) foam

AR-FFFP foams are also based on natural proteins as foaming agents and are suitable for polar solvent liquid fires (Angusfire 2019). Examples of PFAS which have been or are still used in AR-FFFP are also provided in Table 64.

2.14.4 Aqueous film-forming foams (AFFF)

AFFFs are complex mixtures containing fluorocarbon- and hydrocarbon- based surfactants (Rotander et al. 2015). The fluorinated AFFF agents are synthetic chemicals that lower the surface tension of water and form an aqueous film on the fuel surface (Kissa 2001). This water film, which is located between the fuel and the foam, cools the surface of the fuel, acts as a vapor barrier, supports the spreading of the foam on the fuel and promotes the self-healing of the foam blanket after injuries (POPRC 2016a). AFFFs have been used for petroleum fires in, for example, chemical plants, fuel storage facilities, airports, underground parking facilities, tunnels and the marine sector (KEMI Swedish Chemical Agency

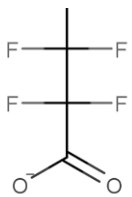
2015b; POPRC 2016a). Table 65 lists more than 90 groups of PFAS that have been or are still used, have been detected, or have been patented for use in AFFF. The groups include perfluoroalkyl acids, perfluoroalkane sulfonyl fluoride (PASF)-based substances, fluorotelomer-based substances, other non-polymeric groups and perfluoropolyether (PFPE).

AFFF concentrates used by the US military must meet the requirements set forth in military specification MIL-F-24385 (Korzenioswski et al. 2019). No perfluorobutane sulfonyl based fluorosurfactants have been qualified under the MIL-F-24385; however, perfluorohexane sulfonyl based surfactants did meet the requirements (Korzenioswski et al. 2019).

Table 65: PFAS historically or currently used, patented or detected in AFFF. Patent number (date, legal status): JP58112565 (1983, expired), US5085786 (1992, expired), JP58038571 (1983, expired), JP2001079108 (2001, pending), JP61076175 (1986, expired), WO9746283 (1997, expired), WO9929373 (1999, active), JP54141100 (1979, expired), WO2001083037 (2001, active), DE2315326 (1973, expired), JP09173498 (1997, pending), EP1013311 (2000, discontinued). The types stand for U – use, U* – current use, P – patent, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl acids (PFAAs)					
Perfluoroalkyl carboxylic acid (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 11	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1	D	(Backe, Day, and Field 2013; Weiner et al. 2013; Mumtaz et al. 2019)
Potassium perfluoroalkyl carboxylate[(1a)]	$K^+ C_nF_{2n+1}COO^-$	n = 7	2395-00-8	P	(CAS 2019 (JP58112565))
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 2 - 10	354-88-1, 423-41-6, 375-73-5, 2706-91-4, 355-46-4, 375-92-8, 1763-23-1, 474511-07-4, 335-77-3	D	(Barzen-Hanson and Field 2015; Backe, Day, and Field 2013)
Potassium perfluoroalkane sulfonate[(1b)]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (US5085786))
Tetraethylammonium perfluoroalkane sulfonate[(1b)]	$N(C_2H_5)_4^+ C_nF_{2n+1}SO_3^-$	n = 8	56773-42-3	U	(Norden 2013)
1-Alkanesulfonic acid, 1-chloro-perfluoro-[1c]	$C_nF_{2n+1}CFClSO_3H$	n = 2 to 7	1651215-29-0, 165125-26-7	D	(Barzen-Hanson et al. 2017)
1-Alkanesulfonic acid, perfluoro-*n*-oxo-[1d]	$CF_3C(O)C_nF_{2n}SO_3H$	n = 3 to 8	2254560-25-1, 2254560-26-2, 2254560-27-3, 165215-27-8	D	(Barzen-Hanson et al. 2017)

1a



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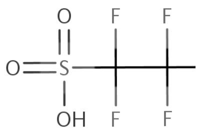

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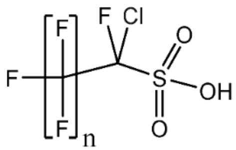

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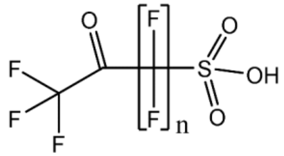
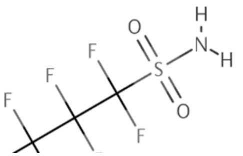


Perfluoroalkane sulfonyl fluoride (PASF)-based substances					
Perfluoroalkane sulfonamides (FASAs)[2a]	$C_nF_{2n+1}SO_2NH_2$	n = 6, 8	41997-13-1, 754-91-6	P, D	(CAS 2019 (JP58038571); Herzke, Posner, and Olsson 2009)
Perfluoroalkane sulfonamidoethanol (FASE)[2b]	$C_nF_{2n+1}SO_2NHCH_2CH_2OH$	n = 8	10116-92-4	D	(Herzke, Posner, and Olsson 2009)
Perfluoroalkane sulfonamido amine (PFASAA)[2c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+H(CH_3)_2$	n = 3 - 8	1513864-23-7, 68555-77-1, 68555-78-2, 50598-28-2, 67584-54-7, 13417-01-1	U, D	(D'Agostino and Mabury 2014; Place and Field 2012)
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-[2d]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 3 - 8	1966131-51-0, 70225-21-7, 70225-23-9, 70248-51-0, 70225-19-3, 70225-25-1	D	(Barzen-Hanson et al. 2017)
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[(2d)]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 4, 8	67939-95-1, 1652-63-7	D, P	(CAS 2019 (JP2001079108); POPRC 2016a)
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[(2d)]	$Cl^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+ (CH_3)_3$	n = 4, 8	53518-00-6, 38006-74-5	D, P	(Norwegian Environment Agency 2017; CAS 2019 (JP61076175))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, bromide (1:1)[(2d)]	$Br^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+ (CH_3)_3$	n = 8	73149-44-7	P	(CAS 2019 (JP2001079108))
Perfluoroalkane sulfonamido amine oxide (PFASNO)[2e]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N(CH_3)_2O$	n = 4 - 10	178094-76-3, 178094-75-2, 30295-56-8, 178094-74-1, 30295-51-3, 1513864-26-0, 200636-64-2	D, P	(Barzen-Hanson et al. 2017; D'Agostino and Mabury 2014; CAS 2019 (WO9746283, WO9929373)

2a



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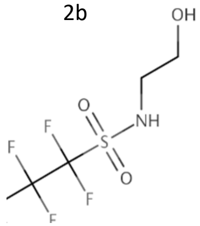

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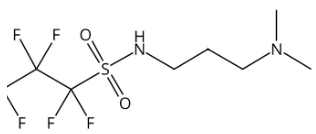

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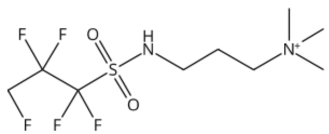
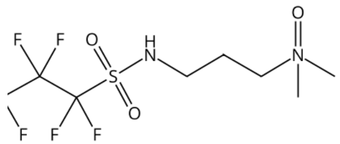


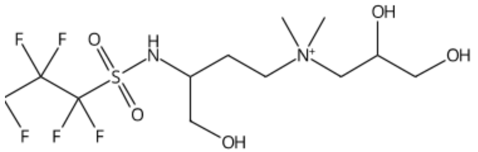
2e



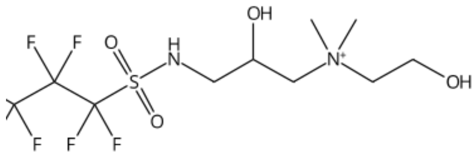
1-Butanaminium, *N*-(2,3-dihydroxypropyl)-4-hydroxy-*N*,*N*-dimethyl-3-[[(perfluoroalkyl)sulfonyl] amino]-[3a]	$C_nF_{2n+1}SO_2NHCH(CH_2OH)CH_2CH_2N^+(CH_3)(CH_3)CH_2CH(OH)CHOH$	n = 3 - 6	2089108-83-6, 2089108-84-7, 2089108-85-8, 2089108-86-9	D	(Barzen-Hanson et al. 2017)
1-Propanaminium, 2-hydroxy-*N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-3-[[(perfluoroalkyl)sulfonyl]amino]-[3b]	$C_nF_{2n+1}SO_2NHCH_2CH(OH)CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 4 - 6	2089109-04-4, 2089109-05-5, 2089109-06-6	D	(Barzen-Hanson et al. 2017)
1-Propanaminium, *N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-3-[[(perfluoroalkyl)sulfonyl]amino]- [3c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 2 - 8	2089109-07-7, 2089109-08-8, 2089109-09-9, 142519-	D	(Barzen-Hanson et al. 2017)

1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] methylamino]-*N*,*N*,*N*-trimethyl-[3d]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2CH_2N^+(CH_3)_3$	n = 4 - 8	28-6, 736877-37-5, 2089109-10-2, 71864-97-6 2089109-11-3, 2089109-12-4, 765219-81-6, 2089109-13-5, 153968-04-8	D	(Barzen-Hanson et al. 2017)

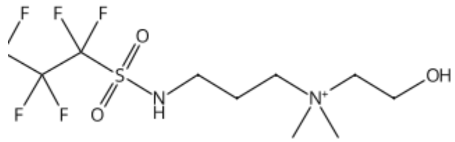
3a



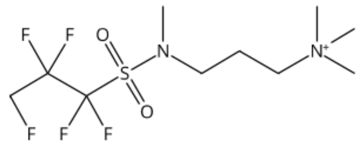
3b



3c

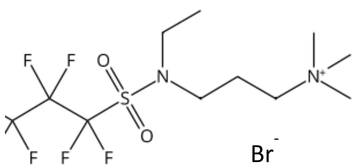


3d

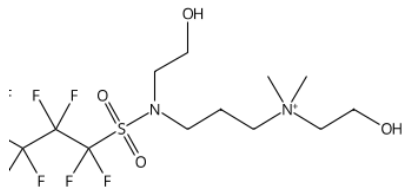


1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] ethylamino]-*N*,*N*,*N*-trimethyl-, bromide (1:1)[4a]	Br^- $C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2CH_2N^+(CH_3)_3$	n = 8	331755-01-2	P	(CAS 2019 (JP2001079108))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] ethylamino]-*N*,*N*,*N*-trimethyl-, ethansulfate (1:1)[(4a)]	$CH_3CH_2SO_4^-$ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2CH_2N^+(CH_3)_3$	n = 4, 6, 8, 10	-	U	(Buck, Murphy, and Pabon 2012)
1-Propanaminium, *N*-(2-hydroxyethyl)-3-[(2-hydroxyethyl)[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl- [4b]	$C_nF_{2n+1}SO_2N(CH_2CHOH)CH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 2 - 8	2089108-97-2, 2089108-98-3, 2089108-99-4, 2089109-00-0, 2089109-01-1, 2089 109-02-2, 2089109-03-3	D	(Barzen-Hanson et al. 2017)
Perfluoroalkane sulfonamido betaine[4c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N+(CH_3)_2CH_2COOH$	n = 3 - 6	2089109-21-5, 2089109-22-6, 2089109-23-7, 2089109-24-8	D	(Barzen-Hanson et al. 2017)
1-Propanaminium, *N*-(2-carboxyethyl)-*N*,*N*-dimethyl-3-[[(perfluoroalkyl)sulfonyl]amino]-, inner salt [4d]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 3 – 6, 8	89148-24-3, 1513864-21-5, 1513864-22-6, 81190-41-2, 73469-65-5	D, P	(D'Agostino and Mabury 2014; CAS 2019 (JP54141100))

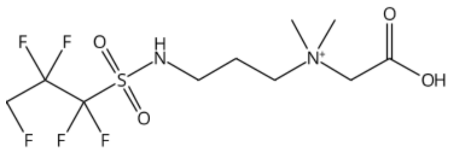
4a



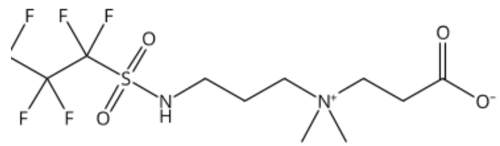
4b



4c



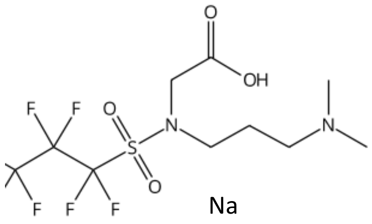
4d



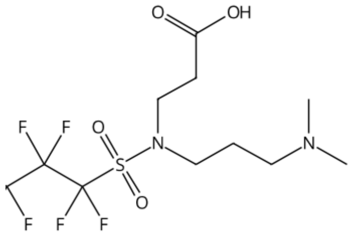
Glycine, *N*-[3-(dimethylamino)propyl]-*N*-[(heptadecafluorooctyl)sulfonyl]-, sodium salt[5a]	Na^+ $C_nF_{2n+1}SO_2N(CH_2COO^-)C_3H_6N(CH_3)_2$	n = 8	98900-84-6	P	(CAS 2019 (JP2001079108))

β-Alanine, *N*-[3-(dimethylamino)propyl]-*N*-[(perfluoroalkyl) sulfonyl]-[5b]	$C_nF_{2n+1}SO_2N(CH_2CH_2COO^-)CH_2CH_2CH_2NH^+(CH_3)_2$	n = 3 - 8	1513864-20-4, 172616-04-5, 1383438-83-2, 141607-32-1, 1432486-91-3, 1432486-92-4	U, D	(D'Agostino and Mabury 2014; Place and Field 2012)
β-Alanine, *N*-[3-(dimethylamino)propyl]-*N*-[(perfluoroalkyl)sulfonyl]-, sodium salt[(5b)]	Na^+ $C_nF_{2n+1}SO2N(CH_2CH_2COO^-)CH_2CH_2CH_2N(CH_3)_2$	n = 6	98900-70-0	P	(CAS 2019 (JP2001079108))
1-Propanaminium, 3-[(2-carboxyethyl)[(per fluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-[5c]	$C_nF_{2n+1}SO_2N(CH_2CH_2COO^-)CH_2CH_2CH_2N^+(CH_3)_3$	n = 3 - 6	2089109-14-6, 2089109-15-7, 2089109-16-8, 2089109-17-9	D	(Barzen-Hanson et al. 2017)
1-Propanaminium, *N*-(2-carboxymethyl)-3-[(2-carboxyethyl)[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl-[5d]	$C_nF_{2n+1}SO_2N(CH_2CH_2COOH)CH_2CH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 4 - 6	-	D	(Barzen-Hanson et al. 2017)

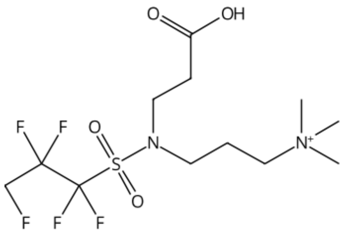
5a



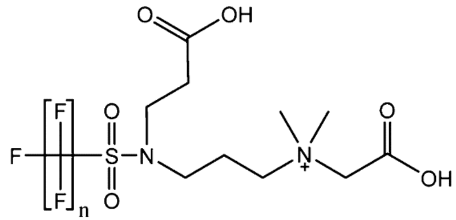
5b



5c

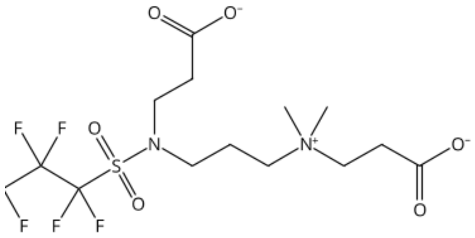


5d

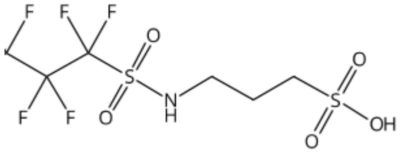


1-Propanaminium, *N*-(2-carboxyethyl)-3-[(2-carboxyethyl)[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*-dimethyl-, inner salt, ion(1-)[6a]	$C_nF_{2n+1}SO_2N(CH_2CH_2COO^-)CH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 3 - 6	1513864-24-8, 1513864-25-9, 1383438-84-3, 1383438-85-4	U, D	(D'Agostino and Mabury 2014; Place and Field 2012)
3-[[(Perfluoroalkyl)sulfonyl]amino]-1-propane sulfonic acid[6b]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2SO_3H$	n = 3 - 6	2089108-61-0, 2089108-62-1, 2089108-63-2, 2089108-64-3	D	(Barzen-Hanson et al. 2017)
1-Propanaminium, *N*,*N*-dimethyl-*N*-[3-[[(per fluoroalkyl)sulfonyl]amino]propyl]-3-sulfo-[6c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2CH_2SO_3H$	n = 3 - 8	2089108-65-4, 2089108-66-5, 2089108-67-6, 2089108-68-7, 2089108-69-8	D	(Barzen-Hanson et al. 2017)

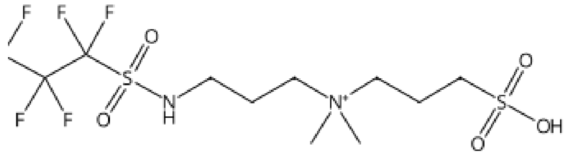
6a



6b

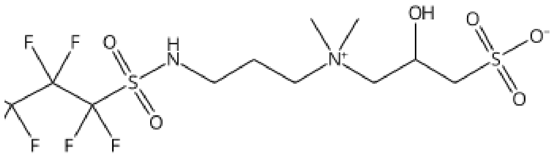


6c

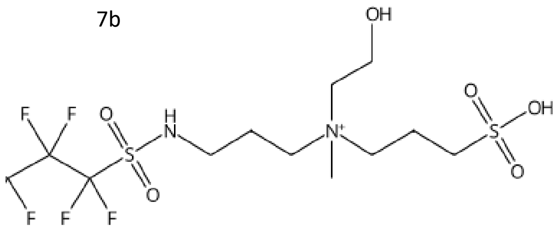


1-Propanaminium, 2-hydroxy-*N*,*N*-dimethyl-*N*-[3-[[(perfluoroalkyl)sulfonyl]amino]propyl]-3-sulfo-[7a]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH(OH)CH_2SO_3H$	n = 3 - 9	2089108-70-1, 2089108-71-2, 2089108-72-3, 2089108-73-4, 133082-79-8	D	(Barzen-Hanson et al. 2017; CAS 2019 (WO2001083037))
1-Propanaminium, *N*-(2-hydroxyethyl)-*N*-methyl-*N*-(3-sulfopropyl)-3-[[(perfluoroalkyl)sulfonyl] amino]-[7b]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)(CH_2CH_2OH)CH_2CH_2CH_2SO_3H$	n = 4 - 6	2089108-74-5, 2089108-75-6, 2089108-76-7	D	(Barzen-Hanson et al. 2017)
Ethanesulfonic acid, 2-[[3-[[perfluoroalkyl) sulfonyl]amino]propyl]amino]-, sodium salt (1:1)[7c]	Na^+ $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2NH CH_2CH_2SO_3^-$	n = 6	80621-18-7	P	(CAS 2019 (JP58038571))

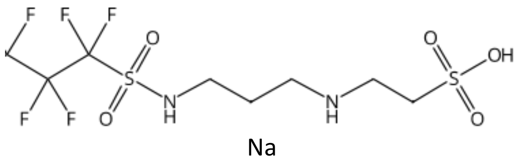
7a



7b

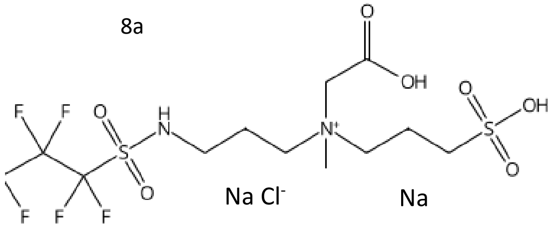


7c

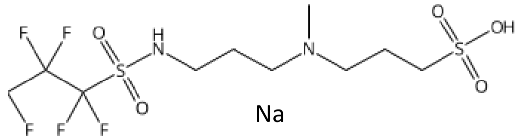


1-Propanaminium, *N*-(carboxymethyl)-*N*-methyl-*N*-(3-sulfopropyl)-3-[[(perfluoroalkyll)sulfonyl] amino]-, chloride, sodium salt (1:1:2)[8a]	Cl^- 2 Na^+ $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_2COO^-)(CH_3)CH_2CH_2CH_2SO_3^-$	n = 6	86402-38-2	P	(CAS 2019 (JP58038571))
1-Propanesulfonic acid, 3-[methyl[3-[[(perfluoro alkyl)sulfonyl]amino]propyl]amino]-, sodium salt (1:1)[8b]	Na^+ $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N(CH_3)CH_2CH_2CH_2SO_3^-$	n = 6, 8	80621-17-6, 85665-65-2	P	(CAS 2019 (JP58038571, JP2001079108))
1-Propanaminium, *N*,*N*-dimethyl-*N*-(3-sulfo propyl)-3-[(3-sulfopropyl) [(perfluoroalkyl) sulfonyl]amino]-[8c]	$C_nF_{2n+1}SO_2N(CH_2CH_2CH_2SO_3H)CH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2CH_2SO_3H$	n = 3 - 8	2089108-77-8, 2089108-78-9, 2089108-79-0, 2089108-80-3, 2089108-81-4, 2089 108-82-5	D	(Barzen-Hanson et al. 2017)

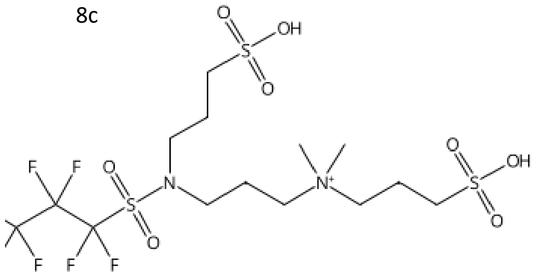
8a



8b

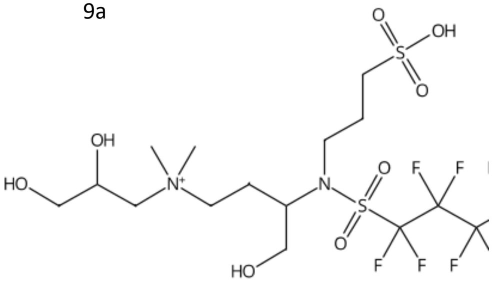


8c

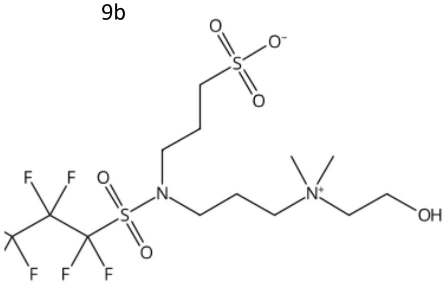


1-Butanaminium, *N*-(2,3-dihydroxypropyl)-4-hydroxy-*N*,*N*-dimethyl-3-[(3-sulfopropyl) [(perfluoroalkyl)sulfonyl]amino]-[9a]	$C_nF_{2n+1}SO_2N(CH_2CH_2CH_2SO_3H)CH(CH_2OH)CH_2CH_2N^+(CH_3)_2CH_2CH(OH)CH_2OH$	n = 2 - 6	2089108-87-0, 2089108-88-1, 2089108-89-2, 2089108-90-5, 2089108-91-3	D	(Barzen-Hanson et al. 2017)
1-Propanaminium, *N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-3-[[(perfluoroalkyl)sulfonyl](3-sulfopropyl)amino]-, inner salt[9b]	$C_nF_{2n+1}SO_2N(CH_2CH_2CH_2SO_3H)CH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 2 - 8	2267980-92-5, Anions (2089108-92-7, 2089108-93-8, 2089108-94-9, 2089108-95-0, 2089108-96-1, 68298-11-3)	D	(Barzen-Hanson et al. 2017; CAS 2019 (US5085786))
1-Propanaminium, *N*-[2-(2-hydroxyethoxy) ethyl]-*N*,*N*-dimethyl-3-[(3-sulfopropyl) [(perfluoroalkyl) sulfonyl]amino]-, inner salt[9c]	$C_nF_{2n+1}SO_2N(CH_2CH_2CH_2SO_3^-)CH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OCH_2CH_2OH$		38850-57-6	P	(CAS 2019 (DE2315326))

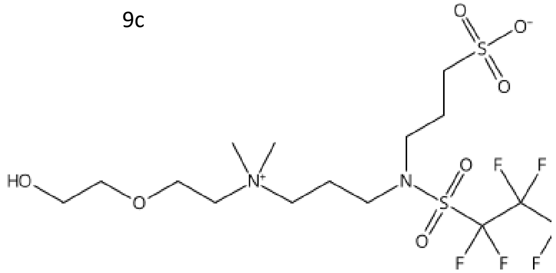
9a



9b

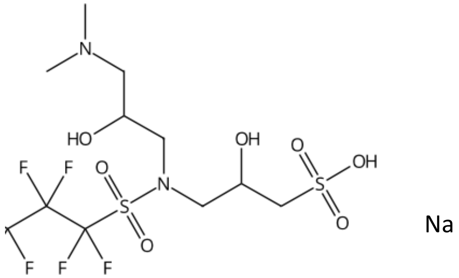


9c



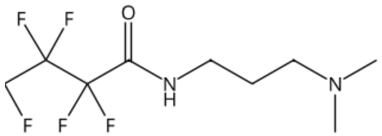
1-Propanesulfonic acid, 3-[[3-(dimethylamino)-2-hydroxypropyl][(perfluoroalkyl)sulfonyl] amino]-2-hydroxy-, sodium salt (1:1)[10a]	Na^+ $C_nF_{2n+1}SO_2N(CH_2CH(OH)CH_2SO_3^-)CH_2CH(OH)CH_2N(CH_3)_2$		98900-72-2	P	(CAS 2019 (JP2001079108))

10a

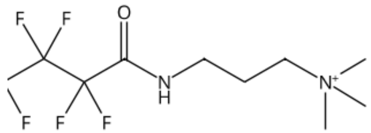


Perfluoroalkane carbonyl fluoride (PACF)-based substances					
Alkanamide, *N*-[3-(dimethylamino)propyl]-perfluoro-[11a]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N(CH_3)_2$	n = 3 - 12, 14	64790-29-0, 153339-13-0, 153339-14-1, 103831-28-3, 376-23-8, 103831-29-4, 1245601-26-6, 1513863-78-9, 1513863-79-0, 1513863-80-3, 1513863-81-4	D	(D'Agostino and Mabury 2014; CAS 2019 (JP09173498))
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, iodid (1:1)[11b]	$I^- C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 7 - 9	335-90-0, 62501-48-8, 2284-73-3	P	(CAS 2019 (JP2001079108))
Alkamide, *N*-[3-(dimethyloxidoamino)propyl]-perfluoro-[11c]	$C_nF_{2n+1}C(=O)NHC_3H_6N(=O)(CH_3)_2$	n = 7, 9, 11	30295-53-5, 70674-76-9, 200636-70-0	P	(CAS 2019 (WO9746283))
Cyclopentanecarboxamide, *N*-[3-(dimethyloxido amino)propyl]-1,2,2,3,3,4,4,5-octafluoro-5-(1,2,2,3,3,4,4,5,5,6,6-undecafluorocyclohexyl)-[11d]	$C_6F_{13}C(=O)NHC_3H_6N(=O)(CH_3)_2$	-	200636-86-8	P	(CAS 2019 (WO9746283))

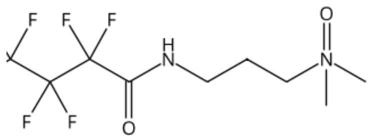
11a



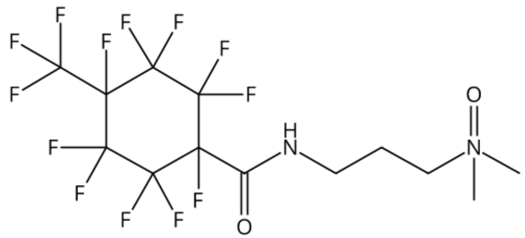
11b



11c



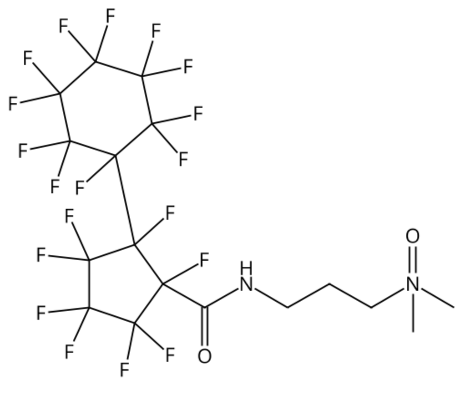
11d



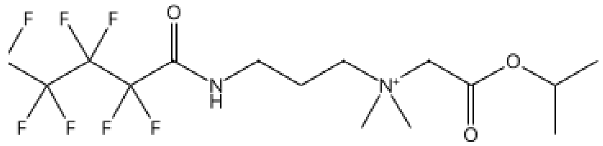
Cyclopentanecarboxamide, *N*-[3-(dimethyloxido amino)propyl]-1,2,2,3,3,4,4,5-octafluoro-5-(1,2,2,3,3,4,4,5,5,6,6-undecafluorocyclohexyl)-[12a]	$C_{11}F_{19}C(=O)NHC_3H_6N(=O)(CH_3)_2$	-	200636-77-7	P	(CAS 2019 (WO9746283))

1-Alkanaminium, 3-[(perfluoro-1-oxononyl) amino]-*N*,*N*-dimethyl-*N*-[2-(1-methylethoxy)-2-oxoethyl]- [12b]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2C(O)OCH(CH_3)_2$	n = 8, 10, 12	1513863-85-8, 1513863-86-9, 1513863-87-0	D	(D’Agostino and Mabury 2014)
Pyridinium, 1-[2-[(perfluoro-1-oxoalkyl) amino]ethyl]-, bromide (1:1)[12c]	Br^- $C_nF_{2n+1}C(O)NHCH_2CH_2N^+C_5H_5$	n = 7	331755-02-3	P	(CAS 2019 (JP2001079108))

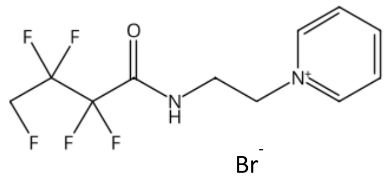
12a



12b

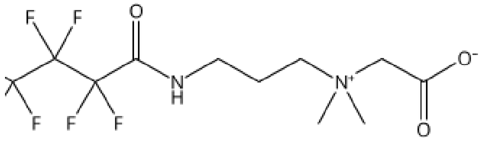


12c

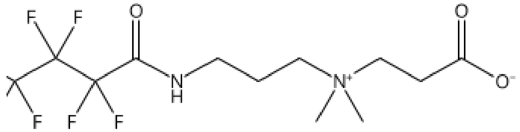


1-Propanaminium, *N*-(carboxymethyl)-*N*,*N*-dimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, inner salt[13a]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 6 - 12, 14	130114-31-7, 90179-39-8, 77958-18-0, 70674-74-7, 77968-31-1, 1513863-82-5, 167997-08-2, 1513863-84-7	D	(D’Agostino and Mabury 2014)
1-Propanaminium, *N*-(2-carboxyethyl)-3-[(perfluoro-1-oxoalkyl)amino]-*N*,*N*-dimethyl-, inner salt[13b]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 6, 8, 10	119131-05-4	U	(Buck, Murphy, and Pabon 2012)
1-Propanesulfonic acid, 3-[(3-aminopropyl)(perfluoro-1-oxooctyl)amino]-2-hydroxy-, sodium salt (1:1)[13c]	Na^+ $C_nF_{2n+1}C(O)N(C_3H_6NH_2)CH_2CH(OH)CH_2SO_3^-$	n = 7	98900-76-6	P	(CAS 2019 (JP2001079108))
Benzenesulfonic acid, 4-[[[3-(methylamino) propyl](perfluoro-1-oxooctyl)amino]methyl]-, sodium salt (1:1)[13d]	Na^+ $C_nF_{2n+1}C(O)N(C_3H_6NHCH_3)CH_2C_6H_4SO_3^-$	n = 7	98900-75-5	P	(CAS 2019 (JP2001079108))

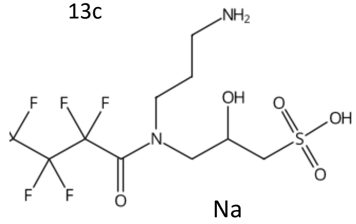
13a



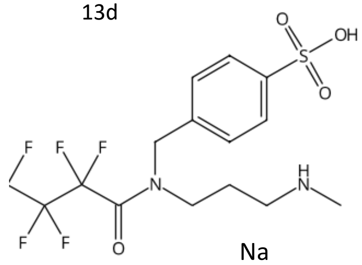
13b



13c

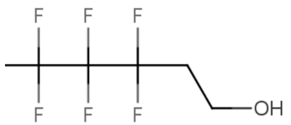


13d

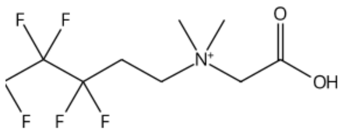


Fluorotelomer-based substances					
(n:2) Fluorotelomer alcohols (FTOHs)[14a]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8, 10	647-42-7, 678-39-7, 865-86-1	D	(Herzke, Posner, and Olsson 2009)
(n:2) Fluorotelomer betaine (FTB)[14b]	$C_nF_{2n+1}CH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 4, 6, 8	2089109-25-9, 2089109-26-0	D	(Barzen-Hanson et al. 2017)
(n:3) Fluorotelomer betaine[14c]	$C_nF_{2n+1}CH_2CH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 5, 7, 9, 11, 13	171184-14-8, 171184-15-9, 171184-16-0, 171184-17-1, 1513864-13-5	U, D	(D'Agostino and Mabury 2014; Place and Field 2012)
(n:1:2) Fluorotelomer betaine[14d]	$C_nF_{2n+1}CFHCH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 5, 7, 9, 11, 13, 15	171184-02-4, 171184-03-5, 171184-04-6, 171184-05-7, 1513864-14-6, 1513864-15-7	U, D	(D'Agostino and Mabury 2014; Place and Field 2012)

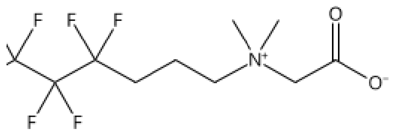
14a



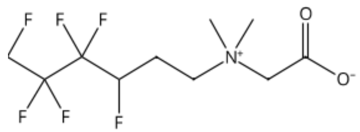
14b



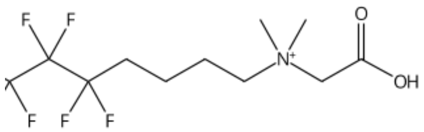
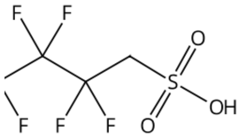
14c



14d



(n:4) Fluorotelomer betaine[15a]	$C_nF_{2n+1}CH_2CH_2CH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 6, 8, 10	2089109-29-3, 2089109-30-6	D	(Barzen-Hanson et al. 2017)
(n:1) Fluorotelomer sulfonic acid[15b]	$C_nF_{2n+1}CH_2SO_3H$	n = 5, 7	678-66-0, 812-79-3	D	(Barzen-Hanson et al. 2017)
(n:2) Fluorotelomer sulfonic acids (FTSs)[15c]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6, 8, 12, 14	27619-97-2, 39108-34-4, 149246-64-0, 1377603-17-2	D	(Mumtaz et al. 2019; Barzen-Hanson et al. 2017)
(n:2) Fluorotelomer thioether acetic acid[15d]	$C_nF_{2n+1}CH_2CH_2SCH_2COOH$	n = 4, 6, 8, 10	-	D	(D'Agostino and Mabury 2014)
(n:2) Fluorotelomer thioether propanoic acid[15e]	$C_nF_{2n+1}CH_2CH_2SCH_2CH_2COOH$	n = 4, 6, 8	1254468-15-9, 149339-57-1, 54207-62-4	D	(D'Agostino and Mabury 2014)

15a

15b

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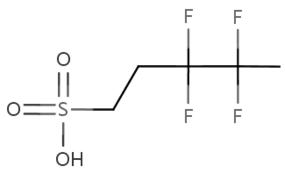
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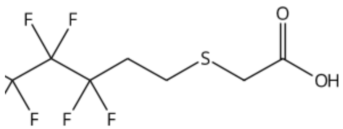
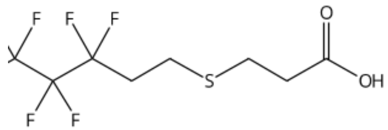
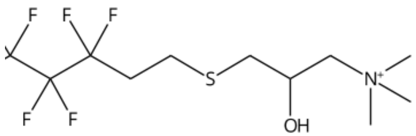
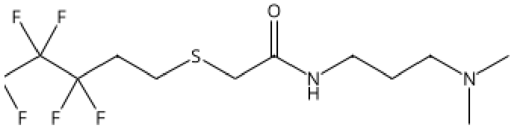
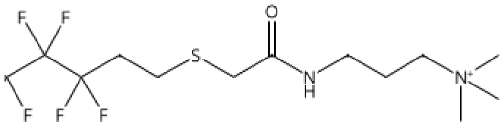
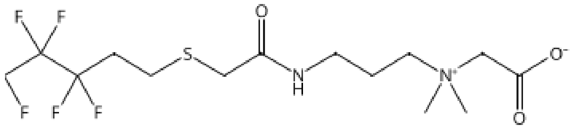

15e


Lithium (n:2) fluorotelomer thioether propionate[(15e)]	$Li^+ C_nF_{2n+1}CH_2CH_2SCH_2CH_2COOH$	n = 6	433333-62-1	U	(Buck, Murphy, and Pabon 2012)
1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)thio]-[16a]	$C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2N^+(CH_3)_3$	n = 4, 6, 8, 10	1513864-16-8, 88992-46-5, 727351-53-3, 1513864-17-9	U, D	(D’Agostino and Mabury 2014; Place and Field 2012)
(n:2) Acetamide, *N*-[3-(dimethylamino)propyl]-2-[(perfluoroalkyl)thio]-[16b]	$C_nF_{2n+1}CH_2CH_2SCH_2C(O)NHCH_2CH_2CH_2N(CH_3)_2$	n = 4, 6, 8, 10, 12	1513863-89-2, 1513863-90-5, 1513863-91-6, 151 3863-92-7, 1513863-93-8	D	(D’Agostino and Mabury 2014)
(n:2) 1-Propanaminium, 3-[[2-[(perfluoroalkyl) thio]acetyl]amino]-*N*,*N*,*N*-trimethyl-[16c]	$C_nF_{2n+1}CH_2CH_2SCH_2C(O)NHCH_2CH_2CH_2N^+H(CH_3)_3$	n = 6, 8, 10	1513864-00-0, 704870-51-9, 1513864-01-1	D	(D’Agostino and Mabury 2014)

16a

16b

16c


1-Propanaminium, *N*-(carboxymethyl)-3-[[2-[(perfluoroalkyl)thio]acetyl]amino]-*N*,*N*-dimethyl-, inner salt[17a]	$C_nF_{2n+1}CH_2CH_2SCH_2C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 4, 6, 8, 10, 12, 14	1513863-94-9, 513863-95-0, 1513863-96-1, 1513863-97-2, 1513863-98-3, 1513863-99-4	D	(D’Agostino and Mabury 2014)
Butanoic acid, 4-[[3-(dimethylamino)propyl] amino]-2-[(perfluoroalkyl)thio]-4-oxo-[17b]	$C_nF_{2n+1}CH_2CH_2SCH(COO^-)CH_2C(O)NHCH_2CH_2CH_2NH^+(CH_3)_2$	n = 6, 8, 10	1383438-88-7, 1383438-89-8, 1383438-90-1	U	(Place and Field 2012)
Glycine, *N*-[3-[(perfluoroalkyl)thio]-2-hydroxy propyl]-*N*-methyl-[17c]	$C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2N(CH_3)CH_2COOH$	undefined	-	U	(Buck, Murphy, and Pabon 2012)

17a

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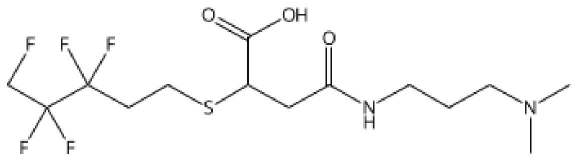
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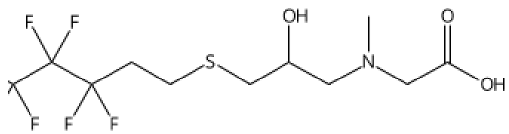
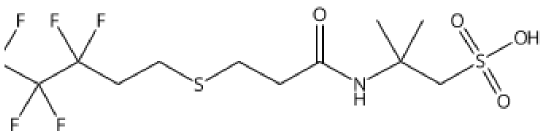
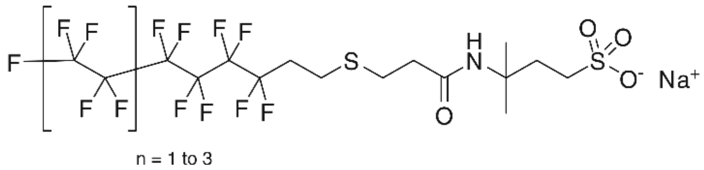


1-Propanesulfonic acid, 2-[[3-[(perfluoroalkyl) thio]-1-oxopropyl]amino]-2-methyl-[18a]	$C_nF_{2n+1}CH_2CH_2SCH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 2, 4, 6, 8, 10, 12, 14	1333933-57-5, 62880-95-9, 755698-73-8, 690947-60-5, 1513864-07-7, 1513864-08-8	D, U	(D'Agostino and Mabury 2014; Barzen-Hanson et al. 2017; Place and Field 2012)
-[18b]	$Na^+ C_nF_{2n+1}CH_2CH_2SCH_2CH_2C(O)NHC(CH_3)_2CH_2 CH_2SO_3^-$	n = 6	-	U	(Buck, Murphy, and Pabon 2012)
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[[2-[(perfluoroalkyl)sulfinyl]acetyl]amino]-[18c]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 6	1513864-03-3	D	(D'Agostino and Mabury 2014)

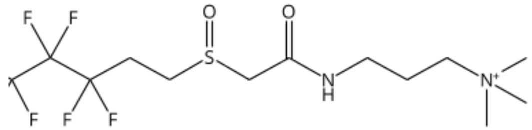
18a



18b

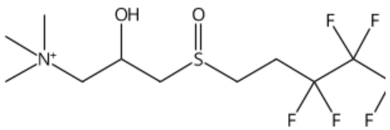


18c

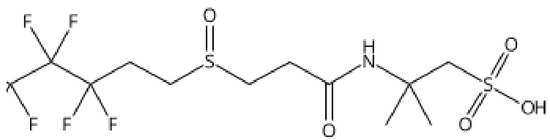


1-Propanaminium, 2-hydroxy-N,N,N-trimethyl-3-[(perfluoroalkyl)sulfinyl]-[19a]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH(OH)CH_2N^+(CH_3)_3$	n = 6, 8	1513864-18-0, 1513864-19-1	D	(D'Agostino and Mabury 2014)
1-Propanesulfonic acid, 2-[[3-[(perfluoroalkyl) sulfinyl]-1-oxopropyl]amino]-2-methyl-[19b]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 4, 6, 8, 10	1513864-09-9, 1513864-10-2, 1513864-12-4, 1513864-11-3	D	(D'Agostino and Mabury 2014)
1-Alkanesulfonyl chloride, perfluoro-	$C_nF_{2n+1}CH_2CH_2SO_2Cl$	n = 6	27619-89-2	U	(USEPA 2016)
1-Alkanesulfonamide, *N*-[3-(dimethyloxidoamino) propyl]-perfluoro-[19d]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N(O)(CH_3)_2$	n = 6, 8	80475-32-7, 80475-33-8	U, P	(Norden 2020; Z. Wang et al. 2013; CAS 2019 (FR2477144))

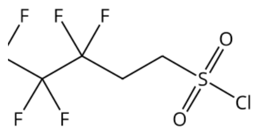
19a



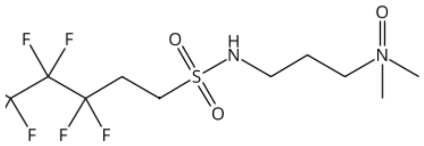
19b



19c



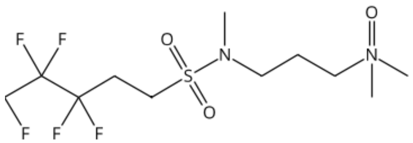
19d



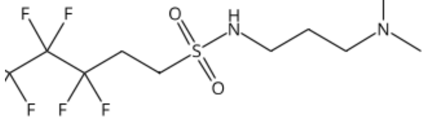
1-Alkanesulfonamide, *N*-[3-(dimethyloxido amino)propyl]-perfluoro-*N*-methyl-[20a]	$C_nF_{2n+1}CH_2CH_2SO_2N(CH_3)CH_2CH_2CH_2N(O)(CH_3)_2$	n = 8	80475-34-9	P	(CAS 2019 (FR2477144))
1-Alkanesulfonamide, *N*-[3-(dimethylamino) propyl]-perfluoro-[20b]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N(CH_3)_2$	n = 4, 6, 8, 10, 12	34455-17-9, 34455-22-6, 34455-23-7, 34455-24-8, 861642-40-2	U, D, P	(D'Agostino and Mabury 2014; Z. Wang et al. 2013; Barzen-Hanson et al. 2017; CAS 2019 (FR2477144))
1-Akanesulfonamide, *N*-[3-(dimethylamino) propyl]-perfluoro-*N*-methyl-[20c]	$C_nF_{2n+1}CH_2CH_2SO_2N(CH_3)CH_2CH_2CH_2N(CH_3)_2$	n = 6	66618-52-8	P	(CAS 2019 (FR2477144))

1-Alkanesulfonamide, *N*-[3-(dimethylamino) propyl]-perfluoro-*N*-hydroxy-[20d]	$C_nF_{2n+1}CH_2CH_2SO_2N(OH)CH_2CH_2CH_2N(CH_3)_2$	n = 6	958822-85-0	D	(KEMI Swedish Chemical Agency 2015a)

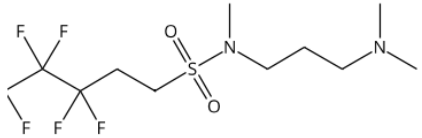
20a



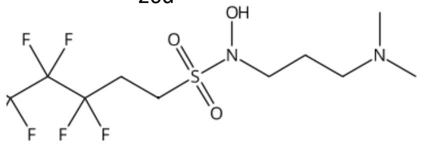
20b



20c

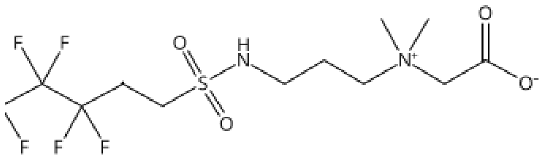


20d

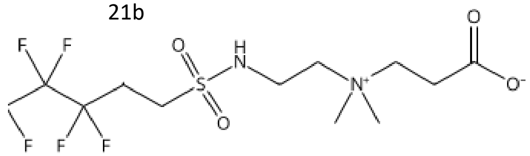


(n:2) Fluorotelomer sulfonamide betaine (FTAB)[21a]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 4, 6, 8, 10, 12, 14, 16	34455-27-1, 34455-29-3, 34455-21-5, 34455-35-1, 278598-45-1, 278598-47-3, 278598-49-5	U, D, P	(D'Agostino and Mabury 2014; Barzen-Hanson et al. 2017; CAS 2019 (EP1013311); USEPA 2016)
Poly(difluoromethylene), α-[2-[[[3-[(carboxy methyl)dimethylammonio]propyl]amino]sulfonyl]ethyl]-ω-fluoro-, inner salt [(21a)]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	-	161278-39-3	U	(Norden 2020)
Ethanaminium, *N*-(2-carboxyethyl)-2-[[(perfluoro alkyl)sulfonyl]amino]-*N*,*N*-dimethyl-, inner salt[21b]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	-	-		(Buck, Murphy, and Pabon 2012)
β-Alanine, *N*-(2-carboxyethyl)-*N*-[6-[[(perfluoro alkyl)sulfonyl]amino]hexyl]-, dipotassium salt[21c]	$2\ K^+\ C_nF_{2n+1}CH_2CH_2SO_2NHC_6H_{12}N(CH_2CH_2COO^-)_2$	n = 8	98900-53-9	P	(CAS 2019 (JP2001079108))

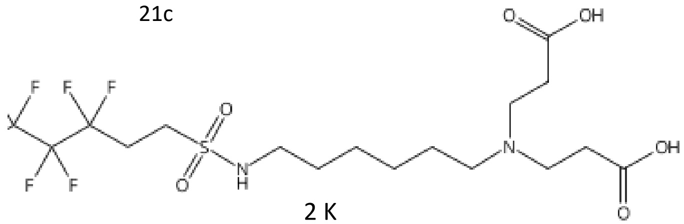
21a



21b



21c

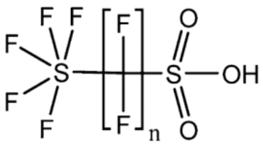


Other non-polymers

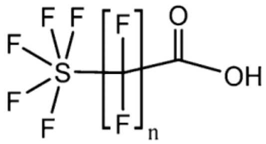
(*N*-Pentafluoro(5)sulfide)-perfluoroalkane sulfonate[22a]	$SF_5C_nF_{2n}SO_3H$	n = 3 - 9	2089109-32-8, 2089109-33-9, 2089109-34-0, 2089109-35-1	D	(Barzen-Hanson et al. 2017)
(*N*+1)-Pentafluoro(5)sulfide-perfluoroalkanoic acid[22b]	$SF_5C_nF_{2n}COOH$	n = 6 - 8	-	D	(Barzen-Hanson et al. 2017)
Perfluoro-*n*-alkene-1-sulfonic acid[22c]	$CF_3CFCFC_nF_{2n}SO_3H$	n = 2 - 10	2089109-40-8, 2089109-41-9, 2089 109-42-0, 2089109-43-1, 2089109-	D	(Barzen-Hanson et al. 2017)

			44-2, 2089109-45-3, 2089109-46-4, 2089 109-47-5, 2089109-48-6		
Polyfluoro-*n*-alkene-1-sulfonic acid[22c]	$CF_3CFCFCFHC_nF_{2n}SO_3H$	n = 2 - 6	2089109-50-0, 2089109-51-1, 2089 109-52-2, 2089109-53-3	D	(Barzen-Hanson et al. 2017)
Polyfluoro-1-alkanesulfonic acid[22e]	$CF_3CFHC_nF_{2n}SO_3H$	n = 2 - 8	2089109-54-4, 2089109-55-5, 2089109-56-6, 2089 109-57-7, 2089109-58-8, 2089109-59-9, 2089109-60-2	D	(Barzen-Hanson et al. 2017)

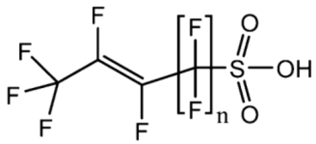
22a



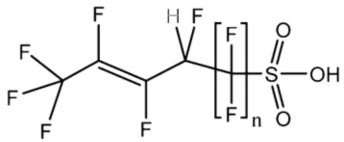
22b



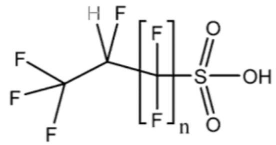
22c



22d

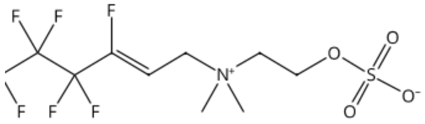


22e

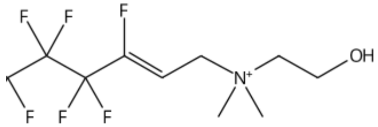


2-Alken-1-aminium, perfluoro-*N*,*N*-dimethyl-*N*-[2-(sulfooxy)ethyl]-, inner salt[23a]	$C_nF_{2n+1}CF{=}CHCH_2N^+(CH_3)_2CH_2CH_2OSO_3^-$	n = 7	70846-84-3	P	(CAS 2019 (DE2749331))
2-Decen-1-aminium, perfluoro-*N*-(2-hydroxy ethyl)-*N*,*N*-dimethyl-, chloride (1:1)[23b]	$Cl^-\ C_nF_{2n+1}CF{=}CHCH_2N^+(CH_3)_2(CH_2CH_2OH)$	n = 7	71248-41-4	P	(CAS 2019 (DE2749331))
Thiols, C_{4-10}, γ-ω-perfluoro	-	-	68140-18-1	U	(USEPA 2016)
Thiols, C_{6-12}, γ-ω-perfluoro	-	-	68140-20-5	U	(USEPA 2016)
Thiols, C_{8-20}, γ-ω-perfluoro, telomers with acrylamide	-	-	70969-47-0	U	(USEPA 2016, Norden 2020)
1-Propanaminium, 3-amino-*N*-(carboxymethyl)-*N*,*N*-dimethyl-, *N*-[2-[(γ-ω-perfluoro-C_{4-20}-alkyl) thio]acetyl] derivs., inner salts	-	-	1078715-61-3	U	(USEPA 2016)
1-Propanesulfonic acid, 2-methyl-, 2-[[1-oxo-3-[(γ-ω-perfluoro-C_{4-16}-alkyl)thio]propyl]amino] derivs., sodium salts	-	-	68187-47-3	U	(USEPA 2016, Norden 2020)
Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly (difluoromethylene) (1:1)	-	-	65545-80-4	U	(USEPA 2016)

23a

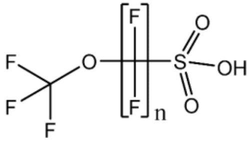


23b

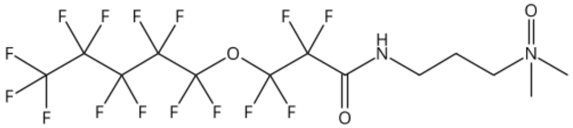


Perfluoropolyether (PFPE) -based substances					
Perfluoro-*n*-(trifluoromethoxy)-1-alkanesulfonic acid[24a]	$CF_3OC_nF_{2n}SO_3H$	n = 2 - 9	1651215-28-9, 914070-83-0	D	(Barzen-Hanson et al. 2017)
Propanamide, *N*-[3-(dimethyloxidoamino) propyl]-2,2,3,3-tetrafluoro-3-[(1,1,2,2,3, 3,4,4,5,5,5-undecafluoropentyl)oxy]-[24b]	$C_5F_{11}OCF_2CF_2C(O)NHC_3H_6C(=O)CH_3)_2$	-	200636-96-0	P	(CAS 2019 (WO9746283))
Propanamide, *N*-[3-(dimethyloxidoamino) propyl]-2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(1,1,2,2,3,3,4,4,4-nonafluorobutoxy) propoxy]propoxy]-[24c]	$C_4F_9O[CF(CF_3)CF_2]_2OCF(CF_3)C(O)NHC_3H_6C(=O)CH_3)_2$	-	200636-74-4	P	(CAS 2019 (WO9746283))

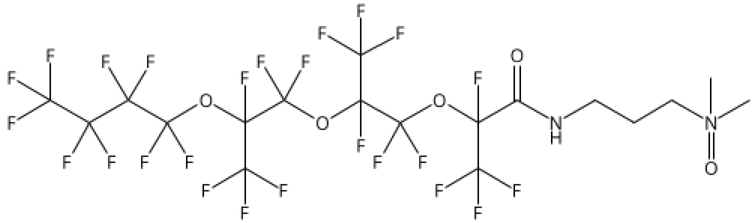
24a



24b

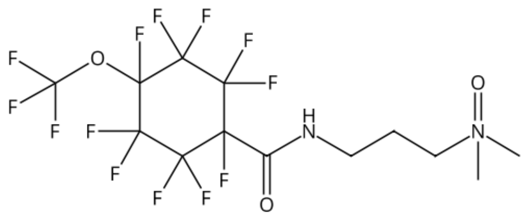


24c

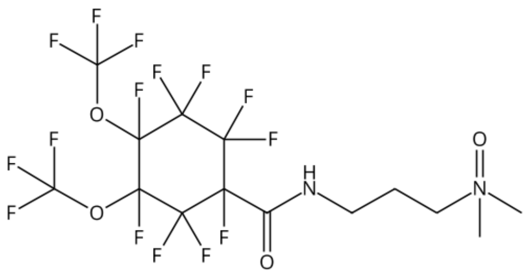


Cyclohexanecarboxamide, *N*-[3-(dimethyloxido amino)propyl]-1,2,2,3,3,4,5,5,6,6-decafluoro-4-(trifluoromethoxy)-[25a]	$C_6F_{10}(OCH_3)C(O)NHC_3H_6C(=O)CH_3)_2$	-	200636-89-1	P	(CAS 2019 (WO9746283))
Cyclohexanecarboxamide, *N*-[3-(dimethyloxido amino)propyl]-1,2,2,3,3,4,5,6,6-nonafluoro-4,5-bis(trifluoromethoxy)-[25b]	$C_6F_9(OCH_3)_2C(O)NHC_3H_6C(=O)CH_3)_2$	-	200636-91-5	P	(CAS 2019 (WO9746283))
Cyclohexanecarboxamide, *N*-[3-(dimethyloxido amino)propyl]-1,2,2,3,4,5,6,6-octafluoro-3,4,5-tris(trifluoromethoxy)-[25c]	$C_6F_8(OCH_3)_3C(O)NHC_3H_6C(=O)CH_3)_2$	-	200636-93-7	P	(CAS 2019 (WO9746283))

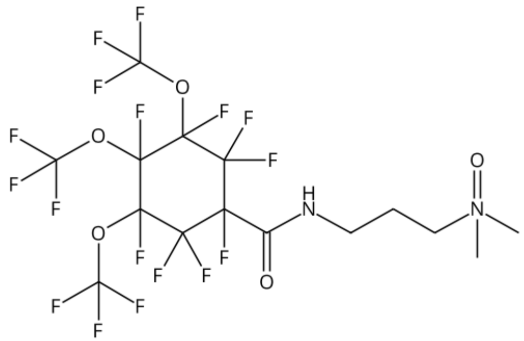
25a



25b



25c



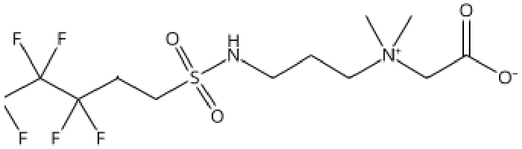
2.14.5 *Alcohol-resistant aqueous film forming foam (AR-AFFF)*

Typical AFFF foams are not effective on fires caused by water-miscible fuels, such as low molecular weight alcohols, ketones, and esters and the like, because the miscibility of the fuel and water in the foam leads to dissolution and destruction of the foam by the fuel (CAS 2019 (US20150251035)). AR-AFFFs (sometimes called universal foam) have been developed by adding high molecular weight polymers such as polysaccharide (e.g. xanthum gums) or artificial polymer gel types. The polymers are water soluble and precipitate on contact with a water-miscible fuel, creating a protective layer between the fuel and the foam (CAS 2019 (US20150251035)). AR-AFFF foams are effective on both hydrocarbon and water-soluble fules. Fluorinated surfactants are used as foam stabilizer in AR-AFFF (KEMI Swedish Chemical Agency 2015b) (see Table 66). Polymeric PFAS are used sometimes in AR-AFFF because they have the same polar fuel performance as xanthan gums, but with much lower viscosity increase (CAS 2019 (US20150251035)). Two patented side-chain fluorinated polymers that may be used in AR-AFFF are shown in Table 67.

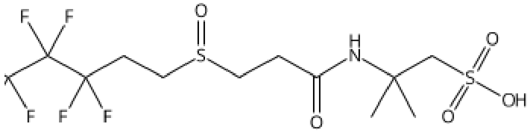
Table 66: PFAS detected in AR-AFFF. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Reference
<u>AR-AFFF</u>				
(n:2) Fluorotelomer sulfonamide betaine (FTAB)[1a]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COOH$	n = 6	34455-29-3	(Dauchy et al. 2017)
1-Propanesulfonic acid, 2-[[3-[(perfluoroalkyl) sulfinyl]-1-oxopropyl]amino]-2-methyl-[1b]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 6	1513864-10-2	(Dauchy et al. 2017)
1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)sulfinyl]-[1c]	$C_nF_{2n+1}CH_2CH_2S(O)CH_2CH(OH)CH_2N^+(CH_3)_3$	n = 6	1513864-18-0	(Dauchy et al. 2017)

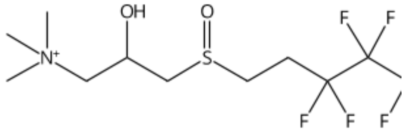
1a



1b

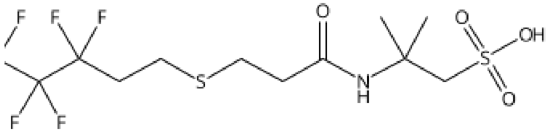


1c



1-Propanesulfonic acid, 2-[[3-[(perfluoroalkyl)thio]-1-oxopropyl]amino]-2-methyl-[2a]	$C_nF_{2n+1}CH_2CH_2SCH_2CH_2C(O)NHC(CH_3)_2CH_2SO_3H$	n = 6	62880-95-9	(Dauchy et al. 2017)
1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)thio]-[2b]	$C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2N^+(CH_3)_3$	n = 6	88992-46-5	(Dauchy et al. 2017)

2a



2b

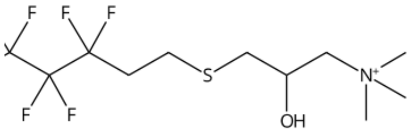
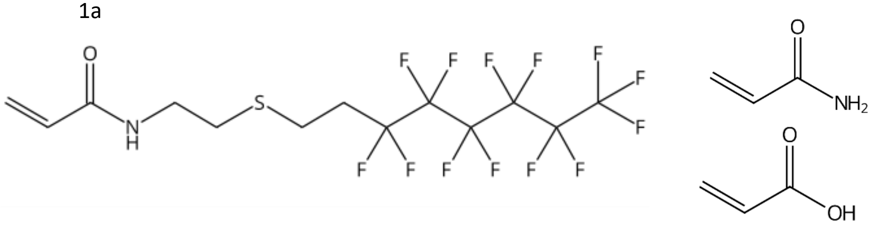


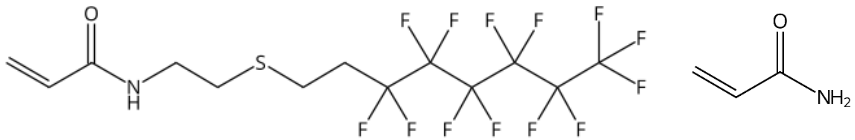
Table 67: Side-chain fluorinated polymers patented for AR-AFFF. Patent number (date, legal status): US20150251035 (2015, active). Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
2-Propenoic acid, polymer with 2-propenamide and *N*-[2-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]ethyl]-2-propenamide[1a]	$-(C_{13}H_{12}F_{13}NOS)_x-(C_3H_5NO)_y-(C_3H_4O_2)_m-$	polymer	1584680-14-7	P	(CAS 2019 (US20150251035))
2-Propenamide, *N*-[2-[(3,3,4,4,5,5,6,6,7,7,8,8,8-trideca fluorooctyl)thio]ethyl]-, polymer with 2-propenamide[1b]	$-(C_{13}H_{12}F_{13}NOS)_x-(C_3H_5NO)_y-$	polymer	1584680-13-6	P	(CAS 2019 (US20150251035))

1a



1b



2.15 Flame retardants

Potassium perfluorobutane sulfonate (K-PFBS, CAS No. 29420-49-3) and perfluorobutane sulfonic acid (PFBS, CAS No. 375-73-5) have been used as flame retardants for polycarbonate resins, mainly in electrical and electronic equipment (Norwegian Environment Agency 2017; CAS 2019 (CN101891943)). K-PFBS might also be used as flame retardant in other plastics (as indicated on product data sheets), but no products have been identified so far (Norwegian Environment Agency 2017). Hubei Hengxin has marketed potassium perfluorohexane sulfonate (CAS No. 3871-99-6) and *N*-methyl perfluorohexane sulfonamide (CAS No. 68259-15-4) for potential use as flame retardants (POPRC 2018b).

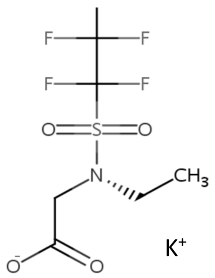
2.16 Floor covering including carpets and floor polish

PFAS have been used and are used in carpets, aftermarket carpet protection products, resilient linoleum, laminated plastic floor coverings and floor polish. Table 68 shows some PFAS that are listed in the SPIN database of the Nordic countries for floor and wall coverings (Norden 2020). More information on PFAS in floor coverings and floor polish are provided in the Subsections 2.16.1 to 2.16.4.

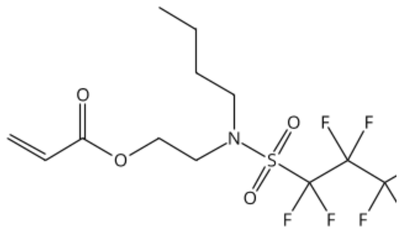
Table 68: PFAS included in the SPIN database of the Nordic countries for floor and wall coverings. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Potassium *N*-ethyl perfluoro alkane sulfonamidoacetate[1a]	$K^+ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 4 - 8	67584-51-4, 67584-52-5, 67584-53-6, 67584-62-7, 2991-51-7	U	(Norden 2020)
2-Propenoic acid, 2-[butyl[(perfluoroalkyl)sulfonyl]amino] ethyl ester[1b]	$C_nF_{2n+1}SO_2N(C_4H_9)CH_2CH_2OC(=O)CHCH_2$	n = 8	383-07-3	U	(Norden 2020)
1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.	-	polymer	115340-95-9	U	(Norden 2020)

1a



1b



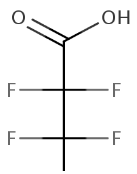
2.16.1 Carpet

The most common carpet fibers are nylon 6, nylon 6,6, polyethylene terephthalate (PET) and polypropylene (FloorDaily 2016; HBN 2017). However, nylon as well as other synthetic fibers are both oleophilic and hydrophobic. This means that they have a great affinity for soils, and soil removal is more difficult than on natural fibers. Many synthetic carpets contain therefore PFAS to impart water and oil repellency, stain resistance and soil release to carpet face fibers (HBN 2017). They also ensure that abrasion is minimized (FluoroIndustry 2019). The soil-release finishes that are used on the fibres are hydrophilic and facilitate removal of fatty or oily soils containing solid matter from fabric (R. E. Banks, Smart, and Tatlow 1994). Major manufacturers in conjunction with global regulators have agreed to discontinue the manufacture of “long-chain” fluorinated products and move to “short-chain” fluorinated products. Both short-chain fluorotelomer-based and perfluorobutane sulfonyl-based products have been applied in carpets (POPRC 2016a). PFAS that have been used or are still used in (synthetic) carpets are shown in Table 69.

Table 69: PFAS historically or currently used, detected in, or patented for (synthetic) carpets. Patent number (date, legal status): Patent number (date, legal status): US4043964 (1977, expired), EP160402 (1985, expired). The types stand for U – use, U* – current use, P – patent, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

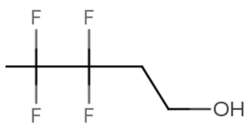
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Carpets in general					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 – 11, 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 376-06-7	D	(Guo, Liu, and Krebs 2009; Kotthoff et al. 2015)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 4, 6, 8	375-73-5, 355-46-4, 1763-23-1	D	(Herzke, Posner, and Olsson 2009; Kotthoff et al. 2015)
(n:2) Fluorotelomer alcohols (FTOHs)[1c]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8, 10	647-42-7, 678-39-7, 865-86-1	D	(Herzke, Posner, and Olsson 2009)
(n:2) Fluorotelomer sulfonic acids (FTSAs)[1d]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	D	(Herzke, Posner, and Olsson 2009)
Potassium *N*-ethyl perfluoroalkane sulfonamidoacetate[1e]	$K^+ \ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	P	(CAS 2019 (US4043964))

1a

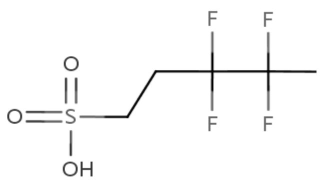


1b

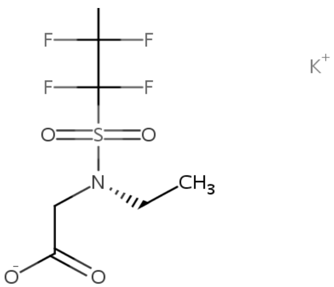
1c



1d

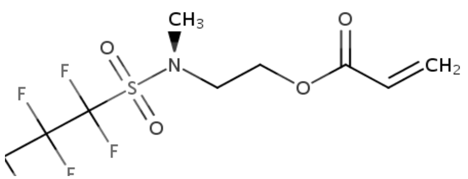


1e

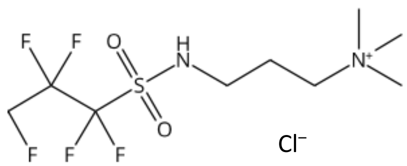


N-Methyl perfluoroalkane sulfonamido ethyl acrylates[2a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH=CH_2$	n = 8	25268-77-3	P	(CAS 2019 (US4043964))
1-Propanaminium, 3-[[(perfluoroalkyl) sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[2b]	$Cl^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (US4043964))
1-Alkanesulfonamide, *N*-ethyl-per fluoro-*N*-[2-[[2-[[2-[(3,4,5,6-tetra hydro-4,6-di oxo-1,3,5-triazin-2-yl) amino]ethyl]amino] ethyl]amino] ethyl]-[2c]	$C_nF_{2n+1}SO_2N(C_2H_5)(CH_2CH_2NH)_3C_3N_3H_2O_2$	n = 8	38006-65-4	P	(CAS 2019 (US4043964))
Side-chain fluorinated polymers based on derivatives of PBSF			949581-65-1, 940891-99-6, 923298-12-8	U	(KEMI Swedish Chemical Agency 2015b)
Acrylate, methacrylate, adipate and urethane side-chain fluorinated polymers of *N*-ethyl perfluorooctane sulfonamidoethanol		-	-	U	(POPRC 2016a)

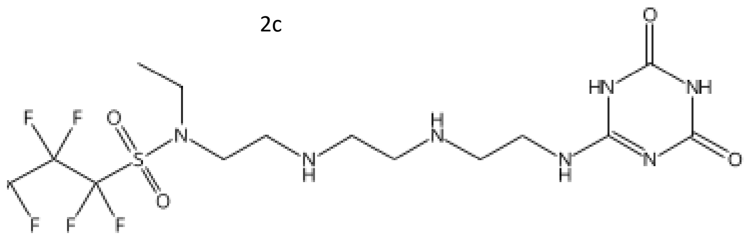
2a



2b

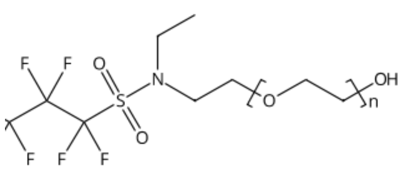


2c

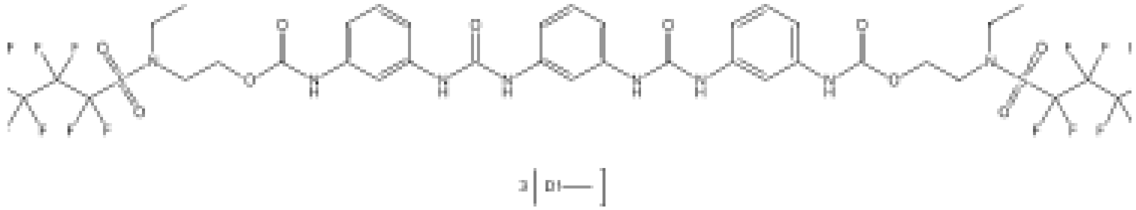


Nylon carpets					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3, 5 – 11	375-22-4, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1	D	(X. Liu et al. 2014)
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl [(perfluoroalkyl)sulfonyl]amino] ethyl]-ω-hydroxy-[3a]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_mOH$	n = 8	29117-08-6	P	(CAS 2019 (EP160402))
Carbamic acid, [(methyl-1,3-phenylene) bis[iminocarbony limino(me thyl-3,1-phenylene)]]bis-, bis[2-[ethyl[(per fluoroalkyl)sulfonyl]amino]ethyl]ester[3b]	$C_6H_4[NHC(O)NHC_6H_4NHC(O)OCH_2CH_2N(C_2H_5)SO_2C_nF_{2n+1}]_2$	n = 8	100155-24-6	P	(CAS 2019 (EP160402))

3a

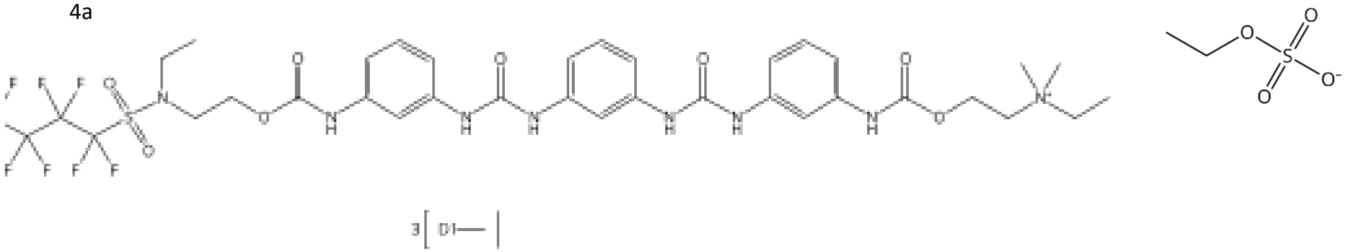


3b



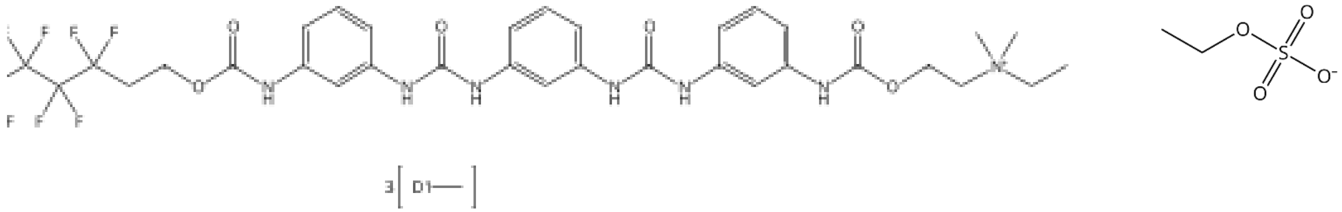
Ethanaminium, *N*-ethyl-2-[[[[3-[[[[3-[[[[3-[[[2-[ethyl[(perfluoroalkyl)sulfonyl]amino] ethoxy] carbonyl]amino]methylphenyl] amino]carbonyl]amino]methylphenyl] amino]carbonyl]amino] methylphenyl] amino]carbonyl]oxy]-*N*,*N*-dimethyl-, ethyl sulfate (1:1)[4a]	$C_2H_5OSO_3^-$ 3 -CH_2 $C_nF_{2n+1}SO_2$ $N(C_2H_5)CH_2$ $CH_2O[C(O)NHC_6H_4$ $NH]_3C(O)OCH_2CH_2N^+(CH_3)_2CH_2$ CH_3	n = 8	100066-53-3	P	(CAS 2019 (EP160402))

4a



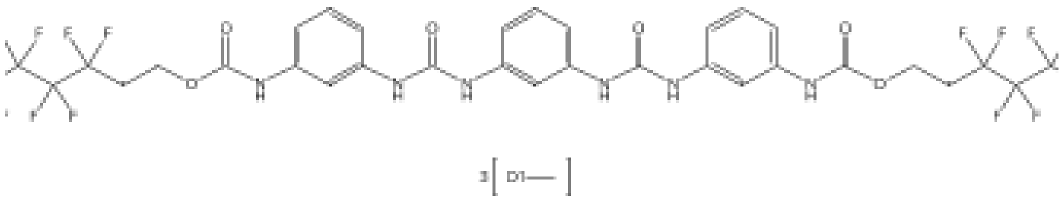
Ethanaminium, *N*-ethyl-2-[[[[3-[[[[3-[[[[3-[[[(perfluoroalkyl)oxy]carbonyl]amino] methylphenyl]amino]carbonyl]amino] methyl phenyl]amino]carbonyl]amino] methylphenyl]amino] carbonyl]oxy]-*N*,*N*-dimethyl-, ethyl sulfate[5a]	$C_2H_5OSO_3^-$ 3 -CH_2 $C_nF_{2n+1}CH_2$ $CH_2O[C(O)NHC_6H_4NH]_3C(O)$ $OCH_2CH_2N^+(CH_3)_2CH_2CH_3$	n = 8	100155-23-5	P	(CAS 2019 (EP160402))

5a



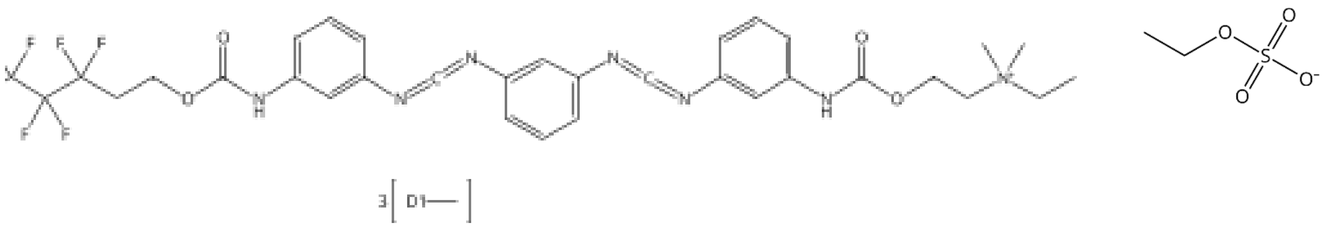
Carbamic acid, [(methyl-1,3-phenylene) bis[iminocarbonylimino(methyl-3,1-phenylene)]]bis-, bis(perfluoroalkyl) ester[6a]	3-CH_2 C_6H_4[$NHC(O)NHC_6H_4NH$ $C(O)OCH_2CH_2C_nF_{2n+1}$]$_2$	n = 6	100107-45-7	P	(CAS 2019 (EP160402))

6a



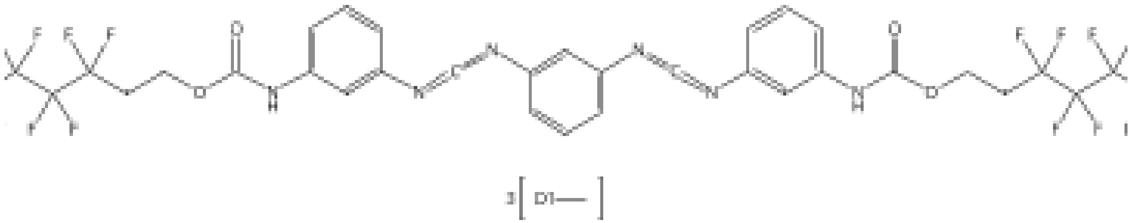
Ethanaminium, *N*-ethyl-2-[[[[3-[[[3-[[[3-[[[(perfluoroalkyl)oxy]carbonyl]amino] methylphenyl] carbonimidoyl]amino] methylphenyl]carbonimidoyl]amino] methylphenyl]amino] carbonyl]oxy]-*N*,*N*-dimethyl-, ethyl sulfate[7a]	$C_2H_5OSO_3^-$ 3 -CH_2 $C_nF_{2n+1}CH_2$ $CH_2OC(O)NHC_6$ H_4[$N{=}C{=}NC_6$ H_4]$_2NHC(O)OCH_2CH_2N^+(CH_3)_2$ CH_2CH_3	n = 8	100107-48-0	P	(CAS 2019 (EP160402))

7a



Carbamic acid, [(methyl-1,3-phenylene) bis [nitrilomethane tetraylnitrilo(methyl-3,1-phenylene)]]bis-, bis(perfluoroalkyl) ester[8a]	3 -CH_2 C_6H_4[N=C=NC_6H_4 NHC(O)O$CH_2CH_2C_nF_{2n+1}$]$_2$	n = 6	100107-46-8	P	(CAS 2019 (EP160402))

8a



2.16.2 Aftermarket carpet protection products

PFAS have also been used in aftermarket carpet protection products (POPRC 2018b) as well as in carpet shampoo and carpet care products (X. Liu et al. 2014; Guo, Liu, and Krebs 2009). PFAS that have been detected in carpet protectors include 6:2, 8:2, and 10:2 FTOHs (CAS No. 647-42-7, 678-39-7, 865-86-1, respectively), *N*-ethyl perfluorooctane sulfonamidoethanol (CAS No. 1691-99-2) (Dinglasan-Panlilio and Mabury 2006), and PFHxS (CAS No. 355-46-4) (Norwegian Environment Agency 2018).

2.16.3 Other floor coverings

PFOS (CAS No. 1763-23-1) and PFDS (CAS No. 335-77-3) have been detected in resilient linoleum, and PFPeA (CAS No. 2706-90-3), PFHxA (CAS No. 307-24-4), PFHpA (CAS No. 375-85-9), PFOS and PFDS have been detected in laminated plastic floor covering (Bečanová et al. 2016).

1-Disiloxanol, 1,3,3-tris(1-methylethoxy)-1,3-bis(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)- (CAS No. 1240203-10-4) has been detected in nano sprays for non-absorbing floor material coatings (Nørgaard, Wolkoff, and Lauritsen 2010). *N*-Ethyl perfluorooctane sulfonamide (CAS No. 4151-50-2) has been detected in wash and care agents for vinyl and cork linoleum (Vejrup, Kark and Lindblom 2002).

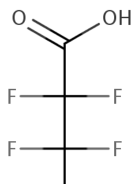
2.16.4 Floor polish

Liquid floor polishes are used to give the floor a shiny appearance. However, some polymer resin formulations do not wet the floor completely and dry to a rough finish, especially on vinyl floors (Kissa 2001). Fluorinated surfactant added to the formulation eliminate streaks and improve the appearance of the dried floor significantly due to improved wetting and levelling (Kissa 2001). Fluorinated surfactants can be used in all types of polishes, including styrene, acrylic, or wax-based floor polishes (Kissa 2001). Table 70 lists some PFAS that have been or are used in floor polish.

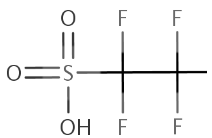
Table 70: PFAS historically or currently used, or detected in floor polishes. The types stand for U – use, U* – current use, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Non-polymers					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 11	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1	D	(X. Liu et al. 2014)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 4, 8, 10	375-73-5, 1763-23-1, 335-77-3	U, D	(X. Liu et al. 2014; Boucher et al. 2019)
Perfluoroalkyl phosphonic acids (PFPAs)[1c]	$C_nF_{2n+1}P(=O)(OH)_2$	n = 6, 8, 10	40143-76-8, 40143-78-0, 52299-26-0	U	(Z. Wang et al. 2016)
Perfluoroalkyl phosphinic acids (PFPiAs)[1d]	$C_nF_{2n+1}P(C_mF_{2m+1})(=O)OH$	n = 6/6, 6/8, 6/10, 6/12, 8/8, 8/10	40143-77-9, 610800-34-5, 1240600-40-1, 1240600-41-2, 40143-79-1, 500776-81-8	U	(Z. Wang et al. 2016)
Potassium *N*-ethyl perfluoro alkane sulfonamidoacetate[1e]	$K^+ \ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 4 - 8	67584-51-4, 67584-52-5, 67584-53-6, 67584-62-7, 2991-51-7	U	(Norden 2020)
(n:2) Fluorotelomer alcohols (FTOHs)[1f]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6	647-42-7	D	(Borg and Ivarsson 2017)

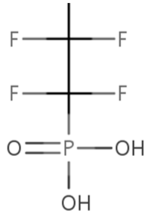
1a



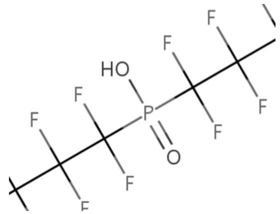
1b



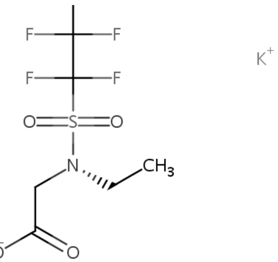
1c



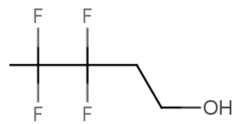
1d



1e

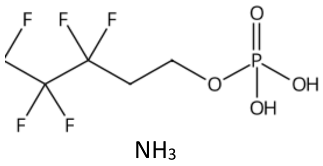


1f

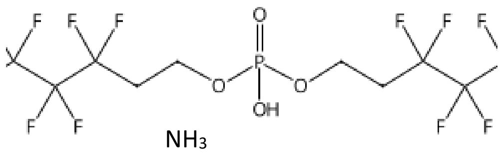


Ammonium (n:2) fluorotelomer phosphate monoester[2a]	$NH_4^+ \ C_nF_{2n+1}CH_2CH_2OPO_3H^-$	undefined	65530-71-4	U*	(Norden 2020)
Diammonium (n:2) fluorotelomer phosphate monoester[(2a)]	$2 \ NH_4^+ \ C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	undefined	65530-72-5	U*	(Norden 2020)
Ammonium (n:2) fluorotelomer phosphate diester[2a]	$NH_4^+ \ OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	undefined	65530-70-3	U*	(Norden 2020)

2a



2b



<u>Polymers</u>					
(Meth)acrylate polymers	-	C = 4 - 20		U	(KEMI Swedish Chemical Agency 2015b)
Polytetrafluoroethylene (PTFE)	-$(CF_2CF_2)_n$-	polymer	9002-84-0	U	(Norden 2020)

2.17 Glass

2.17.1 *Surface treatment of glass*

PFAS have been used to make glass surfaces hydrophobic and oleophobic (Kissa 2001). Examples are optical glass lenses for cameras or optical instruments which can be made resistant to fingerprints (Kissa 2001). PFAS have also been used in dirt-repellent coatings for glass surfaces on smartphones and solar cells (KEMI Swedish Chemical Agency 2015b; CAS 2019 (WO2013012753)). A compound that has been patented for coatings on the outer glass of solar cells is silane, trimethoxy(3,3,4,4,5,5,6, 6,7,7,8,8,8-tridecafluorooctyl)- (CAS No 85857-16-5). Additionally, PFAS are very effective in preventing misting of glass surfaces exposed to humid atmospheres, such as mirrors in bathrooms, automobile windshields, eyeglass lenses, and greenhouse windows (Kissa 2001). An example is OBS (CAS No. 70829-87-7). Fluoropolymers, such as PTFE and PVDF, can be used as surface treatments in various building materials (for example, tiles and glass material) to impart fire- or weather-resistant properties (KEMI Swedish Chemical Agency 2015b). The mentioned PFAS and others that have been used or are used in the surface treatment of glass are listed in Table 71.

2.17.2 *Etching and polishing of glass*

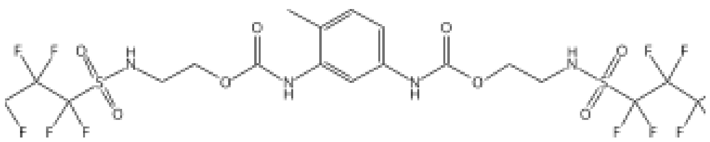
Fluorinated surfactants have also been used to polish and etch glass. They increase the speed of etching, acid polishing or frosting of flat glass with hydrofluoric acid (Kissa 2001). PFAS that can be used as wetting agents in the etching and polishing of glass are also listed in Table 71.

Table 71: PFAS patented for the surface treatment of glass and in etching and polishing of glass. Patent number (date, legal status): JP58213057 (1983, expired), GB1588962 (1981, expired), WO2013012753 (2013, active), WO2014038288 (2014, active), DE3038985 (1982, expired), DE2556429 (1977, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

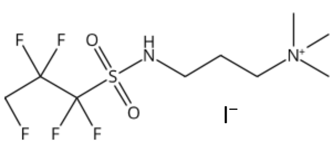
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
<u>Surface treatment of glass</u>					

Carbamic acid, (4-methyl-1,3-phenylene)bis-, bis[2-[[(perfluroroalkyl)sulfonyl]amino]ethyl] ester[1a]	$C_6H_3(CH_3)[NHC(O)OCH_2CH_2NHSO_2C_nF_{2n+1}]_2$	n = 8	89946-29-2	P	(CAS 2019 (JP58213057))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[1b]	$I^- \; C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	P	(CAS 2019 (GB1588962))
(n:2) Fluorotelomer phosphat monoester (monoPAPs)[1c]	$C_nF_{2n+1}CH_2CH_2OP(=O)(OH)_2$	n = 8	57678-03-2	P	(CAS 2019 (JP58213057))
Perfluoroalkyltrimethoxysilane[1d]	$C_nF_{2n+1}CH_2CH_2Si(OCH_3)_3$	n = 6, 8	85857-16-5, 83048-65-1	P	(CAS 2019 (WO2013012753, WO2012041661))

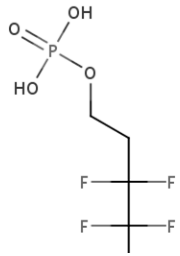
1a



1b

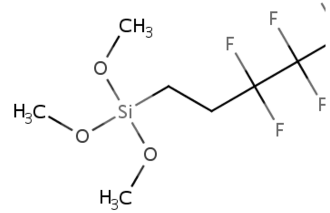


1c



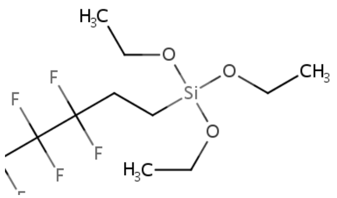
· Cl⁻

1d

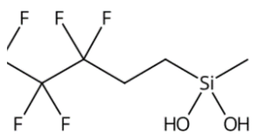


Perfluoroalkyltriethoxysilane[2a]	$C_nF_{2n+1}CH_2CH_2Si(OC_2H_5)_3$	n = 6, 8	51851-37-7, 101947-16-4	P	(CAS 2019 (WO2013012753, WO2012041661))
Silanediol, dimethyl-, polymer with methyl(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silanediol[2b]	$-[Si(CH_3)_2(OH)_2]_x-(C_nF_{2n+1}CH_2CH_2Si(OH)_2CH_3)-$	polymer	156048-38-3	P	(CAS 2019 (WO2010127034))
Silane, chlorodimethyl(perfluoroalkyl)-[2c]	$C_nF_{2n+1}CH_2CH_2Si(CH_3)_2Cl$	n = 6	102488-47-1	P	(CAS 2019 (WO2010127034))
Benzenemethanaminium, *N*-[3-[(perfluoro-1-oxoalkyl)propylamino]propyl]-*N*,*N*-dimethyl-, chloride (1:1)[2d]	$Cl^- \; C_nF_{2n+1}C(O)N(C_3H_7)CH_2CH_2CH_2N^+(CH_3)_2CH_2C_6H_5$	n = 8	89932-72-9	P	(CAS 2019 (JP58213057))

2a



2b



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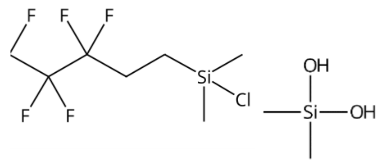

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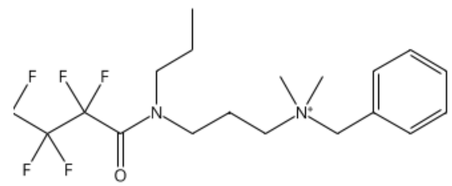
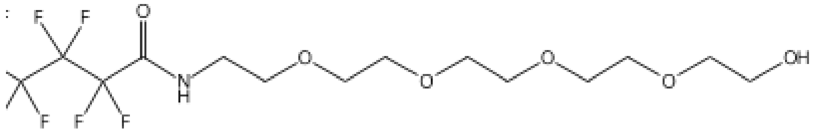


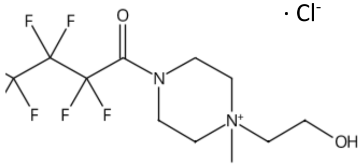
Alkanamide, perfluoro-*N*-(14-hydroxy-3,6,9,12-tetraoxatetradec-1-yl)-[3a]	$C_nF_{2n+1}C(O)NHCH_2CH_2(OCH_2CH_2)_4OH$	n = 7	89932-71-8	P	(CAS 2019 (JP58213057))
Piperazinium, 1-(2-hydroxyethyl)-1-methyl-4-(perfluoro-1-oxoalkyl)-, chloride (1:1)[3b]	$Cl^- \; C_nF_{2n+1}C(O)NC_4H_8N^+(CH_3)CH_2CH_2OH$	n = 6	89932-73-0	P	(CAS 2019 (JP58213057))

Alkanamide, perfluoro-*N*-[3-(trimethoxysilyl) propyl]-[3c]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2Si(OCH_3)_3$	n = 5	154380-34-4	U	(Z. Wang et al. 2013)

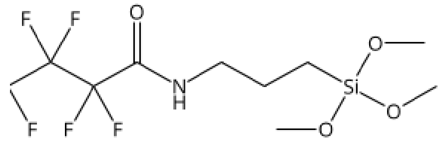
3a



3b

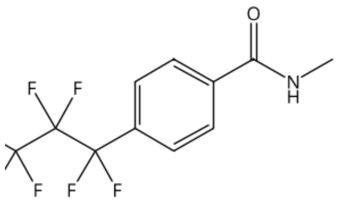


3c

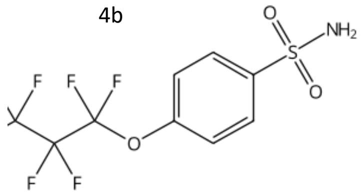


Benzamide, 4-(perfluoroalkyl)-*N*-methyl-[4a]	$C_nF_{2n+1}C_6H_4C(O)NHCH_3$	n = 8	89932-69-4	P	(CAS 2019 (JP58213057))
Benzenesulfonamide, 4-[(perfluoroalkyl)oxy]-[4b]	$C_nF_{2n+1}OC_6H_4SO_2NH_2$	n = 8	89932-76-3	P	(CAS 2019 (JP58213057))
1-Propanaminium, *N*-(carboxymethyl)-3-[[[4-[(perfluoroalkyl)oxy]phenyl]sulfonyl]amino]-*N*,*N*-dimethyl-, inner salt[4c]	$C_nF_{2n+1}OC_6H_4SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 8	89932-75-2	P	(CAS 2019 (JP58213057))

4a



4b



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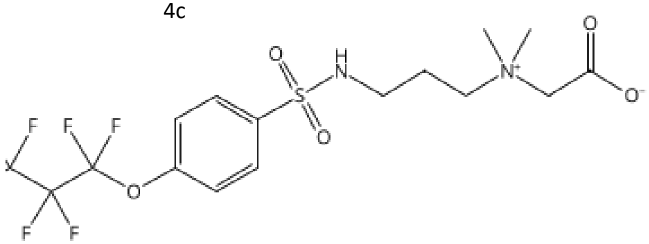


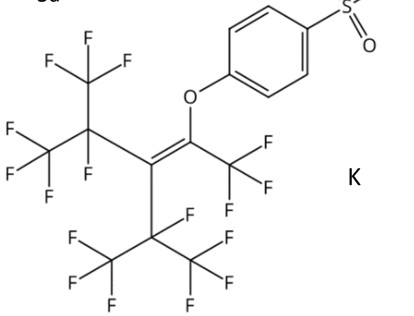
Benzoic acid, 4-[(perfluoroalkyl)oxy]-, potassium salt (1:1)[5a]	$K^+ C_nF_{2n+1}OC_6H_4COO^-$	n = 8	89932-68-3	P	(CAS 2019 (JP58213057))
Benzenesulfonic acid, 4-[[3,4,4,4-tetrafluoro-2-[1,2,2,2 -tetrafluoro-1-(trifluoromethyl)ethyl]-1,3-bis(trifluoro methyl)-1-buten-1-yl]oxy]-, sodium salt (1:1) (OBS)[5b]	$Na^+ CF_3CF(CF_3)C[CF(CF_3)_2]=C(CF_3)OC_6H_4SO_3^-$	-	70829-87-7	P	(CAS 2019 (WO2014038288))
Polytetrafluoroethylene (PTFE)	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(KEMI Swedish Chemical Agency 2015b)
Polyvinylidene fluoride (PVDF)	$-(CH_2CF_2)_n-$	polymer	24937-79-9	U	(KEMI Swedish Chemical Agency 2015b)

Etching and polishing of glass

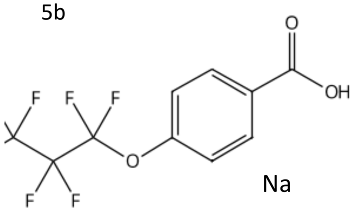
Potassium perfluoroalkane sulfonate[(5c)]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (DE3038985))
Tetraethylammonium perfluoroalkane sulfonate[5c]	$N(C_2H_5)_4^+ C_nF_{2n+1}SO_3^-$	n = 8	56773-42-3	P	(CAS 2019 (DE2556429))

Ammonium perfluoroalkyl carboxylate[5d]	$NH_4^+ C_nF_{2n+1}COO^-$	n = 7	3825-26-1	P	(CAS 2019 (DE2556429))
Carbamic acid, [(perfluoroalkyl)sulfonyl]-, 3,6,9,12, 15,18,21,24,27,30-decaoxatetratriacont-1-yl ester	$C_nF_{2n+1}SO_2NHC(O)(OCH_2CH_2)_{11}CH_2CH_3$	n = 8	64309-62-2	P	(CAS 2019 (DE2556429))

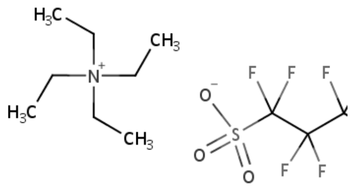
5a



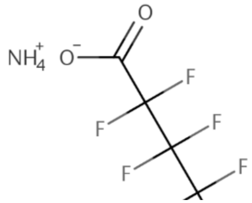
5b



5c



5d



2.17.3 *Drying of glass*

The dewatering of processed parts is an important production step in glass finishing. There are a number of processes that can be used for this purpose, whereby solvent displacement drying is one of the most common ones (Chemours 2019d). PFAS used in solvent displacement drying need to have a higher density and lower surface tension than water so that they are able to penetrate underneath the water droplet and lift the droplet away from the glass surface (Chemours 2019d). A PFAS marketed by Chemours for this purpose is pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro- (CAS No. 138495-42-8) (Chemours 2019d).

2.18 Household applications

Teflon tape (PTFE) has been used for sealing of threads and joints for domestic piping and plumbing applications (Gardiner 2015).

2.19 Laboratory supplies, equipment and instrumentation

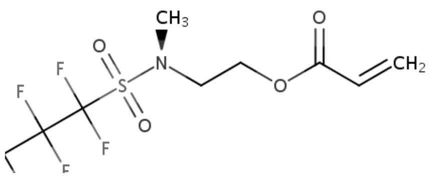
2.19.1 *Consumable materials*

Various fluoropolymer (e.g. PTFE) and fluoroelastomer-based products (e.g. Viton) have been used in research laboratories. Examples include the use of fluoropolymer-based vials, caps and tape, and fluoropolymers in the solvent degassers of liquid chromatography (LC) instruments (Cousins et al. 2019). Also, specialty LC-columns are based on fluorinated materials. Personal protective equipment, including protective gloves can also contain PFAS (Cousins et al. 2019). There are also particle filters in the laboratory that are made of or are coated with PFAS to minimize the sorption of compounds to the filter itself (Cousins et al. 2019). PFAS like PFBA (CAS No. 375-22-4) are added to reversed phase LC-MS solvents (Cousins et al. 2019). Other laboratory agents are listed in Table 72.

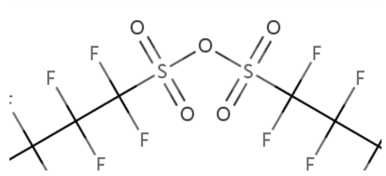
Table 72: PFAS historically or currently used in laboratory agents. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
N-Methyl perfluoroalkane sulfonamidoethyl acrylates (MeFASEACs)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH{=}CH_2$	n = 4	67584-55-8	U	(Hodgkins 2018)
Perfluoroalkane sulfonic anhydride[1b]	$(C_nF_{2n+1}SO_2)_2O$	n = 4	36913-91-4	U	(Norwegian Environment Agency 2017)
Perfluorobutanoic acid, 1,1′-anhydride[1c]	$[C_nF_{2n+1}C(O)]_2O$	n = 3	336-59-4	U	(Norden 2020)
Perfluoroalkyl methyl ether[1d]	$C_nF_{2n+1}OCH_3$	n = 3 (HFE-7000)	375-03-1	U	(3M 2008)
Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd.	-	polymer	69991-61-3	U	(Z. Wang et al. 2020)

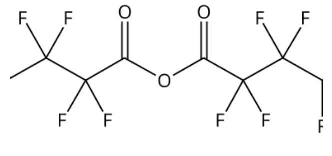
1a



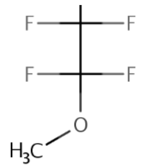
1b



1c



1d



Ionic liquids containing a tris(pentafluoroethyl)trifluorophosphate anion (e.g., CAS No. 713512-19-7) can be used as ultra hydrophobic solvents for the extraction of polycyclic aromatic hydrocarbons using single drop microextraction (Yao, Pitner, and Anderson 2009).

2.19.2 Parts of technical equipment

PFAS-containing products have also been used in analytical instruments in the laboratory (Cousins et al. 2019). Ultra high-performance liquid chromatography instruments (UPLCs), autoclaves, and ovens contain fluoroelastomers as seals and membranes (Cousins et al. 2019; R. E. Banks, Smart, and Tatlow 1994). UPLCs also contain PTFE as inert surfaces and sometimes in tubings (Cousins et al. 2019). Perfluoropolyether-based lubricants are used as oils and greases in pumps and equipment (Cousins et al. 2019).

2.19.3 Vapor sterilization of laboratory/medical equipment

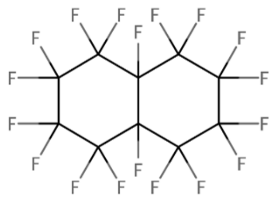
Perfluorocarbons and perfluorotributylamine have been used to sterilize an insulated vessel in a hospital in Hastings, U.K. between 1970 and 1976 (R. E. Banks, Smart, and Tatlow 1994). There is no information on whether PFAS are still used in vapor sterilization today. The historically applied PFAS are listed in Table 73.

Table 73: PFAS historically used in vapor sterilization of laboratory/medical equipment. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

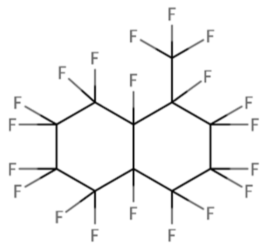
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference

Perfluorodecalin[1a]	$C_{10}F_{18}$	Flutec PP6	306-94-5	U	(R. E. Banks, Smart, and Tatlow 1994)
Perfluoromethyldecalin[1b]	$C_{11}F_{20}$	Flutec PP9	306-92-3	U	(F2_Chemicals 2019a)
Perfluorotetradecahydrophenanthrene[1c]	$C_{14}F_{24}$	Flutec TG PPHP	306-91-2	U	(F2_Chemicals 2019a)
Perfluoroperhydrofluoranthene[1d]	$C_{16}F_{26}$	Flutec TG PPHF	662-28-2	U	(F2_Chemicals 2019a)
Perfluoroperhydrofluorene[1e]	$C_{13}F_{22}$	Flutec PPIO	307-08-4	U	(R. E. Banks, Smart, and Tatlow 1994)
Perfluorotrialkyl amine[1f]	$N(C_nF_{2n+1})_3$	n = 4	311-89-7	U	(R. E. Banks, Smart, and Tatlow 1994)

1a



1b



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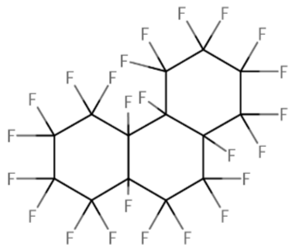
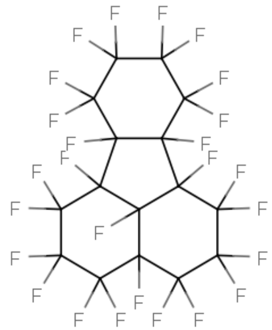
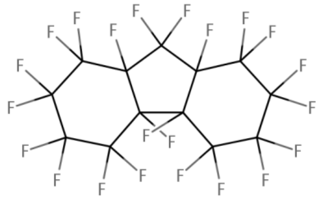


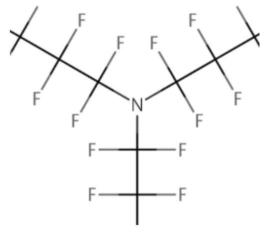
1d



1e



1f



2.19.4 Others

PVDF protein-sequencing membranes can be used for electroblotting procedures in protein research (Dohany 2000). PVDF membranes are also suitable for analyzing the phosphoamino content in proteins under acidic and basic conditions or in solvents (Dohany 2000).

2.20 Leather

2.20.1 Genuine leather

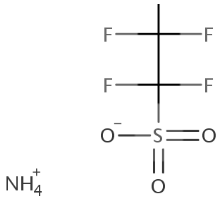
PFAS have been used in the leather manufacturing process as well as in repellent treatments of tanned leather (Kissa 2001). In the production of leather, fluorinated surfactants improve the efficiency of hydrating, pickling, degreasing and tanning. They also reduce the process time and increase the quality of the product (CAS 2019 (EP422954, 1991)). PFAS that are patented for the leather manufacturing process are listed in Table 74.

Table 74: PFAS patented for use in leather manufacturing. Patent number (date, legal status): EP422954 (1991, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

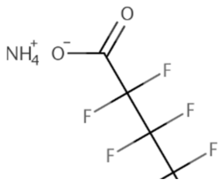
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference

Ammonium perfluoroalkane sulfonate[1a]	$NH_4^+\ C_nF_{2n+1}SO_3^-$	n = 10	67906-42-7	P	(CAS 2019 (EP422954))
Potassium perfluoroalkane sulfonate[(1a)]	$K^+\ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (EP422954))
Ammonium perfluoroalkyl carboxylate[1b]	$NH_4^+\ CnF_{2n+1}COO^-$	n = 7	3825-26-1	P	(CAS 2019 (EP422954))
1-Propanaminium, *N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-3-[(2-hydroxy-3-sulfopropyl)[(perfluoro alkyl)sulfonyl]amino]-, inner salt[1c]	$C_nF_{2n+1}SO_2N(CH_2CH(OH)CH_2SO_3H)CH_2CH_2CH_2N^+(CH_3)_2CH_2\ CH_2OH$	n = 6	112972-61-9	P	(CAS 2019 (EP422954))
1-Propanaminium, 3-[[(perfluoroalkyl) sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[1d]	$Cl^-\ C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 6	38006-74-5	P	(CAS 2019 (EP422954))
1-Propanaminium, 3-[[(perfluoroalkyl) sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[(1d)]	$I^-\ C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	P	(CAS 2019 (EP422954))
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoro alkyl)sulfonyl]amino]ethyl]-ω-hydroxy-[1e]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_nOH$	n = 8	29117-08-6	P	(CAS 2019 (EP422954))

1a



1b



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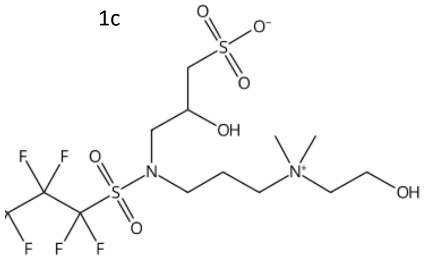

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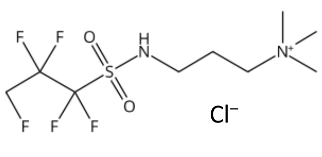

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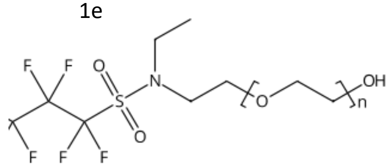
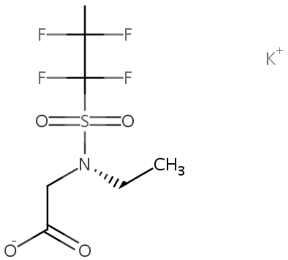


Potassium *N*-ethyl perfluoroalkane sulfonamido acetate[2a]	$K^+\ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	P	(CAS 2019 (EP422954))

2a

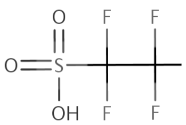


PFAS are also used to impregnate leather against dirt, water and greases while still allowing water vapor to escape (Kissa 2001; UNEP 2017). The PFAS are applied in the drum at the tanneries, either before or after the introduction of the fat liquor (Norwegian Environment Agency 2017). PFAS have been used in leather for shoes, handbags, office furniture, and upholsteries (Herzke, Olsson, and Posner 2012; Norwegian Environment Agency 2017; COP 2015). A list with PFAS that have been used, or are still used for leather impregnation, or detected in leather is provided in Table 75. The tables shows that polymers and non-polymers have been used as impregnation agents. There is a general trend (at least in the western countries) to use nowadays PFAS with shorter chain length. Instead of side chains consisting of fluorotelomers with 6 to 14 perfluorinated carbons or POSF-based derivatives, PFAS with six and less perfluorinated carbons are now being used (KEMI Swedish Chemical Agency 2015b; Z. Wang et al. 2013; POPRC 2019).

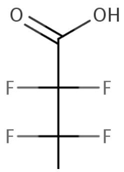
Table 75: PFAS historically or currently used to impregnate leather or detected in impregnated leather. Patent number (date, legal status): DE1952762 (1970, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Non-polymers					
Perfluoroalkane sulfonic acids (PFSAs)[1a]	$C_nF_{2n+1}SO_3H$	n = 4, 6 - 8, 10	375-73-5, 355-46-4, 375-92-8, 1763-23-1, 335-77-3	D	(Kotthoff et al. 2015)
Potassium perfluoroalkane sulfonates[(1a)]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (DE1952762))
Perfluoroalkyl carboxylic acids (PFCAs)[1b]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Kotthoff et al. 2015)
Carbamic acid, (methylphenylene)bis-, bis[2-[ethyl [(heptadecafluorooctyl)sulfonyl]amino]ethyl] ester[1c]	$C_6H_6\ C[C_8F_{17}SO_2N(C_2H_5)CH_2CH_2OC(O)NH]_2$		28959-69-5	P	(CAS 2019 (DE1952762))
Carbanilic acid, methylenedi-, diester with 1,1, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadeca fluoro-*N*-(2-hydroxyethyl)-*N*-methyl-1-octanesulfonamide[1d]	$C_6H_6\ CH_2[C_8F_{17}SO_2N(CH_3)CH_2CH_2OC(O)H]_2$		28959-68-4	P	(CAS 2019 (DE1952762))

1a



1b



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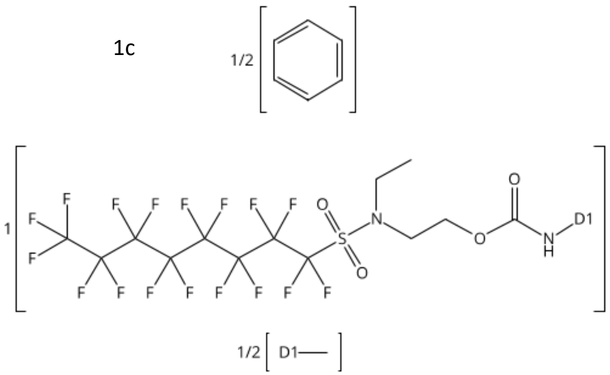
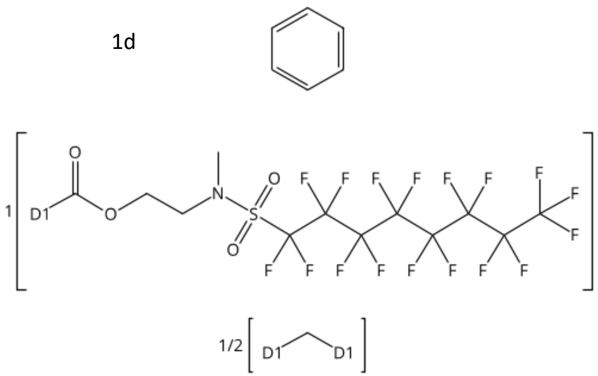
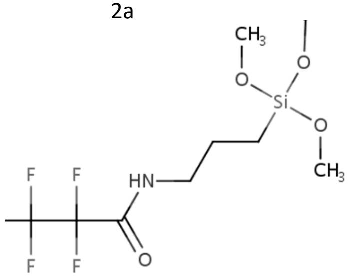


1d



Alkanamide, perfluoro-*N*-[3-(trimethoxysilyl) propyl]-[2a] *(building block)*	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2SI(OCH_3)_3$	n = 5	154380-34-4	U	(Z. Wang et al. 2013)
Polymers					
2-Propenoic acid, butyl ester, polymer with 2-[[(heptadecafluorooctyl)sulfonyl]methylamino] ethyl 2-propenoate[2b]	$-[C_8F_{17}SO_2N(CH_3)CH_2CH_2OC(O)CHCH_2]_x-[C_4H_9OC(O)CHCH_2]_y-$	polymer	29133-22-0	P	(CAS 2019 (DE1952762))
2-Propenoic acid, 2-[[(heptadecafluorooctyl) sul fonyl]methylamino] ethyl ester, homopolymer[2c]	$-[C_8F_{17}SO_2N(CH_3)CH_2CH_2OC(O)CHCH_2]_x-$	polymer	27119-23-9	P	(CAS 2019 (DE1952762))

2a



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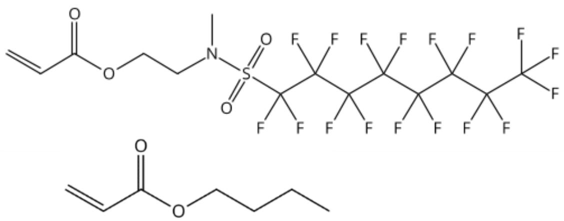

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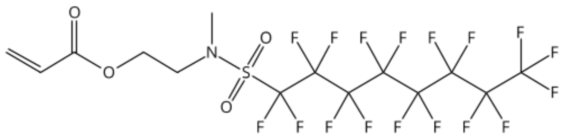
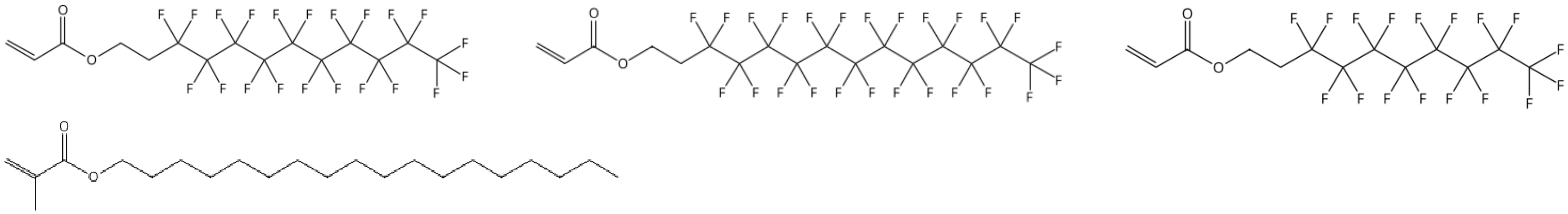


Perfluoropolyether (PFPE)		polymer		U	(POPRC 2019)
Side-chain fluorinated polymers based on derivatives of PBSF		polymer	949581-65-1, 940891-99-6, 923298-12-8	U	(KEMI Swedish Chemical Agency 2015b)
2-Propenoic acid, 2-methyl-, octadecyl ester, polymer with 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10, 11,11,12,12,12-heneicosafluoro dodecyl 2-propenoate, 3,3,4,4,5,5, 6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl 2-propenoate and 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10, 11,11,12,12,13,13,14,14,14-pentacosafluorotetradecyl 2-propenoate[3a]	$-(C_{22}H_{42}O_2)_x-(C_{17}H_7F_{25}O_2)_y-(C_{15}H_7F_{21}O_2)_m-(C_{13}H_7F_{17}O_2)_w-$	polymer	142636-88-2	U	(USEPA 2016)

3a



Side-chain fluorinated polymers, with side chains containing a mixture of 6:2–14:2 fluorotelomer moieties ($C_nF_{2n+1}C_2H_4$–,n = 6–14) or moieties derived from POSF	polymer	U	(Z. Wang et al. 2013)
Fluorinated urethane polymers	C = 8 - 14, polymer	U	(KEMI Swedish Chemical Agency 2015b)

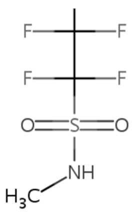
2.20.2 *Synthetic leather*

PFAS are also used in the manufacturing of synthetic leather as polymer melt additives (Norwegian Environment Agency 2017). During the manufacturing process (the polymer melt process), a side-chain fluorinated polymer may be added to impart oil and water repellency to the finished fibres. Table 76 lists PFAS that have been found in 3M™ Protective Material PM – 1000 which is used to manufacture synthetic leather and resins utilized in the production of synthetic leather (Norwegian Environment Agency 2017).

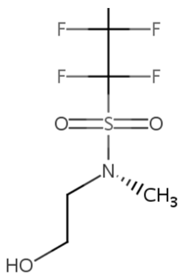
Table 76: PFAS detected in 3M™ Protective Material PM – 1000 that is used in the manufacturing of synthetic leather and resins utilized in the production of synthetic leather. D under type stands for detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
N-Methyl perfluoroalkane sulfonamides (MeFASAs)[1c]	$C_nF_{2n+1}SO_2NH(CH_3)$	n = 4	68298-12-4	D	(Norwegian Environment Agency 2017)
N-Methyl perfluoroalkane sulfonamidoethanols (MeFASEs)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 4	34454-97-2	D	(Norwegian Environment Agency 2017)
N-Methyl perfluoroalkane sulfonamidoethyl acrylates (MeFASEACs)[1b]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH=CH_2$	n = 4	67584-55-8	D	(Norwegian Environment Agency 2017)

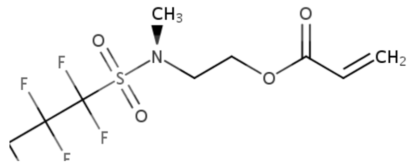
1a



1b



1c



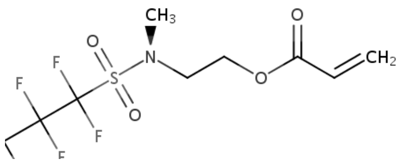
2.20.3 *Shoe brightener*

Fluorinated surfactants can improve the leveling of shoe brighteners (Kissa 2001). A Chinese patent discloses a perfluoroalkyl betaine (unknown identity) that is used in an aqueous wax emulsion to increase the brightness of leather (CAS 2019 (CN104087183, 2014)). The SPIN database of the Nordic countries lists three PFAS that have been used to polish leather, including leather of shoes (Norden 2020). These three PFAS are shown in Table 77. PFHxA (CAS No. 307-24-4) and PFOA (CAS No. 335-67-1) have been detected in shoe wax (Borg and Ivarsson 2017).

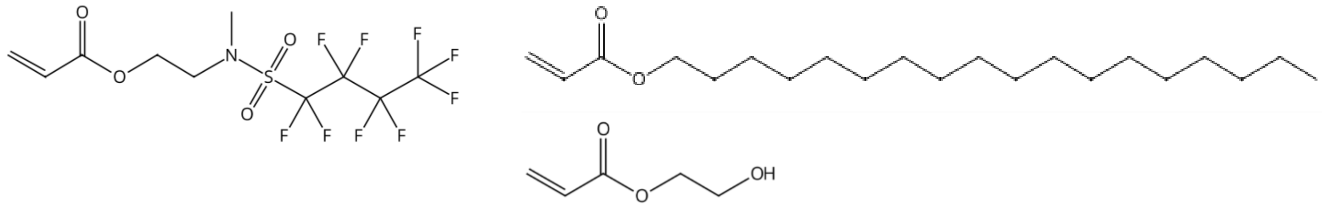
Table 77: PFAS used in polish for leather, including leather for shoes. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
N-Methyl perfluoroalkane sulfonamidoethyl acrylates (MeFASEACs)[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH=CH_2$	n = 4	67584-55-8	U	(Norden 2020)
2-Propenoic acid, 2-hydroxyethyl ester, polymer with 2-[methyl [(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]ethyl 2-propenoate and octadecyl 2-propenoate[1b]	$-(C_{21}H_{40}O_2)_x-(C_{10}H_{10}F_9NO_4S)_y-(C_5H_8O_3)_m-$	n = 4	1190367-98-6	U	(Norden 2020)
2-Propenoic acid, 2-methyl-, hexadecyl ester, polymers with 2-hydroxyethyl methacrylate, γ-ω-perfluoro-C_{10-16}-alkyl acrylate and stearyl methacrylate	-	n = 8-14	203743-03-7	U	(Norden 2020)

1a



1b



2.20.4 Impregnation spray

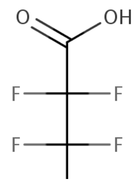
PFAS have also been detected in impregnation sprays for leather and textiles (Kotthoff et al. 2015; Herzke, Olsson, and Posner 2012; Vejrup, Kark and Lindblom 2002) (see Table 78).

Table 78: PFAS detected in impregnation spray. D under type stands for detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

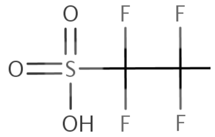
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl carboxylic acids (PFCA)[1a]	$C_nF_{2n+1}COOH$	n = 3, 5-13	375-22-4, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Kotthoff et al. 2015)

Perfluoroalkane sulfonamides (FASAs)	$C_nF_{2n+1}SO_2NH_2$	n = 8	754-91-6	D	(Vejrup, Kark and Lindblom 2002)
Perfluoroalkane sulfonic acids (PFSA)[1c]	$C_nF_{2n+1}SO_3H$	n = 4	375-73-5	D	(Herzke, Olsson, and Posner 2012)
(n:2) Fluorotelomer alcohols (FTOH)[1d]	$C_nF_{2n+1}CH_2CH_2OH$	n = 4, 6, 8, 10	2043-47-2, 647-42-7, 678-39-7, 865-86-1	D	(Kotthoff et al. 2015)

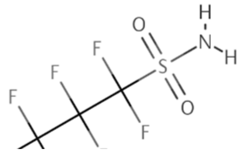
1a



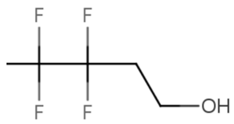
1b



1c



1d



2.21 Lubricants and greases

2.21.1 Sintered bearings, gearboxes and seals

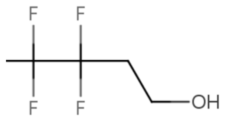
PFAS are used as lubricants in a variety of sintered bearing applications such as lubed-for-life sintered roller and roll-neck bearings in electric motors, automotive components, computer peripherals and other machinery (Chemours 2019b). The PFAS form a film layer that decreases wear on bearings. Additionally, they do not oxidize and are resistant to corrosion and rust during storage and in wet environments (Chemours 2019b). Fluorinated lubricants are also used in gearboxes where they have the advantage that they do not degrade at high temperatures and do not form sludge or varnish that is often the cause of bearing and gear failures (Chemours 2019b). PFAS are also used to lock down seals that provide the barrier integrity required for superior performance (Chemours 2019b). PFAS that have been described, detected, or patented for use as lubricants are shown in Table 79. There are some more perfluoropolyethers (PFPEs) that are marketed for use as lubricants, but the CAS numbers cannot be related to a specific chemical structure, and the chemical names are also very vague (e.g. CAS No. 200013-65-6 – diphosphoric acid, polymers with ethoxylated reduced Me esters of reduced polymd. oxidized tetrafluoroethylene). Examples for those PFPEs used as lubricants are CAS Nos. 76415-97-9, 156559-18-1, 161075-02-1, 161075-14-5, 200013-65-6, 370097-12-4, 69991-67-9 (Z. Wang et al. 2020).

Table 79: PFAS used, detected or patented as lubricants. HFE-7100 and HFE-7200 are commercial products. Patent number (date, legal status): CN104611101 (2015, rejected), DE102011104507 (2012, withdrawn due to failure to request examination), CN108264956 (2018, not yet active). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

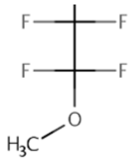
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
(n:2) Fluorotelomer alcohols (FTOHs)[1a]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8, 10	647-42-7, 678-39-7, 865-86-1	D	(Fiedler, Pfister, and Schramm 2010)
Methyl perfluorobutyl ether[1b]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	U	(Norden 2020)
Methyl perfluoroisobutyl ether[1c]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(Norden 2020)
Ethyl perfluorobutyl ether[1d]	$C_4F_9OCH_2CH_3$	(part of HFE-7200)	163702-05-4	U	(Norden 2020)

Ethyl perfluoroisobutyl ether[1e]	$CF_3CF(CF_3)CF_2OCH_2CH_3$	(part of HFE-7200)	163702-06-5	U*	(Norden 2020)
Poly(difluoromethylene), α-chloro-ω-(2,2-dichloro-1,1,2-trifluoroethyl)-[1f]	$CFCl_2CF_2C_nF_{2n}Cl$	undefined	79070-11-4	U	(Norden 2020)
Poly(difluoromethylene), α-(cyclohexylmethyl)-ω-hydro-[1g]	$HC_nF_{2n}CH_2C_6H_{11}$	undefined	65530-85-0	U*	(Norden 2020)

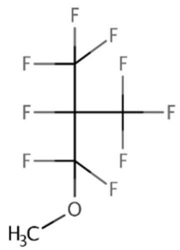
1a



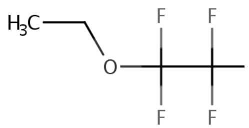
1b



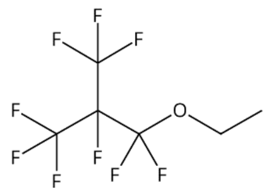
1c



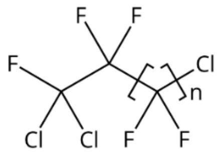
1d



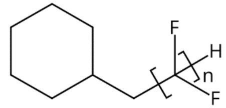
1e



1f

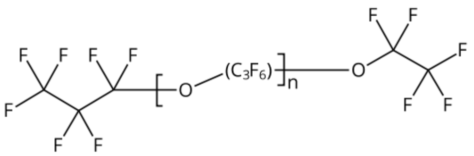


1g

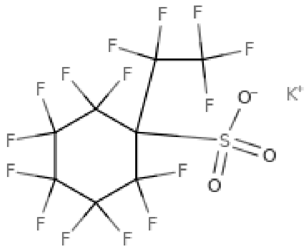


Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethane diyl]], α-(1,1,2,2,3,3,3-heptafluoropropyl)-ω-(1,1,2,2,2-penta fluoroethoxy)-[2a]	$CF_3CF_2CF_2(OC_3F_6)_nOCF_2CF_3$	polymer	52700-35-3	P	(CAS 2019 (CN104611101))
Cycloalkanesulfonic acid, perfluoro(pentafluoro ethyl)-, potassium salt (1:1)[2b]	K^+ $c\text{-}C_nF_{2n-1}SO_3^-$	n = 8	67584-42-3	U	(USEPA 2016)
Propylene tetrafluorethylene copolymer[2c]	$(CH_3CHCH_2)_x\text{-}(CF_2CF_2)_y$	polymer	27029-05-6	P	(CAS 2019 (CN104611101))
Polytetrafluoroethylene (PTFE)[2d]	$\text{-}(CF_2CF_2)_x\text{-}$	polymer	9002-84-0	U*	(Norden 2020)
Polychlorotrifluoroethylene (PCTFE)[2e]	$\text{-}(CF_2CFCl)_x\text{-}$	polymer	9002-83-9	U	(USEPA 2016)

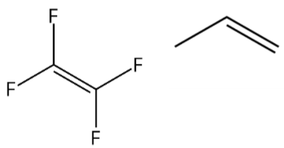
2a



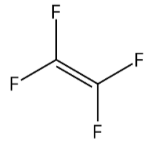
2b



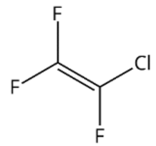
2c



2d



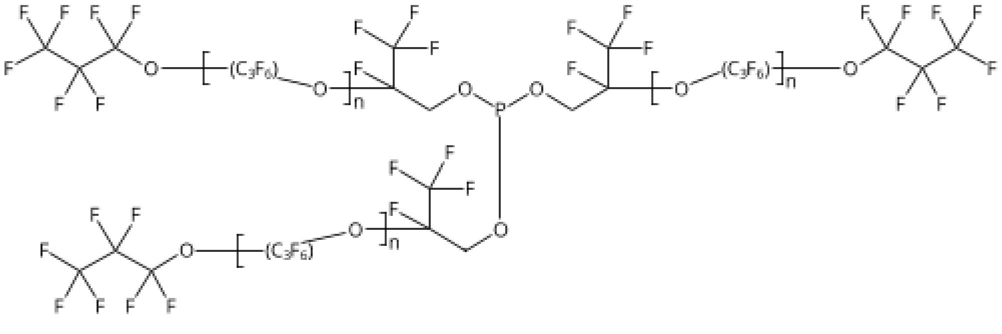
2e



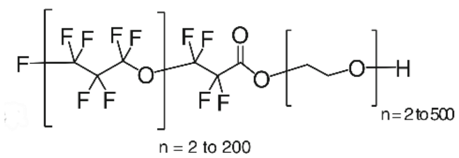
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethane diyl]], α,α′, α′′-[phosphinidynetris[oxy[1-fluoro-1-(trifluoro methyl)-2,1-ethanediyl]]]tris[ω-(1,1,2,2, 3,3,3-heptafluoro propoxy)-[3a]	$P[OCH_2CF(CF_3)(OC_3F_6)_nOC_3F_7]_3$	polymer	2247153-51-9	P	(CAS 2019 (CN108264956))

-[3b]	$F(C_3F_6O)_nC_2F_4C(O)O(CH_2CH_2O)_mH$	n = 2 to 200, m = 2 to 500	-	U	(Buck, Murphy, and Pabon 2012)

3a

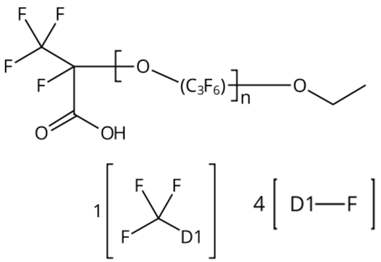


3b

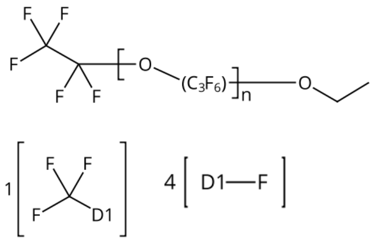


Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethane diyl]], α-(1-carboxy-1,2,2,2-tetrafluoroethyl)-ω-[tetrafluoro (trifluoromethyl)ethoxy]-[4a]	$(C_3F_6O)_nC_6HF_{11}O_3$	polymer	51798-33-5	U*	(Norden 2020)
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], α-(1,1,2,2,2-pentafluoroethyl)-ω-[tetrafluoro(trifluoro methyl)ethoxy]-[4b]	$(C_3F_6O)_nC_5F_{12}O$	polymer	60164-51-4	U*	(Norden 2020)
Polyperfluoromethylisopropyl ether[4c]	$-CF_3O[CF(CF_3)CF_2O]_x(CF_2O)_yCF_3-$	polymer	69991-67-9	U*	(Norden 2020)

4a



4b



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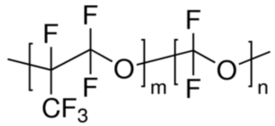


2.21.2 Others

Chemours uses PFPE-based lubricants in their Krytox series (Chemours 2019b). In the light mechanical arena, PFPEs show superior performance in plastic-to-metal or plastic-to-plastic lubrication in typewriters or photocopying machines (R. E. Banks, Smart, and Tatlow 1994). PFPEs (e.g. CAS No. 88645-29-8) have also been used to lubricate push-buttom and sliding-switch contacts. Poly(hexafluorooxetane) has been shown to work effectively as a lubricant for pumps, valves, and compressors for oxygen and halogens (R. E. Banks, Smart, and Tatlow 1994).

Some PFAS, e.g. poly(difluoromethylene), .alpha.-(cyclohexylmethyl)-.omega.-hydro- (CAS No. 65530-85-0) or PTFE are also used as additives to lubricating agents. However, the function is not always clear (Norden 2020). Ionic liquids with phosphate(1-), trifluorotris(1,1,2,2,2-pentafluoroethyl)- (CAS No. 429679-87-8) have been investigated as base oil additives in the lubrication of titanium nitride coatings (Blanco et al. 2011).

2.22 Medical utensils

2.22.1 Electronic devices for medical applications

Fluoropolymers serve as high dielectric insulators for electronic devices that rely on high frequency signals such as defibrillators, pacemakers, cardiac resynchronization therapy (CRT), positron-emission tomography and magnetic resonance imaging (MRI) devices (FluoroIndustry 2019) (see also Section 2.12.2 under 'Electronic devices`).

2.22.2 CCD colour filter in video endoscopes

PFOS (CAS No. 1763-23-1) has been used in charge-coupled device (CCD) colour filters in video endoscopes. A video endoscope is a long, thin, flexible tube that has light and a camera at one end. Thus, images from the inside of the body are shown on a screen outside. It is estimated that around 70% of the video endoscopes used worldwide, or about 200'000 endoscopes, contain a CCD colour filter that contains a small amount (150 ng) of PFOS (POPRC 2019). The use of PFOS in new CCD colour filters is not longer allowed (COP 2019).

2.22.3 Contrast agent

Microbubble-based ultrasound contrast agents

Microbubble-based ultrasound contrast agents have a diameter usually smaller than 10 µm and contain a fluorinated gas inner core, which provides osmotic stabilization and contributes to interfacial tension reduction (Dichiarante, Milani, and Metrangolo 2018). Due to the low solubility of fluorinated gases in aqueous media (if compared to air, oxygen or nitrogen), fluorinated gases dissolve more slowly, and thus create longer lived microbubbles. Their gas core can resonate when exposed to ultrasounds, making the microbubbles useful contrast agents for ultrasound imaging (especially for the detection and treatment of cardiovascular diseases), or targeted drug and gene delivery (Dichiarante, Milani, and Metrangolo 2018). Gaseous PFAS that habe been used in the gas inner core are perfluoropropane (CAS No. 76-19-7) and perfluorobutane (CAS No. 355-25-9) (Dichiarante, Milani, and Metrangolo 2018).

X-Ray imaging

Perfluorocarbons and their brominated analogues are radio-opaque, especially the latter. Compounds such as 1-bromoperfluorooctane (CAS No. 423-55-2) have been used extensively for X-ray imaging of the lungs, gastrointestinal tract, and RES tissues (R. E. Banks, Smart, and Tatlow 1994).

Magnetic resonance imaging

1-Bromoperfluorooctane has also been used as contrast agent for magnetic resonance imaging (MRI) (NIH 2019). F-based MRI using perfluoropolymer labelled cells has recently entered the clinic offering new insights into cell imaging. Fluoropolymer-tagged cells showed excellent contrast and resolution due to the lack of fluorine in organs and tissue and it was even possible to quantify them using 19F NMR spectroscopy (Gardiner 2015).

Other techniques

1-Bromoperfluorooctane and other perfluorocarbons have also been used effectively as contrast agents for both proton and 19F NMR imaging studies of various tissues. 1-Bromoperfluorooctane has additionally been used as a contrast agent in computed tomography and sonography. The uptake of perfluorocarbon emulsion particles by macrophages of malignant tissues has provided a convenient method for localizing tumors (R. E. Banks, Smart, and Tatlow 1994).

2.22.4 Radio-opaque materials

ETFE (CAS No. 25038-71-5) has been used as radio-opaque material (POPRC 2016a).

2.22.5 Surgical drapes and gowns

Surgical drapes and gowns are treated with PFAS (for example side-chain fluorinated polymers or PTFE) to enhance water-, oil- and dirt-resistance (KEMI Swedish Chemical Agency 2015b) (see also Section 2.4. 'Apparel`).

2.22.6 X-Ray films

Fluorinated surfactants have been used in the manufacture of x-ray films for photoimaging with medical equipment (KEMI Swedish Chemical Agency 2015b) (see also Section 1.16 'Photographic industry`)

2.22.7 Dispersant in medical applications

PFOS (CAS No. 1763-23-1) and PFBS (CAS No. 375-73-5) have been used as dispersant to incorporate contrast agents into an ETFE copolymer layer (UNEP 2017). Fluorinated surfactants such as potassium *N*-ethyl perfluorooctane sulfonamidoacetate (CAS No. 2991-51-7) can be used to disperse cell aggregates to diagnose cell abnormalities (CAS 2019 (JP52105208, 1977)).

2.22.8 Ophthalmology

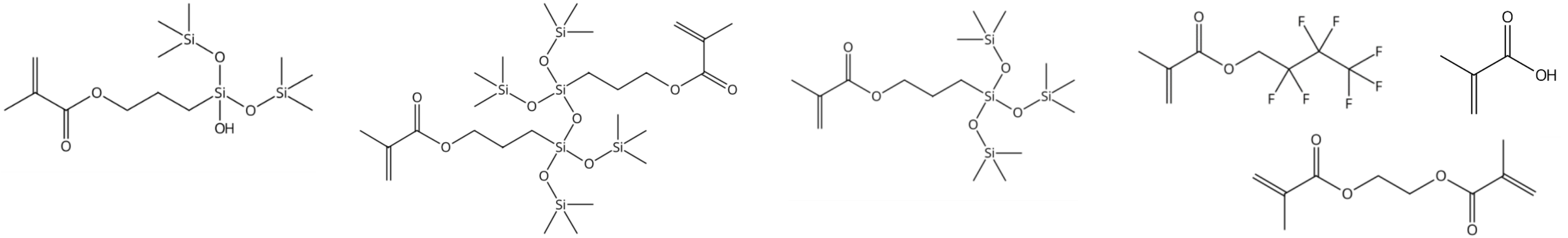
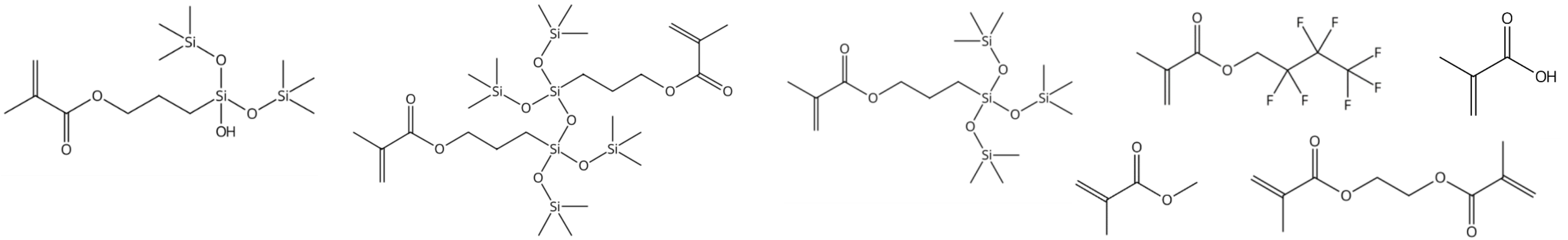
Eye drops

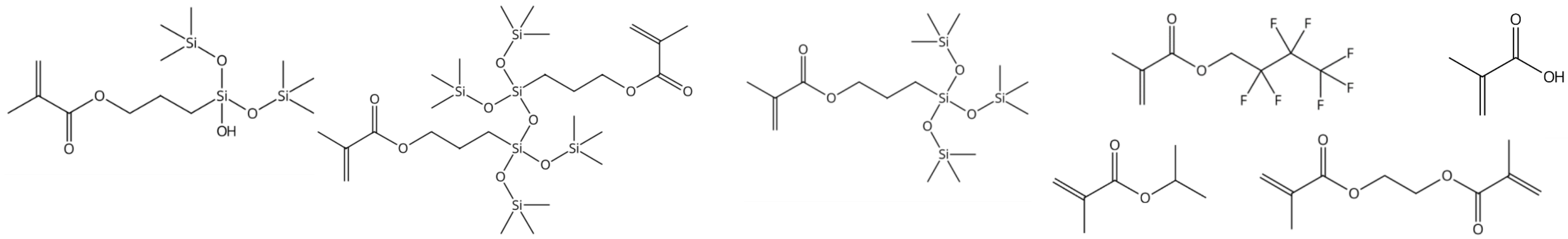
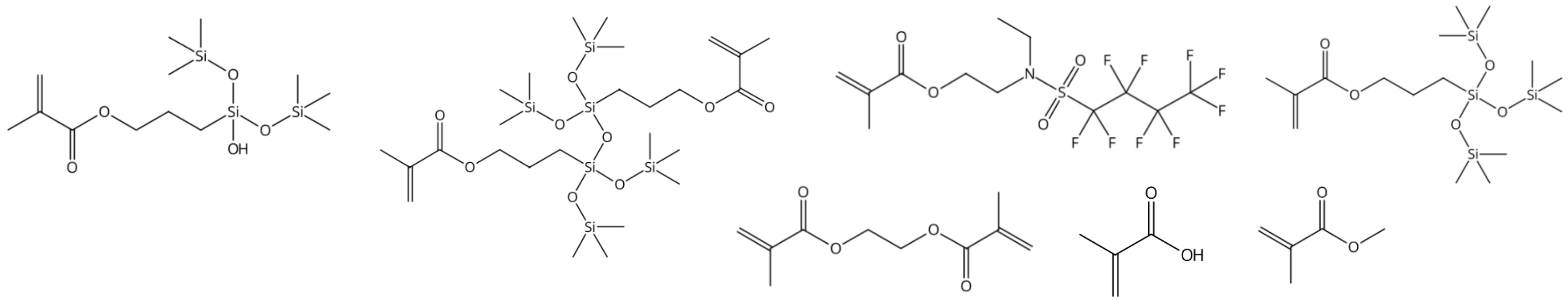
A disorder in the tear film homeostasis can lead to the dry eye syndrome (DES) (Chachaj-Brekiesz et al. 2019). Perfluorohexyloctane (CAS No. 133331-77-8) is used as delivery agent for one of the most effective DES treatments (cyclosporine A – cyclic polypeptide) (Chachaj-Brekiesz et al. 2019). Perfluorohexyloctane is used, for example, in eye drops from Novaliq (Novaliq 2020).

Contact lenses

Contact lenses are manufactured with PFAS as raw materials. Side-chain fluorinated (meth)acrylate polymers have been of particular interest for this application (R. E. Banks, Smart, and Tatlow 1994). Table 80 lists PFAS polymers that habe been patented or marketed for contact lenses. Additionally, a research article (Qin et al. 2017) describes a method to load drugs into commercially available contact lenses. The method was demonstrated by using model compounds including fluorous-tagged fluorescein and antibiotic ciprofloxacin. The tags were fluorocarbon chains with 2 to 6 perfluorocarbons (Qin et al. 2017).

Table 80: PFAS polymers that have been patented or marketed for contact lenses. Patent number (date, legal status): US4661573 (1987, expired), US5346976 (1994, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Copolymer of 2-Propenoic acid, 2-methyl-, 2,2,3,3,4,4,4-heptafluorobutyl ester	-$(C_{26}H_{58}O_9Si_6)_x$-$(C_{16}H_{38}O_5Si_4)_y$-$(C_{13}H_{30}O_5Si_3)_m$-$(C_{10}H_{14}O_4)_n$-$(C_8H_7F_7O_2)_w$-$(C_4H_6O_2)_u$-	polymer	109550-14-3	P	(CAS 2019 (US4661573))
					
Copolymer of 2-Propenoic acid, 2-methyl-, 2,2,3,3,4,4,4-heptafluorobutyl ester	-$(C_{26}H_{58}O_9Si_6)_x$-$(C_{16}H_{38}O_5Si_4)_y$-$(C_{13}H_{30}O_5Si_3)_m$-$(C_{10}H_{14}O_4)_n$-$(C_8H_7F_7O_2)_w$-$(C_5H_8O_2)_u$-$(C_4H_6O_2)_v$-	polymer	109550-12-1	P	(CAS 2019 (US4661573))
					
Copolymer of 2-Propenoic acid, 2-methyl-, 2,2,3,3,4,4,4-heptafluorobutyl ester	-$(C_{26}H_{58}O_9Si_6)_x$-$(C_{16}H_{38}O_5Si_4)_y$-$(C_{13}H_{30}O_5Si_3)_m$-$(C_{10}H_{14}O_4)_n$-$(C_8H_7F_7O_2)_w$-$(C_7H_{11}O_2.C_4H_6O_2)_u$-	polymer	109550-15-4	P	(CAS 2019 (US4661573))

					
Copolymer of 2-Propenoic acid, 2-methyl-, 2-[ethyl[(1,1,2,2,3,3,4,4,4-nonafluoro butyl)sulfonyl]amino]ethyl ester	-$(C_{26}H_{58}O_9Si_6)_x$-$(C_{16}H_{38}O_5Si_4)_y$-$(C_{13}H_{30}O_5Si_3)_m$-$(C_{12}H_{14}F_9NO_4S)_n$-$(C_{10}H_{14}O_4)_w$-$(C_5H_8O_2.C_4H_6O_2)_u$-	polymer	109550-13-2	P	(CAS 2019 (US4661573))
					
Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd., reduced, Me esters, reduced	-	polymer	88645-29-8	U	(Z. Wang et al. 2020)

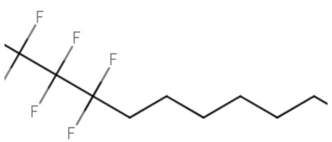
Retinal detachment surgery and proliferative vitreoretinopathy

Perfluoroethane (CAS No. 76-16-4), perfluoropropane (CAS No. 76-19-7), perfluorooctane (CAS No. 307-34-6) and perfluorodecalin (CAS No. 306-94-5) are used as endotamponades in retinal detachment surgeries (Spandau, Tomic, and Ruiz-Casas 2018; F2_Chemicals 2019a). Perfluorotripropylamine (CAS No. 338-83-0) and perfluorooctane have been used as intraoperative tools during vitreoretinal surgery for trauma-induced retinal detachment (R. E. Banks, Smart, and Tatlow 1994). A review on perfluorocarbon liquids in vitreoretinal surgery and related ocular inflammation additionally mentions the use of perfluorotetradecahydrophenanthrene (CAS No. 306-91-2), perfluorotributylamine (CAS No. 311-89-7), and 1-bromoperfluorooctane (CAS No. 423-55-2) (Yu et al. 2014). The review describes the use of perfluorocarbons for “relocating and stabilizing the detached retina for further maneuvers”, “floating the foreign bodies in the vitreous body”, “protecting the macula”, and “suprachoroidal haemorrhage”. For more detailed information, see Yu et al. (2014). PFAS that have additionally been patented for retinal deployment are listed in Table 81.

Table 81: PFAS that have been patented for retinal deployment. Patent number (date, legal status): DE19536504 (1997, expired), DE19719280 (1998, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Semifluorinated *n*-alkanes[1a]	$C_nF_{2n+1}(CH_2)_mH$	n = 2, m = 2 - 10	37826-35-0, 154381-43-8, 94099-50-0, 118559-22-1, 1287702-49-1, 1824054-32-1, 1024003-30-2, 1823562-65-7, 69125-77-5	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mH$	n = 4, m = 2 - 10	38436-17-8, 154381-51-8, 253342-14-2, 1190430-21-7, 1190430-19-3, 1190430-22-8, 69125-79-7, 234433-63-7, 214196-02-8	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mH$	n = 6, m = 2 - 10	80793-17-5, 168834-06-8, 154478-86-1, 1287702-48-0, 69125-80-0, 1835249-87-0, 133331-77-8, 113659-13-5, 147492-59-9	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mH$	n = 8, m = 2 - 10	77117-48-7, 1835250-28-6, 182130-12-7, 1835250-47-9, 182130-14-9, 182130-15-0, 6145-05-7, 931415-52-0, 138472-76-1	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mH$	n = 10, m = 2 – 10	154478-87-2, 1835251-22-3, 1244062-17-6, 250738-42-2, 116177-54-9, 200817-54-5, 93454-70-7, 125635-85-0, 90499-29-9	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mC_nF_{2n+1}$	n = 2, m = 2, 4, 6, 8, 10	95576-25-3, 1835251-87-0, 1835251-86-9, 69125-81-1, 1835251-85-8	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mC_nF_{2n+1}$	n = 3, m = 2, 4, 6, 8, 10	1835251-92-7, 377-06-0, 69125-82-2, 1835251-91-6, 168169-26-4	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mC_nF_{2n+1}$	n = 4, m = 2, 4, 6, 8, 10	142083-52-1, 345944-97-0, 1835252-03-3, 1835252-00-0, 1835251-99-4	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mC_nF_{2n+1}$	n = 5, m = 2, 4, 6, 8, 10	1835255-38-3, 1835255-26-9, 1835255-25-8, 1835255-24-7, 1835252-07-7	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mC_nF_{2n+1}$	n = 6, m = 2, 4, 6, 8, 10	53749-64-7, 76597-99-4, 959462-53-4, 959462-54-5, 1835255-18-9	P	(CAS 2019 (DE19536504))
Semifluorinated *n*-alkanes	$C_nF_{2n+1}(CH_2)_mC_nF_{2n+1}$	n = 8, m = 4, 8	133299-41-9, 100550-08-1	P	(CAS 2019 (DE19536504))
Alkane, perfluoro-*n*-methyl-[1b]	$C_nF_{2n+1}CH_2CH_2CH(CH_3)_2$	n = 6, 8	212957-52-3, 212957-55-6	P	(CAS 2019 (DE19719280))
Alkane, perfluoro-*n*-methyl-(2)[1c]	$C_nF_{2n+1}CH_2CH(CH_3)_2$	n = 6, 8	212957-45-4, 212957-49-8	P	(CAS 2019 (DE19719280))

1a



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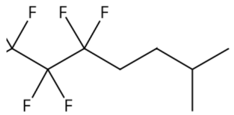

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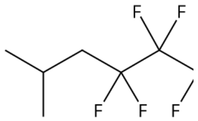


2.22.9 Dialysis

Fluoropolymers are used in protein-resistant and sterile filters, tubings, O-rings, seals and gaskets for kidney dialysis machines and immuno-diagnostic instruments (FluoroIndustry 2019). The water permeability of dialysis membranes containing fluorocarbon polymers can be increased by surface treatment with a cationic fluorinated surfactant (unknown identity) (Kissa 2001).

2.22.10 Catheters, stents and needles

Fluoropolymers provide low-friction and clot-resistant coatings for catheters, stents and needles (FluoroIndustry 2019). PTFE is used in surgical patches and vascular catheters (POPRC 2018a). Expanded PTFE has been used as surgical sutures, arterial and stent grafts as well as preformed subcutaneous implants in reconstructive and cosmetic facial surgery (Gardiner 2015). 2-Pyrrolidinone, 1-ethenyl-, polymer with 1,1-difluoroethene and 1,1,2,3,3,3-hexafluoro-1-propene (CAS No. 215653-67-1) has been patended to coat drug delivery stents (CAS 2019 (US20060047095, 2006)) and Teflon AF (CAS No. 37626-13-4) to coat vascular stents (CAS 2019 (US20050131527, 2005)).

2.22.11 Oxygen carrier

<u>*Supplement conventional blood transfusion and artificial blood*</u>

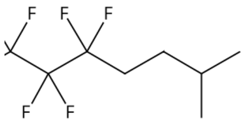
PFAS have been used as vehicles for respiratory gas transport, primarily as O_2-carrying resuscitation fluids designed to supplement conventional blood transfusion (R. E. Banks, Smart, and Tatlow 1994). PFAS have also been used as oxygen carrier in artificial blood (also termed “white blood”) (Dichiarante, Milani, and Metrangolo 2018). Table 82 lists some of the PFAS that have been used or have been patented as oxygen carrier for (artificial) blood.

Table 82: PFAS that have been or are currently used or have been patented as oxygen carrier for (artificial) blood. Patent number (date, legal status): DE19719280 (1998, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Alkane, perfluoro-ω-methyl-[1a]	$C_nF_{2n+1}CH_2CH_2CH(CH_3)_2$	n = 6, 8	212957-52-3, 212957-55-6	P	(CAS 2019 (DE19719280))
Alkane, perfluoro-ω-methyl-(2)	$C_nF_{2n+1}CH_2CH(CH_3)_2$	n = 6, 8	212957-45-4, 212957-49-8	P	(CAS 2019 (DE19719280))
Perfluorotrialkyl amine [1b]	$N(C_nF_{2n+1})_3$	n = 3	338-83-0	U	(Dichiarante, Milani, and Metrangolo 2018)
1-Bromoperfluoroalkanes[1c]	BrC_nF_{2n+1}	n = 8, 10	423-55-2, 307-43-7	U	(Dichiarante, Milani, and Metrangolo 2018)
Perfluoro-dichlorooctane	-	Oxyfluor	-	U	(Dichiarante, Milani, and Metrangolo 2018)

Perfluoro(tert-butylcyclohexane)[1d]	c-$C_{10}F_{20}$	-	84808-64-0	U	(Dichiarante, Milani, and Metrangolo 2018)
Perfluorodecalin[1e]	c-$C_{10}F_{18}$	-	306-94-5	U	(Dichiarante, Milani, and Metrangolo 2018)
Perfluoromethyldecalin[1f]	c-$C_{11}F_{20}$	-	306-92-3	U	(Clark et al. 1974)
Perfluorodimethyl-adamantane	-	-	-	U	(Clark et al. 1974)

1a



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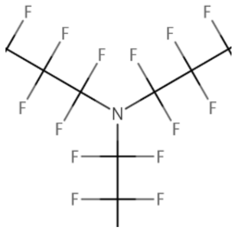

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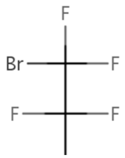

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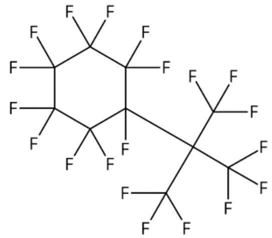

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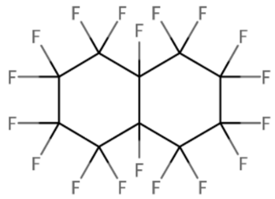

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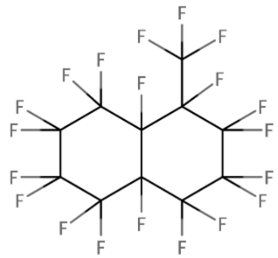


Perfusion of isolated organs

PFAS emulsions have been employed for the perfusion of isolated organs including the heart, liver, kidney, lung, pancreas and testis (R. E. Banks, Smart, and Tatlow 1994). The PFAS that have been used are the same ones used as oxygen carrier for (artificial) blood (R. E. Banks, Smart, and Tatlow 1994; F2_Chemicals 2019a).

Angioplasty

PFAS emulsions (e.g. Fluosol, which contains perfluorotripropyl amine (CAS No. 338-83-0) and perfluorodecalin (CAS No. 306-94-5)) have been used as oxygen-carrying fluid to overcome ischemic myocardial damage during percutaneous transluminal coronary angioplasty (R. E. Banks, Smart, and Tatlow 1994).

2.22.12 Dentistry

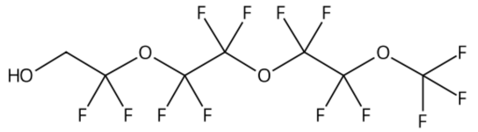
A dental caries-inhibiting composition, such as a toothpaste or mouthwash, has been patetented with a fluorinated surfactant which increases the formation of fluorapatite from enamel-fluoride interactions (CAS 2019 (US4353892, 1982)). 6:2 and 8:2 fluorotelomer alcohols (CAS No. 647-42-7 and 678-39-7) and C_5, C_7 -C_9, C_{11} and C_{12} perfluorocarboxylic acids have been detected in dental floss (KEMI Swedish Chemical Agency 2015b; Guo, Liu, and Krebs 2009). PFAS that have been patetend for UV-hardened dental restorative materials are listed in Table 83.

Table 83: PFAS that have been patented for UV-hardened dental restorative materials. Patent number (date, legal status): WO2009079534 (2009, active), US8962708 (2015, active). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference

Ethanol, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-[1,1,2,2-tetrafluoro-2-(trifluoromethoxy)ethoxy]ethoxy]-[1a]	$CF_3O(CF_2CF_2O)_2CF_2CH_2OH$	-	147492-57-7	P	(CAS 2019 (WO2009079534))
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], α-(1,1,2,2,3,3,3-heptafluoropropyl)-ω-[1,2,2,2-tetrafluoro-1-[[(2-hydroxyethyl) amino]carbonyl]ethoxy]-[1b]	$CF_3CF[C(O)NHCH_2CH_2OH]O[(C_3F_6)O]_nCF_2CF_2CF_3$	-	627909-42-6	P	(CAS 2019 (US8962708))

1a



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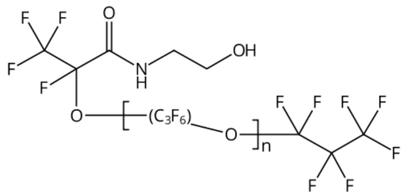


2.22.13 Ventilation of the respiratory airways

Studies using fetal lambs and miniature pigs have shown that ventilation of the respiratory airways with perfluorocarbon liquids can improve lung compliance and increase arterial O_2 tensions. In addition, the small quantity of perfluorocarbons remaining in the alveoli after evaporation acted as a wetting agent enabling subsequent ventilation to occur at lower pressures (R. E. Banks, Smart, and Tatlow 1994). Alkanes, perfluoro-ω-methyl (CAS No. 212957-52-3, 212957-55-6, 212957-45-4, 212957-49-8) have been patented for the regeneration of lung tissue by rinsing the lungs (CAS 2019 (DE19719280, 1998)).

2.22.14 Others

Nafion membranes have been used to dry or humidify breath for anaesthesia and respiratory care as well as for biomedical inserts (Gardiner 2015). Fluorine-containing segmented polyurethanes have superior blood compatibility and durability for use in an artificial heart pump (R. E. Banks, Smart, and Tatlow 1994). Alkanes, perfluoro-ω-methyl- (CAS No. 212957-52-3, 212957-55-6, 212957-45-4, 212957-49-8) have been patented as a component of a liquid implant and medical aid in wound care, in particular burns for cleaning burn residues (CAS 2019 (DE19719280, 1998)). Fluoropolymers are suitable materials for implants, and enzyme immobilization and bioaffinity separation systems (R. E. Banks, Smart, and Tatlow 1994).

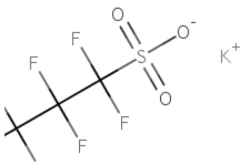
2.23 Metallic and ceramic surfaces

A patent discloses fluorinated surfactants that can be used to treat metalic or ceramic surfaces (hot plates, metallic moulds and the like) at a high temperature of 200° C or above, wherein organic treating agents (finishes, release agents and the like) will not form a tar or sludge (CAS 2019 (US4497720, 1984)). The patented PFAS are listed in Table 84.

Table 84: PFAS patented for surface treatment of metalic or ceramic surfaces. Patent number (date, legal status): US4497720) (1984, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Potassium perfluoroalkane sulfonate[1a]	K^+ $C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (US4497720))
Potassium *N*-methyl perfluoroalkane sulfonamidoacetate[1b]	K^+ $C_nF_{2n+1}SO_2N(CH_3)CH_2COO^-$	n = 8	70281-93-5	P	(CAS 2019 (US4497720))
Potassium *N*-ethyl perfluoroalkane sulfonamidoacetate[1c]	K^+ $C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	P	(CAS 2019 (US4497720))
Poly(oxy-1,2-ethanediyl), α-[2-[[(pentadecafluoroheptyl) sulfonyl]propylamino]ethyl]-ω-hydroxy-[1d]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2(OCH_2CH_2)_xOH$	n = 8	52550-45-5	P	(CAS 2019 (US4497720))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[1e]	Cl^- $C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (US4497720))

1a



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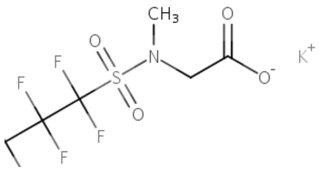

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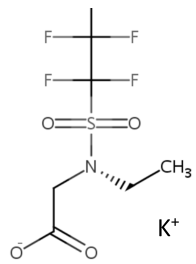

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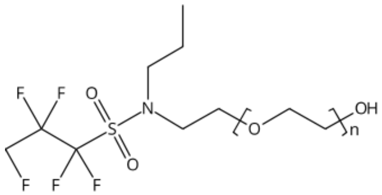

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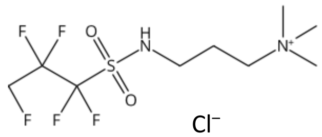
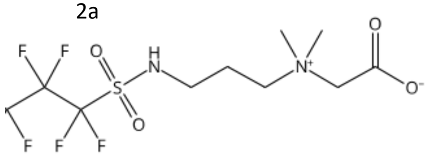


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkane sulfonamido betaine[2a]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 8	75046-16-1	P	(CAS 2019 (US4497720))
Ethanaminium, *N*-[[3-[[(perfluoroalkyl)sulfonyl]propylamino] propyl]sulfonyl]-2-hydroxy-*N*,*N*-dimethyl-, chloride[2b]	Cl^- $C_nF_{2n+1}SO2N(C_3H_7)CH_2CH_2CH_2SO_2$ $N^+(CH_3)_2CH_2CH_2OH$	n = 8	90179-38-7	P	(CAS 2019 (US4497720))
Poly(oxy-1,2-ethanediyl), α-sulfo-ω-[2-[[(perfluoro alkyl)sulfonyl]propylamino]ethoxy]-[2c]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2O(CH_2CH_2O)_n$ SO_3H	n = 8	90168-34-6	P	(CAS 2019 (US4497720))

2a



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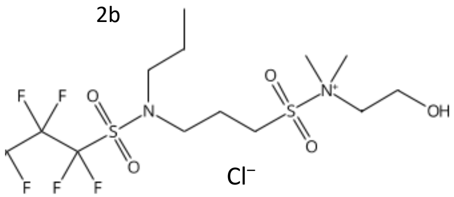

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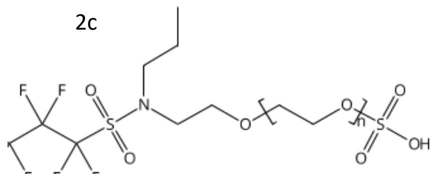
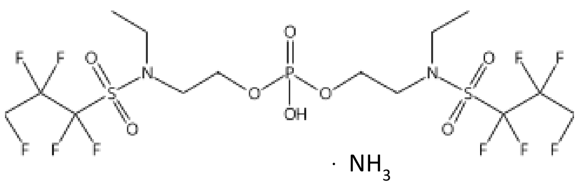


Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Alkanesulfonamide, *N*,*N*′-[phosphinicobis(oxy-2,1-ethane diyl)]bis[N-ethyl-perfluoro-, ammonium salt (1:1)[3a]	NH_4^+ $[C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2O]_2PO_2^-$	n = 8	30381-98-7	P	(CAS 2019 (US4497720))

Poly(oxy-1,2-ethanediyl), α-[2-[ethyl(perfluoro-1-oxoalkyl) amino]ethyl]-ω-hydroxy-[3b]	$C_nF_{2n+1}C(O)N(C_2H_5)CH_2CH_2(OCH_2CH_2)_nOH$	n = 7	115633-66-4	P	(CAS 2019 (US4497720))
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, chloride (1:1)[3c]	$Cl^- \ C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 7	53517-98-9	P	(CAS 2019 (US4497720))
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, iodide (1:1)[(3c)]	$I^- \ C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 7	335-90-0	P	(CAS 2019 (US4497720))
1-Propanaminium, *N*-(carboxymethyl)-*N*,*N*-dimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, inner salt[3d]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 7	90179-39-8	P	(CAS 2019 (US4497720))

3a



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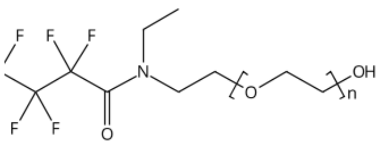

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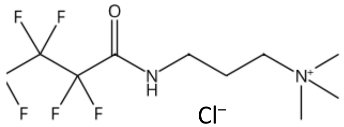

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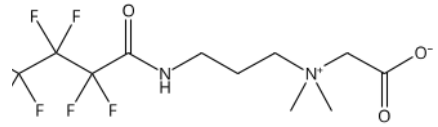
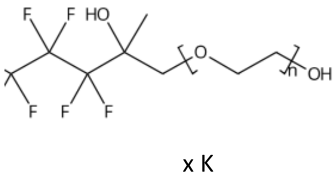
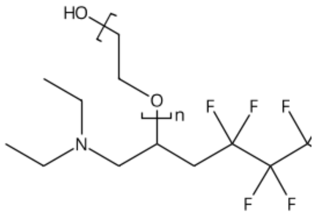


Poly(oxy-1,2-ethanediyl), α-(perfluoro-2-hydroxy-2-methylalkyl)-ω-hydroxy-[4a]	$C_nF_{2n+1}C(OH)(CH_3)CH_2(OCH_2CH_2)_nOH$	n = 9	90168-35-7	P	(CAS 2019 (US4497720))
Poly(oxy-1,2-ethanediyl), α-[1-[(diethylamino)methyl]-perfluoroalkyll]-ω-hydroxy-[4b]	$C_nF_{2n+1}CH_2CH[(OCH_2CH_2)_nOH]CH_2N(C_2H_5)_2$	n = 9	90168-36-8	P	(CAS 2019 (US4497720))
2-Alkanol, perfluoro-, dihydrogen phosphate, potassium salt[4c]	$x\ K^+ \ C_nF_{2n+1}CH_2CH(CH_3)OPO_3^{2-}$	n = 8	90179-37-6	P	(CAS 2019 (US4497720))
1-Heptanol, 4,4,5,5,6,7,7,7-octafluoro-6-(trifluoromethyl)-, dihydrogen phosphate, diammonium salt[4d]	$2\ NH_4^+ \ CF_3CF(CF_3)C_2F_4CH_2CH_2CH_2OPO_3^{2-}$	-	63295-21-6	P	(CAS 2019 (US4497720))

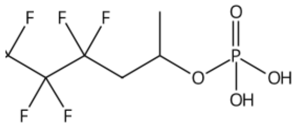
4a



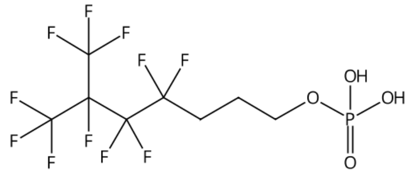
4b



4c



4d



2.24 Musical instruments and related equipement

Elixir (a related ePTFE product) has been used to coat guitar strings to prevent loss of vibration due to residue build up (Gardiner 2015). A recent patent decribes piano keys which contain PVDF (CAS No. 24937-79-9) (CAS 2019 (CN109280339, 2019)). According to the information on the product, the TFL-50 dry lubricant used by piano tuners to eliminate squeaking in piano keys contains fluorocarbons.

2.25 Optical devices

2.25.1 Optical lenses

Teflon-AF (CAS No. 37626-13-4) has excellent thermal, chemical, and electrical properties, also possess outstanding optical clarity and the lowest refractive index of all known organic materials. This makes it ideal for optical lenses, fibreoptic applications, and high quality transparent coatings (Gardiner 2015). A low refractive index and high transparency are also provided when perfluoro(allyl vinyl ether) homopolymer (CAS No. 101182-88-1) or 1-butene, 3,3,4,4-tetrafluoro-4-[(1,2,2-trifluoroethenyl)oxy]-, homopolymer (CAS No. 122817-52-1) are used (CAS 2019 (JP01147501, 1989)).

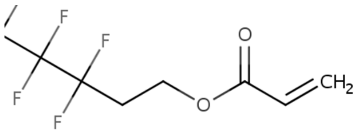
2.25.2 Resin composition for optical materials (e.g. optical fibers)

Transparent and flexible resin compositions with low refractive index are needed for optical materials (CAS 2019 (JP2002212261, 2002)). Table 85 gives some example of PFAS that have been patented for those resin compositions. R. E. Banks, Smart, and Tatlow (1994) stated that side-chain fluorinated (meth)acrylate polymers are of particular interest as cladding materials for optical fibers.

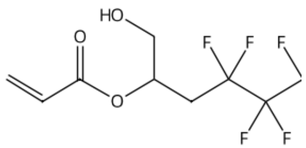
Table 85: PFAS that have been patented for resin compositions for optical materials. Patent number (date, legal status): JP2002212261 (2002, active), JP2003292536 (2003, rejected), JP2004168840 (2004, rejected), JP2004043671 (2004, pending). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
(n:2) Fluorotelomer acrylates (FTACs)[1a]	$C_nF_{2n+1}CH_2CH_2OC(O)CH=CH_2$	n = 8	27905-45-9	P	(CAS 2019 (JP2002212261))
2-Propenoic acid, perfluoro-1-(hydroxymethyl)alkyl ester[1b]	$C_nF_{2n+1}CH_2CH(CH_2OH)OC(O)CH=CH_2$	n = 6, 8	146955-23-9, 146955-29-5	P	(CAS 2019 (JP2002212261, JP2004168840))
2-Propenoic acid, perfluoro-2-hydroxyalkyl ester[1c]	$C_nF_{2n+1}CH_2CH(OH)CH_2OC(O)CH=CH_2$	n = 6, 8	146955-22-8, 76962-34-0	P	(CAS 2019 (JP2002212261, JP2004168840))
2-Propenoic acid, 1-(hydroxymethyl)-2-[perfluoroalkyl)oxy]ethyl ester[1d]	$C_nF_{2n+1}CH_2CH_2OCH_2CH(CH_2OH)OC(O)CH=CH_2$	n = 6	147187-54-0	P	(CAS 2019 (JP2003292536))

1a



1b



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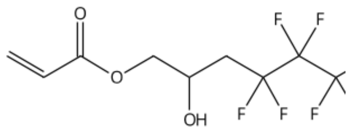
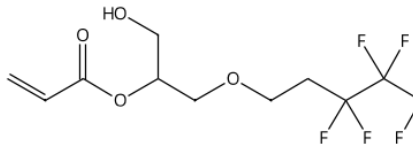


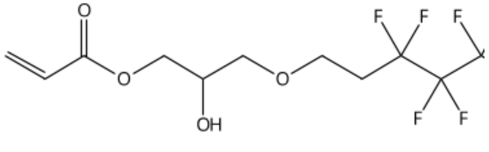
1d



2-Propenoic acid, 2-hydroxy-3-[(perfluoroalkyl)oxy]propyl ester[2a]	$C_nF_{2n+1}CH_2CH_2OCH_2CH(OH)CH_2OC(O)CH=CH_2$	n = 6	145756-59-8	P	(CAS 2019 (JP2003292536))
Oxirane, 2-(perfluoroalkyl)-[2b]	$C_nF_{2n+1}CH_2C_2OH_3$	n = 8	38565-53-6	P	(CAS 2019 (JP2002212261))

Oxirane, 2-[[(perfluoroalkyl)oxy]methyl]-[2c]	$C_nF_{2n+1}CH_2CH_2OCH_2C_2OH_3$	n = 6	122193-68-4	P	(CAS 2019 (JP2004168840))
1,10-Decanediol, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9-hexadecafluoro-[2d]	$HOCH_2C_8F_{16}CH_2OH$	n = 8	754-96-1	P	(CAS 2019 (JP2002212261))

2a



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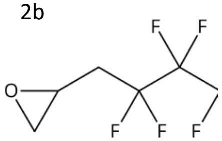

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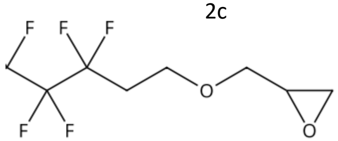
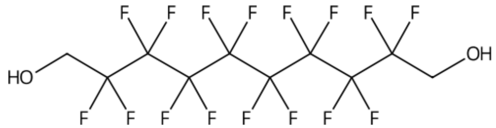
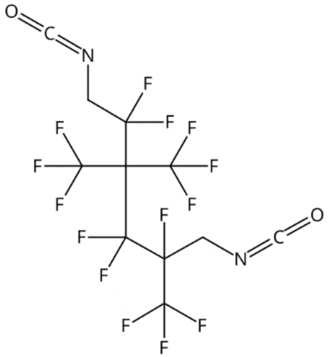


2d

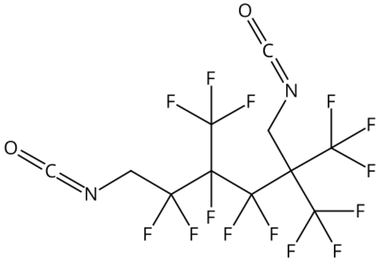


Hexane, 1,1,1,2,3,3,5,5-octafluoro-6-isocyanato-2-(isocyanato methyl)-4,4-bis(trifluoromethyl)-[3a]	$CF_3CF(CH_2N{=}C{=}O)CF_2C(CF_3)_2CF_2CH_2N{=}C{=}O$	-	444122-27-4	P	(CAS 2019 (JP2002212261))
Hexane, 1,1,1,3,3,4,5,5-octafluoro-6-isocyanato-2-(isocyanato methyl)-2,4-bis(trifluoromethyl)-[3b]	$CF_3C(CF_3)(CH_2N{=}C{=}O)CF_2CF(CF_3)CF_2CH_2N{=}C{=}O$	-	444122-26-3	P	(CAS 2019 (JP2002212261))
Ethanol, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-[1,1,2,2-tetra fluoro-2-(1,1,2,2,3,3,4,4,4-nonafluorobutoxy)ethoxy]ethoxy]-[3c]	$CF_2CF2(CF_2CF_2O)_3CF_2CH_2OH$	-	317817-24-6	P	(CAS 2019 (JP2004043671))
Ethanol, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-[1,1,2,2-tetra fluoro-2-[1,1,2,2-tetrafluoro-2-(1,1,2,2,3,3,4,4,4-nonafluoro butoxy)ethoxy]ethoxy]ethoxy]-[3d]	$CF_2CF2(CF_2CF_2O)_4CF_2CH_2OH$	-	653573-80-9	P	(CAS 2019 (JP2004043671))

3a



3b



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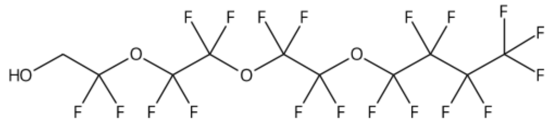
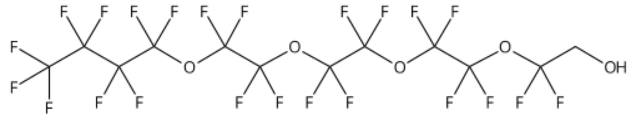


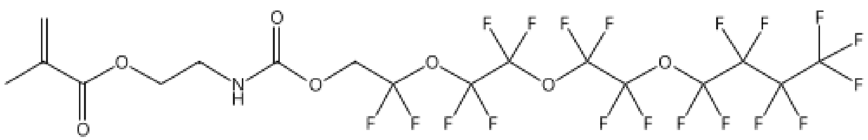
3d



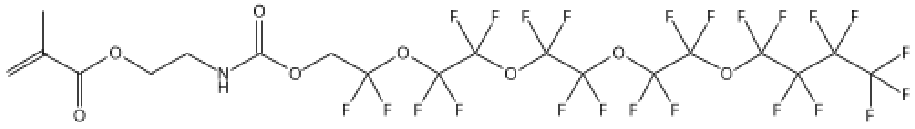
2-Propenoic acid, 2-methyl-, 7,7,9,9,10,10,12,12,13,13,15, 15,16,16,17,17,18,18,18-nonadecafluoro-4-oxo-5,8,11,14-tetraoxa-3-azaoctadec-1-yl ester[4a]	$CF_2CF_2(CF_2CF_2O)_3CF_2CH_2OC(O)NHCH_2CH_2OC(O)C(CH_3){=}CH_2$	-	549549-24-8	P	(CAS 2019 (JP2004043671))
2-Propenoic acid, 2-methyl-, 7,7,9,9,10,10,12,12,13,13,15,15,16, 16,18,18,19,19,20,20,21,21,21-tricosafluoro-4-oxo-5,8,11,14,17-pentaoxa-3-azaheneicos-1-yl ester[4b]	$CF_2CF_2(CF_2CF_2O)_4CF_2CH_2OC(O)NHCH_2CH_2OC(O)C(CH_3){=}CH_2$	-	653573-81-0	P	(CAS 2019 (JP2004043671))

2,2-Bis(trifluoromethyl)propyl methacrylate	-	-	-	U	(R. E. Banks, Smart, and Tatlow 1994)

4a



4b



2.25.3 Other optical devices

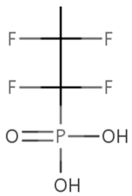
Fiber optics are increasingly employed in long distance communications metropolitan network and local access communications and there is an increasing need for efficient, compact optical amplification. Optical communication systems based on glass optical fibers allow communication signals to be transmitted not only over long distances with low attenuation but also at extremely high data rates, or bandwidth capacity (CAS 2019 (WO2003082884, 2003)). Optical network near the end user, starting at the LAN stage, are characterized by numerous fiber connections, splices, and couplings, especially those associated with splitting of the input signal into numerous channels. All of these introduce optical loss. To compensate for the loss penalty, current solutions rely on expensive erbium-doped fiber amplifier that are bulky at fiber lengths of about 40 m. One of the most critical components in the module is the erbium doped silica fiber (EDF). Present EDF is limited by low concentrations of erbium atoms (maximum is about 0.1%) (CAS 2019 (WO2003082884, 2003)). Compositions of PFAS with reare earth atoms overcome these limitation (see Table 86). Additionally, Teflon AF (CAS No. 37626-13-4), Cytop, and Hyflon AD (CAS No. 161611-79-6) have been used as core and cladding for a new generation of optical fibres (Gardiner 2015). PFAS have also been used in optical elements such as waveguides (e.g., optical fibers and films), optical amplifiers, lasers, compensated optical splitters, multiplexers, isolators, interleavers, demultiplexers, filters, photodetectors, and switches (CAS 2019 (WO2003018592, 2003)). PFAS that are used in those optical devices are also shown in Table 86.

Table 86: PFAS that have been patented for optical devices. Patent number (date, legal status): WO2003018592 (2003, active), WO2003082884 (2003, active), US20030189193 (2003, abandoned application). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

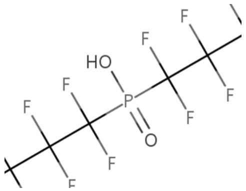
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl phosphonic acids (PFPAs)[1a]	$C_nF_{2n+1}P(=O)(OH)_2$	n = 8	40143-78-0	P	(CAS 2019 (WO2003018592))
Perfluoroalkyl phosphinic acids (PFPiAs)[1b]	$C_nF_{2n+1}P(C_mF_{2m+1})(=O)OH$	n/m = 2/2, 4/4, 4/8, 6/6, 6/8, 7/7, 8/8, 8/10, 10/10, 12/12	103321-11-5, 52299-25-9, 610800-35-6, 40143-77-9, 610800-34-5, 158986-67-5, 40143-79-1, 500776-81-8, 52299-27-1, 63225-54-7	P	(CAS 2019 (WO2003082884))
Phosphinic acid, perfluoroalkyl-, ytterbium (3^+) salt[(1b)]	1/3 Yb^{3+} $C_nF_{2n+1}P(C_mF_{2m+1})O_2^-$	n/m = 4/4, 6/6, 8/8, 8/10, 10/10	500776-86-3, 500776-72-7, 500776-71-6, 500776-94-3, 500776-92-1	P	(CAS 2019 (WO2003018592))

Phosphinic acid, perfluoroalkyl-, erbium (3⁺) salt[(1b)]	1/3 Er^{3+} $C_nF_{2n+1}P(C_mF_{2m+1})O_2^-$	n/m = 4/4, 6/6, 8/8, 8/10, 10/10	500776-85-2, 500776-73-8, 500776-70-5, 500776-93-2, 500776-91-0	P	(CAS 2019 (WO2003018592))
Phosphinic acid, bis(perfluoroalkyl)-, methyl ester[1c]	$(C_nF_{2n+1})_2P(=O)OCH_3$	n = 6	610800-37-8	P	(CAS 2019 (WO2003082884))
Phosphinothioic acid, bis(perfluoroalkyl)-[1d]	$(C_nF_{2n+1})_2P(=O)SH$	n = 8	610800-36-7	P	(CAS 2019 (WO2003082884))
Phosphinic acid, bis[perfluoro-*n*-(trifluoromethyl)alkyl]-[1e]	$[CF_3CF(CF_3)C_nF_{2n}]_2P(=O)OH$	n = 4, 6, 11	610800-33-4, 500776-76-1, 610800-82-3	P	(CAS 2019 (WO2003082884), (US20030189193))
Phosphinic acid, bis[perfluoro-*n*-(trifluoromethyl)alkyl]-, ytterbium (3⁺) salt (3:1) [(1e)]	1/3 Yb^{3+} $[CF_3CF(CF_3)C_nF_{2n}]_2PO_2^-$	n = 6	500776-88-5	P	(CAS 2019 (WO2003018592))

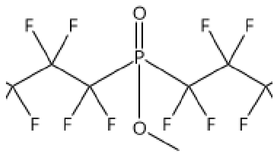
1a



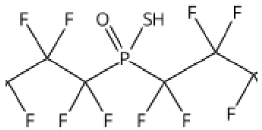
1b



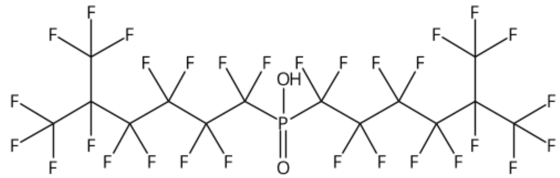
1c



1d

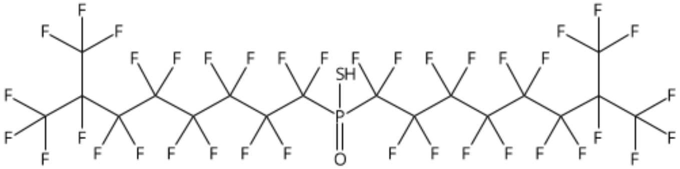


1e

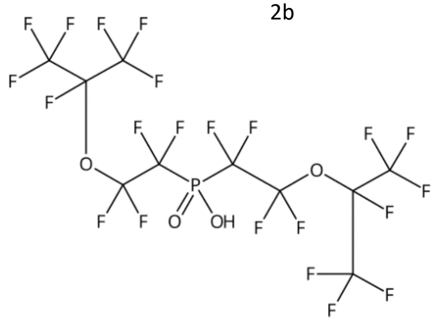


Phosphinic acid, bis[perfluoro-*n*-(trifluoromethyl) alkyl]-, erbium (3⁺) salt (3:1) [(1e)]	1/3 Er^{3+} $[CF_3CF(CF_3)C_nF_{2n}]_2PO_2^-$	n = 6	500776-87-4	P	(CAS 2019 (WO2003018592))
Phosphinothioic acid, bis[perfluoro-*n*-(trifluoromethyl) alkyl]-[2a]	$[CF_3CF(CF_3)C_nF_{2n}]_2P(=O)SH$	n = 6	500776-78-3	P	(CAS 2019 (WO2003082884))
Phosphinothioic acid, bis[perfluoro-*n*-(trifluoromethyl) alkyl]- , ytterbium (3⁺) salt (3:1)[(2a)]	1/3 Yb^{3+} $[CF_3CF(CF_3)C_nF_{2n}]_2 P(=O)S^-$	n = 6	500776-90-9	P	(CAS 2019 (WO2003018592))
Phosphinothioic acid, bis[perfluoro-*n*-(trifluoromethyl) alkyl]- , erbium (3⁺) salt (3:1) [(2a)]	1/3 Er^{3+} $[CF_3CF(CF_3)C_nF_{2n}]_2 P(=O)S^-$	n = 6	500776-89-6	P	(CAS 2019 (WO2003018592))
Phosphinic acid, bis[1,1,2,2-tetrafluoro-2-[1,2,2,2-tetra fluoro-1-(trifluoromethyl) ethoxy]ethyl]-[2b]	$[CF(CF_3)_2OCF_2CF_2]_2P(=O)OH$	-	500776-74-9	P	(CAS 2019 (WO2003082884))
Phosphinic acid, bis[1,1,2,2-tetrafluoro-2-[1,2,2,2-tetra fluoro-1-(trifluoromethyl) ethoxy]ethyl]-, ytterbium(3⁺) salt[(2b)]	1/3 Yb^{3+} $[CF(CF_3)_2OCF_2CF_2]_2PO_2^-$	-	800776-84-1	P	(CAS 2019 (WO2003082884))
Phosphinic acid, bis[1,1,2,2-tetrafluoro-2-[1,2,2,2-tetra fluoro-1-(trifluoromethyl)ethoxy]ethyl]-, erbium (3⁺) salt[(2b)]	1/3 Er^{3+} $[CF(CF_3)_2OCF_2CF_2]_2PO_2^-$	-	500776-83-0	P	(CAS 2019 (WO2003082884))
-[2c]	$C_3F_7(OCF(CF_3))_{10}COOH$	-		U	(Buck, Murphy, and Pabon 2012)
Teflon AF[2d]	$-(CF_2CF_2)_x-[C(CF_3)_2O_2C_2F_2]_y-$	polymer	37626-13-4	U	(Gardiner 2015)
Cytop	-	polymer	-	U	(Gardiner 2015)

2a



2b



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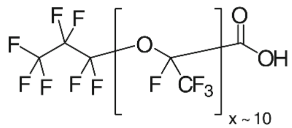
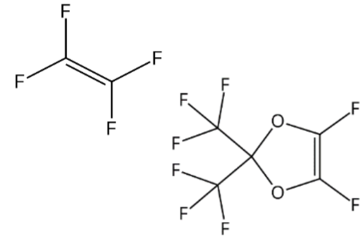
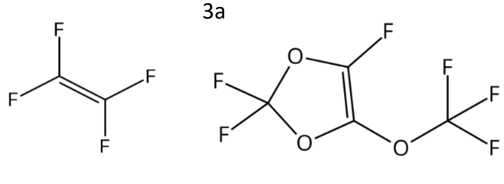


2d



Hyflon AD[3a]	$-(CF_2CF_2)_x-(CF_2O_2C_2FOCF_3)_y-$	polymer	161611-79-6	U	(Gardiner 2015)

3a



2.26 Paper and packaging

PFAS have been used in the paper industry to produce water and greaseproof paper (Poulsen, Jensen, and Wallström 2005). PFAS can be added to the pulp slurry, applied to the paper surface, or included in pigment coatings. The surface treatment process has been the most effective mode of PFAS application and has been easier to control than the internal application process (Kissa 2001). Fluorinated surfactants have also been used as release agents for paper-coating compositions (Kissa 2001). Cast-coated paper is produced by coating the paper with pigment- and adhesive-containing solutions, air drying the paper, rewetting a polyethylene emulsion, and pressing the wet surface with a PFAS-coated hot drum to yield a paper with a high gloss.

2.26.1 Food-contact articles

PFAS have been use in food contact articles since the early 1960s (POPRC 2016a). Perfluorooctane sulfonamido ethanol-based phosphate esters were the first substances used to provide grease repellency to food contact papers. In 2000, 3M ceased its production of POSF-based side-chain fluorinated polymers (e.g., CAS No. 92265-81-1) and phosphate diesters (e.g. CAS No. 30381-98-7, 67969-69-1, 1691-99-2, 2250-98-8) that were used in food contact materials (see Table 88). Products based on 6:2 fluorotelomers [both side-chain fluorinated polymers and phosphate diesters (diPAPs)] took over the market share left by 3Ms phase-out (Z. Wang et al. 2013). Examples of 6:2 florotelomer-based side-chain fluorinated polymers are provided in Table 89. 6:2 Fluorotelomer phosphate esters (PAPs) may be still used in food-contact paper products and as leveling and wetting agents (POPRC 2016a). If phosphate-based fluorinated surfactants are used, they are added to the paper through the wet end press where cellulosic fibers are mixed with paper additives before entering the paper forming table of a paper machine. This is necessary because paper fibers and phosphate-based fluorinated surfactants are both anionic, and cationic bridge molecules need to be used in order to ensure the electrostatic adsorption of the surfactant onto the paper fiber. The wet end press treatment provides excellent coverage of the fiber with the surfactant and results in good folding resistance. An alternative treatment method uses fluorinated polymers which are applied at the size press and film press stage to the surface of the formed paper face treatment (POPRC 2016a).

Phosphate-based fluorinated surfactants provide good oil repellency, but have limited water repellency. Side-chain fluorinated acrylate polymers derived from perfluoroalkane sulfonamido alcohols or fluorotelomer alcohols have been the most widely used polymers in this application because they deliver oil, grease, and water repellency. Additionally, perfluoropolyether-based phosphates and polymers have become widely used treatments for food contact paper and paper packaging (POPRC 2016a). An example of a product based on PFPEs is Solvera® from Solvay. The chemical structure ist likely similar to $HO(=O)(OH)PO\text{-}(CH_2CH_2O)_n\text{-}CH_2CF_2\text{-}(OCF_2)_p\text{-}(OCF_2CF_2)_q\text{-}OCF_2CH_2\text{-}(OCH_2CH_2)_n\text{-}OP(=O)(OH)_2$ (Z. Wang et al. 2013; Trier, Granby, and Christensen 2011).

Examples for food-contact articels with PFAS are plates, food containers, cupcake forms, popcorn bags, pizza boxes, baking paper, and candy & fast food wrappers (Poulsen, Jensen, and Wallström 2005; UNEP 2017; Blom and Hanssen 2015). Table 87 shows PFAS that have been detected in food paper and packaging. The treatment of paper and paperboards used for food and pet food packaging in the US requires approval by the Food and Drug Administration (FDA).

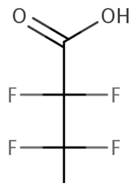
Table 88 lists PFAS that were approved in the past by the US FDA for food contact materials. It is to be noted that some of these PFAS might have been used in other packaging materials than paper (e.g. plastic), but they might also have been used in paper and packaging. Table 89 lists PFAS that are currently approved by the US FDA for food contact materials. Again, these substances might have been used in other packaging materials than paper. More information on PFAS in paper and board for food contact is available in Trier et al. (2017), including information on allowed PFAS in paper and board by the German Bundesamt für Risikobewertung (BfR) 2016, the Council of Europe, the EU Commission regulation on plastic materials and articles intended to come into contact with food (Regulation (EU) no 10/2011), the Netherlands, Italy, Belgium, and the People’s Republic of China.

Table 87: PFAS that have been detected in paper and packaging for food-contact articels. D under type stands for deteced. Additional explanations to the table are provided on Page 2 and 3 of this document.

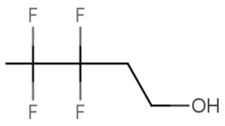
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4 , 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Gebbink et al. 2013; Blom and Hanssen 2015)
Perfluoroalkane sulfonic acids (PFSAs)	$C_nF_{2n+1}SO_3H$	n = 8	1763-23-1	D	(Blom and Hanssen 2015)
(n:2) Fluorotelomer alcohols (FTOHs)[1b]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8, 10, 12, 14, 16, 18	647-42-7, 678-39-7, 865-86-1, 39239-77-5, 60699-51-6, 65104-67-8, 65104-65-6	D	(Blom and Hanssen 2015; Trier et al. 2017)
(n:2) Fluorotelomer phosphate monoester (monoPAPs)[1c]	$C_nF_{2n+1}CH_2CH_2OP(=O)(OH)_2$	n = 6, 8, 10	57678-01-0, 57678-03-2, 57678-05-4	D	(Gebbink et al. 2013)
(n:2) Fluorotelomer phosphate diester (diPAPs)[1d]	$(O)P(OH)(OCH_2CH_2C_nF_{2n+1})(OCH_2CH_2C_mF_{2m+1})$	n/m = 6/6, 6/8, 6/10, 6/12, 8/8, 8/10	57677-95-9, 943913-15-3, 1578186-50-1, 1578186-69-2, 678-41-1, 1158182-60-5	D	(Gebbink et al. 2013)

(n:2) Fluorotelomer phosphate triester[1e]	$OP(OCH_2CH_2C_nF_{2n+1})(OCH_2CH_2C_mF_{2m+1})OCH_2CH_2C_pF_{2p+1}$	n/m/p = 6/6/6, 6/6/8, 6/8/8, 6/8/10, 6/6/10, 8/8/8	165325-62-2, 1578186-53-4, 1578186-56-7, 1578186-64-7, 1578186-57-8, 149790-22-7	D	(Gebbink et al. 2013)
PFPE	$(OH)_2OPO(C_2H_4O)_n(C_2H_2F_2O)_o(C_2F_4O)_p(CF_2O)_qPO\ (OH)_2$	polymer	-	D	(Dimzon et al. 2016)

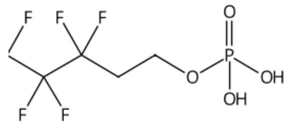
1a



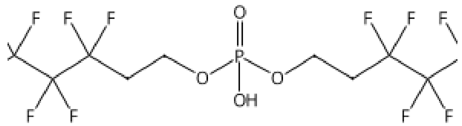
1b



1c



1d



1e

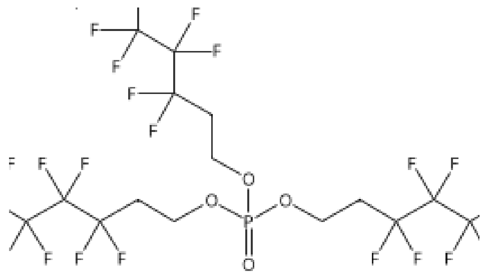
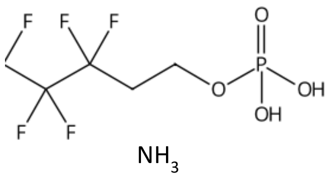


Table 88: PFAS that were approved in the past by the US FDA for food contact materials. It is to be noted that some of these PFAS might have been used in other packaging materials than paper (e.g. plastic). AP – approved in the past. Patent number (date, legal status): US3083224 (1963, expired), US3096207 (1963, expired), JP60064990 (1985, expired). Additional explanations to the table are provided on Page 2 and 3 of this document.

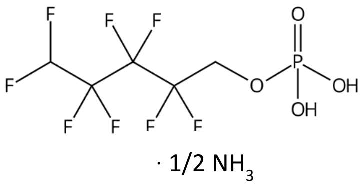
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Ammonium (n:2) fluorotelomer phosphate monoester[1a]	$NH_4^+\ C_nF_{2n+1}CH_2CH_2OPHO_3^-$	n = 6	2353-52-8	AP	(Kissa 2001; CAS 2019 (US3083224))
Diammonium (n:2) fluorotelomer phosphate monoester[(1a)]	$2\ NH_4^+\ C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	n = 7	63439-39-4	AP	(Kissa 2001; CAS 2019 (US3083224))
1-Alkanol, perfluoro-, dihydrogen phosphate, ammonium salt[(1a)]	$x\ NH_4^+\ C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	n = 6	92401-44-0	AP	(Kissa 2001; CAS 2019 (US3083224))
1-Alkanol, perfluoro, phosphate, ammonium salt (2:1)[1b]	$1/2\ NH_4^+\ HC_nF_{2n}CH_2OPO_3^{2-}$	n = 10	100738-12-3	AP	(Kissa 2001; CAS 2019 (US3096207))
Diphosphoric acid, mono(perfluoroalkyl) ester, compd. with 2,2′,2′′-nitrilotris[ethanol] (1:3)[1c]	$N(CH_2CH_2OH)_3\ C_nF_{2n+1}CH_2CH_2OP(=O)(OH)OP(=O)(OH)_2$	n = 8	98005-85-7	AP	(Kissa 2001; CAS 2019 (JP60064990))
Diphosphoric acid, mono(perfluoroalkyl) ester, with 2-aminoethanol (1:3)	$NH_2CH_2CH_2OH\ C_nF_{2n+1}CH_2CH_2OP(=O)(OH)\ OP(=O)(OH)_2$	n = 8	98005-84-6	AP	(Kissa 2001; CAS 2019 (JP60064990))
(n:2) Fluorotelomer phosphat diester (diPAPs)[1d]	$(O)P(OH)(OCH_2CH_2C_nF_{2n+1})_2$	n = 8, 10	678-41-1, 1895-26-7	AP	(Kissa 2001; CAS 2019 (US3083224))

Ammonium (n:2) fluorotelomer phosphate diester	$NH_4^+ PO_2^-(OCH_2CH_2C_nF_{2n+1})_2$	n = 7	1895-79-0	AP	(Kissa 2001; CAS 2019 (US3083224))

1a



1b



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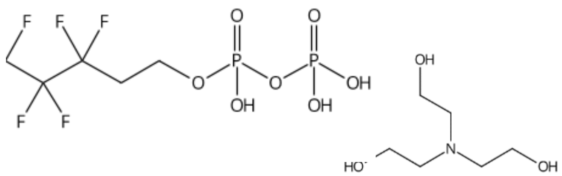
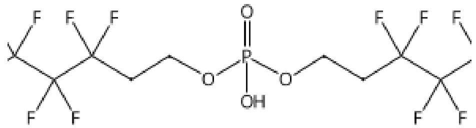
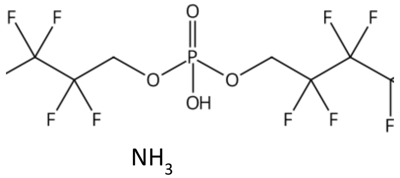


1d

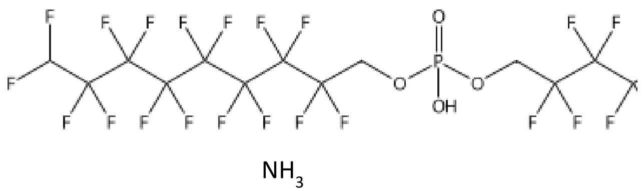


1-Alkanol, perfluoro-, phosphate (2:1), ammonium salt[2a]	$NH_4^+ PO_2^- (OCH_2C_nF_{2n+1})_2$	n = 7	1555-33-5	AP	(Kissa 2001; CAS 2019 (US3096207))
1-Alkanol, perfluoro-, hydrogen phosphate, ammonium salt[2b]	$NH_4^+ PO_2^- (OCH_2C_nF_{2n}H)_2$	n = 8, 10	7757-53-1, 1765-83-9	AP	(Kissa 2001; CAS 2019 (US3096207))
1-Alkanol, perfluoro, 1,1′-(hydrogen phosphate), ammonium salt (1:1)[2c]	$NH_4^+ PO_2^- (OCH_2CH_2CH_2CH_2C_nF_{2n+1})_2$	n = 4	3803-40-5	AP	(Kissa 2001; CAS 2019 (US3083224))
1-Alkanol, perfluoro-, dihydrogen phosphate	$OP(OH)[O(CH_2)_{11}C_nF_{2n+1}]_2$	n = 8	2342-53-5	AP	(Kissa 2001; CAS 2019 (US3083224))

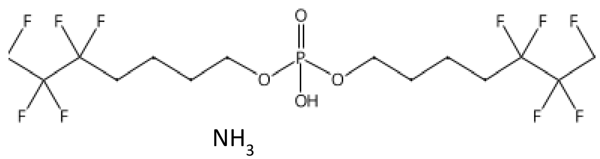
2a



2b

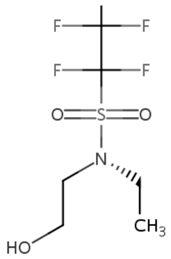


2c

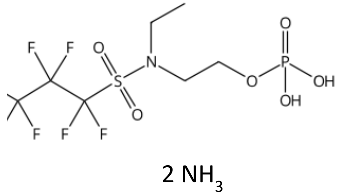


N-Ethyl perfluoroalkane sulfonamidoethanols (EtFASEs)[3a]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2OH$	n = 8	1691-99-2	U	(3M 1999)
1-Alkanesulfonamide, *N*-ethyl-perfluoro-*N*-[2-(phosphonooxy)ethyl]-, ammonium salt (1:2)[3b]	$2\ NH_4^+\ C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2OPO_3^{2-}$	n = 8	67969-69-1	U	(3M 1999)
1-Alkanesulfonamide, *N*,*N*′-[phosphinicobis(oxy-2,1-ethanediyl)]bis[*N*-ethyl-perfluoro-, ammonium salt (1:1)[3c]	$NH_4^+ [C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2O]_2PO_2^-$	n = 8	30381-98-7	AP, U	(Z. Wang et al. 2013; 3M 1999)
1-Alkanesulfonamide, *N*,*N*′,*N*′′-[phosphinylidynetris (oxy-2,1-ethanediyl)]tris[N-ethyl-perfluoro-[3d]	$[C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2O]_3P(=O)$	n = 8	2250-98-8	U	(3M 1999)

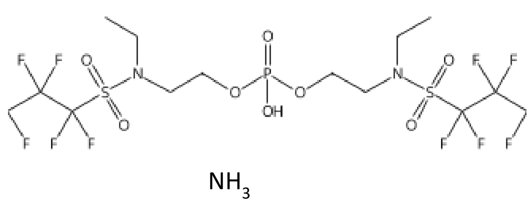
3a



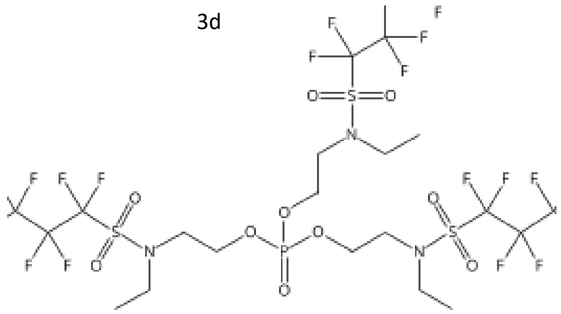
3b



3c

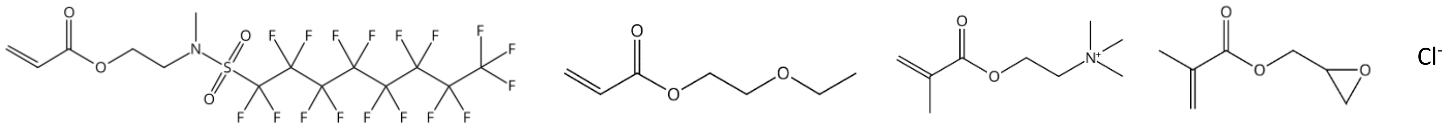


3d



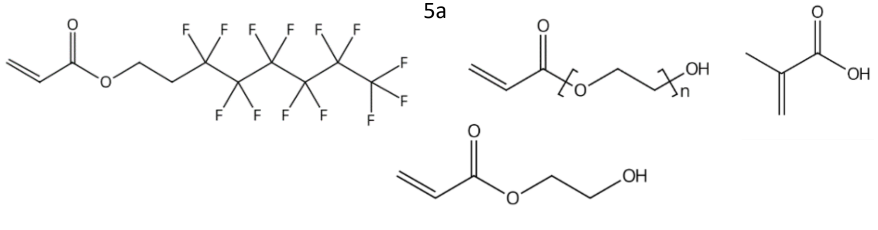
Ethanaminium, *N*,*N*,*N*-trimethyl-2-[(2-methyl-1-oxo-2-propenyl)oxy]-, chloride, polymer with 2-ethoxyethyl 2-propenoate, 2-[[(heptadecafluor ooctyl)sulfonyl] methylamino]ethyl 2-propenoate and oxiranylmethyl 2-methyl-2-propenoate[4a]	$-(C_{14}H_{10}F_{17}NO_4S)_x-(C_9H_{18}NO_2)_y-(C_7H_{12}O_3)_m-(C_7H_{10}O_3)_n-Cl_w-$	polymer	92265-81-1	AP, U	(Z. Wang et al. 2013)

4a

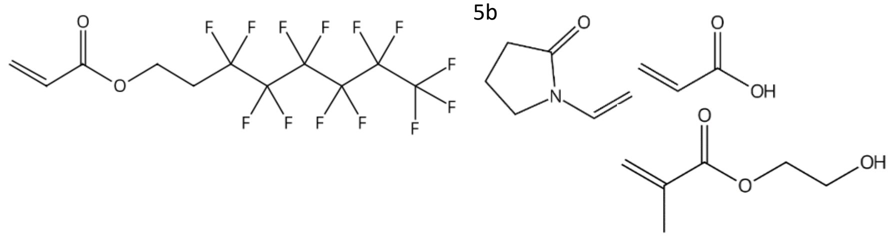


2-Propenoic acid, 2-methyl-, polymer with 2-hydroxy ethyl 2-methyl-2-propenoate, α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl) and 3,3,4,4,5,5,6,6, 7,7,8,8,8-tridecafluorooctyl 2-propenoate[5a]	$-(C_{11}H_7F_{13}O_2)_x-(C_6H_{10}O_3)_y-(C_4H_6O_2)_m-[(C_2H_4O)_nC_3H_4O_2]_n-$	polymer (Daikin)	1158951-85-9	AP	(Z. Wang et al. 2013)
2-Propenoic acid, 2-methyl-, 2-hydroxyethyl ester, polymer with 1-ethenyl-2-pyrrolidinone, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate[5b]	$-(C_{11}H_7F_{13}O_2)_x-(C_6H_{10}O_3)_y-(C_6H_9NO)_m-(C_3H_4O_2)_n-$	polymer (Daikin)	1206450-09-0	AP	(Z. Wang et al. 2013)

5a



5b



2-Propenoic acid, 2-methyl-, polymer with 2-(diethyl amino)ethyl 2-methyl-2-propenoate, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-trideca fluorooctyl 2-methyl-2-propenoate[6a]	$-(C_{12}H_9F_{13}O_2)_x-(C_{10}H_{19}NO_2)_y-(C_4H_6O_2)_m-(C_3H_4O_2)_n-$	polymer (DuPont)	1071022-25-7	AP	(Z. Wang et al. 2013)
Diethanolamine salts of mono- and bis (1H, 1H, 2H, 2H perfluoroalkyl) phosphates	-	-		AP	(POPRC 2016a)
Pentanoic acid, 4,4-bis [(gamma-omega-perfluoro-C8-20-alkyl)thio] derivatives, compounds with diethanol amine (CAS No: 71608-61-2)	-	-		AP	(POPRC 2016a)
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	-	-		AP	(POPRC 2016a)

6a

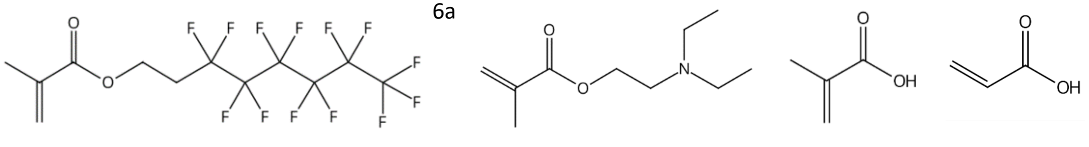
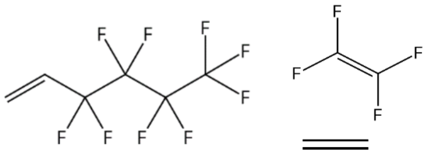


Table 89: PFAS that are currently approved by the FDA for food contact materials. It is to be noted that some of these PFAS might have been used in other packaging materials than paper (e.g. plastic). A – currently approved. Additional explanations to the table are provided on Page 2 and 3 of this document.

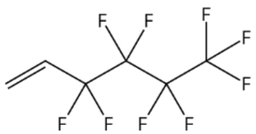
Chemical name	Molecular formula	Manufacturer/supplier, effective date	CAS No./*FCN No.*	Type	Reference
Fluorocarbon cured elastomer produced by copolymerizing tetrafluoroethylene (CAS No. 116-14-3) and propylene (CAS No. 115-07-1) and subsequent curing with triallylisocyanurate (CAS No. 1025-15-6)	-	polymer (AGC Chemicals Americas, Inc.), Jul 17, 2019	*FCN No. 1958*	A	(FDA 2020b)

or triallylcyanurate (CAS No. 101-37-1) and 2,2’-bis(tert-butylperoxy) diisopropylbenzene (CAS No. 25155-25-3).					
Tetrafluoroethylene-ethylene-3,3,4,4,5,5,6,6,6-nonafluoro-1-hexene terpolymer[1a]	$-(C_6H_3F_9)_x-(C_2H_4)_y-(C_2F_4)_m-$	polymer (Asahi Glass Co., Ltd. AGC Chemicals Europe), Dec 13, 2018	68258-85-5	A	(FDA 2020b)
Siloxanes and silicones, methyl-phenyl, methyl-3,3,3-trifluoropropyl	-	polymer (Dow Silicones Corporation DDP Specialty Electronic Materials US 9, LLC), Dec 1, 2017	1643944-25-5	A	(FDA 2020b)
A polymer produced from tetrafluoroethylene (CAS No. 116-14-3) and 1,1,2,2-tetrafluoro-2-((1,2,2-trifluoroethenyl)oxy)ethanesulfonyl fluoride (CAS No. 29514-94-1). The polymer is hydrolyzed and may optionally be further neutralized to its ammonium salt.	-	polymer (Solvay Specialty Polymers USA, LLC), Dec 20, 2017	*FCN No. 1805*	A	(FDA 2020b)
1-Hexene, 3,3,4,4,5,5,6,6,6-nonafluoro-, polymer with 1,1,2,2-tetrafluoroethene[1b]	$-(C_6H_3F_9)_x-(C_2F_4)_y-$	polymer (Asahi Glass Co., Ltd. AGC Chemicals Europe and Americas, Inc), Jan 13, 2017	82606-24-4	A	(FDA 2020b)
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[1c]	$-(C_{12}H_9F_{13}O_2)_x-(C_6H_{10}O_3)_y-(C_3H_4O_2)_m$-xNa-	polymer (Asahi Glass Co., Ltd. AGC Chemicals Americas, Inc.), Sep 21, 2016	1878204-24-0	A	(FDA 2020b)

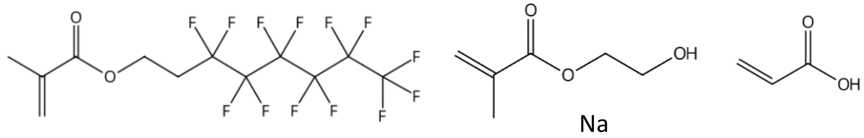
1a



1b

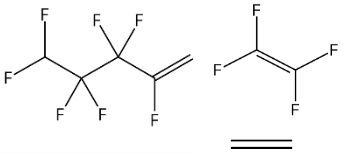


1c

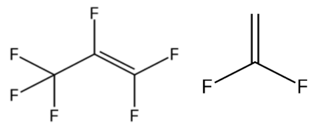


2,3,3,4,4,5,5-Heptafluoro-1-pentene polymer with ethene and tetrafluoroethene[2a]	$-(C_5H_3F_7)_x-(C_2H_4)_y-(C_2F_4)_m-$	polymer (Daikin Industries, LTD), Mar 5, 2016	94228-79-2	A	(FDA 2020b)
Vinylidene fluoride-hexafluoropropene copolymer[2b]	$-(CH_2CF_2)_x-[CF_2CF(CF_3)]_y-$	polymer (Arkema, Inc; Arkema, Inc.; 3M), Sep 18, 2015	9011-17-0	A	(FDA 2020b)
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	-	polymer (Archroma Management GmbH), Dec 31, 2014	1440528-04-0	A	(FDA 2020b)
2-Propenoic acid, 2-methyl-, 2-(dimethylamino)ethyl ester, polymer with 1-ethenyl-2-pyrrolidinone and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate, acetate[2c]	$(C_{11}H_7F_{13}O_2)_x-(C_8H_{15}NO_2)_y-(C_6H_9NO)_m-(C_2H_4O_2)_w-$	polymer (Daikin America, Inc.), Sep 4, 2014	1334473-84-5	A	(FDA 2020b)

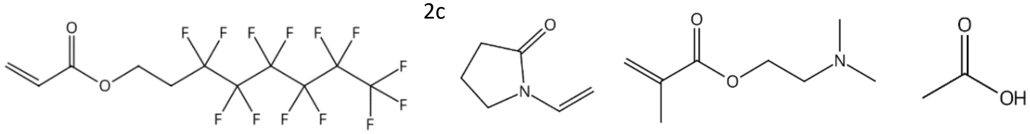
2a



2b

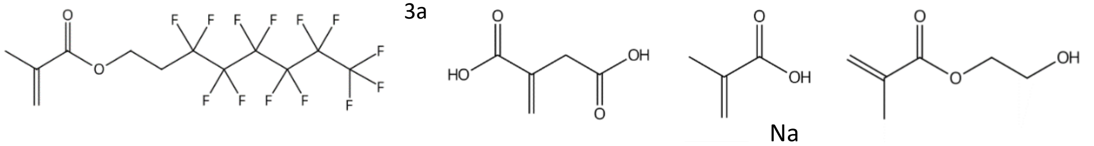


2c

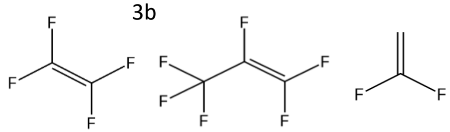


Butanedioic acid, 2-methylene-, polymer with 2-hydroxyethyl 2-methyl-2-propenoate, 2-methyl-2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, sodium salt[3a]	$(C_{12}H_9F_{13}O_2)_x$-$(C_6H_{10}O_3)_y$-$(C_5H_6O_4)_m$-$(C_4H_6O_2)_n$-xNa	polymer (Asahi Glass Co., Ltd. AGC Chemicals Americas, Inc.), Sep 21, 2012	345817-52-8	A	(FDA 2020b)
Tetrafluoroethylene-hexafluoropropylene-vinylidene fluoride copolymers[3b]	-$(CF_2CF_2)_x$-$[CF_2CF(CF_3)]_y$-$(CF_2CH_2)_m$-	polymer (3M, Dyneon LLC), Jan 17, 2012	25190-89-0	A	(FDA 2020b)

3a

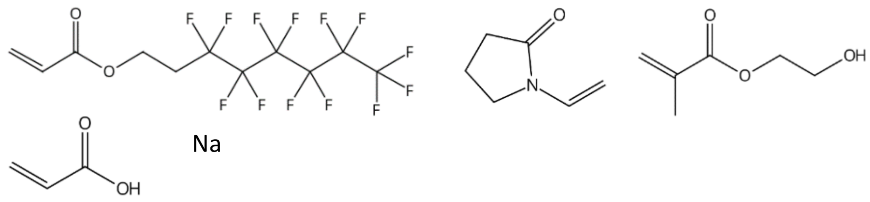


3b

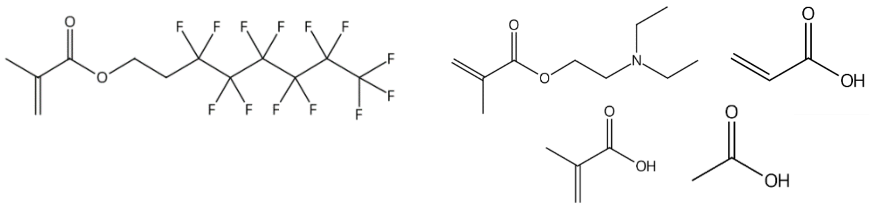


A copolymer of tetrafluoroethylene (CAS No. 116-14-3) and trifluoromethyl trifluorovinyl ether (CAS No. 1187-93-5), and optionally employing a halogenated alkene.	-	polymer (Dupont Specialty Products USA, LLC), Nov 24, 2011	*FCN No. 1116*	A	(FDA 2020b)
Hexane, 1,6-diisocyanato-, homopolymer, α-[1-[[[3-[[3 (dimethylamino)propyl]amino]propyl]amino]carbonyl]-1,2,2,2-tetrafluoroethyl]-ω-(1,1,2,2,3,3-heptafluoropropoxy) poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]]-blocked	-	polymer (Archroma U.S., Inc.), Aug 24, 2011	1279108-20-1	A	(FDA 2020b)
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[4a]	$(C_{11}H_7F_{13}O_2)_x$-$(C_6H_{10}O_3)_y$-$(C_6H_9NO)_m$-$(C_3H_4O_2)_n$-xNa	polymer (Daikin America, Inc.), Feb 16, 2011	1206450-10-3	A	(FDA 2020b)
2-Propenoic acid, 2-methyl-, polymer with 2-(diethylamino)ethyl 2-methyl-2-propenoate, 2-propenoic acid and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-methyl-2-propenoate, acetate[4b]	-$(C_{12}H_9F_{13}O_2)_x$-$(C_{10}H_{19}NO_2)_y$-$(C_4H_6O_2)_m$-$(C_3H_4O_2)_n$-$(C_2H_4O_2)_w$-	polymer (The Chemours Company FC), Jan 12, 2011	1071022-26-8	A	(FDA 2020b)

4a

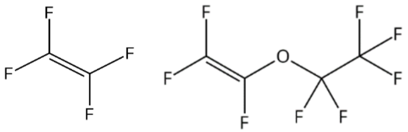


4b

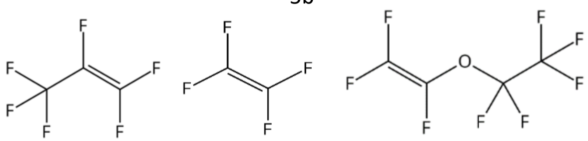


Diphosphoric acid, polymers with ethoxylated reduced methyl esters of reduced polymerized oxidized tetrafluoroethylene	-	polymer (Solvay Specialty Polymers USA), May 11, 2010	200013-65-6	U, A	(FDA 2020b; USEPA 2016)
Ethene, 1,1,2,2-tetrafluoro-, polymer with 1,1,2-trifluoro-2-(1,1,2,2,2-pentafluoroethoxy)ethene[5a]	$-(CF_2CF_2)_x-[CF_2CFO(C_2F_5)]_y-$	polymer (The Chemours Company FC), Apr 6, 2010	31784-04-0	A	(FDA 2020b)
Copolymer of hexafluoropropylene (CAS No. 116-15-4), tetrafluoroethene (CAS No. 116-14-3), and perfluoroethyl vinyl ether (CAS No. 10493-43-3)[5b]	-	polymer (The Chemours Company FC), Apr 30, 2010	-	A	(FDA 2020b)
Hexane, 1,6-diisocyanato-, homopolymer, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol-blocked	-	polymer (The Chemours Company FC), Apr 3, 2010	357624-15-8	A	(FDA 2020b)
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-ethane diyl) and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate, sodium salt[5c]	$-(C_{11}H_7F_{13}O_2)_x-(C_6H_{10}O_3)_y-(C_4H_6O_2)_m-[(C_2H_4O)_n C_3H_4O_2]_w-xNa-$	polymer (Daikin America, Inc.), Dec 30, 2009	1158951-86-0	A	(FDA 2020b)

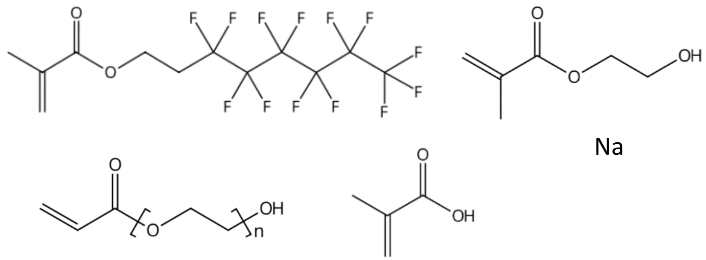
5a



5b



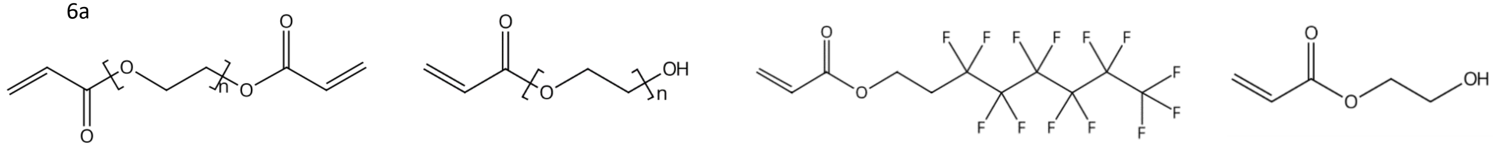
5c



Fluorocarbon cured elastomer produced by copolymerizing tetrafluoroethylene (CAS No. 116-14-3) and propylene (CAS No. 115-07-01) and subsequent curing of the copolymer with triallylisocyanurate (CAS No. 1025-15-6) and 2,2'-bis(tert-butylperoxy)diisopropylbenzene (CAS Reg. No 25155-25-3)	-	polymer (Process Technologies, Inc.), Jul 23, 2009	-	A	(FDA 2020b)

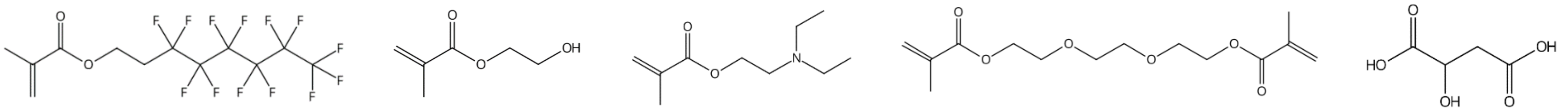
2-propenoic acid, 2-hydroxyethyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl), α-(1-oxo-2-propen-1-yl)-ω-[(1-oxo-2-propen-1-yl)oxy]poly(oxy-1,2-ethanediyl) and 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl 2-propenoate[6a]	$-(C_{11}H_7F_{13}O_2)_x-(C_5H_8O_3)_y-[(C_2H_4O)_nC_6H_6O_3]_w-[(C_2H_4O)_nC_3H_4O_2]_u-$	polymer (Daikin America, Inc.), Jun 18, 2009	1012783-70-8	A	(FDA 2020b)

6a



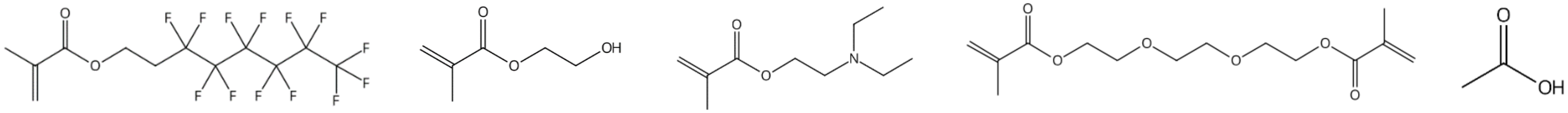
2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester, polymer with α-(1-oxo-2-propen-1-yl)-ω-hydroxypoly(oxy-1,2-ethanediyl)	-	polymer (Daikin America, Inc.), Jul 31, 2008	-	A	(FDA 2020b)
2-propen-1-ol, reaction products with 1,l,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-6-iodohexane, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine	-	polymer (Solenis LLC), Mar 6, 2008	464178-94-7	A	(FDA 2020b)
1-Propene,1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene (CAS No. 9011-17-0) modified with a halogenated ethylene as described in the food contact notification	-	polymer (Dyneon), Oct 26, 2007	-	A	(FDA 2020b)
Copolymer of perfluorohexylethyl methacrylate, 2-*N*,*N*-diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, malic acid salt[7a]	$-(C_{14}H_{22}O_6)_x-(C_{12}H_9F_{13}O_2)_y-(C_{10}H_{19}NO_2)_m-(C_6H_{10}O_3)_n-(C_4H_6O_5)_w-$	polymer (Asahi Glass Company, Ltd. (Manufacturer) AGC Chemicals Americas, Incorporated), Aug 5, 2006	1225273-44-8	A	(FDA 2020b)

7a



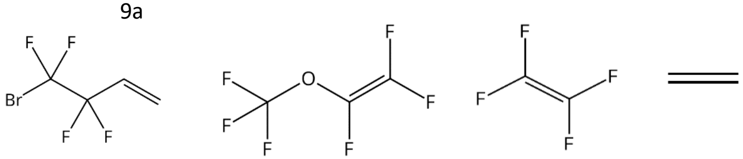
Copolymer of perfluorohexylethyl methacrylate, 2-*N*,*N*-diethylaminoethyl methacrylate, 2-hydroxyethyl methacrylate, and 2,2'-ethylenedioxydiethyl dimethacrylate, acetic acid salt[8a]	$-(C_{14}H_{22}O_6)_x-(C_{12}H_9F_{13}O_2)_y-(C_{10}H_{19}NO_2)_m-(C_6H_{10}O_3)_n-(C_2H_4O_2)_w-$	polymer (Asahi Glass Company, Ltd. (Manufacturer) AGC Chemicals Americas, Incorporated) Aug 5, 2006	863408-20-2	A	(FDA 2020b)

8a



A copolymer of propylene (CAS No. 115-07-1), tetrafluoroethylene (CAS No. 116-14-3), and 3,3,3-trifluoropropene (CAS No. 677-21-4) cured with a salt of a quaternary ammonium compound and phenol, 4,4'-(2,2,2-trifluoro-1-(trifluoromethyl)ethylidene)bis-	-	polymer (The Chemours Company FC), Apr 29, 2006	-	A	(FDA 2020b)
Copolymer of tetrafluoroethylene, perfluoromethylvinylether and 1-iodo-2-bromotetrafluoroethane intended to be cross-linked with triallylisocyanurate	-	polymer (Unimatec Com pany, Ltd.), Mar 30, 2006	-	A	(FDA 2020b)
A copolymer of 4-bromo-3,3,4,4-tetrafluoro-1-butene, ethylene, tetrafluoroethylene and trifluoromethyl trifluorovinyl ether optionally cured with triallyl isocyanurate and 2,5-dimethyl-2,5-di(tert-butylperoxy)hexane[9a]	$-(C_4H_3BrF_4)_x-(C_3F_6O)_y-(C_2H_4)_m-(C_2F_4)_n-$	polymer (The Chemours Company FC), Nov 22, 2005	105656-63-1	A	(FDA 2020b)

9a



Perfluoropolyether dicarboxylic acid (CAS No. 69991-62-4), ammonium salt	-	polymer (Solvay Specialty Polymers Italy S.p.A.), Nov 19, 2005	-	A	(FDA 2020b)
2-propen-1-ol, reaction products with pentafluoroiodoethane-tetrafluoroethylene telomer, dehydroiodinated, reaction products with epichlorohydrin and triethylenetetramine	-	polymer (Solenis LLC), Oct 20, 2005	464178-90-3	A	(FDA 2020b)
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	-	polymer (The Chemours Company FC), Oct 13, 2005	-	A	(FDA 2020b)
Copolymer of 1,1-difluoroethylene, hexafluoropropene, tetrafluoroethylene, and a halogenated alkene, optionally cured with triallyl isocyanurate and 2,5-dimethyl-2,5-di(tert-butylperoxy)hexane	-	polymer (The Chemours Company FC), Oct 13, 2005	-	A	(FDA 2020b)
A copolymer of tetrafluoroethylene and perfluoromethylvinyl ether (CAS No. 26425-79-6) \ 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	-	polymer (Precision Polymer Engineering, Ltd.), Jul 2, 2004	-	A	(FDA 2020b)

A perfluorocarbon cured elastomer (PCE) produced by terpolymerizing tetrafluoroethylene, (CAS No. 116-14-3), perfluoro-2,5-dimethyl-3,6-dioxanonane vinyl ether (CAS No. 2599-84-0), and perfluoro-6,6-dihydro-6-iodo-3-oxa-1-hexene (CAS No. 106108-22-9), and subsequent curing of the terpolymer (CAS No. 106108-23-0) with triallylisocyanurate (CAS No. 1025-15-6) and 2,5-dimethyl-2,5-di(t-butylperoxy)hexane (CAS No. 78-63-7).	-	polymer (Greene, Tweed and Company, Inc.), Aug 13, 2002	-	A	(FDA 2020b)
Fluorocarbon cured elastomer produced by copolymerizing tetrafluoroethylene (CAS No. 116-14-3) and propylene (CAS No. 115-07-01) and subsequent curing of the copolymer (CAS No. 27029-05-6) with triallylisocyanurate (CAS No. 1025-15-6) and 2,2'-bis(tert-butylperoxy)diisopropylbenzene (CAS No. 25155-25-3).	-	polymer (Greene, Tweed and Company, Inc.), Aug 13, 2002	-	A	(FDA 2020b)
A perfluorocarbon cured elastomer (PCE) produced by terpolymerizing tetrafluoroethylene, (CAS No. 116-14-3), perfluoromethyl vinyl ether (CAS No. 1187-93-5), and perfluoro-6,6-dihydro-6-iodo-3-oxa-1-hexane (CAS No. 106108-22-9), and subsequent curing of the terpolymer (CAS No. 193018-53-0) with triallylisocyanurate (CAS No. 1025-15-6) and 2,5-dimethyl-2,5-di(t-butylperoxy)hexane (CAS No. 78-63-7).	-	polymer (Greene, Tweed and Company, Inc.), Aug 13, 2002	-	A	(FDA 2020b)
Fluorinated polyurethane anionic resin (CAS No. 328389-91-9) prepared by reacting perfluoropolyether diol (CAS No. 88645-29-8), isophorone diisocyanate (CAS No. 4098-71-9), 2,2-dimethylolpropionic acid (CAS No. 4767-03-7), and triethylamine (CAS No. 121-44-8).	-	polymer (Solvay Specialty Polymers Italy S.p.A.), Mar 23, 2002	-	A	(FDA 2020b)
Ethene, tetrafluoro-, polymer with 1,1-difluoroethene and trifluoro(trifluoromethoxy)ethene (CAS No. 56357-87-0) 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	-	polymer (Solvay Specialty Polymers Italy S.p.A.), Jul 21, 2001	-	A	(FDA 2020b)
A copolymer of tetrafluoroethylene (TFE) and perfluoromethylvinyl ether (PFMVE) (CAS No. 26425-79-6) 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	-	polymer (Solvay Specialty Polymers Italy S.p.A.), Jul 21, 2001	-	A	(FDA 2020b)
1-Propene,1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene and tetrafluoroethene (CAS No. 25190-89-0) modified with triallyl isocyanurate 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	-	polymer (Solvay Specialty Polymers Italy S.p.A.), Jul 21, 2001	-	A	(FDA 2020b)
1,9-Decadiene,3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-, polymer with tetrafluoroethene and trifluoro(trifluoromethoxy)ethene (CAS No. 190062-24-9), manufactured and characterized as further described in the notification	-	polymer (Solvay Specialty Polymers Italy S.p.A.), Jul 21, 2001	-	A	(FDA 2020b)

Perfluorocarbon cured elastomers produced by polymerizing perfluoro (methyl vinyl ether) (CAS No. 1187-93-5) with tetrafluoroethylene (CAS No. 116-14-3) and perfluoro(8-cyano -5-methyl -3,6-dioxa -1-octene) (CAS No. 69804-19-9), followed by curing with trimethylallyl isocyanurate (CAS No. 6291-95-8) and/or triallyl isocyanurate (CAS No. 1025-15-6), and with 2,5 -dimethyl -2,5-di (t-butylperoxy) hexane (CAS No. 78-63-7) and as further described in this notification	-	polymer (Dupont Specialty Products USA, LLC), Dec 19, 2000	-	A	(FDA 2020b)
A perfluorocarbon-cured elastomer produced by terpolymerizing tetrafluoroethylene (CAS No. 116-14-3), perfluoro(2,5-dimethyl-3,6-dioxanone vinyl ether) (CAS No. 2599-84-0) and perfluoro (6,6-dihydro-6-iodo-3-oxa-1-hexene) (CAS No. 106108-22-9) and subsequent curing of the terpolymer (CAS No. 106108-23-0) by crosslinking with triallylcyanurate (CAS No. 101-37-1) and vulcanizing with 2,5-dimethyl-2,5-di(t-butylperoxy) hexane (CAS No. 78-63-7), as a 68% dispersion on finely divided silica	-	polymer (Greene, Tweed and Company, Inc.), Mar 30, 2000	-	A	(FDA 2020b)

2.26.2 *Non-food contact articles*

Similar to food-contact articles made out of paper, the types of PFAS used to protect paper and board for non-food articles have changed over time. Long-chain PFAS were used in the early 1960s and were phased out in the 2000s. Current PFAS-treated paper and board products are largely based on “short-chain” fluorotelomer-based polymeric products, typically with six perfluorinated carbons, and poly- and perfluoropolyethers. Examples for non-food contact articels with fluorinated chemicals are folding cartons, containers, carbonless forms, masking papers, table cloths and wall papers (Poulsen, Jensen, and Wallström 2005; UNEP 2017).

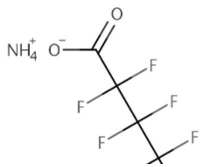
Information from the Swedish Products Register, the IUCLID database and various inventory lists shows that on the global paper industry market there has been a large number of polymers and polymer raw materials, mainly side-chain fluorinated polymers based on fluorinated acrylates and methacrylates and their monomers. Table 90 shows some PFAS that have been used or patented for paper and board not in contact with food (CAS 2019 (JP03213595, 1991)).

Table 90: PFAS that have been patented for paper packaging of non-food articels. Patent number (date, legal status): JP03213595 (1991, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Ammonium perfluoroalkyl carboxylate[1a]	$NH_4^+ C_nF_{2n+1}COO^-$	n = 8	4149-60-4	P	(CAS 2019 (JP03213595))
Potassium perfluoroalkane sulfonate[1b]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (JP03213595))
Carbamic acid, [(perfluoroalkyl)sulfonyl]propyl-, sodium salt[1c]	$Na^+ C_nF_{2n+1}SO_2N(C_3H_7)COO^-$	n = 4	138473-78-6	P	(CAS 2019 (JP03213595))

Poly(oxy-1,2-ethanediyl), α-[2-[[(pentadecafluoroheptyl) sulfonyl]propylamino]ethyl]-ω-hydroxy-[1d]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2(OCH_2CH_2)_xOH$	n = 7	138226-35-4	P	(CAS 2019 (JP03213595))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[1e]	$Cl^- \ C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (JP03213595))
1-Propanaminium, *N*-(carboxymethyl)-*N*,*N*-diethyl-3-[propyl [(perfluoroalkyl)sulfonyl]amino]-, inner salt[1f]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2CH_2N^+(C_2H_5)_2CH_2COO^-$	n = 6	138473-80-0	P	(CAS 2019 (JP03213595))

1a



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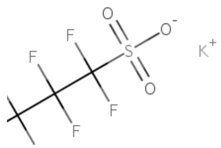

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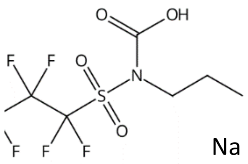

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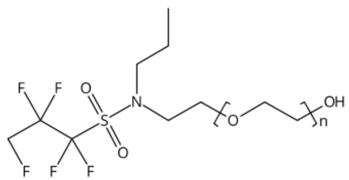

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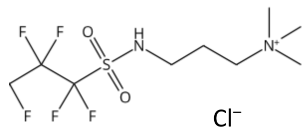

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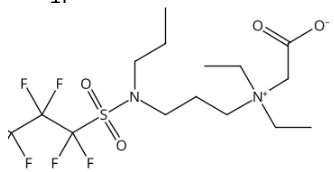
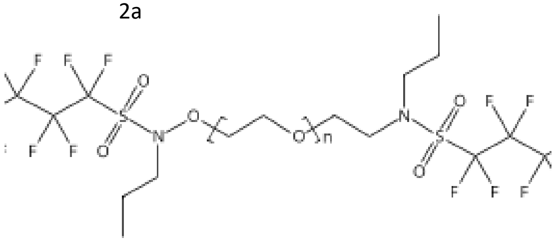
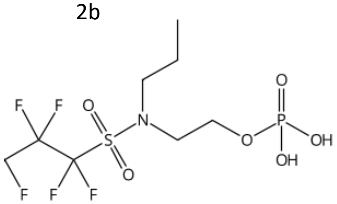


Poly(oxy-1,2-ethanediyl), α-[2-[[(perfluoroalkyl)sulfonyl]propyl amino]ethyl]-ω-[2-[[(perfluoroalkyl)sulfonyl]propylamino]ethoxy]-[2a]	$C_nF_{2n+1}SO_2N(C_3H_7)O(CH_2CH_2O)_x CH_2CH_2N(C_3H_7)SO_2C_nF_{2n+1}$	n = 8	138570-74-8	P	(CAS 2019 (JP03213595))
1-Alkanesulfonamide, perfluoro-*N*-[2-(phosphonooxy)ethyl]-*N*-propyl-[2b]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2OP(=O)(OH)_2$	n = 8	64264-44-4	P	(CAS 2019 (JP03213595))
Glycine, *N*-ethyl-*N*-(perfluoro-1-oxoalkyl)-, ammonium salt[2c]	$NH_4^+ \ C_nF_{2n+1}C(O)N(C_2H_5)CH_2COO^-$	n = 7	138473-79-7	P	(CAS 2019 (JP03213595))
Piperazinium, 1-(2-hydroxyethyl)-1-methyl-4-(perfluoro-1-oxoalkyl)-, chloride (1:1)[2d]	$Cl^- \ C_nF_{2n+1}C(O)NC_4H_8N^+(CH_3)CH_2CH_2OH$	n = 7	103555-98-2	P	(CAS 2019 (JP03213595))

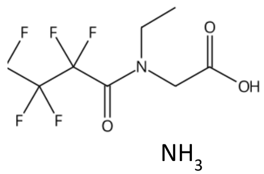
2a



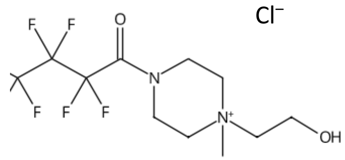
2b



2c

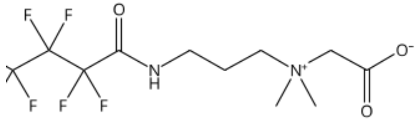


2d



1-Propanaminium, *N*-(carboxymethyl)-*N*,*N*-dimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, inner salt[3a]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2COO^-$	n = 7	90179-39-8	P	(CAS 2019 (JP03213595))
Poly(oxy-1,2-ethanediyl), α-sulfo-ω-[(perfluoroalkyl)oxy]-, sodium salt[3b]	$Na^+ \ C_nF_{2n+1}CH_2O(CH_2CH_2O)_nSO_3^-$	n = 11	138226-34-3	P	(CAS 2019 (JP03213595))
Ethanol, 2-[methyl(perfluoroalkyl)amino]-, hydrogen phosphate (ester), ammonium salt[3c]	$NH_4^+ \ PO_2^-(OCH_2CH_2N(CH_3)CH_2CH_2C_nF_{2n+1})_2$	n = 5	138473-76-4	P	(CAS 2019 (JP03213595))

3a



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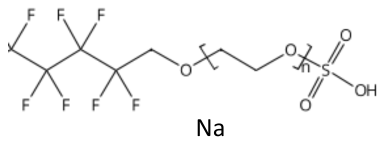

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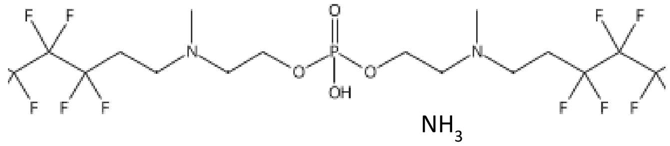
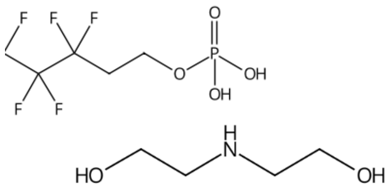


Ethanol, 2,2′-iminobis-, compd. with α-fluoro-ω-[2-(phosphonooxy) ethyl]poly(difluoromethylene) (2:1)[4a]	$NH_2^+ (CH_2CH_2OH)C_nF_{2n+1}CH_2CH_2O PO_3H^-$	not specified	65530-63-4	U	(USEPA 2016)
Ethanol, 2,2′-iminobis-, compd. with α,α′-[phosphinicobis (oxy-2,1-ethanediyl)]bis[ω-fluoropoly(difluoromethylene)] (1:1)[4b]	$NH_2^+(CH_2CH_2OH)(O)P(O^-)(OCH_2CH_2 C_nF_{2n+1})_2$	not specified	65530-64-5	U	(USEPA 2016)
Ethanol, 2-[2-[(perfluoroalkyl)oxy]ethoxy]-, dihydrogenphosphate, disodium salt[4c]	$2\ Na^+ C_nF_{2n+1}CH_2OCH_2CH_2OCH_2CH_2 OPO_3^{2-}$	n = 10	138473-75-3	P	(CAS 2019 (JP03213595))

4a



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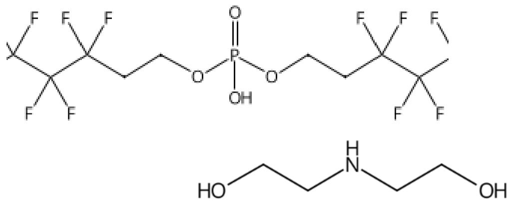

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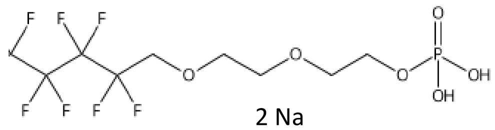
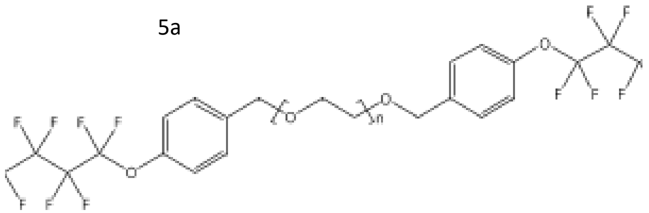
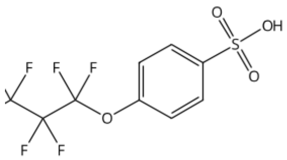


Poly(oxy-1,2-ethanediyl), α-[[4-[(perfluoroalkyl)oxy] phenyl]methyl]-ω-[[4-[(nonadecafluorononyl)oxy] phenyl]methoxy]-[5a]	$C_nF_{2n+1}OC_6H_4CH_2(OCH_2CH_2)_xOCH_2 C_6H_4OC_nF_{2n+1}$	n = 9	138226-36-5	P	(CAS 2019 (JP03213595))
Benzenesulfonic acid, 4-[(perfluoroalkyl)oxy]-, ammonium salt (1:1)[5b]	$NH_4^+ C_nF_{2n+1}OC_6H_4SO_3^-$	n = 8	138473-77-5	P	(CAS 2019 (JP03213595))

5a



5b



The SPIN database of the Nordic countries lists two substances for the manufacture of pulp, paper and paper products (Norden 2020). These are poly[oxy[trifluoro(trifluoro methyl)-1,2-ethanediyl]], α-(1,1,2,2,2-pentafluoroethyl)-ω-[tetrafluoro(trifluoromethyl)ethoxy]- (CAS No. 60164-51-4) and PTFE (CAS No. 9002-84-0). PTFE is currently in use (Norden 2020).

2.27 Particle physics

Perfluorocarbons have been used in detection assemblies for "atom-smashing" machines (R. E. Banks, Smart, and Tatlow 1994). When subatomic particles are accelerated at very high velocities and then caused to collide with one another, mass is converted to energy according to Einstein's equation, $E = mc^2$. The energy then reverts to new mass structures in an analogous way to water droplets condensing to form steam. However, for some unknown reason, specifically structured particles are formed. The detection of those particles has been one of the main reasons for building “atom-smashing" machines (R. E. Banks, Smart, and Tatlow 1994). The Delphi detector at CERN incorporates gaseous perfluoropentane and liquid perfluorohexane. The SLAC (Stanford University, California) detector uses a similar system (R. E. Banks, Smart, and Tatlow 1994).

2.28 Personal care products and cosmetics

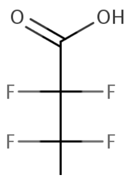
PFAS have been used in cosmetics as emulsifiers, lubricants, or oleophobic agents (Kissa 2001). PFAS in hair-conditioning formulations can enhance wet combing and render hair oleophobic (Kissa 2001). PFAS have been used in creams e.g. to make the creams penetrate the skin more easily, make the skin brighter, make the skin absorb more oxygen, or make the cosmetic product more durable and weather resistant (Brinch, Jensen, and Christensen 2018). PFAS have been identified in cosmetics and personal care products in general, but also in anti-aging, anti-frizz, bar soap, BB/CC cream/foundation, blush/highlighter, body lotion/body cream, body oil, brow products, concealer/corrector, cream/lotion, cuticle treatment, eye cream/eyeshadow, eye pencil/eyeliner, face cream, facial cleanser, hair creams and rinses/conditioner, hair spray/mousse, hair shampoo, hand sanitizer, highlighter, lip balm/lip stick/lip gloss, lip liner, manicure products, makeup remover, mask, mascara/lashes, moisturer, nail polish/nail strenghtner/nail treatment, powder, primer/fixer, scrub/peeling, shaving cream/shaving foam/shaving gel, sunscreen, and sunscreen makeup. Table 91 and Table 92 list some PFAS that have been used or detected or have been patented for use in personal care products and cosmetics. The information is divided into 2 tables, as this has simplified subsequent changes in the tables.

Table 91: PFAS that have been used or detected or have been patented for the use in personal care products and cosmetics (1). HFE-7100 is a commercial product. Patent number (date, legal status): JP10130302 (1998, discontinued), WO9427944 (1994, expired), WO9427960 (1994, expired), US3993745 (1976, expired), US4183367 (1980, expired), US3993744 (196, expired), DE2816828 (1978, expired), US4176176 (1979, expired), DE2051523 (1971, expired). The types stand for U – use, U* – current use, P – patent, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

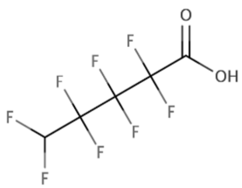
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
<u>Cosmetics and personal care products in general</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D, P	(Schultes et al. 2018; CAS 2019 (JP10130302))

ω-Hydroperfluoroalkanoate[1b]	$CF_2HC_nF_{2n}COOH$	n = 5	1546-95-8	D	(Brinch, Jensen, and Christensen 2018)
Perfluoro-3,7-dimethyloctanoic acid[1c]	$CF_3CF(CF_3)C_3F_6CF(CF_3)CF_3COOH$	-	172155-07-6	D	(Brinch, Jensen, and Christensen 2018)
(n:2) Fluorotelomer sulfonic acid (FTSs)[1d]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6, 8	27619-97-2, 39108-34-4	D	(Schultes et al. 2018)
(n:2) Fluorotelomer phosphate monoester (monoPAPs)[1e]	$C_nF_{2n+1}CH_2CH_2OP(=O)(OH)_2$	not specified	65530-61-2	U	(USEPA 2016)
(n:2) Fluorotelomer phosphate monoester (monoPAPs)[1e]	$C_nF_{2n+1}CH_2CH_2OP(=O)(OH)_2$	n = 4, 6, 8, 10	150065-76-2, 57678-01-0, 57678-03-2, 57678-05-4	D	(Schultes et al. 2018)
(n:2) Fluorotelomer phosphate diester (diPAPs)[1f]	$OP(OH)(OCH_2CH_2C_nF_{2n+1})_2$	not specified	65530-62-3	U	(USEPA 2016)
(n:2) Fluorotelomer phosphate diester (diPAPs)[1f]	$OP(OH)(OCH_2CH_2C_nF_{2n+1})_2$	n = 4, 6, 8, 10	135098-69-0, 57677-95-9, 678-41-1, 1895-26-7	D	(Schultes et al. 2018)
(n:2) Fluorotelomer phosphate diester (diPAPs)[1f]	$OP(OH)(OCH_2CH2C_nF_{2n+1})(OCH_2CH_2C_mF_{2m+1})$	n = 4/6, 6/8, 6/10, 6/12, 8/10, 8/12	1158182-59-2, 943913-15-3, 1578186-50-1, 1578186-69-2, 1158182-60-5, 1578186-42-1	D	(Schultes et al. 2018)

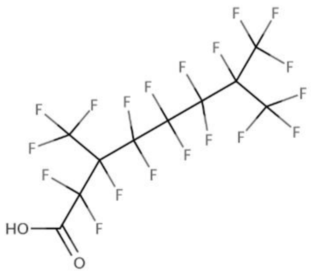
1a



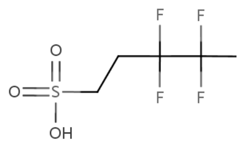
1b



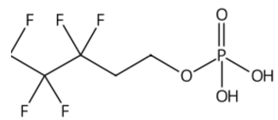
1c



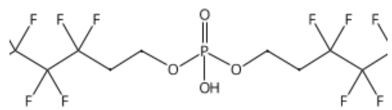
1d



1e

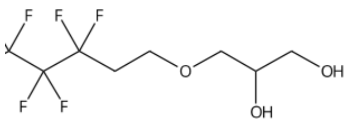


1f

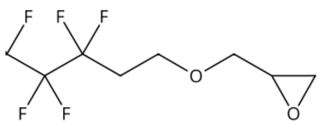


1,2-Propanediol, 3-[(perfluoroalkyl)oxy]-[2a]	$C_nF_{2n+1}CH_2CH_2OCH_2CH(OH)CH_2OH$	n = 6, 8	126814-93-5, 121500-31-0	P	(CAS 2019 (JP10130302))
Oxirane, 2-[[(perfluoroalkyl)oxy]methyl]-[2b]	$C_nF_{2n+1}CH_2CH_2OCH_2C_2OH_3$	n = 6	122193-68-4	P	(CAS 2019 (WO9427944))
Perfluoro-1-alkanethiol[2c]	$C_nF_{2n+1}CH_2CH_2SH$	n = 6, 8	34451-26-8, 34143-74-3	P	(CAS 2019 (WO9427944, WO9427960))
2-Propanol, 1,3-bis[(perfluoroalkyl)thio]-[2d]	$HOCH(CH_2SCH_2CH_2CnF_{2n+1})_2$	n = 6, 8	160819-46-5, 160819-47-6	P	(CAS 2019 (WO9427944))

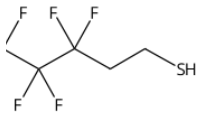
2a



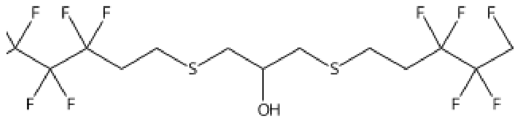
2b



2c

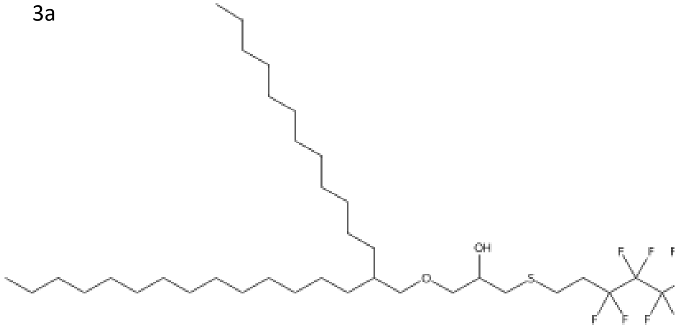


2d

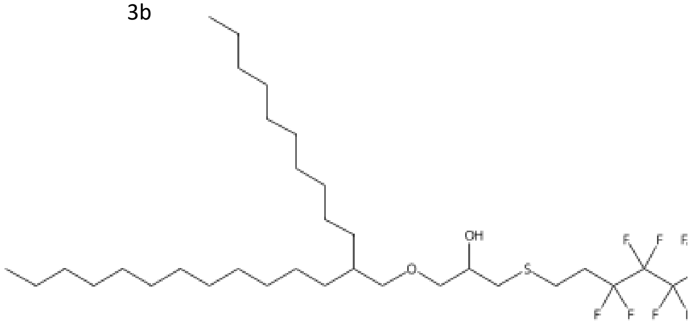


2-Propanol, 1-[(2-dodecylhexadecyl)oxy]-3-[(perfluoroalkyl)thio]-[3a]	$C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2OCH_2CH(C_{14}H_{29})C_{12}H_{25}$	n = 8	160819-50-1	P	(CAS 2019 (WO9427960))
2-Propanol, 1-[(2-decyltetradecyl)oxy]-3-[(perfluoroalkyl)thio]- [3b]	$C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2OCH_2CH(C_{10}H_{21})C_{12}H_{25}$	n = 8	160819-49-8	P	(CAS 2019 (WO9427960))
Perfluorodecalin[3c]	c-$C_{10}F_{18}$	-	306-94-5	U	(F2_Chemicals 2019b)
Perfluorotetradecahydrophenanthrene	c-$C_{14}F_{24}$	-	306-91-2	U	(F2_Chemicals 2019b)

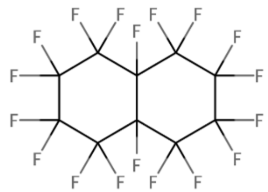
3a



3b



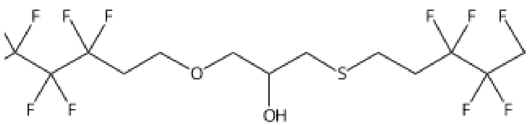
3c



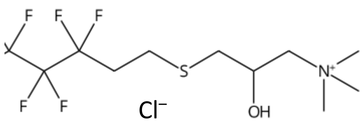
2-Propanol, 1-[(perfluoroalkyl)oxy]-3-[(perfluoroalkyl)thio]-[4a]	$C_nF_{2n+1}CH_2CH_2OCH_2CH(OH)CH_2SCH_2CH_2C_nF_{2n+1}$	n = 6	155604-47-0	P	(CAS 2019 (WO9427944))
1-Propanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-3-[(perfluoroalkyl)thio]-, chloride (1:1)[4b]	$Cl^- C_nF_{2n+1}CH_2CH_2SCH_2CH(OH)CH_2N^+(CH_3)_3$	n = 6, 8, 10	88992-45-4, 71940-07-3	U	(Buck, Murphy, and Pabon 2012)
Perfluoropolyether	-	polymer	-	U	(Costello, Flynn, and Owens 2000)
Phosphoric trichloride, reaction products with ethylene oxide and reduced methanol-reduced polymd. oxidized 1,1,2,3,3,3-hexafluoro-1-propene reaction product, hydrolyzed	-	polymer	162567-74-0	U	(Z. Wang et al. 2020)
Phosphoric trichloride, reaction products with ethylene oxide and reduced methanol-reduced polymd. oxidized 1,1,2,3,3,3-	-	polymer	162567-75-1	U	(Z. Wang et al. 2020)

hexafluoro-1-propene reaction product, hydrolyzed, compds. with diethanolamine					
<u>Anti-aging cream</u>					
Methyl perfluoroalkyl ether[4c]	$C_nF_{2n+1}OCH_3$	n = 4	163702-07-6	U	(GSP 2014)
Linear perfluoroalkanes[4d]	C_nF_{2n+2}	n = 6	355-42-0	U	(GSP 2014)
Perfluorononyl dimethicone	-		259725-95-6	U	(GSP 2014)
<u>Anti-frizz</u>					
Perfluoroester	-	-	-	U	(GSP 2014)
Perfluorononyl dimethicone	-	-	259725-95-6	U	(GSP 2014)
<u>Bar soap</u>					
1,2,3-Propanetricarboxylic acid, 2-hydroxy-, 1,2-bis(2-octyldodecyl) 3-(3,3,4,4,5,5,6,6,7,7,7-undecafluoro heptyl) ester[4e]	$C_nF_{2n+1}CH_2CH_2OC(O)CH_2C(OH)[C(O)OCH_2CH(C_8H_{17})C_{10}H_{21}]CH_2CH(C_8H_{17})C_{10}H_{21}$	n = 5	214334-16-4	U	(GSP 2014)

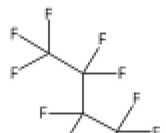
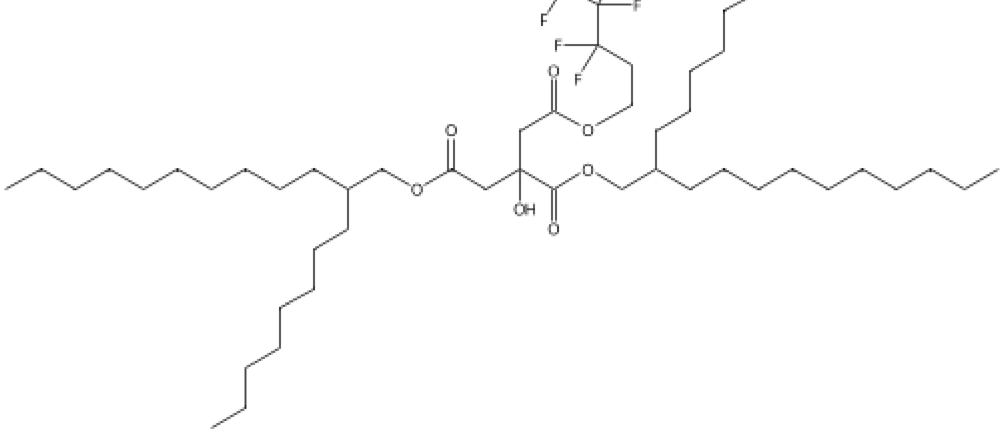
4a



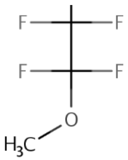
4b



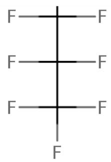
4e

4c



4d



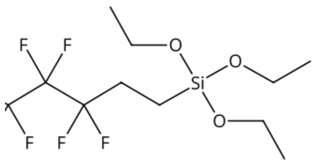
Ethanol, 2,2′-iminobis-, compd. with α-fluoro-ω-[2-(phosphonooxy)ethyl]poly(difluoro methylene) (2:1)[(1e)]	$NH_2^+(CH_2CH_2OH)$ $C_nF_{2n+1}CH_2CH_2OPO_3H^-$	not spec ified	65530-63-4	U	(USEPA 2016)

Ethanol, 2,2′-iminobis-, compd. with α,α′-[phosphinicobis (oxy-2,1-ethanediyl)]bis[ω-fluoropoly(difluoromethylene)] (1:1)[(1f)]	$NH_2^+(CH_2CH_2OH)\ OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	not spec ified	65530-64-5	U	(USEPA 2016)
Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly (difluoromethylene) (1:1)	-	-	65545-80-4	U	(USEPA 2016)
Phosphonic acid, perfluoro-C_{6-12}-alkyl derivs	-	-	68412-68-0	U	(USEPA 2016)
Phosphinic acid, bis(perfluoro-C_{6-12}-alkyl) derivs.	-	-	68412-69-1	U	(USEPA 2016)
BB/CC cream, foundation					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Brinch, Jensen, and Christensen 2018)
Perfluoro-3,7-dimethyloctanoic acid[1c]	$CF_3CF(CF_3)C_3F_6CF(CF_3)CF_3COOH$	-	172155-07-6	D	(Brinch, Jensen, and Christensen 2018)
(n:2) Fluorotelomer sulfonic acid (FTSs)[1d]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	D	(Brinch, Jensen, and Christensen 2018)
Perfluoroalkyltriethoxysilane[5a]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6, 8	51851-37-7, 101947-16-4	U	(Brinch, Jensen, and Christensen 2018)
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Fluoroalcohol phophate	-	n = 9 - 15	-	U	(Brinch, Jensen, and Christensen 2018)
Perfluoroalkyl dimethicone	-	n = 2 - 8	-	U	(GSP 2014)
Perfluorononyl octyldodecyl glycol	-	-	-	U	(GSP 2014)
Dea-C_{8-18} perfluoroalkylethyl phosphate	-	-	-	U	(GSP 2014)
Blush/highlighter					
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Perfluorononyl octyldodecyl glycol meadowfoamate	-	-	-	U	(GSP 2014)
Fluoro octyldodecyl meadowfoamate	-	-	-	U	(GSP 2014)
Perfluorononyl octyldodecyl glycol	-	-	-	U	(GSP 2014)

Perfluorononyl octydodecyl glycol grapeseedate	-	-	-	U	(GSP 2014)
Body lotion/ body cream/ body oil					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Brinch, Jensen, and Christensen 2018)
(n:2) Fluorotelomer sulfonic acid (FTSs)[1d]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	D	(Brinch, Jensen, and Christensen 2018)
Perfluoroalkyltriethoxysilane[5a]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	U	(GSP 2014)
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Polyfluoroalkyl phosphonic acids	-	-	-	U	(KEMI Swedish Chemical Agency 2015b)
Brow products					
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Perfluorononyl dimethicone	-		259725-95-6	U	(GSP 2014)
Concealer/corrector					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Brinch, Jensen, and Christensen 2018)
ω-Hydroperfluoroalkanoate[1b]	$CF_2HCnF_{2n}COOH$	n = 5	1546-95-8	D	(Brinch, Jensen, and Christensen 2018)
(n:2) Fluorotelomer sulfonic acid (FTSs)[1d]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 4, 6	757124-72-4, 27619-97-2	D	(Brinch, Jensen, and Christensen 2018)
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Fluoroalcohol phophate	-	n = 9 - 15	-	U	(Brinch, Jensen, and Christensen 2018)

Creams/lotions					
Polyperfluoromethylisopropyl ether[5c]	$CF_3O[CF(CF_3)CF_2O]_x(CF_2O)_y CF_3$	polymer	69991-67-9	U	(Brinch, Jensen, and Christensen 2018)
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Polyperfluoroisopropyl ether	-	-	-	U	(Brinch, Jensen, and Christensen 2018)
Cuticle treatment					
Perfluorononyl octyldodecyl glycol	-	-	-	U	(GSP 2014)
Perfluorononyl octyldodecyl glycol meadow-foamate	-	-	-	U	(GSP 2014)
Eye cream/ eye shadow					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 13	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Brinch, Jensen, and Christensen 2018)
Linear perfluoroalkanes[4d]	C_nF_{2n+2}	n = 6	355-42-0	U	(GSP 2014)
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Polyperfluoromethylisopropyl ether[5c]	$-CF_3O[CF(CF_3)CF_2O]_x(CF_2O)_yCF_3-$	polymer	69991-67-9	U	(Brinch, Jensen, and Christensen 2018)
Perfluorononyl dimethicone	-		259725-95-6	U	(Brinch, Jensen, and Christensen 2018)
Eye pencil/ eye liner					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 4, 13	2706-90-3, 376-06-7	D	(Brinch, Jensen, and Christensen 2018)
Fluoroalcohol phophate	-	n = 9 - 15	-	U	(GSP 2014)
Perfluorononyl dimethicone	-		259725-95-6	U	(Brinch, Jensen, and Christensen 2018)
Face cream					
Polytetrafluoroethylene (PTFE)[5b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)

Polyperfluoromethylisopropyl ether[5c]	$-CF_3O[CF(CF_3)CF_2O]_x(CF_2O)_yCF_3-$	polymer	69991-67-9	U	(Brinch, Jensen, and Christensen 2018)
Fluoroalcohol phophate	-	n = 9 - 15	-	U	(GSP 2014)
<u>Hair creams, rinses, and conditioner</u>					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 8	375-95-1	P	(CAS 2019 (US3993745))
N-Ethyl perfluoroalkane sulfonamidoacetic acid (EtFASAAs)[5d]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2COOH$	n = 10	61481-04-7	P	(CAS 2019 (US3993745))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[5e]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	P	(CAS 2019 (US4183367))

5a

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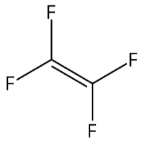
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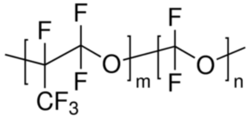
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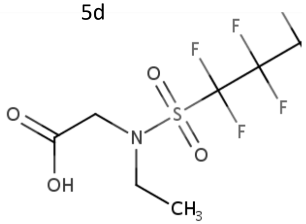
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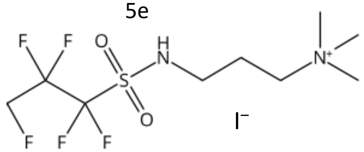
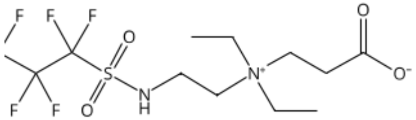


Ethanaminium, 2-carboxy-*N*,*N*-diethyl-*N*-[2-[[(perfluoroalkyl)sulfonyl]amino]ethyl]-, inner salt[6a]	$C_nF_{2n+1}SO_2NHCH_2CH_2N^+(C_2H_5)_2CH_2CH_2COO^-$	n = 8	61481-08-1	P	(CAS 2019 (US3993744))
1-Alkanesulfonamide, perfluoro-*N*-methyl-*N*-[2-(sulfooxy)ethyl]-[6b]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2SO_3H$	n = 12	61481-06-9	P	(CAS 2019 (US3993745))
1-Alkanesulfonamide, *N*-ethyl-perfluoro-*N*-[2-(phosphonooxy)ethyl]-[6c]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2OP(=O)(OH)_2$	n = 10	61481-05-8	P	(CAS 2019 (US3993745))
Alkanamide, *N*-[3-(diethylamino)propyl]-perfluoro-[6d]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N(C_2H_5)_2$	n = 8	61481-09-2	P	(CAS 2019 (US3993744))

6a

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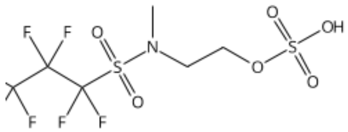
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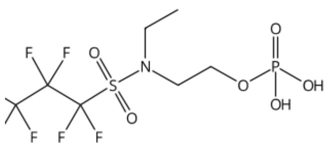
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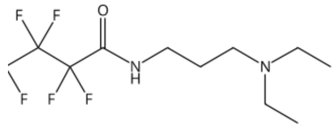
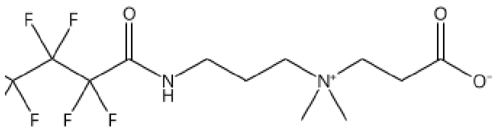


1-Propanaminium, *N*-(2-carboxyethyl)-3-[(perfluoro-1-oxoalkyl)amino]-*N*,*N*-dimethyl-, inner salt[7a]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 7	5158-52-1	P	(CAS 2019 (US3993745))

1H, 1H, ωH-Perfluoroalkyl methacrylate[7b]	$CF_2HC_nF_{2n}CH_2OC(O)C(CH_3)=CH_2$	n = 3	355-93-1	U	(GSP 2014)
Poly(oxy-1,2-ethanediyl), α-(perfluoroalkyl)-ω-hydroxy-[7c]	$C_nF_{2n+1}CH_2CH_2O(CH_2CH_2O)_{18}H$	n = 6	-	U	(Kissa 2001)
11,14,17,20,23,26,29,32-Octaoxaocta tetracontan-33-one, perfluoro-	$C_nF_{2n+1}(CH_2CH_2O)_8C(O)C_{15}H_{31}$	n = 8	67549-47-7	U	(Kissa 2001)
11,14,17,20,23,26,29,32-Octaoxaoctatetra contan-33-one, 1,1,1,2,2,3,3,4,4,5,5, 6,6,7,7,8,8-heptadecafluoro-	$C_nF_{2n+1}(CH_2CH_2O)_8C(O)C_{15}H_{31}$	n = 8	67549-47-7	U	(Kissa 2001)
Lithium (n:2) fluorotelomer thioether propionate[7d]	$Li^+ C_nF_{2n+1}CH_2CH_2SCH_2CH_2COO^-$	-	65530-69-0	U	(Kissa 2001)

7a



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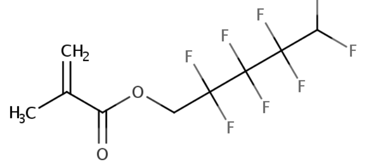

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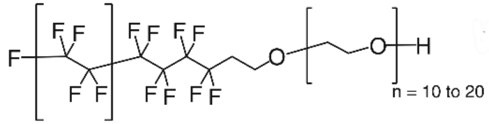
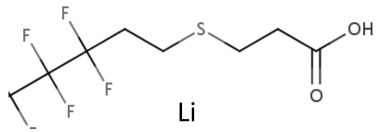
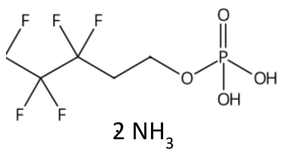


7d



-	$C_nF_{2n+1}(CH_2)_yS(CH_2)_xCOOM$, where x=1-20, y=1-4, M= alkali metal or ammonium	n = 7	-	U	(Kissa 2001)
Diammonium (n:2) fluorotelomer phosphate monoester[8a]	$2\ NH_4^+ C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	(Zonyl FSP)	-	U	(Kissa 2001)
Ammonium (n:2) fluorotelomer phosphate diester[8b]	$NH_4^+ PO_2^-(OCH_2CH_2C_nF_{2n+1})_2$	(Zonyl FSP)	-	U	(Kissa 2001)
(n:2) Fluorotelomer phosphate triester	$(O)P(OCH_2CH_2CnF_{2n+1})_3$	(Zonyl FSP)	-	U	(Kissa 2001)
(n:2) Fluorotelomer phosphate ester derivates	$(C_nF_{2n+1}CH_2CH_2O)_xPO(O^- NH_4^+)_y(OCH_2CH_2OH)_m$	x+y+z=3 (Zonyl FSE)	-	U	(Kissa 2001)
Perfluoroalkylethyl thiohydroxypropyl trimonium chloride		-	-	U	(Brinch, Jensen, and Christensen 2018)
Perfluoroester	-	-	-	U	(GSP 2014)
Perfluorononyl dimethicone	-		259725-95-6	U	(GSP 2014)
Perfluorononylethyl carboxydecyl peg- 10 dimethicone		-	-	U	(GSP 2014)
Polyperfluoroethoxymethoxy difluoroethyl peg phosphate		-	-	U	(GSP 2014)
Polytetrafluoroethylene acetoxypropyl betaine		-	-	U	(GSP 2014)

8a



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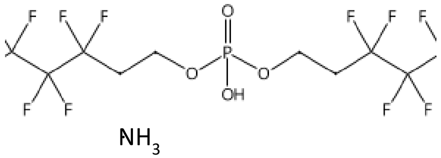
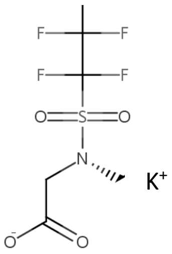


Hair spray/ mousse					
1H, 1H, ωH-Perfluoroalkyl methacrylate[7b]	$CF_2HC_nF_{2n}CH_2OC(O)C(CH_3)=CH_2$	n = 3	355-93-1	U	(Brinch, Jensen, and Christensen 2018)
(n:2) Fluorotelomer sulfonic acid (FTSs)[1d]	$C_nF_{2n+1}CH_2CH_2SO_3H$	n = 6	27619-97-2	D	(Brinch, Jensen, and Christensen 2018)
Perfluoroester	-	-	-	U	(GSP 2014)
Perfluorononyl dimethicone	-		259725-95-6	U	(GSP 2014)
Polyperfluoroethoxymethoxy difluoroethyl peg phosphate		-	-	U	(Brinch, Jensen, and Christensen 2018)
Hair shampoo					
Potassium *N*-ethyl perfluoroalkane sulfonamidoacetate[9a]	$K^+ C_nF_{2n+1}SO_2N(C_2H_5)CH_2COO^-$	n = 8	2991-51-7	P	(CAS 2019 (DE2816828))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[5e]	$I^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	1652-63-7	P	(CAS 2019 (DE2816828))
1-Alkanesulfonamide, *N*-ethyl-perfluoro-*N*-[2-(phosphonooxy)ethyl]-[6c]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2OP(=O)(OH)_2$	n = 8, 10	3820-83-5, 61481-05-8	P	(CAS 2019 (DE2816828, US4176176))
Alkanoic acid, perfluoro-, ethyl ester	$C_nF_{2n+1}C(O)OCH_2CH_3$	n = 10	41506-11-0	P	(CAS 2019 (US4176176))
1H, 1H, ωH-Perfluoroalkyl methacrylate[7b]	$CF_2HC_nF_{2n}CH_2OC(O)C(CH_3)=CH_2$	n = 3	355-93-1	U	(GSP 2014)
1,2,3-Propanetricarboxylic acid, 2-hydroxy-, 1,2-bis(2-octyldodecyl) 3-(3,3,4,4,5,5,6,6,7,7,7-undecafluoro heptyl) ester[4e]	$C_nF_{2n+1}CH_2CH_2OC(O)CH_2C(OH)[C(O)OCH_2CH(C_8H_{17})C_{10}H_{21}]CH_2CH(C_8H_{17})C_{10}H_{21}$	n = 5	214334-16-4	U	(GSP 2014)
2-Propenoic acid, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl ester, homopolymer[9c]	$-(C_{11}H_5F_{15}O_2)_x-$	polymer	26337-50-8	P	(CAS 2019 (DE2051523))
2-Propenoic acid, 2,2,3,3,4,4,5,5,6,6,7,7-dodecafluoroheptyl ester, homopolymer[9d]	$-(C_{10}H_6F_{12}O_2)_x-$	polymer	26246-67-3	P	(CAS 2019 (DE2051523))
2-Propenoic acid, 2-methyl-, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl ester, homopolymer[9e]	$-(C_7F_{15}CH_2OC(O)C(=CH_2)CH_3)_x-$	polymer	29014-57-1	P	(CAS 2019 (DE2051523))

9a



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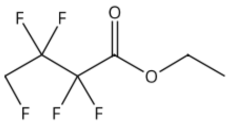

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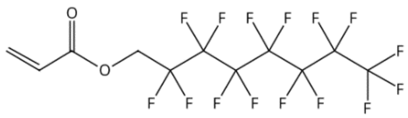

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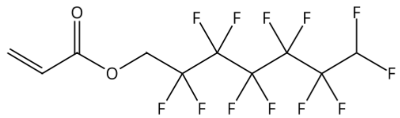

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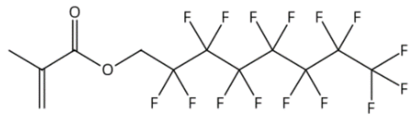
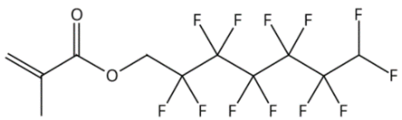
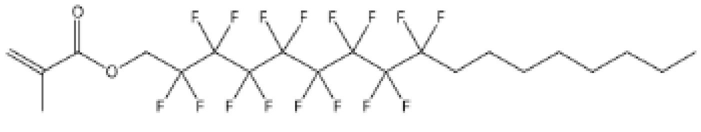


2-Propenoic acid, 2-methyl-, 2,2,3,3,4,4,5, 5,6,6 ,7,7-dodecafluoroheptyl ester, homopolymer[10a]	$-(C_{11}H_8F_{12}O_2)_x-$	polymer	25656-09-1	P	(CAS 2019 (DE2051523))
Methacrylic acid, 2,2,3,3,4,4,5,5,6,6,7,7, 8,8,9,9-hexadecafluoroheptadecyl ester, polymers[10b]	$-(C_{21}H_{24}F_{16}O_2)_x-$	polymer	34482-06-9	P	(CAS 2019 (DE2051523))
Methacrylic acid, 2-(diethylamino)ethyl ester, polymer with 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl acrylate[10c]	$-(C_{11}H_5F_{15}O_2.C_{10}H_{19}NO_2)_x-$	polymer	34482-03-6	P	(CAS 2019 (DE2051523))

10a



10b



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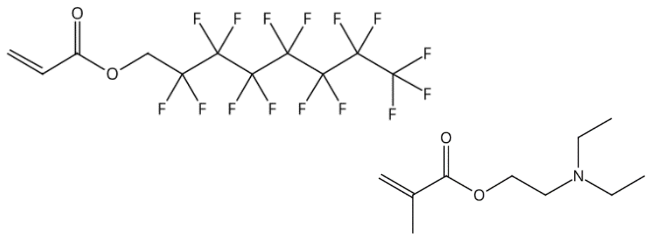
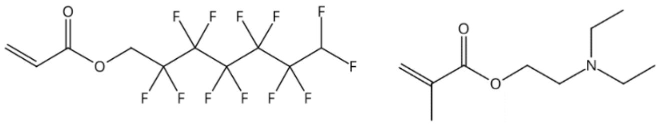
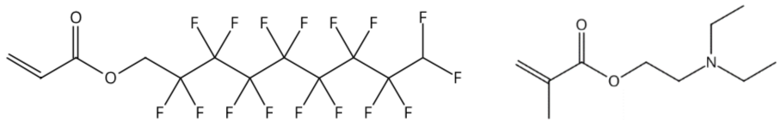


Methacrylic acid, 2-(diethylamino)ethyl ester, polymer with 2,2,3,3,4,4,5,5,6,6,7,7-dodeca fluoroheptyl acrylate[11a]	$-(C_{10}H_{19}NO_2)_x-(C_{10}H_6F_{12}O_2)_y-$	polymer	34438-56-7	P	(CAS 2019 (DE2051523))(CAS 2019 (DE2051523))
Methacrylic acid, 2-(diethylamino)ethyl ester, polymer with 2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9-hexadecafluorononyl acrylate[11b]	$-(C_{12}H_6F_{16}O_2)_x-(C_{10}H_{19}NO_2)_y-$	polymer	34514-87-9	P	(CAS 2019 (DE2051523))(CAS 2019 (DE2051523))

11a

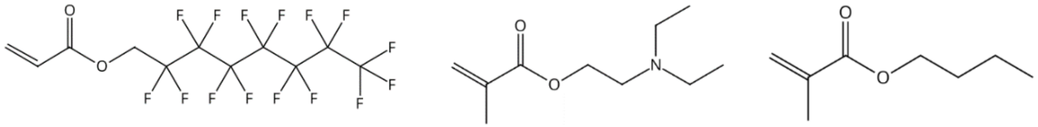


11b

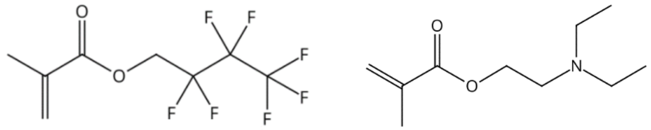


Methacrylic acid, 2-(diethylamino)ethyl ester, polymer with butyl methacrylate and 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl acrylate[12a]	-$(C_{11}H_5F_{15}O_2)_x$-$(C_{10}H_{19}NO_2)_y$-$(C_8H_{14}O_2)_m$-	polymer	34482-04-7	P	(CAS 2019 (DE2051523))	(CAS 2019 (DE2051523))
Methacrylic acid, 2-(diethylamino)ethyl ester, polymer with 2,2,3,3,4,4,4-heptafluorobutyl methacrylate[12b]	-$(C_8H_7F_7O_2)_x$-$(C_{10}H_{19}NO_2)_y$-	polymer	34438-55-6	P	(CAS 2019 (DE2051523))	(CAS 2019 (DE2051523))

12a

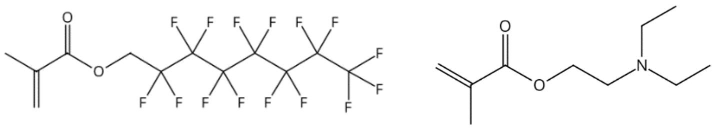


12b



Methacrylic acid, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctyl ester, polymer with 2-(diethylamino)ethyl methacrylate[13a]	-$(C_{12}H_7F_{15}O_2)_x$-$(C_{10}H_{19}NO_2)_y$-	polymer	34438-51-2	P	(CAS 2019 (DE2051523))	(CAS 2019 (DE2051523))
Methacrylic acid, 2,2,3,3,4,4,5,5,6,6,7,7-dodecafluoroheptyl ester, polymer with 2-(diethylamino)ethyl methacrylate[13b]	-$(C_{11}H_8F_{12}O_2)_x$-$(C_{10}H_{19}NO_2)_y$-	polymer	34438-59-0	P	(CAS 2019 (DE2051523))	(CAS 2019 (DE2051523))

13a



13b

Methacrylic acid, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9-hexadecafluorononyl ester, polymer with 2-(diethylamino)ethyl methacrylate[14a]	-$(C_{13}H_8F_{16}O_2)_x$-$(C_{10}H_{19}NO_2)_y$-	polymer	34447-80-8	P	(CAS 2019 (DE2051523))	(CAS 2019 (DE2051523))
Perfluoroester	-	-	-	U	(GSP 2014)	

14a

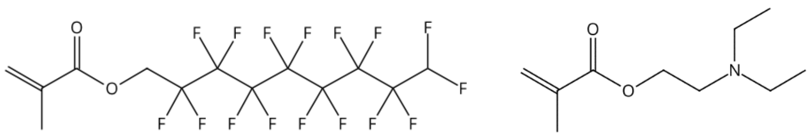
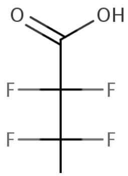


Table 92: PFAS that have been used or detected or have been patented for the use in personal care products and cosmetics (2). The types stand for U – use, U* – current use, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

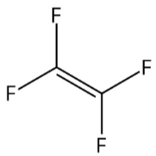
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Hand sanitizer					
Tea-C8-18 perfluoroalkylethyl phosphate	-	-	-	U	(GSP 2014)
Highlighter					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 5 - 13	307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Brinch, Jensen, and Christensen 2018)
Polytetrafluoroethylene (PTFE)[1b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Lip balm/lip stick/lip gloss					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 7- 13	335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	(Brinch, Jensen, and Christensen 2018)
Perfluoroalkyltriethoxysilane[1c]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	U	(GSP 2014)
Perfluorononyl dimethicone	-	-	259725-95-6	U	(GSP 2014)
1,2,3-Propanetricarboxylic acid, 2-hydroxy-, 1,2-bis(2-octyldodecyl) 3-(3,3,4,4,5,5,6,6,7,7,7-undecafluoro heptyl) ester[1d]	$C_nF_{2n+1}CH_2CH_2OC(O)CH_2C(OH)[C(O)OCH_2CH(C_8H_{17})C_{10}H_{21}]CH_2CH(C_8H_{17})C_{10}H_{21}$	n = 5	214334-16-4	U	(GSP 2014)
Polyperfluoromethylisopropyl ether[1e]	$-CF_3O[CF(CF_3)CF_2O]_x(CF_2O)_yCF_3-$	polymer	69991-67-9	U	(Brinch, Jensen, and Christensen 2018)
Fluoro octyldodecyl meadowfoamate	-	-	-	U	(GSP 2014)

Polyperfluoroethoxymethoxy difluoroethyl peg phosphate	-	-	-	U	(GSP 2014)
Perfluorononyl octyldodecyl glycol	-	-	-	U	(GSP 2014)
Perfluorononylethyl stearyl dimethicone	-	-	-	U	(GSP 2014)
Perfluorononyl dimethicone crosspolymer	-	-	-	U	(GSP 2014)

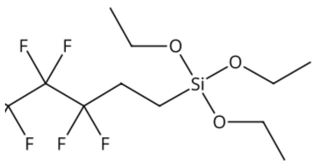
1a



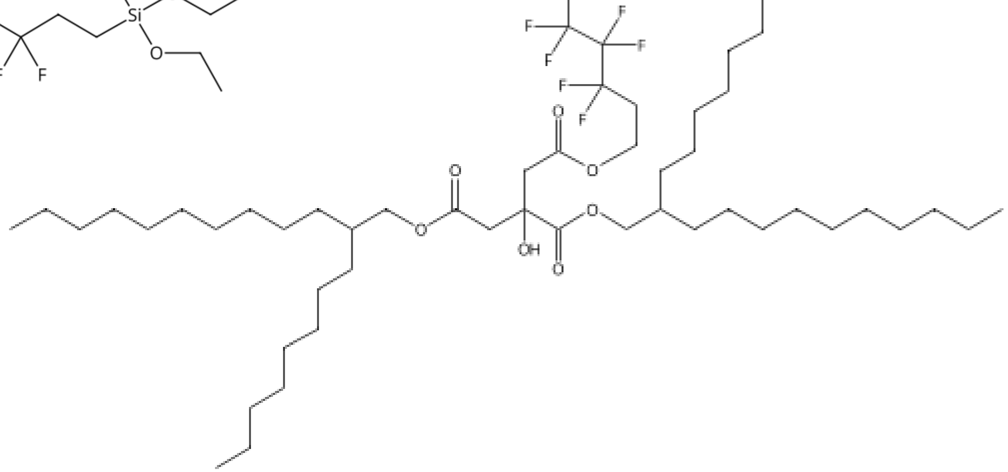
1b



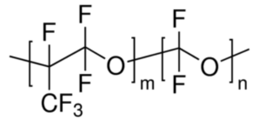
1c



1d



1e



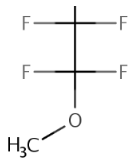
Lip liner					
Perfluorononyl dimethicone	-	-	259725-95-6	U	(GSP 2014)
Manicure product					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 5 - 13	307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7	D	Brinch, Jensen, and Christensen 2018)
Makeup remover/ facial cleaner					
Methyl perfluoroalkyl ether[2a]	$C_nF_{2n+1}OCH_3$	n = 4	163702-07-6	U	(GSP 2014)
Mask					

Methyl perfluoroalkyl ether[2a]	$C_nF_{2n+1}OCH_3$	n = 4	163702-07-6	U	(GSP 2014)
Ethyl perfluoroalkyl ether[2b]	$C_nF_{2n+1}OCH_2CH_3$	n = 4	163702-05-4	U	(GSP 2014)
Linear perfluoroalkanes[2c]	C_nF_{2n+2}	n = 6	355-42-0	U	(GSP 2014)
Perfluorononyl dimethicone	-	-	259725-95-6	U	(GSP 2014)
Mascara/lashes					
Polytetrafluoroethylene (PTFE)[1b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Polytetrafluoroethylene acetoxypropyl betaine	-	-	-	U	(GSP 2014)
Fluoroalcohol	-	n = 9 - 13	-	U	(GSP 2014)
Moisturer					
Perfluoroalkyltriethoxysilane[1c]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	U	(GSP 2014)
1,2,3-Propanetricarboxylic acid, 2-hydroxy-, 1,2-bis(2-octyldodecyl) 3-(3,3,4,4,5,5,6,6,7,7,7-undecafluoro heptyl) ester[1d]	$C_nF_{2n+1}CH_2CH_2OC(O)CH_2C(OH)[C(O)OCH_2CH(C_8H_{17})C_{10}H_{21}]CH_2CH(C_8H_{17})C_{10}H_{21}$	n = 5	214334-16-4	U	(GSP 2014)
Methyl perfluoroalkyl ether[2a]	$C_nF_{2n+1}OCH_3$	n = 4	163702-07-6	U	(GSP 2014)
Linear perfluoroalkanes[2c]	C_nF_{2n+2}	n = 6	355-42-0	U	(GSP 2014)
Fluoroalcohol phophate	-	n = 9 - 15	-	U	(GSP 2014)
Polytetrafluoroethylene acetoxypropyl betaine		-	-	U	(GSP 2014)
Nail polish/nail strenghtner/nail treatment					
Fluoroaliphatic polymeric esters	-	-	-	U	(GSP 2014)
Perfluorononyl octyldodecyl glycol meadowfoamate		-	-	U	(GSP 2014)
Powder					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 6	375-22-4, 2706-90-3, 307-24-4, 375-85-9	D	(Brinch, Jensen, and Christensen 2018)
Polytetrafluoroethylene (PTFE)[1b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Fluoroalcohol phophate	-	n = 9 - 15	-	U	(GSP 2014)
Fluoro octyldodecyl meadowfoamate	-	-	-	U	(GSP 2014)
Perfluorononyl octyldodecyl glycol meadowfoamate		-	-	U	(GSP 2014)
Polyperfluoroethoxymethoxy difluoroethyl peg phosphate		-	-	U	(GSP 2014)
Perfluorononyl octyldodecyl glycol	-	-	-	U	(GSP 2014)

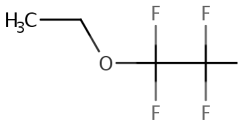
Primer/fixer					
Methyl perfluorobutyl ether[2a]	$C_4F_9OCH_3$	(part of HFE-7100)	163702-07-6	U	(Brinch, Jensen, and Christensen 2018)
Methyl perfluoroisobutyl ether[2d]	$CF_3CF(CF_3)CF_2OCH_3$	(part of HFE-7100)	163702-08-7	U	(Brinch, Jensen, and Christensen 2018)
Srub/peeling					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 6	375-22-4, 2706-90-3, 307-24-4, 375-85-9	D	(Brinch, Jensen, and Christensen 2018)
Perfluorononylethyl carboxydecyl peg- 10 dimethicone		-	-	U	(Brinch, Jensen, and Christensen 2018)
Shaving cream/shaving foam/shaving gel					
Polytetrafluoroethylene (PTFE)[1b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Perfluorononyl dimethicone	-	-	259725-95-6	U	(GSP 2014)
Polytetrafluoroethylene acetoxypropyl betaine	-	-	-	U	(GSP 2014)
Sunscreen					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 6 - 14	375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7, 141074-63-7	D	(Brinch, Jensen, and Christensen 2018)
Perfluoroalkyltriethoxysilane[1c]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	U	(GSP 2014)
Perfluorononyl dimethicone	-	-	259725-95-6	U	(GSP 2014)
Polyfluoroalkyl phosphonic acids	-	-	-	U	(KEMI Swedish Chemical Agency 2015b)
Polytetrafluoroethylene acetoxypropyl betaine	-	-	-	U	(GSP 2014)
Polyperfluoroethoxymethoxy difluoroethyl peg phosphate		-	-	U	(Brinch, Jensen, and Christensen 2018)
Sunscreen makeup					
Polytetrafluoroethylene (PTFE)[1b]	$-(CF_2CF_2)_n-$	polymer	9002-84-0	U	(Brinch, Jensen, and Christensen 2018)
Perfluorononyl dimethicone	-	n = 2 - 8	259725-95-6	U	(GSP 2014)
Fluoroalcohol phophate	-	n = 9 - 15	-	U	(GSP 2014)

Perfluorononyl octyldodecyl glycol	-	-	-	U	(GSP 2014)

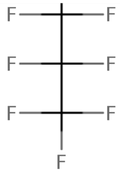
2a



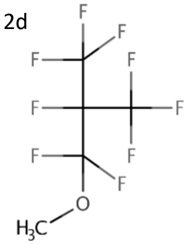
2b



2c



2d



2.29 Pesticides

PFOA (CAS No. 335-67-1) has been detected in pesticide solutions (Fiedler, Pfister, and Schramm 2010).

2.29.1 PFAS as active ingredients

PFAS can be used as insecticides against the common housefly and the carmine mite (Kissa 2001). The mechanism of insecticidal activity appears to be suffocation of the insect by the adsorbed PFAS (Kissa 2001). Patents that describe the use of PFAS for insect control are US758856, BR8301452, or US455727 (CAS 2019).

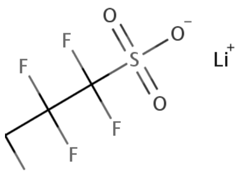
The insecticide sulfluramid (*N*-ethyl perfluorooctane sulfonamide, CAS No. 4151-50-2) was developed for control of ants and cockroaches. Registrations for this insecticide have been withdrawn in the United States but are still permitted in many developing countries (Buck, Murphy, and Pabon 2012). The use of sulfluramid for control of leaf-cutting ants *Atta spp.* and *Acromyrmex spp*. is listed as an acceptable purpose for the production and use of PFOS, its salts and PFOSF in Annex B of the Stockholm Convention (COP 2019). Other PFAS that have been used against invasive ants, red fire ants, and cockroaches are flursulamid (CAS No. 31506-34-0) and lithium perfluorooctane sulfonate (CAS No. 29457-72-5) (Ogawa et al. 2020). The stuctures of these PFAS are shown in Table 93. Lithium perfluorooctane sulfonate is also known as Super-Arinosu-Korori, and has been a popular component of commercially available insecticides in Japan for the control of household pest ants (Ogawa et al. 2020). No specific information is available on EL-499-1 and EL-499-2, so it is not clear if these substances have been in use or have just been registered. Novaluron is an insecticide which inhibits chitin synthesis, affecting the moulting stages of insect development (FAO 2004). Novaluron was used in the European Union until 2012 but is no longer permitted. However, Novaluron is still permitted in the US und Canada (PPDB 2019). No information is available for Nifluiridide.

Table 93: PFAS that have been used as insecticides. The names in brackets under "specification of chemical(s)" are the ISO common names for pesticides. The types stand for U – use, U* – current use, and ? – unclear. Additional explanations to the table are provided on Page 2 and 3 of this document.

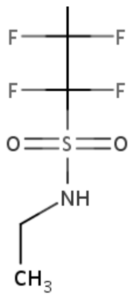
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Lithium perfluoroalkane sulfonate[1a]	$Li^+\ C_nF_{2n+1}SO_3^-$	n = 8	29457-72-5	U	(Ogawa et al. 2020)
N-Ethyl perfluoroalkane sulfonamides (EtFASAs)[1b]	$C_nF_{2n+1}SO_2NHC_2H_5$	n = 8 (Sulfuramid)	4151-50-2	U*	(COP 2019)
1-Alkanesulfonamide, *N*-butyl-perfluoro-[1c]	$C_nF_{2n+1}SO_2NHC_4H_9$	n = 8 (Flursulamid)	31506-34-0	U	(Ogawa et al. 2020)

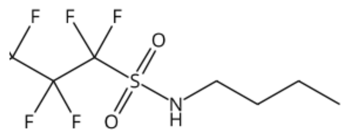
Cyclohexanecarboxamide, *N*-(2-bromo-4-nitrophenyl)-1,2,2,3,3,4,4,5,5,6,6-undecafluoro-[1d]	c-$C_6F_{11}C(O)NHC_6H_3BrNO_2$	(EL-499-1)	107349-85-9	?	(Ogawa et al. 2020)
Cyclohexanecarboxamide, *N*-(2-bromo-4-nitrophenyl)-1,2,2,3,3,4,4,5,5,6-decafluoro-6-(trifluoromethyl)-[1e]	c-$C_7F_{13}C(O)NHC_6H_3BrNO_2$	(EL-499-2)	107351-23-5	?	(Ogawa et al. 2020)

1a

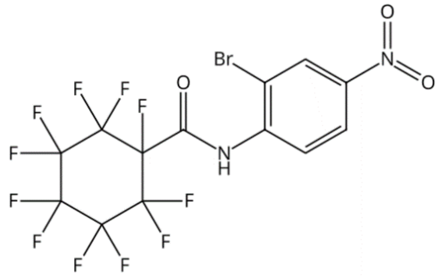


1b





1c



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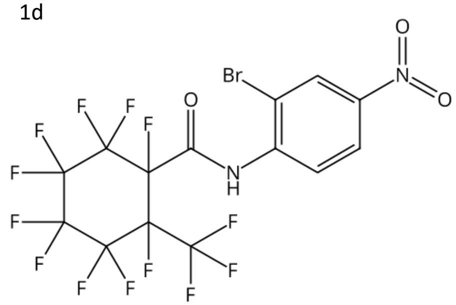
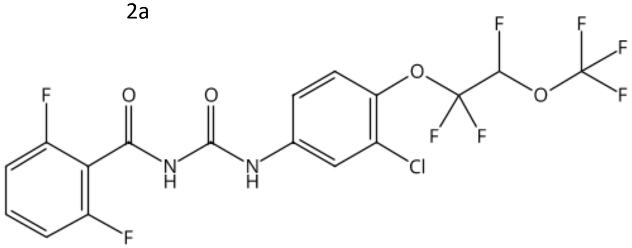
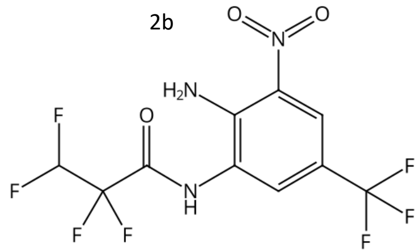


Benzamide, *N*-[[[3-chloro-4-[1,1,2-trifluoro-2-(trifluoromethoxy)ethoxy] phenyl]amino]carbonyl]-2,6-difluoro-[2a]	$C_6H_3F_2C(O)NHC(O)NHC_6H_3ClOCF_2CFHOCF_3$	(Novaluron)	116714-46-6	U	(Ogawa et al. 2020)
Propanamide, *N*-[2-amino-3-nitro-5-(trifluoromethyl)phenyl]-2,2,3,3-tetrafluoro-[2b]	$HCF_2CF_2C(O)NHC_6H_2(NH_2)(NO_2)CF_3$	(Nifluridide)	61444-62-0	U	(Ogawa et al. 2020)

2a



2b



Another substance that has been marketed for potential use in pesticides *is N*-methyl perfluorohexane sulfonamide (POPRC 2018b).

2.29.2 PFAS as formulation additives

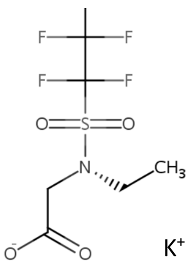
Perfluoroalkyl phosphonic acids (PFPAs) and perfluoroalkyl phosphinic acids (PFPiAs) have been used as anti-foaming agents in various pesticide formulations and adjuvants (Z. Wang et al. 2016). The Chemical Data Reporting database under the TSCA lists that phosphonic acid, perfluoro-C_{6-12}-alkyl derivs. (CAS No. 68412-68-0) and phosphinic acid, bis(perfluoro-C_{6-12}-alkyl) derivs. (CAS No. 68412-69-1) were used above 11.3 t in the US as surface active agents in pesticide, fertilizer and other agricultural chemical manufacturing in the US between 2012 and 2015 (USEPA 2016). PFAS have also been used in pesticides as dispersants, to facilitate the spreading of plant protection agents on insects and plant leaves and to increase uptake by insects and plants (KEMI Swedish Chemical Agency 2015b). An example for a PFAS that aids wetting and penetration of insecticides into the insect is potassium *N*-ethyl perfluoroalkane sulfonamidoacetate (CAS No. 2991-51-7) (Kissa 2001; CAS 2019 (JP51035436, 1976)). Currently, this chemical, PFPAs and PFPiAs are no longer permitted as pesticide additives, at least in the US (POPRC 2016a; Z. Wang et al. 2016).

Table 94 lists additional substances that have been approved in the past as inert additives in pesticide formulations in the United States, but are no longer permitted.

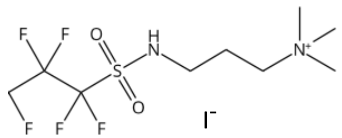
Table 94: PFAS that were approved in the past as inert additives in pesticide formulations in the United States, but are no longer permitted in the US. Patent number (date, legal status): WO9817113 (1998, active). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl phosphonic acids (PFPAs)	$C_nF_{2n+1}P(=O)(OH)_2$	-	-	U	(Buck, Murphy, and Pabon 2012)
Perfluoroalkyl phosphinic acids (PFPiAs)	$C_nF_{2n+1}P(C_mF_{2m+1})(=O)OH$	-	-	U	(Buck, Murphy, and Pabon 2012)
Fluorotelomer alcohol-based phosphates	-	-	-	U	(Buck, Murphy, and Pabon 2012)
Potassium *N*-ethyl perfluoroalkane sulfonamido acetate[1a]	$K^+\ C_nF_{2n+1}SO_2N(C_2H_5)CH_2\,COO^-$	n = 8	2991-51-7	U	(POPRC 2016a)
1-Propanaminium, 3-[[(perfluoroalkyl) sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, iodide (1:1)[1b]	$I^-\ C_nF_{2n+1}SO_2NHCH_2CH_2\,CH_2N^+(CH_3)_3$	n = 8	1652-63-7	U	(POPRC 2016a)
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[1c]	$Cl^-\ C_nF_{2n+1}SO_2NHCH_2CH_2\,CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (WO9817113))

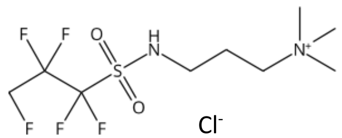
1a



1b



1c



2.30 Pharmaceuticals

2.30.1 PFAS as active ingredients

There are only a few drugs that have the moiety $–CF_2CF_2$-. We have checked the list of active ingredients in approved drugs in the US from the FDA, but none of the chemcials had the moiety -CF_2CF_2- (FDA 2020a; Mei et al. 2019). J. Wang et al. (2014) listed fluorine-containing drugs which were introduced in the market between 2001 and 2011. The only drug with the moiety -CF_2CF_2- was Fulvestrant (CAS No. 129453-61-8). Fulvestrant is an estrogen antagonist and inhibits the growth stimulus that estrogen exerts on cells. Fulvestrant has been used to treat breast cancer (J. Wang et al. 2014). Many drugs contain the moiety -CF_3 and thus are PFAS, according to Buck et al. (2011); however, they are outside the working scope of this study, as defined in the methods section of the main text. Beside the approved drugs, there are drugs that have been withdrawn from the market or have not (yet) been approved (Zhou et al. 2016). Many of them are described in patents. An example of a patented drug with the moiety -CF_2CF_2- is 1H-thieno[3,4-d]imidazole, 2-[[[4-(2,2,3,3,4,4,4-heptafluorobutoxy)-2-pyridinyl]methyl]sulfinyl]- (CAS No. 121617-11-6). The chemical can be used in a pharmaceutical combination of dabigatran (an agent that thins the blood) and proton pump inhibitors (CAS 2019 (TR2014004232, 2015)).

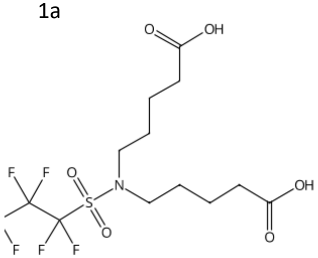
2.30.2 PFAS as formulation additives

PFAS can be used as dispersants in self-propelling aerosol pharmaceuticals (CAS 2019 (US4352789, 1982)). Some exemplary molecules are listed in Table 95.

Table 95: PFAS that have been patented as dispersants in self-propelling aerosol pharmaceuticals. Patent number (date, legal status): US4352789 (1982, expired).

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Pentanoic acid, 5,5′-[[(perfluoroalkyl)sulfonyl] imino]bis-[1a]	$C_nF_{2n+1}SO_2N(C_4H_8COOH)_2$	n = 8	83903-90-6	P	(CAS 2019 (US4352789))
1-Decanaminium, *N*-[3-[[(perfluoroalkyl)sulfonyl] amino]propyl]-*N*,*N*-dimethyl-, bromide (1:1)[1b]	$Br^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2 C_{10}H_{21}$	n = 8	14513-26-9	P	(CAS 2019 (US4352789))
1-Alkanesulfonamide, *N*-ethyl-perfluoro-*N*-[2-(phosphonooxy)ethyl]-[1c]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2OP(=O)(OH)_2$	n = 8	3820-83-5	P	(CAS 2019 (US4352789))
1-Alkanesulfonamide, *N*,*N*′-[phosphinicobis(oxy-2,1-ethanediyl)]bis[*N*-ethyl-perfluoro- [1d]	$[C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2O]_2P(=O)OH$	n = 6, 8, 10	67939-92-8, 2965-52-8, 83903-91-7	P	(CAS 2019 (US4352789))

1a



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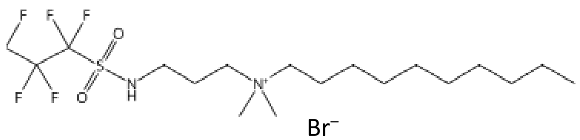

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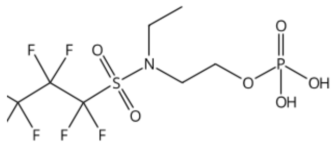

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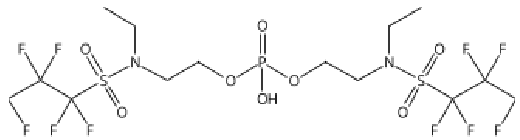
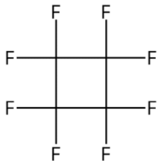


1-Alkanesulfonamide, *N*,*N*′-[phosphinicobis(oxy-2,1-ethanediyl)]bis[*N*-ethyl-perfluoro-, ammonium salt (1:1)[(1d)]	$NH_4^+ [C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2O]_2PO_2^-$	n = 8	30381-98-7	P	(CAS 2019 (US4352789))
Perfluorocycloalkane[2a]	c-C_nF_{2n}	n = 4	115-25-3	P	(CAS 2019 (US4352789))
Linear perfluoroalkanes[2b]	C_nF_{2n+2}	n = 3	76-19-7	P	(CAS 2019 (US4352789))
Perfluorotrialkyl amine[2c]	$N(C_nF_{2n+1})_3$	n = 4	311-89-7	P	(CAS 2019 (US4352789))

2a



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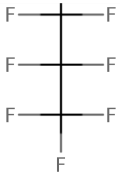

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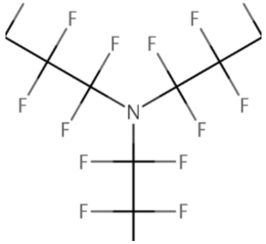


Furthermore, PFAS can be used as solvents in pharmaceuticals. Examples are semifluorinated *n*-alkanes (SFAs) with $F(CF_2)_n(CH_2)_mH$ n/m = 4/5 (CAS No. 1190430-21-7), n/m = 6/6 (CAS No. 69125-80-0) or n/m = 6/8 (CAS No. 133331-77-8) (CAS 2019 (US8796340, 2014)).

2.31 Pipes, pumps, fittings and liners

Fluoropolymers like PVDF (CAS No. 24937-79-9) have been used to make solid and lined pipes, fittings, valves, pumps, tower packing, and tank and trailer linings for fluid-handling applications (R. E. Banks, Smart, and Tatlow 1994; Dohany 2000). Additional information on the fluoropolymers used in pipes and pipe linings are provided in Section 1.4.7 ‘Technical equipment in the chemical process industry` and in Section 1.14.4 ‘Oil and gas transport`.

Another fluoropolymer used in pump impellers and casings, pipe linings, and valves is ETFE. ETFE is most suitable for electrostatic powder coating for anticorrosive, antistick, and electrical applications in both the home and industries (R. E. Banks, Smart, and Tatlow 1994).

CTFE telomers and perfluoropolyethers are used (or have been used) as working fluid/vacuum pump oils in the electronics industry where reactive gases and aluminum chloride would be harmful to hydrocarbon oils (see also Section 1.18.10 Working fluids for pumps in the semiconductor industry).

2.32 Plastic, rubber and resins

PFAS that are used in the production of plastic and rubber are described in Section 1.17. PFAS that are used as additives in plastic, rubber and resins are described in this Section.

2.32.1 Plastic

PTFE micropowders are used as additives in plastics (R. E. Banks, Smart, and Tatlow 1994). Lower molecular weight-PCTFE oils, waxes, and greases are used as plasticizers for thermoplastics (Millet and Kosmala 2000).

2.32.2 Rubber

The most commercially available fluoroelastomers (in 1994) were copolymers of vinylidene fluoride and hexafluoropropylene (VDF-HFP, CAS No. 9011-17-0) and, optionally, terpolymers with tetrafluoroethylene (THV, CAS No. 25190-89-0) (R. E. Banks, Smart, and Tatlow 1994). Fluorinated surfactants added to rubber allows adhesive less bonding of rubber to steel (Kissa 2001). Rubber insulation in a fridge contained PFHxS (CAS No. 355-46-4) and PFOS (CAS No. 1763-23-1) (Bečanová et al. 2016).

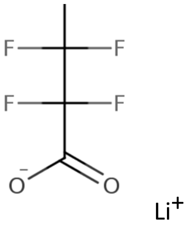
2.32.3 Antistat in rubber and plastic

Antistats prevent the buildup of static electricity and dissipate the electric charge formed on the substrate (Kissa 2001). Antistatic agents can be applied to the surface (external antistat) or incorporated into the bulk (internal antistat) of an otherwise insulating material. Antistats for plastic are commonly employed as internal antistat and have to be thermally stable to withstand polymer melt processing temperatures, which can be as high as 250 to 400 °C or more (CAS 2019 (WO2001025326, 2001)). Since static buildup is typically a surface phenomenon, internal antistats that are capable of migrating to and enriching the surface of a material are generally most effective. Table 96 shows fluorinated surfactants that hae been used or patented as antistats in plastic or rubber.

Table 96: PFAS that have been used or patented as antistat in plastic or rubber. Patent number (date, legal status): WO2001025326 (2001, active), US20050228194 (2005, active), JP57133060 (1982, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Lithium perfluoroalkyl carboxylate[1a]	$Li^+ C_nF_{2n+1}COO^-$	n = 6	60871-90-1	P	(CAS 2019 (WO2001025326))
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 4, 8	375-73-5, 1763-23-1	P	(CAS 2019 (WO2001025326))
Lithium perfluoroalkane sulfonate[(1b)]	$Li^+ C_nF_{2n+1}SO_3^-$	n = 4, 6	131651-65-5, 55120-77-9	P, U	(CAS 2019 (WO2001025326); Norwegian Environment Agency 2018)
Tetrabutylphosphonium perfluoroalkane sulfonate[1c]	$P^+H(C_4H_9)_4\ C_nF_{2n+1}SO_3^-$	n = 4	220689-12-3	P, U	(CAS 2019 (US20050228194); Hodgkins 2018)
Pyridinium, 1-butyl-, perfluoro-1-alkanesulfonate (1:1)[1d]	$C_4H_9N^+C_5H_5\ C_nF_{2n+1}SO_3^-$	n = 4	334529-64-5	P	(CAS 2019 (WO2001025326))
Pyridinium, 1-hexadecyl-, perfluoro-1-alkanesulfonate (1:1)[(1d)]	$C_{16}H_{33}N^+C_5H_5\ C_nF_{2n+1}SO_3^-$	n = 4, 8	334529-62-3, 334529-63-4	P	(CAS 2019 (WO2001025326))

1a



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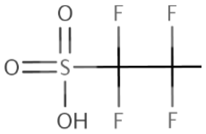
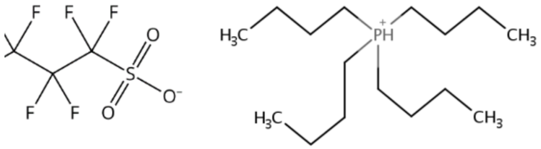
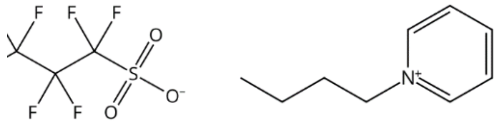


1c

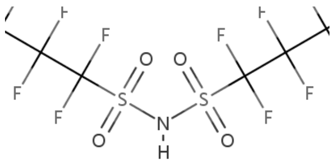


1d



Bis(perfluoroalkane-sulfonyl)imide[2a]	$(C_nF_{2n+1}SO_2)_2NH$	n = 2	152894-10-5	P	(CAS 2019 (WO2001025326))
Lithium bis(perfluoroalkane-sulfonyl)imide[(2a)]	$Li^+ (C_nF_{2n+1}SO_2)_2N^-$	n = 2, 4	132843-44-8, 119229-99-1	P	(CAS 2019 (WO2001025326))
Pyridinium, 1-hexadecyl-, salt with perfluoro-*N*-[(perfluoroalkyl)sulfonyl]alkanesulfonamide (1:1)[2b]	$C_{16}H_{33}N^+C_5H_5\ (C_nF_{2n+1}SO_2)_2N^-$	n = 2	334529-61-2	P	(CAS 2019 (WO2001025326))
Ethanaminium, 2-hydroxy-*N*,*N*,*N*-trimethyl-, salt with perfluoro-*N*-[(perfluoroalkyl)sulfonyl]-1-alkane sulfonamide (1:1)[(2b)]	$HOCH_2CH_2N^+(CH_3)_3\ (C_nF_{2n+1}SO_2)_2N^-$	n = 4	334529-59-8	P	(CAS 2019 (WO2001025326))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-[2c]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	70225-25-1	P	(CAS 2019 (WO2001025326))
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[(2c)]	$Cl^-\ C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (WO2001025326))

2a



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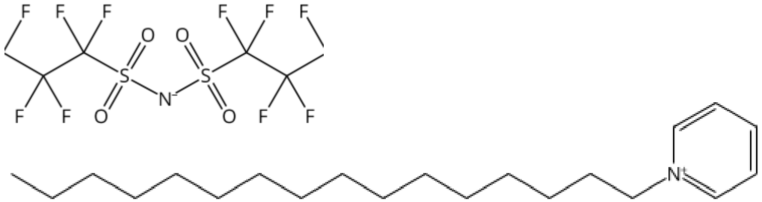

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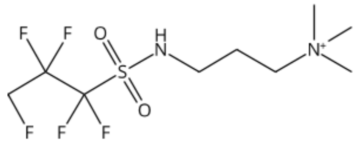
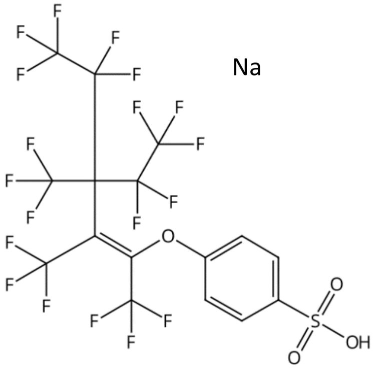


Benzenesulfonic acid, 4-[[4,4,5,5,5-pentafluoro-3-(1,1,2,2,2-pentafluoroethyl)-1,2,3-tris(trifluoromethyl)-1-penten-1-yl]oxy]-, sodium salt (1:1)[3a]	$Na^+\ CF_3CF_2C(CF_3)(C_2F_5)C(CF_3)=C(CF_3)OC_6H_4SO_3^-$	-	52584-45-9	P	(CAS 2019 (JP57133060))
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoroalkyl) sulfonyl]amino]ethyl]-ω-hydroxy-[3b]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_mOH$	n = 8	29117-08-6	P	(CAS 2019 (JP57133060))

3a



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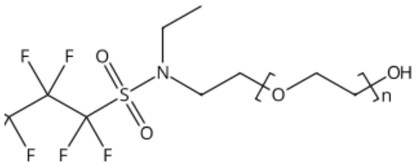


2.32.4 Resins

Resin is a solid or highly viscous substance of plant or synthetic origin that can be converted to polymers. Fluorinated surfactants are incorporated in this polymer to improve weatherability, elasticity, or flammability.

Potassium perfluorobutane sulfonate (K-PFBS, CAS No. 29420-49-3) and perfluorobutane sulfonic acid (PFBS, CAS No. 375-73-5) are marketed as flame retardant for polycarbonate resins (Z. Wang et al. 2013; CAS 2019 (CN101891943, 2010)). For more information, see Section 2.15 ‘Flame retardants`.

2.33 Printing (inks)

PFAS have been used or have been patented for use in toner and printer inks, ink-jet recording heads, recording and printing paper and lithographic printing plates. Additionally, PFOS (CAS No. 1763-23-1) has been found in tested intermediate transfer belts of colour copiers and printers (POPRC 2019).

2.33.1 Toner and printer inks

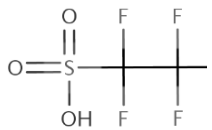
Many ink formulations contain fluorinated surfactants to enhance ink flow and leveling, to improve cylinder life, and to eliminate snowflaking or nonuniform printing (R. E. Banks, Smart, and Tatlow 1994). Fluorinated surfactants also improve wetting which is essential for printing on difficult-to-wet surfaces such as plastics and metals (Kissa 2001). Additionally, fluorinated surfactants aid pigment dispersion and control problems such as pigment flooding and flotation. They also impart water resistance to water-based inks (Kissa 2001) and improve the storage stability (CAS 2019 (JP2007056175)). Fluorinated surfactants are added to inks for ballpoint pens, marking pens, anticlogging jet recording inks, and printing inks for plastics (Kissa 2001).

The Chemical Data Reporting database under the TSCA lists poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly(difluoromethylene) (1:1) (CAS No. 65545-80-4) as a processing aid for printing ink manufacturing (USEPA 2016).

Table 97: PFAS historically or currently used in, detected in, or patented for printing inks. Patent number (date, legal status): CN109810567 (2019, not yet active), JP2003277664(2003, withdrawn), JP2007056175 (2007, refused). The types stand for U – use, U* – current use, P – patent, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Nonpolymers					
Perfluoroalkane sulfonic acids (PFSAs)[1a]	$C_nF_{2n+1}SO_3H$	n = 6 - 8	1763-23-1	D	(Herzke, Posner, and Olsson 2009)
N-Methyl perfluoroalkane sulfonamides (MeFASAs)[1b]	$C_nF_{2n+1}SO_2NHCH_3$	n = 4	68298-12-4	U	(Norwegian Environment Agency 2017)
N-Alkyl perfluoroalkane sulfonamides[(1b)]	$C_nF_{2n+1}SO_2NH(R)$ R = C_mH_{2m+1} (m = 1, 2, 4)	n = 4 - 9	-	U	(KEMI Swedish Chemical Agency 2015b)
N-Methyl perfluoroalkane sulfonamido ethanols (MeFASEs)[1c]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 4	34454-97-2	U	(Norwegian Environment Agency 2017)
N-Methyl perfluoroalkane sulfonamidoethyl acrylates (MeFASEACs)[1d]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH{=}CH_2$	n = 4	67584-55-8	U	(Norwegian Environment Agency 2017)
1-Propanesulfonic acid, 3-[hexyl[(perfluoro alkyl)sulfonyl] amino]-2-hydroxy-, ammo nium salt (1:1)[1e]	NH_4^+ $C_nF_{2n+1}SO_2N(C_6H_{13})CH_2CH(OH)CH_2SO_3^-$	n = 4	606967-06-0	U	(Norwegian Environment Agency 2017)
2-Alkanone, perfluoro-[1f]	$C_nF_{2n+1}C(O)CH_3$	n = 9	150049-87-9	P	(CAS 2019 (CN109810567))

1a



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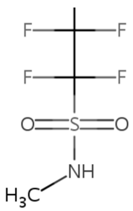

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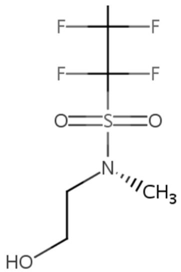

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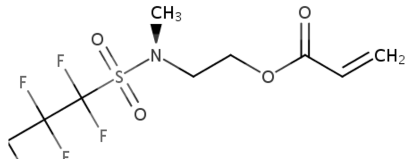

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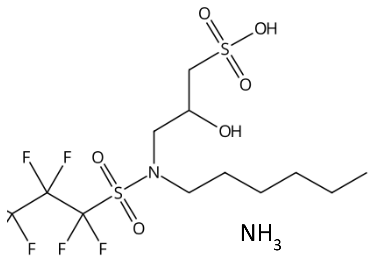

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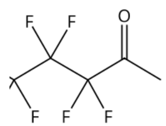
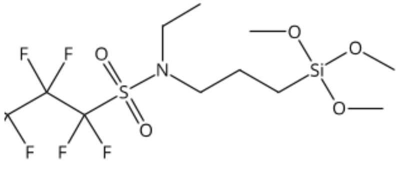


1-Alkanesulfonamide, *N*-ethyl-perfluoro-*N*-[3-(trimethoxysilyl)propyl]-[2a]	$C_nF_{2n+1}SO_2N(CH_2CH_3)CH_2CH_2CH_2Si(OCH_3)_3$	n = 8	61660-12-6	U	(POPRC 2016a)
(n:2) Fluorotelomer alcohols (FTOHs)[2b]	$C_nF_{2n+1}CH_2CH_2OH$	n = 8, 10	678-39-7, 865-86-1	D	(Herzke, Posner, and Olsson 2009)
1H, 1H, ωH-Perfluoroalkyl methacrylate[2c]	$CF_2HC_nF_{2n}CH_2OC(O)C(CH_3){=}CH_2$	n = 3	355-93-1	P	(CAS 2019 (CN109810567))

Oxirane, 2-[[(2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9-hexadecafluorononyl)oxy]methyl]-[2d]	$CFHC_7F_{14}CH_2OCH_2C_2OH_3$		125370-60-7	P	(CAS 2019 (CN109810567))

2a



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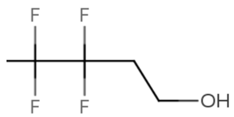

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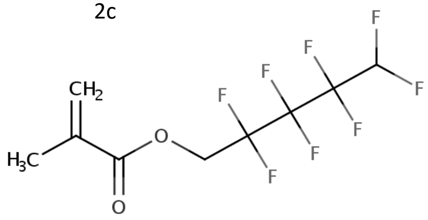

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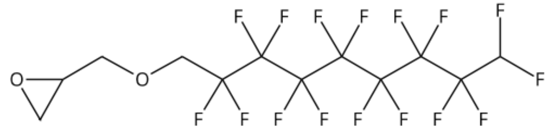
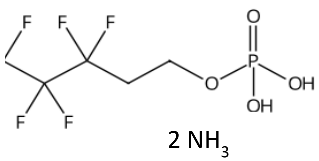
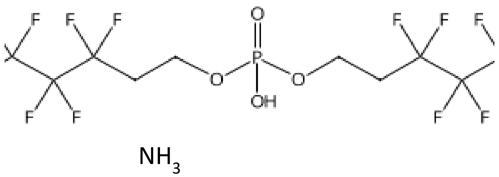


Diammonium (n:2) fluorotelomer phosphate monoester[3a]	$2\ NH_4^+\ C_nF_{2n+1}CH_2CH_2OPO_3^{2-}$	n = 6, 8, 10	1000852-37-8, 93857-44-4, 93857-45-5	U	(Buck, Murphy, and Pabon 2012)
Ammonium (n:2) fluorotelomer phosphate diester[3b]	$NH_4^+\ OP(O^-)(OCH_2CH_2C_nF_{2n+1})_2$	n = 6, 8, 10	1764-95-0, 93776-20-6, 93776-21-7	U	(Buck, Murphy, and Pabon 2012)
Silane, methoxydimethyl(perfluoroalkyl)-[3c]	$C_nF_{2n+1}CH_2CH_2Si(CH_3)_2OCH_3$	n = 2 – 6	252653-06-8, 608298-96-0, 608299-03-2, 608299-08-7, 94237-08-8	P	(CAS 2019 (JP2003277664))
Silane, ethoxydimethyl(perfluoroalkyl)-[3d]	$C_nF_{2n+1}CH_2CH_2Si(CH_3)_2OCH_2CH_3$	n = 2 – 6	608300-94-3, 608301-01-5, 608301-21-9, 608301-28-6, 107978-57-4	P	(CAS 2019 (JP2003277664))

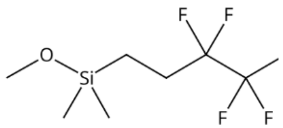
3a



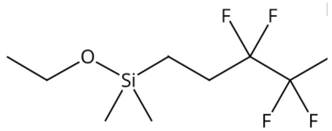
3b



3c

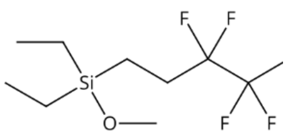


3d

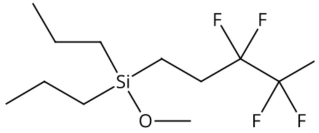


Silane, methoxydiethyl(perfluoroalkyl)-[4a]	$C_nF_{2n+1}CH_2CH_2Si(CH_2CH_3)_2OCH_3$	n = 2 – 6	608299-25-8, 608299-33-8, 608299-39-4, 608299-46-3, 608299-52-1	P	(CAS 2019 (JP2003277664))
Silane, methoxydipropyl(perfluoroalkyl)-[4b]	$C_nF_{2n+1}CH_2CH_2Si(C_3H_7)_2OCH_3$	n = 3 – 6	608299-70-3, 608299-76-9, 608299-82-7, 608299-88-3	P	(CAS 2019 (JP2003277664))
Perfluoroalkyltriethoxysilane[4c]	$C_nF_{2n+1}CH_2CH_2Si(OCH_2CH_3)_3$	n = 6	51851-37-7	P	(CAS 2019 (CN109810567))
Silane, methoxy(perfluoroalkyl)propyl(3,3,3-trifluoropropyl)-[4d]	$C_nF_{2n+1}CH_2CH_2Si(C_3H_7)(OCH_3)CH_2CH_2CF_3$	n = 2 – 6	608300-04-5, 608300-10-3, 608300-17-0, 608300-24-9, 608300-34-1	P	(CAS 2019 (JP2003277664))

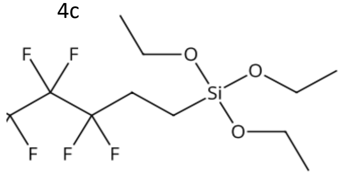
4a



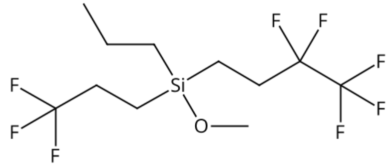
4b



4c

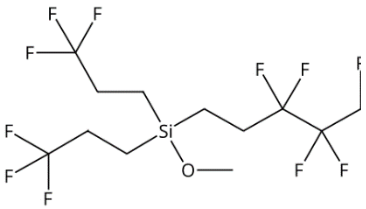


4d

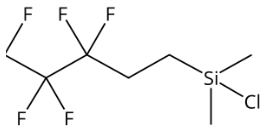


Silane, (perfluoroalkyl)methoxybis(3,3,3-trifluoropropyl)-[5a]	$C_nF_{2n+1}CH_2CH_2Si(CH_2CH_2CF_3)_2OCH_3$	n = 3 – 6	608300-52-3, 608300-66-9, 608300-73-8, 608300-81-8	P	(CAS 2019 (JP2003277664))
Silane, chlorodimethyl(perfluoroalkyl)-[5b]	$C_nF_{2n+1}CH_2CH_2Si(CH_3)_2Cl$	n = 2 – 6	648-51-1, 32523-11-8, 119386-82-2, 1425 15-42-2, 102488-47-1	P	(CAS 2019 (JP2003277664))
Silane, chlorodiethyl(perfluoroalkyl)-[5c]	$C_nF_{2n+1}CH_2CH_2Si(CH_2CH_3)_2Cl$	n = 2 – 6	608295-57-4, 608295-70-1, 608295-76-7, 608295-82-5, 60829 5-89-2	P	(CAS 2019 (JP2003277664))
Silane, chlorodipropyl(perfluoroalkyl)-[5d]	$C_nF_{2n+1}CH_2CH_2Si(C_3H_7)_2Cl$	n = 2 – 6	608296-02-2, 608296-07-7, 608296-13-5, 608296-18-0, 608296-24-8	P	(CAS 2019 (JP2003277664))
Silane, chloro(perfluoroalkyl)propyl(3,3,3-trifluoropropyl)-[5e]	$C_nF_{2n+1}CH_2CH_2Si(C_3H_7)(Cl)CH_2CH_2CF_3$	n = 2 – 6	608296-34-0, 608296-40-8, 608296-47-5, 608296-53-3, 608296-60-2	P	(CAS 2019 (JP2003277664))

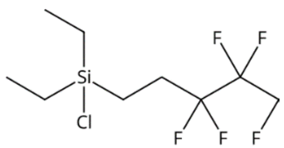
5a



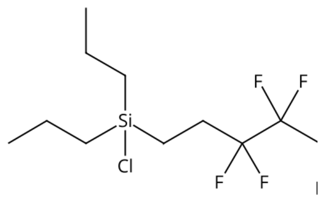
5b



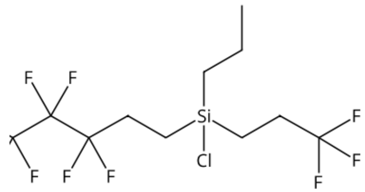
5c



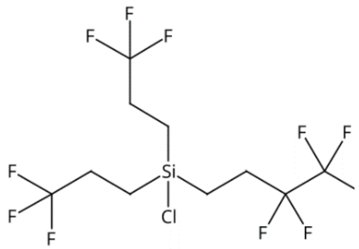
5d

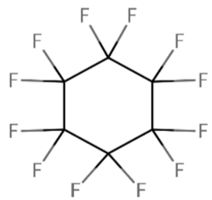


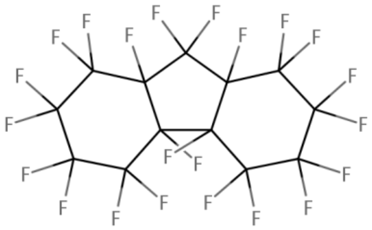
5e

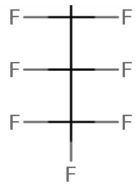


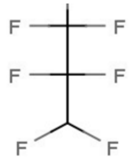
Silane, chloro(perfluoroalkyl)bis(3,3,3-trifluoropropyl)-[6a]	$C_nF_{2n+1}CH_2CH_2Si(CH_2CH_2CF_3)_2Cl$	n = 2 – 6	608296-74-8, 608296-81-7, 608296-86-2, 608296-92-0, 608296-98-6	P	(CAS 2019 (JP2003277664))
Perfluorocycloalkane[6b]	$c\text{-}C_nF_{2n}$	n = 6	355-68-0	P	(CAS 2019 (CN109810567))
Perfluoroperhydrofluorene[6c]	$c\text{-}C_{13}F_{22}$	-	307-08-4	P	(CAS 2019 (CN109810567))
Linear perfluoroalkanes[6d]	C_nF_{2n+2}	n = 6, 7	355-42-0, 335-57-9	P	(CAS 2019 (CN109810567))
1H-Polyfluoroalkane[6e]	$C_nF_{2n+1}CF_2H$	n = 5	355-37-3	P	(CAS 2019 (CN109810567))
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-[6f]	$C_2F_5(CFH)_2CF_3$	-	138495-42-8	P	(CAS 2019 (CN109810567))

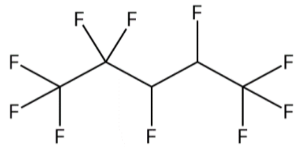
6a


6b


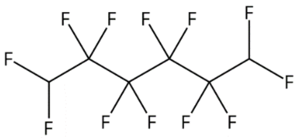
6c


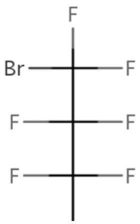
6d


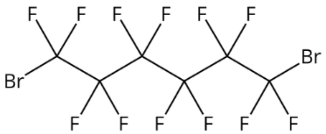
6e


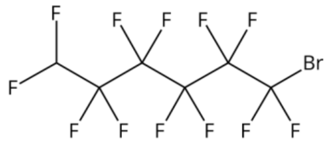
6f


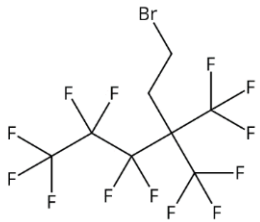
Hexane, 1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-[7a]	$CFHCF_2CF_2CF_2CF_2CFH$	-	336-07-2	P	(CAS 2019 (CN109810567))
1-Bromoperfluoroalkanes[7b]	BrC_nF_{2n+1}	n = 6, 8	335-56-8, 423-55-2	P	(CAS 2019 (CN109810567))
Hexane, 1,6-dibromo-1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-[7c]	$BrC_6F_{12}Br$	-	918-22-9	P	(CAS 2019 (CN109810567))
Hexane, 1-bromo-1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-[7d]	$CFHC_5F_{10}Br$	-	355-36-2	P	(CAS 2019 (CN109810567))
Hexane, 6-bromo-1,1,1,2,2,3,3-heptafluoro-4,4-bis(trifluoromethyl)-[7e]	$C_3F_7C(CF_3)_2CH_2CH_2Br$	-	128454-91-1	P	(CAS 2019 (CN109810567))

7a


7b


7c


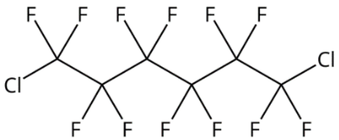
7d


7e


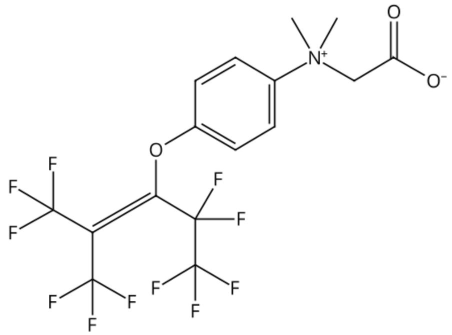
Hexane, 1,6-dichloro-1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-[8a]	$ClC_6F_{12}Cl$	-	355-40-8	P	(CAS 2019 (CN109810567))
Benzenaminium, *N*-(carboxymethyl)-*N*,*N*-dimethyl-4-[[3,3,3-trifluoro-1-(1,1,2,2,2-pentafluoroethyl)-2-(trifluoromethyl)-1-propen-1-yl]oxy]-, inner salt[8b]	$CF_3C(CF_3)=C(C_2F_5)OC_6H_4N^+(CH_3)_2CH_2COO^-$	-	927408-20-6	P	(CAS 2019 (JP2007056175))
Benzoic acid, 4-[[3,3,3-trifluoro-1-(1,1,2,2,2-pentafluoroethyl)-2-(trifluoromethyl)-1-propen-1-yl]oxy]-, sodium salt (1:1)[8c]	$Na^+\ CF_3C(CF_3)=C(C_2F_5)OC_6H_4COO^-$	-	927408-18-2	P	(CAS 2019 (JP2007056175))

Benzenaminium, N-(carboxymethyl)-*N*,*N*-dimethyl-4-[[3,4,4,4-tetrafluoro-2-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]-1,3-bis (trifluoromethyl)-1-buten-1-yl]oxy]-, inner salt[8d]	$CF_3CF(CF_3)C[CF(CF_3)_2]=C(CF_3)OC_6H_4N^+(CH_3)_2CH_2COO^-$		927408-19-3	P	(CAS 2019 (JP2007056175))

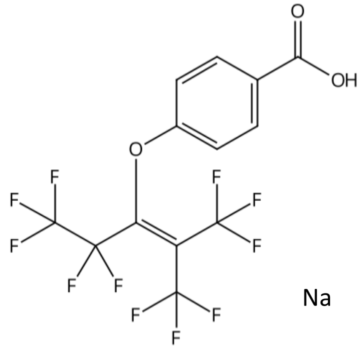
8a



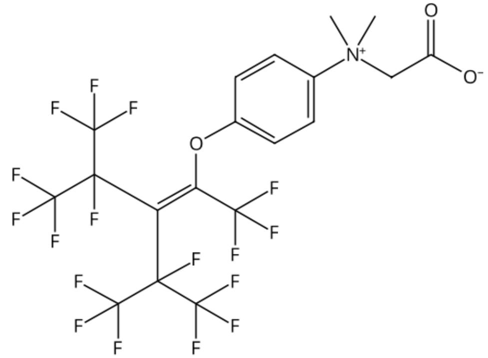
8b



8c

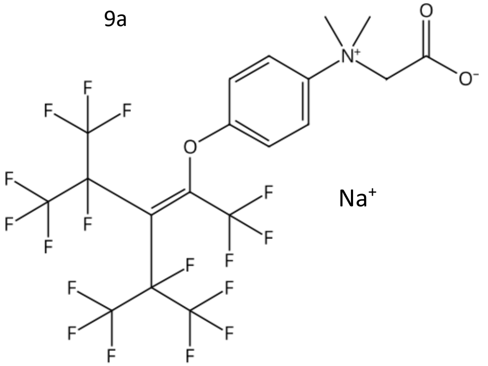


8d

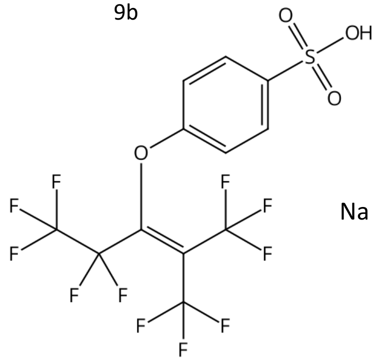


Benzenaminium, *N*-(carboxymethyl)-*N*,*N*-dimethyl-4-[[3,4,4,4-tetrafluoro-2-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]-1,3-bis(trifluoromethyl)-1-buten-1-yl]oxy]-, sodium salt[9a]	Na^+ $CF_3CF(CF_3)C[CF(CF_3)_2]=C(CF_3)OC_6H_4N^+(CH_3)_2CH_2COO^-$	-	123088-71-1	P	(CAS 2019 (JP2007056175))
Benzenesulfonic acid, 4-[[3,3,3-trifluoro-1-(1,1,2,2,2-pentafluoroethyl)-2-(trifluorome thyl)-1-propen-1-yl]oxy]-, sodium salt (1:1)[9b]	Na^+ $CF_3C(CF_3)=C(C_2F_5)OC_6H_4SO_3^-$	-	85284-17-9	P	(CAS 2019 (JP2007056175))
Benzenesulfonic acid, 4-[[3,4,4,4-tetrafluo ro-2-[1,2,2,2-tetrafluoro-1-(trifluoromethyl) ethyl]-1,3-bis(trifluoromethyl)-1-buten-1-yl]oxy]-, sodium salt (1:1)[9c]	Na^+ $CF_3CF(CF_3)C[CF(CF_3)_2]=C(CF_3)OC_6H_4SO_3^-$	-	70829-87-7	P	(CAS 2019 (JP2007056175))

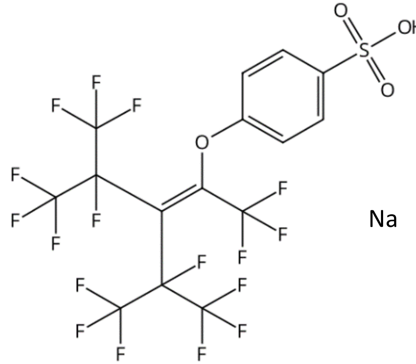
9a



9b

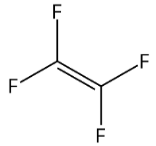


9c

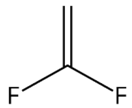


<u>Polymers</u>					
Polytetrafluoroethylene (PTFE)[10a]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Gardiner 2015; Norden 2020)
Poly(vinylidene fluoride) (PVDF)[10b]	$-(CH_2CF_2)_x-$	polymer	24937-79-9	U	(Dohany 2000; Norden 2020)
Ethylene tetrafluoroethylene copolymer (ETFE)[10c]	$-(CH_2CH_2)_x-(CF_2CF_2)_y-$	polymer	25038-71-5	U	(Norden 2020)
2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5, 6,6,7,7,8,8,8-heptadeca fluorooctyl)sulfonyl] amino]ethyl ester, telomer with 2-[butyl[(1,1, 2,2,3,3, 4,4,5,5,6,6,7,7,7-pentadecafluoro heptyl)sulfonyl]amino]ethyl 2-prope noate, 2-methyloxirane polymer with oxirane di-2-pro penoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[10d]	$-(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O)_m-(C_2H_4O)_n-(C_8H_{18}S)_w-$	polymer	68298-62-4	U	(Norden 2020)
2-Propenoic acid, 2-[methyl[(nonafluoro butyl)sulfonyl]amino]ethyl ester, telomer with methyloxirane polymer with oxirane di-2-propenoate and methyloxirane polymer with oxirane mono-propenoate	-	polymer	1017237-78-3	U	(Norwegian Environment Agency 2017)

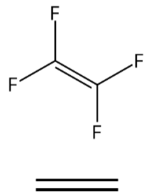
10a



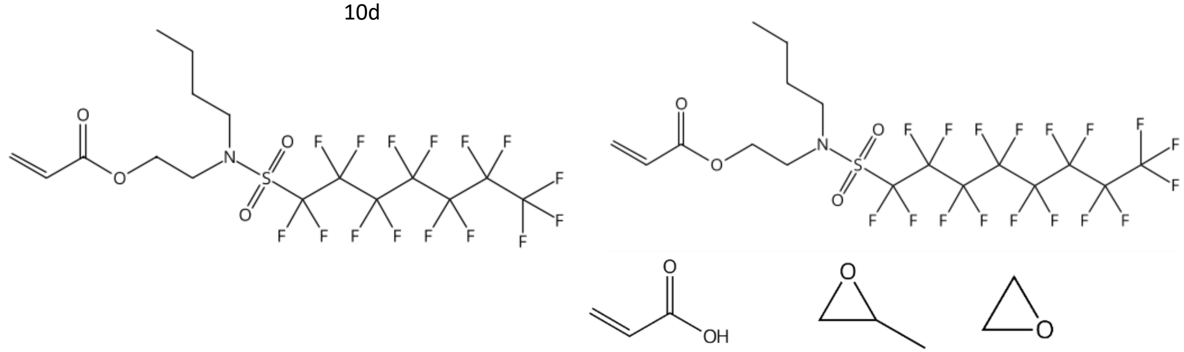
10



10c



10d



2.33.2 *Ink-jet recording heads*

A patent discloses that 2-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)oxy]methyl]oxirane (CAS No. 122193-68-4) can be used in ink-jet recording heads to make them ink repellent (CAS 2019 (JP2010120390, 2010)).

2.33.3 *Recording and printing paper*

Fluorinated surfactants have been used in the manufacture of heat-sensitive recording paper and ink-jet printing paper (Kissa 2001).

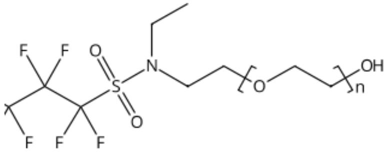
2.33.4 *Lithographic printing plates*

A patent discloses that PFAS can be used in printing plates for waterless lithography (CAS 2019 (JP02062543, 1990)). The patented PFAS are shown in Table 98. Buck, Murphy, and Pabon (2012) stated that 1-alkanaminium, 2-(acetyloxy)-*N*-(carboxymethyl)-perfluoro-*N*,*N*-dimethyl-, inner salts (CAS No. 80234-02-2, 80234-03-3, 80244-66-2) have been used for lithographic printing (but without giving further details). The three substances are fluorotelomer-based PFAS with 6, 8, and 10 perfluorocarbons, respectively.

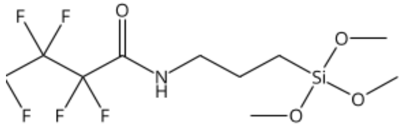
Table 98: PFAS that can be used in lithographic printing plates. Patent number (date, legal status): JP01048849 (1989, expired), JP02062543 (1990, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Poly(oxy-1,2-ethanediyl), α-[2-[ethyl[(perfluoroalkyl) sulfonyl]amino]ethyl]-ω-hydroxy-[1a]	$C_nF_{2n+1}SO_2N(C_2H_5)CH_2CH_2(OCH_2CH_2)_nOH$	n = 8	29117-08-6	P	(CAS 2019 (JP01048849))
Alkanamide, perfluoro-*N*-[3-(trimethoxy silyl)propyl]-[1b]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2Si(OCH_3)_3$	n = 6	130043-47-9	P	(CAS 2019 (JP02062543))
1,2-Propanediol, 3-[(perfluoroalkyl)oxy]-[1c]	$C_nF_{2n+1}CH_2CH_2OCH_2CH(OH)CH_2OH$	n = 6	126814-93-5	P	(CAS 2019 (JP02062543))
Oxirane, 2-[[(perfluoroalkyl)oxy]methyl]-[1d]	$C_nF_{2n+1}CH_2CH_2OCH_2C_2OH_3$		122193-68-4	P	(CAS 2019 (JP02062543))

1a



1b



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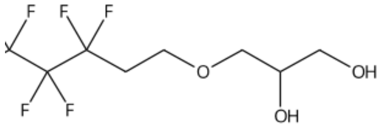
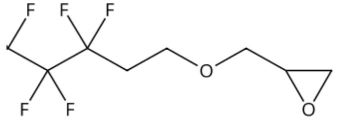


1d



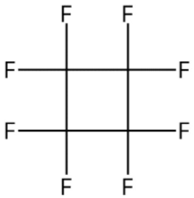
2.34 Refrigerant systems

PFAS are used in refrigerants as heat transfer fluids and refrigerant blends (USEPA 2016). Possibly used substances are listed in Table 99. Perfluoropolyethers have also been used in refrigerant compressors as lubricants (R. E. Banks, Smart, and Tatlow 1994).

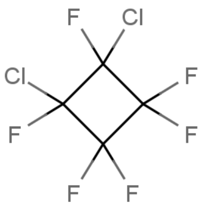
Table 99: PFAS that can be used as refrigerants. Patent number (date, legal status): JP10152452 (1998, expired). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluorocycloalkane[1a]	c-C_nF_{2n}	n = 4	115-25-3	U	(Ashrae 2019)
Dichloroperfluorocyclobutane[1b]	c-$C_4Cl_2F_6$	R-C316	356-18-3	U	(Ashrae 2019)
Chloroperfluorocyclobutane	c-C_4ClF_7	R-C317	377-41-3	U	(Ashrae 2019)
Linear perfluoroalkane[1c]	C_nF_{2n+2}	n = 2 (R-116), 3 (R-218), 4 (R-3-1-10), 5 (R-4-1-12), 6 (R-5-1-14)	76-16-4, 76-19-7, 355-25-9, 678-26-2, 355-42-0	U	(Ashrae 2019)
Hexafluoropropene trimer[1d]	$CF_3CF(CF_3)CF=C(CF_3)CF(CF_3)_2$	R-1218	6792-31-0	U	(Ashrae 2019)
1H-Perfluoroalkane[1e]	$C_nF_{2n+1}CF_2H$	n = 1 (R-125), 2 (R-227ca), 3 (R-329ccb)	354-33-6, 2252-84-8, 375-17-7	U	(Ashrae 2019; USEPA 2016)
N-Methylperfluoroalkane[2a]	$C_nF_{2n+1}CH_3$	n = 3 (R-247ccd)	662-00-0	U	(Ashrae 2019)
1-Chloroperfluoroalkane[2b]	ClC_nF_{2n+1}	n = 2 (R-115), 3 (R-217)	76-15-3, 422-86-6	U	(Ashrae 2019)

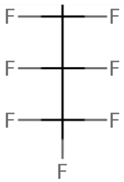
1a



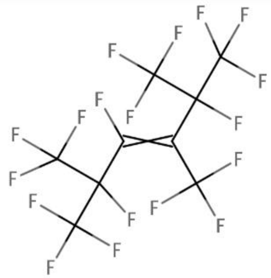
1b



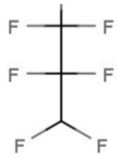
1c



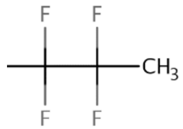
1d



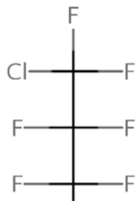
1e



1f

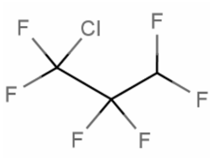


1g

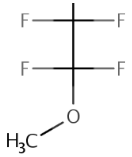


1-Chloro-1,1,2,2,3,3-hexafluoropropane[2a]	$CF_2ClCF_2CF_2H$	R-226cb	422-55-9	U	(Ashrae 2019)
Methyl perfluoroalkyl ether[2b]	$C_nF_{2n+1}OCH_3$	n = 2, 3 (R-347mcc)	22410-44-2, 375-03-1	U, P	(Tsay 2005; CAS 2019 (JP10152452))
1,1,1,2-Tetrafluoro-2-(trifluoromethoxy) ethane[2c]	$CF_3OCFHCF_3$	-	2356-62-9	U	(Tsay 2005)
1,1,2,2-Tetrafluoro-1-(trifluoromethoxy) ethane[2d]	$CF_2CF_2OCF_3$	R-227ca2	2356-61-8	U	(Ashrae 2019)

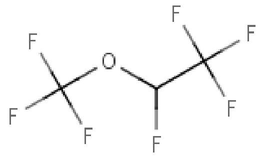
2a



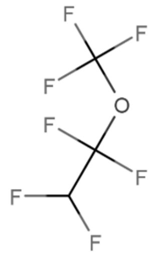
2b



2c



2d



2.35 Sealants and adhesives

The Chemical Data Reporting database under the TSCA lists three substances that were used in sealants and adhesives in the US between 2012 and 2015: poly(difluoromethylene), α-fluoro-ω-[2-(phosphonooxy) ethyl]-, ammonium salt (1:2) (CAS No. 65530-72-5), poly(difluoromethylene), α,α'-[phosphinicobis(oxy-2,1-ethane diyl)]bis[ω-fluoro-, ammonium salt (1:1) (CAS No. 65530-70-3), and poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly(difluoromethylene) (1:1) (CAS No. 65545-80-4) (USEPA 2016).

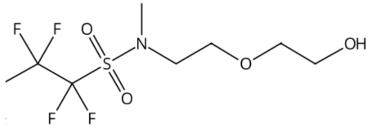
2.35.1 Sealants

Fluoroelastomers are used in the chemical processing industry, semiconductor inducstry, aircraft/aerospace applications, oil/gas production, and chemical plant valve applications (Marshall 1997) where they have to resist acid environments and high temperatures. Elastomeric seals are mostly O-rings of all sizes, V-rings, flat or lathe-cut gaskets, and lip-type rotating or reciprocating shaft seals. Coated fabrics for diaphragms, sheet goods, expansion joints, chimney, and duct coatings accounted also for considerable sales (R. E. Banks, Smart, and Tatlow 1994). An example of a fluoropolymer that is currently marketed as sealant is perfluoro(methyl vinyl ether)-tetrafluoroethylene copolymer (CAS No. 26425-79-6) (Solvay 2020). The SPIN database of the Nordic countires lists PTFE as currently used sealing compound (Norden 2020). In addition, not only polymeric PFAS have been used in seals, but also non-polymeric PFAS. A patent decribes the use of fluorinated surfactants in soiling-resistant silicone rubber sealants (CAS 2019 (JP58167647, 1983)). Table 100 lists the patented PFAS. Furthermore, X. Liu et al. (2014) detected C_4 - C_8 perfluorocarboxylic acids and C_6 perfluoroalkyl sulfonates in thread sealant tape. Guo, Liu, and Krebs (2009) detected C_5 - C_{12} perfluorocarboxyl acids in thread seal tapes and pastes. 8:2 and 10:2 fluorotelomer alcohols were detected in one of two investigated sealants by Janousek, Lebertz, and Knepper (2019).

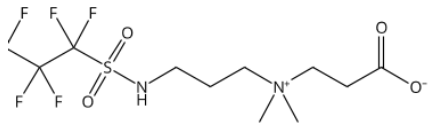
Table 100: PFAS patented for soiling-resistant silicone rubber sealants. Patent number (date, legal status): JP58167647 (1983, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
1-Propanesulfonamide, perfluoro-*N*-[2-(2-hydroxyethoxy) ethyl]-*N*-methyl-[1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OCH_2CH_2OH$	n = 3	89148-26-5	P	(CAS 2019 (JP58167647))
1-Propanaminium, *N*-(2-carboxyethyl)-*N*,*N*-dimethyl-3-[[(perfluoroalkyl)sulfonyl]amino]-, inner salt[1b]	$C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 3	89148-24-3	P	(CAS 2019 (JP58167647))
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, chloride (1:1)[1c]	$Cl^- C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 3	89148-25-4	P	(CAS 2019 (JP58167647))
1-Propanaminium, *N*-(2-carboxyethyl)-3-[(perfluoro-1-oxoalkyl)amino]-*N*,*N*-dimethyl-, inner salt[1d]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 3	89148-23-2	P	(CAS 2019 (JP58167647))

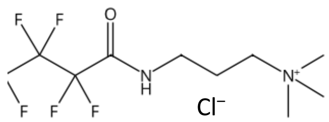
1a



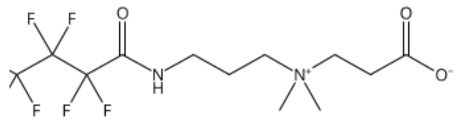
1b



1c



1d



2.35.2 Adhesives

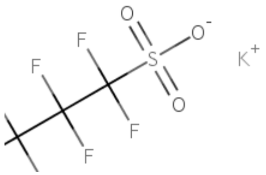
Adhesive applications exist in many forms, such as adhesives for tape, for hot-melt, for wood and other porous surfaces (Chemours 2019a). Fluorinated surfactants improve the levelling and spreading of adhesives and assure a complete contact between the joining surfaces (Kissa 2001). They also improve the penetration of the adhesive into the pore structure of the substrates, thus strengthening the bond (Chemours 2019a). Some patented PFAS for adhesives are shown in Table 101. Table 101 shows additionally two PFAS that have been listed in the SPIN database under “adhesives”.

Table 101: PFAS used or patented for adhesives. Patent number (date, legal status): JP58074771 (1983, expired), EP2719737 (2014, active). The types stand for U – use, U* – current use, and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

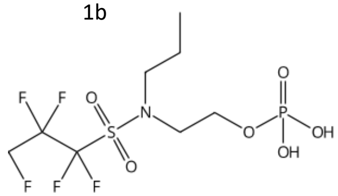
Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Potassium perfluoroalkane sulfonate[1a]	$K^+ C_nF_{2n+1}SO_3^-$	n = 8	2795-39-3	P	(CAS 2019 (JP58074771))
1-Alkanesulfonamide, perfluoro-*N*-[2-(phosphonooxy) ethyl]-*N*-propyl-[1b]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2OP(=O)(OH)_2$	n = 8	64264-44-4	P	(CAS 2019 (JP58074771))
Poly(oxy-1,2-ethanediyl), α-(perfluoroalkyl)-ω-hydroxy-(Zonyl FSN 100)[1c]	$C_nF_{2n+1}CH_2CH_2(OCH_2CH_2)_mOH$	m = 10 - 20, n = 6	52550-44-4	U	(Kissa 2001)

1-Pentyn-3-ol, 5-[[dimethyl(perfluoroalkyl)silyl]oxy]-3-methyl-[1d]	$C_nF_{2n+1}C_3H_6Si(CH_3)_2OCH_2CH_2C(CH_3)(OH)CC$	n = 6	1592562-42-9	P	(CAS 2019 (EP2719737))

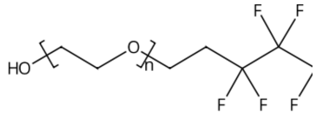
1a



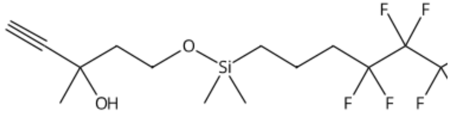
1b



1c

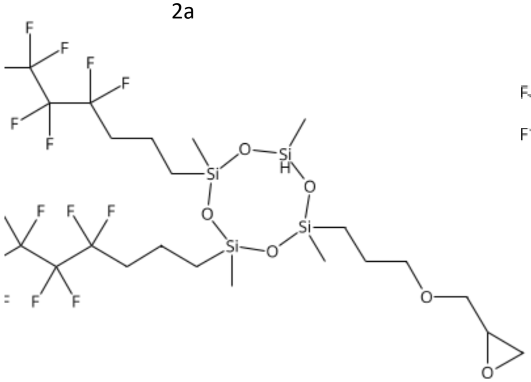


1d

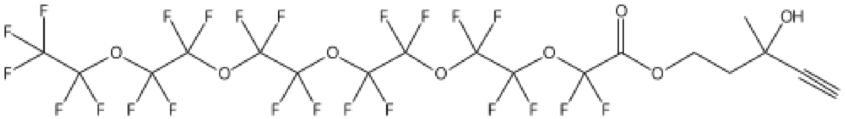


Cyclotetrasiloxane, 2,4,6,8-tetramethyl-2-[3-(2-oxiranyl methoxy)propyl]-4,6-bis(perfluoroalkyl)-[2a]	$OSi(CH_3)(C_3H_6OCH_2C_2H_3O)OSiH(CH_3)[OSi(CH_3)(C_3H_6C_nF_{2n+1})]_2$	n = 6	1428232-90-9	P	(CAS 2019 (EP2719737))
3,6,9,12,15-Pentaoxaheptadecanoic acid, 2,2,4,4,5,5,7,7,8,8,10,10,11,11,13,13,14,14,16,16,17,17,17-tricosafluoro-, 3-hydroxy-3-methyl-4-pentyn-1-yl ester[2b]	$CF_3(CF_2OCF_2)_5C(=O)OCH_2CH_2C(CH_3)(OH)C{\equiv}CH$	-	1592562-41-8	P	(CAS 2019 (EP2719737))
Propanoic acid, 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propoxy]-, 3-hydroxy-3-methyl-4-pentyn-1-yl ester[2c]	$C_3F_7OCF(CF_3)CF_2OCF(CF_3)C(=O)OCH_2CH_2C(CH_3)(OH)C{\equiv}CH$	-	1592562-40-7	P	(CAS 2019 (EP2719737))

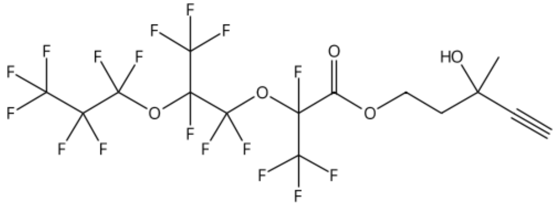
2a



2b

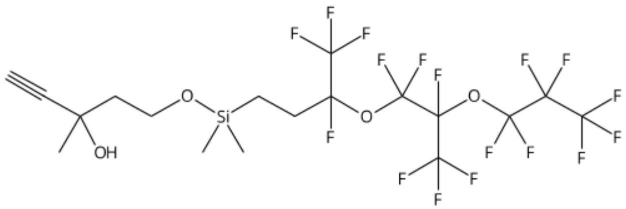


2c

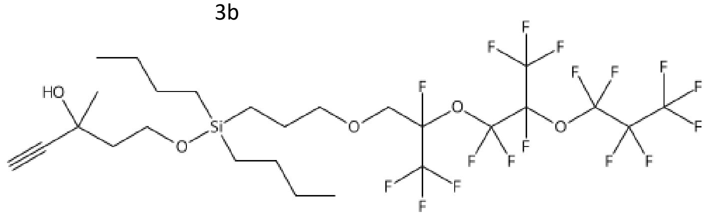


6,11,14-Trioxa-7-silaheptadec-1-yn-3-ol, 10,12,12,13,15,15,16,16,17,17,17-undecafluoro-3,7,7-trimethyl-10,13-bis(trifluoromethyl)-[3a]	$C_3F_7OCF(CF_3)CF_2OCF(CF_3)CH_2CH_2Si(CH_3)_2[OCH_2CH_2C(CH_3)(OH)C{\equiv}CH]$	-	1592562-45-2	P	(CAS 2019 (EP2719737))
6,11,14,17-Tetraoxa-7-silaeicos-1-yn-3-ol, 7,7-dibutyl-13,15,15,16,18,18,19,19,20,20,20-undecafluoro-3-methyl-13,16-bis(trifluoromethyl)-[3b]	$C_3F_7OCF(CF_3)CF_2OCF(CF_3)CH_2OC_3H_6Si(C_4H_9)_2[OCH_2CH_2C(CH_3)(OH)C{\equiv}CH]$	-	717825-76-8	P	(CAS 2019 (EP2719737))

3a

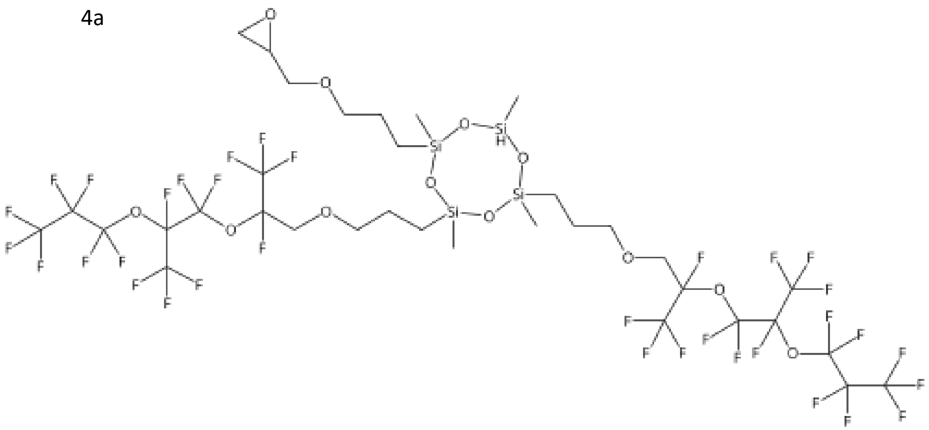


3b



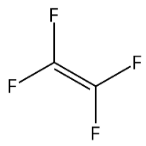
Cyclotetrasiloxane, 2,4,6,8-tetramethyl-2-[3-(2-oxiranyl methoxy)propyl]-4,6-bis[3-[2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propoxy] propoxy]propyl]-[4a]	$OSi(CH_3)(C_3H_6OCH_2C_2H_3O)OSiH(CH_3)[OSi(CH_3)(C_3H_6OCH_2CF(CF_3)OCF_2CF(CF_3)OC_3F_7)]_2$	-	1428232-89-6	P	(CAS 2019 (EP2719737))

4a

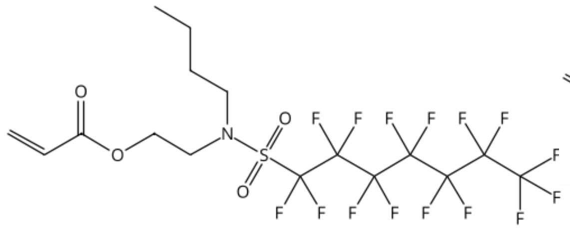


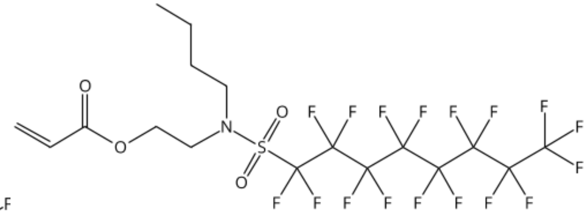
Polytetrafluoroethylene (PTFE)[5a]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)
2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]amino]ethyl ester, telomer with 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,7-pentadecafluoro heptyl)sulfonyl]amino]ethyl 2-propenoate, 2-methyloxirane polymer with oxirane di-2-pro penoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[5b]	$(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O)_m-(C_2H_4O)_n-(C_8H_{18}S)_w-$	polymer	68298-62-4	U	(Norden 2020)

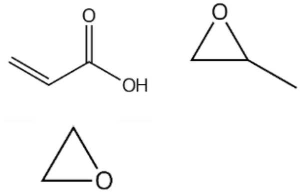
5a



5b







PFAS can also be used as antistatic agent in adhesives. Patent WO2003011958 discloses several fluorinated compounds as antistatic agents, two of them with the moiety $–CF_2CF_2$-. These are 1-octanaminium, *N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1) (CAS No. 334529-55-4) and 1-octanaminium, *N*-methyl-*N*,*N*-dioctyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1) (CAS No. 495417-51-1) (CAS 2019 (WO2003011958, 2003)).

Another patent describes the use of a PFAS (*N*-methyl perfluorobutane sulfonamidoethyl acrylate, CAS No. 67584-55-8) in a light absorbing adhesive (CAS 2019 (WO2005062081, 2005)). The adhesive is used in an optical element such as a rear projection screen that incorporates internally reflecting structures to disperse the light passing through the screen. *N*-Methyl perfluorobutane sulfonamidoethyl acrylate was choosen as an additive due to its low refrective index and good mechanical properties (CAS 2019 (WO2005062081, 2005)).

2.36 Soldering

2.36.1 PFAS as vapor phase fluids for vapor phase soldering

There are different reflow soldering methods, one of them is vapor phase soldering. Vapor phase soldering uses the condensation heat released during the phase change of a heat transfer medium from a gaseous to a liquid state to heat the assembly (Hwang 1989). Condensation takes place on the surface of the workpiece until the entire assembly has reached the temperature of the vapour. When the liquid boils, a saturated, chemically inert vapour zone is formed above it, the temperature of which is largely identical to the boiling point of the liquid, so that an optimum protective gas atmosphere is formed and oxidation is ruled out.

The first PFAS used as vapor phase fluids/heat transfer medium in the 1970s were perfluorocarbons, fluoropolyethers, perfluorotrialkyl amines (e.g. CAS No. 311-89-7, 338-84-1, 432-08-6) and perfluorophenanthrene (CAS No. 306-91-2) (Hwang 1989). During the 1980s, perfluoropolyether (commercially available under the brand name Galden) were introduced as alternatives to the first-mentioned PFAS (R. E. Banks, Smart, and Tatlow 1994). F2 Chemicals Ltd is currently offering perfluoroperhydrofluorene (CAS No. 307-08-4) and perfluorophenanthrene (CAS No. 306-91-2) for vapour phase soldering (F2_Chemicals 2019a).

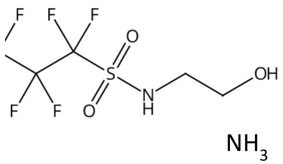
2.36.2 PFAS as fluxing agents in solder paste

Solder paste for soldering is obtained from powdery solder which is mixed with a fluxing agent (Almit 2020). Fluorinated surfactants have been used as low-foaming noncorrosive wetting agents in solders for electronic parts (Kissa 2001). PFAS that have been or are currently still used in solder paste are shown in Table 102. The SPIN database of the Nordic countries lists polyperfluoromethylisopropyl ether (CAS No. 69991-67-9) as a welding and soldering agent (Norden 2020). However, the exact function is not specified.

Table 102: PFAS historically or currently used in solder paste. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Ammonium perfluoroalkane sulfonamidoethanol[1a]	$NH_4^+ C_nF_{2n+1}SO_2NHCH_2CH_2O^-$	n = 4	484024-67-1	U	(Norwegian Environment Agency 2017)
N-Methyl perfluoroalkane sulfonamidoethyl acrylates (MeFASEACs)[1b]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH{=}CH_2$	n = 4	67584-55-8	U	(Norwegian Environment Agency 2017)
1-Propanesulfonic acid, 3-[hexyl[(perfluoroalkyl) sulfonyl]amino]-2-hydroxy-, ammonium salt (1:1)[1c]	$NH_4^+ C_nF_{2n+1}SO_2N(C_6H_{13})CH_2CH(OH)CH_2SO_3^-$	n = 4	606967-06-0	U	(Norwegian Environment Agency 2017)
2-Propenoic acid, 2-[methyl[(nonafluorobutyl) sulfonyl]amino]ethyl ester, telomer with methyl oxirane polymer with oxirane di-2-propenoate and methyloxirane polymer with oxirane mono-propenoate	-	n = 4	1017237-78-3	U	(Norwegian Environment Agency 2017)

1a



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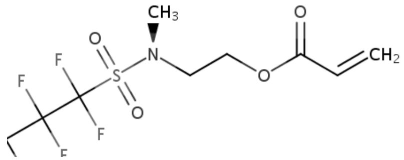

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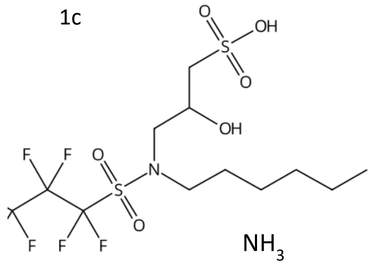


When using leaded soldering tin, it is necessary to use a soldering flux to prepare the surface for the plumbing (Poulsen, Jensen, and Wallström 2005). Data from the Danish Product Register from around 2005 showed that ammonium perfluorooctane sulfonate (CAS No. 29081-56-9) and 8:2 fluorotelomer alcohol (CAS No. 678-39-7) were used as fluxing agents for plumbing with leaded soldering tin (Poulsen, Jensen, and Wallström 2005). However, leaded solder is not allowed anymore in Europe, because the “European Directive 2002/95/EC of January 27 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment” stated that after July 1st 2006, lead is no longer permitted in electrical and electronic equipment (Poulsen, Jensen, and Wallström 2005). Lead-free soldering tin can use use water-based fluxing agents instead of the solvent based fluxing agents with PFAS (Poulsen, Jensen, and Wallström 2005).

2.37 Soil remediation

1-Propanaminium, 3-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,9-heptadecafluoro octyl)sulfonyl]amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1) (CAS No. 38006-74-5) has been patented for use in a vapor barrier material for soil remediation (CAS 2019 (US5782580, 1998)). The vapor barrier material is placed on top of the contaminated soil and thus reduces the amount of volatile hydrocarbon contaminants which can volatilize into the atmosphere during subsequent remediation activities.

Experiments with PCB contaminated soil showed that PCBs in soil can be effectively photodegraded in a dispersion containing ammonium perfluorooctanoate (CAS No. 3825-26-1) and TiO_2 (Huang and Hong 2000). The anionic fluorinated surfactant may form semimicelles and/or admicelles on the surface of positively charged TiO_2. The hydrophobic surface of TiO_2 provides then a nonpolar phase that acts as a partioning medium for hydrophobic PCBs (Huang and Hong 2000).

2.38 Sport articles

PFAS have been used in various sport articles like skiwax, (sailing) boat equipment, tennis rackets, bycicle lubricants, climping ropes, and fishing lines.

2.38.1 Ski and ski wax

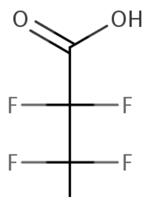
Patent information disclose that the first generation of PFAS in ski wax consisted of semifluorinated *n*-alkanes (KEMI Swedish Chemical Agency 2015b). Examplary PFAS are disclosed in patent EP444752 (CAS 2019 (EP444752, 1991)). Fluoropolymers and other non-polymeric PFAS appeared in later patents. Some of them are shown in Table 103. Skies made out of PTFE (CAS No. 9002-84-0) which require no wax are disclosed in patent US20100102533 (CAS 2019 (US20100102533, 2010)).

Table 103: PFAS currently or historically used or patented for ski wax or detected in ski wax. Patent number (date, legal status): EP444752 (1991, expired), RU2500705 (2013, invalid), JP2005132943 (2005, discontinued), EP2107063 (2009, withdrawn), US6465398 (2002, active), EP1626073 (2006, withdrawn). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
In general					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3 - 21	375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7, 141074-63-7, 67905-19-5, 57475-95-3, 16517-11-6, 133921-38-7, 68310-12-3, 2153498-16-7	D	(Blom and Hanssen 2015; Plassmann and Berger 2013)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 8	1763-23-1	D	(Blom and Hanssen 2015)
(n:2) Fluorotelomer alcohols (FTOHs)[1c]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 8	647-42-7, 678-39-7	D	(Blom and Hanssen 2015)

<u>First generation ski wax</u>					
Semifluorinated *n*-alkanes[1d]	$C_nF_{2n+1}(CH_2)_mH$	n = 6, m = 16	133310-71-1	P	(CAS 2019 (EP444752))
Semifluorinated *n*-alkanes[1d]	$C_nF_{2n+1}(CH_2)_mH$	n = 8, m = 16, 18, 20, 22, 24	117146-18-6, 133310-73-3, 137338-39-7, 137338-40-0, 137338-41-1	P	(CAS 2019 (EP444752))
Semifluorinated *n*-alkanes[1d]	$C_nF_{2n+1}(CH_2)_mH$	n = 16, m = 16	137338-42-2	P	(CAS 2019 (EP444752))

1a



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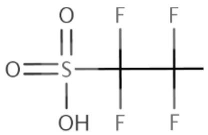

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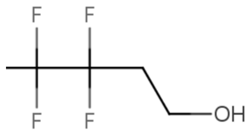

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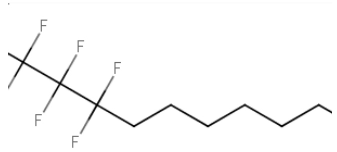
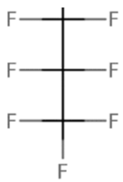


<u>Second generation ski wax</u>					
Linear perfluoroalkanes[2a]	C_nF_{2n+2}	n = 12, 18	307-59-5, 24768-65-8	P	(CAS 2019 (RU2500705))
1-Propanaminium, 3-[(perfluoro-1-oxononyl) amino]-*N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-, chloride (1:1)[2b]	Cl^- $C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	n = 6, 8	89375-44-0, 83579-63-9	P	(CAS 2019 (RU2500705))
1-Propanaminium, *N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-3-[[2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propoxy]-1-oxo propyl] amino]-, chloride (1:1)[2c]	Cl^- $C_3F_7OCF(CF_3)CF_2OCF(CF_3)C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	-	137506-17-3	P	(CAS 2019 (RU2500705))

2a



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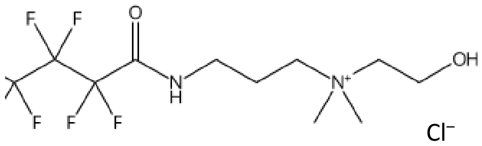

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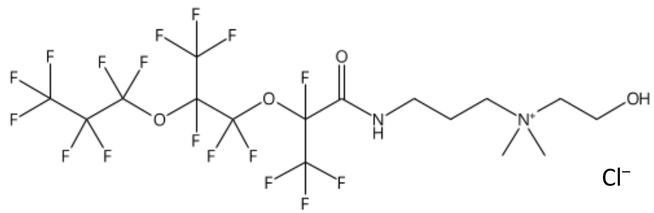
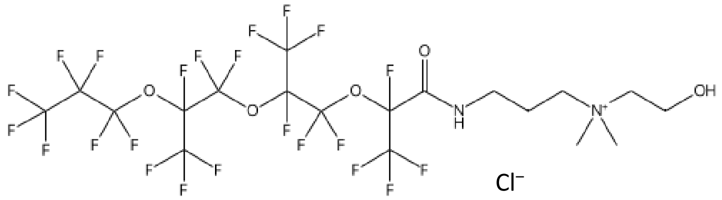


4,7,10-Trioxa-13-azahexadecan-16-aminium, 1,1,1,2,2,3,3,5,6,6,8,9,9,11-tetradecafluoro-*N*-(2-hydroxyethyl)-*N*,*N*-dimethyl-12-oxo-5,8,11-tris(trifluoromethyl)-, chloride[3a]	Cl^- $C_3F_7[OCF(CF_3)CF_2]_2OCF(CF_3)C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2OH$	-	141056-27-1	P	(CAS 2019 (RU2500705))

2-Propenoic acid, 2-[[(perfluoroalkyl)sulfonyl] propylamino]ethyl ester[3b]	$C_nF_{2n+1}SO_2N(C_3H_7)CH_2CH_2OC(=O)CHCH_2$	n = 8	2357-60-0	P	(CAS 2019 (JP2005132943))
Silane, tetrakis[2-[(perfluoroalkyl)thio]ethyl]-[3c]	$Si(CH_2CH_2SCH_2CH_2C_nF_{2n+1})_4$	n = 8	1189587-64-1	P	(CAS 2019 (EP2107063))

3a



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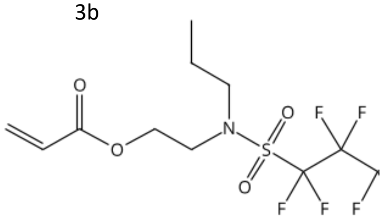

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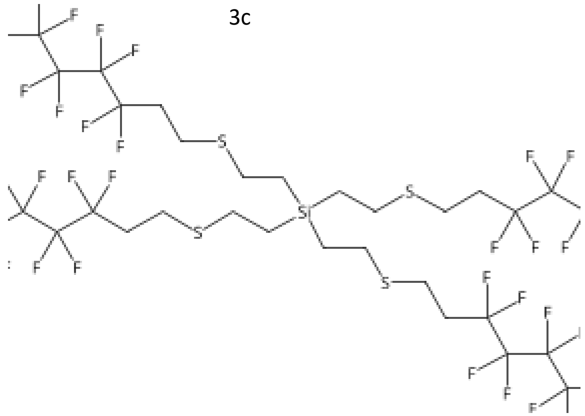
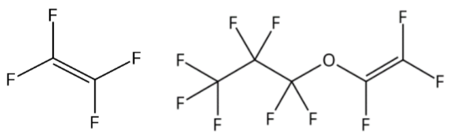


Perfluoralkoxy polymer (PFA)[4a]	$-(CF_2CF_2)_x-[CF_2CF(OC_3F_7)]_y-$	polymer	26655-00-5	P	(CAS 2019 (US6465398))
Polychlorotrifluoroethylene (PCTFE)[4b]	$-(CF_2CFCl)_x-$	polymer	9002-83-9	P	(CAS 2019 (EP1626073))
Ethene, chlorotrifluoro-, polymer with ethene, diblock[4c]	$-(CF_2CFCl)_x-(CH_2CH_2)_y-$	polymer	875919-63-4	P	(CAS 2019 (EP1626073))
Ethene, chlorotrifluoro-, polymer with tetrafluoroethene, diblock[4d]	$-(CF_2CFCl)_x-(CF_2CF_2)_y-$	polymer	875919-64-5	P	(CAS 2019 (EP1626073))
1-Propene, polymer with chlorotrifluoroethene, diblock[4e]	$-(CF_2CFCl)_x-(CH_3CHCH_2)_y-$	polymer	875906-95-9	P	(CAS 2019 (EP1626073))

4a



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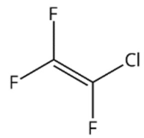

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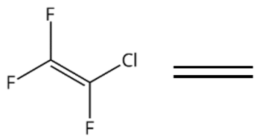

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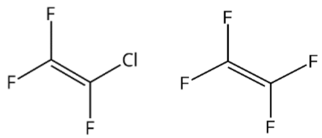
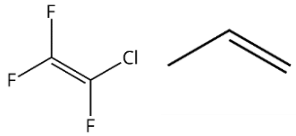


4e



2.38.2 (Sailing) boat equipment

PFAS such as PFHxA (CAS No. 307-24-4), PFOA (CAS No. 335-67-1) and 6:2, 8:2 and 10:2 fluorotelomer alcohols (CAS No. 647-42-7, 678-39-7, 865-86-1) have been detected in various textiles for maritime applications. These included bimini tops, console housings, seat covers, sail covers, weather protection for wooden boats and complete covers (Janousek, Lebertz, and Knepper 2019). Boat sails might also contain side-chain fluorinated polymers (POPRC 2019). The SPIN database of the Nordic countries discloses that siloxanes and silicones, di-Me, Me 3-(1,1,2,2-tetrafluoroethoxy)propyl, Me 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl (CAS No. 104780-70-3), polysiloxanes, di-Me, Me

3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl (CAS No. 115340-95-9), and PTFE were used for the building and repairing of ships and boats in the past (Norden 2020). PTFE has also been used for stores for boats and boating accessories (Norden 2020).

Additonally, PFAS are also used as anti-fouling protection of ships hulls. More information on PFAS in anti-fouling protection is provided in Section 2.8.1 (Paints).

2.38.3 Tennis rackets

PTFE (Teflon) (CAS No. 9002-84-0) has been used as coating for tennis rackets (Lerner 2015).

2.38.4 Bicycle lubricants

PTFE (Teflon) (CAS No. 9002-84-0) has also been used as bicycle lubricant (Lerner 2015). C_4, C_7, and C_8 PFCAs (CAS No. 375-22-4, 375-85-9, and 335-67-1, respectively) and 6:2 fluorotelomer alcohol (CAS No. 647-42-7) have been detected in bicycle lubricants (Blom and Hanssen 2015).

2.38.5 Climping ropes

PFAS have been and are currently used in climbing ropes to impart water- and stain resistance (Edelrid 2020).

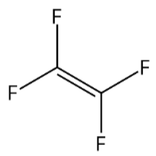
2.38.6 Fishing lines

PVDF monofilaments for fishing lines do not display water absorption, are not visible in water, and have high knot strength and high specific gravity. They are mostly used in Japan (Dohany 2000). A patent from Japan discloses fishing lines that are prepared by coating steel wires with fluoropolymers (CAS 2019 (JP01160443, 1989)). The patented fluoropolymers are listed in Table 104.

Table 104: PFAS patented as coatings for fishing lines. Patent number (date, legal status): JP01160443 (1989, expired). P under type stands for patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Polytetrafluoroethylene (PTFE)[1a]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	P	(CAS 2019 (JP01160443))
Poly(vinylidene fluoride) (PVDF)[1b]	$-(CF_2CH_2)_x-$	polymer	24937-79-9	P	(CAS 2019 (JP01160443))
Polychlorotrifluoroethylene (PCTFE)[1c]	$-(CF_2CFCl)_x-$	polymer	9002-83-9	P	(CAS 2019 (JP01160443))
Ethylene tetrafluoroethylene copolymer (ETFE)[1d]	$-(CH_2CH_2)_x-(CF_2CF_2)_y-$	polymer	25038-71-5	P	(CAS 2019 (JP01160443))
Fluorinated ethylene propylene (FEP)[1e]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-$	polymer	25067-11-2	P	(CAS 2019 (JP01160443))
Chlorotrifluoroethylene-ethylene copolymer (ECTFE)[1f]	$-(CF_2CFCl)_x-(CH_2CH_2)_y-$	polymer	25101-45-5	P	(CAS 2019 (JP01160443))

1a



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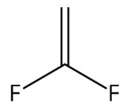

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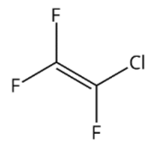

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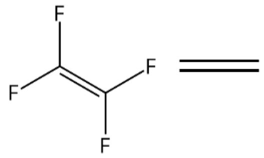

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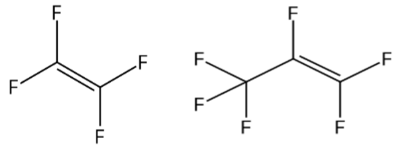

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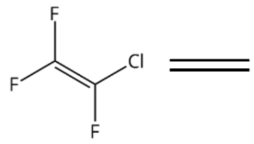


2.38.7 *Golf gloves*

Perfluorobutanesulfonic acid (CAS No. 375-73-5) has been patetend for the use as antifouling coating material in golf glove comprises a natural sheep leather (CAS 2019 (KR2002532, 2019)).

2.39 Stone, concrete and tile

PFAS can be used for surface treatments of natural stone and other porous hard surfaces such as concrete, grout, unglazed tile, granite, clay, slate, limestone, sandstone, marble and terracotta (Norwegian Environment Agency 2017). The treatments are mostly done to impart oil and water repellency to the surfaces. The repellent agents can be used either as penetrating sealers or as additives in various coating and sealer formulations (Norwegian Environment Agency 2017). Table 105 lists some PFAS that have been or are still used for the surface treatment of porous surfaces.

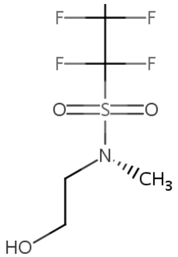
It has also been mentioned that fluoro-functionalized poly(lactic acid) polymers are able to delay the oxidation and ageing of stone surfaces (Giuntoli et al. 2012). Fluoroalky-lsilanes are used to to achieve low-energy surfaces with easy-to-clean, anti-graffiti and anti-fouling properties (Weißenbach, Standke, and Jenkner 2003). An example for such a fluorinated acrylic copolymer with silane groups is Faceal oleo HD from Ecograffiti. Coatings out of this material e.g. on concrete can repell water and stain and at the same time are permeable for water vapor (Eco-Graffiti 2012).

Table 105: PFAS historically or currently used or patented for surface treatments of porous hard surfaces. Patent number (date, legal status): US20080113200 (2008, active). The types stand for U – use and P – patent. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Natural stone					
N-Methyl perfluoroalkane sulfonamidoethanols (MeFASEs) [1a]	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 4	34454- 97-2	U	(Norwegian Environment Agency 2017)
Alkanamide, perfluoro-*N*-[3-(trimethoxysilyl)propyl]- [1b]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2Si(OCH_3)_3$	n = 5	154380-34-4	U	(Z. Wang et al. 2013)
Perfluoropolyether	$-CF_2O(CF_2CF_2O)_m(CF_2O)_nCF_2–$	polymer	-	U	(Buck et al. 2011)

PFBS-related polymers, such as fluoroacrylate modified urethane and fluorochemical acrylate polymer	-	polymer		U	(Norwegian Environment Agency 2017)
Ceramics, tile, cement or stone					
1-Alkanol, polyfluoro-, 1-(dihydrogen phosphate), ammonium salt (1:2)[1c]	2 NH_4^+ $C_nF_{2n+1}CH_2CF_2CH_2CH_2OPO_3^{2-}$	n = 4, 6	1025044-20-5, 1025044-22-7	P	(CAS 2019 (US20080113200))
1-Alkanol, polyfluoro-, 1-(dihydrogen phosphate), compd. with 2,2′-iminobis[ethanol] (1:2)	$NH_2^+(CH_2CH_2OH)$ $C_nF_{2n+1}CH_2CF_2CH_2$ $CH_2OPO_3^{2-}$	n = 4, 6	1025044-02-3, 1025044-12-5	P	(CAS 2019 (US20080113200))
1-Alkanol, polyfluoro-, 1-(dihydrogen phosphate), ammonium salt (1:2)[1d]	2 NH_4^+ $C_nF_{2n+1}(CH_2CF_2)_2CH_2CH_2O$ PO_3^{2-}	n = 4, 6	1025044-24-9, 1025044-26-1	P	(CAS 2019 (US20080113200))
1-Alkanol, polyfluoro-, 1-(dihydrogen phosphate), compd. with 2,2′-iminobis[ethanol] (1:2)	$NH_2^+(CH_2CH_2OH)$ $C_nF_{2n+1}(CH_2CF_2)_2$ $CH_2CH_2OPO_3^{2-}$	n = 4, 6	1025044-15-8, 1025044-18-1	P	(CAS 2019 (US20080113200))

1a



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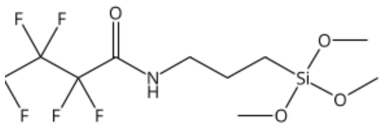
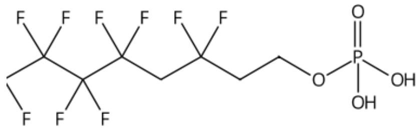


1c



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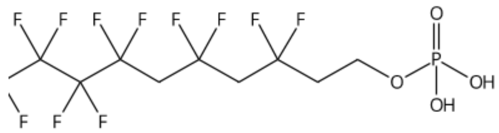
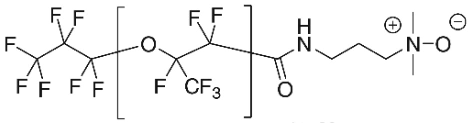


Ceramic tile treatment					
-[2a]	$C_3F_7(OCF(CF_3)CF_2)_xC(O)NHCH_2CH_2C$ $H_2N^+(CH_3)_2O^-$	x = 4 - 30	-	U	(Buck, Murphy, and Pabon 2012)
Concrete					
C_8-C_{20}-γ-ω-perfluorotelomer thiols with acrylamide	-	-	70969-47-0	U	(KEMI Swedish Chemical Agency 2015b)

2a



2.40 Textile and upholstery

2.40.1 Textile and upholstery itself

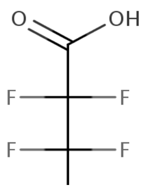
Fluorinated surfactants impart water and oil repellency, stain resistance and soil release to textiles and upholstery (Poulsen, Jensen, and Wallström 2005). PFAS and expecially PFCAs and PFSAs have been detected in awnings, seat covers (public tansport and furnitures), truck trailer covers, stain resistant upholstery material, curtains, pillow fills, textile foams, textile bed covers, teddy bear fillings, teddy bear covers, table cloths, and blankets (Janousek, Lebertz, and Knepper 2019; Bečanová et al. 2016). Other textiles in which PFAS are or were used are antiballistic fabrics, backpacks/bags, car seats, ropes, sleeping bags, tents and umbrellas (Norwegian Environment Agency 2017; POPRC 2019; Greenpeace 2016). The most frequently used PFAS in textiles are side-chain fluorinated polymers, where long-chain fluorotelomer- or POSF-based derivatives on side-chains have (largely) been replaced with shorter-chain homologues (Z. Wang et al. 2013). Table 106 lists some PFAS that have been used or are still used or have been detected or patented for use in textiles and upholstery.

Table 106: PFAS historically or currently used, detected in, or patented for textiles and upholstery. Patent number (date, legal status): JP04164990 (1992, expired), WO9748780 (1997, expired), DE2120868 (1971, expired), KR2016012293 (2016, active), WO2002095121 (2002, active), DE2208020 (1977, expired). The types stand for U – use, U* – current use, P – patent, and D – detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
PFAAs					
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 2 -14	422-64-0, 375-22-4, 2706-90-3, 307-24-4, 375-85-9, 335-67-1, 375-95-1, 335-76-2, 2058-94-8, 307-55-1, 72629-94-8, 376-06-7, 141074-63-7	D	(Berger and Herzke 2006; Herzke, Posner, and Olsson 2009; Guo, Liu, and Krebs 2009; Janousek, Lebertz, and Knepper 2019)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 4, 6 - 8, 10	375-73-5, 355-46-4, 375-92-8, 1763-23-1, 335-77-3	D	(Bečanová et al. 2016)
PASF-based substances					
N-Methyl perfluoroalkane sulfonamides[1c] *(building block)*	$C_nF_{2n+1}SO_2NHCH_3$	n = 6	68259-15-4	U	(POPRC 2018b)
N-Alkyl perfluoroalkane sulfonamides[(1c)]	$C_nF_{2n+1}SO_2NH(R)$ $R = C_mH_{2m+1}$ (m = 1, 2, 4)	n = 4 - 8	-	U	(KEMI Swedish Chemical Agency 2015b)
N-Methyl perfluoroalkane sulfonamidoethanols[1d] *(building block)*	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OH$	n = 6	68555-75-9	U	(POPRC 2018b; Hodgkins 2018)
N-Methyl perfluoroalkane sulfonamidoethyl acrylates[1e] *(building block)*	$C_nF_{2n+1}SO_2N(CH_3)CH_2CH_2OC(O)CH{=}CH_2$	n = 6	67584-57-0	U	(POPRC 2018b)

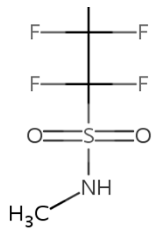
N-Alkyl perfluoroalkane sulfonamidoethyl acrylates[(1e)]	$C_nF_{2n+1}SO_2N(R)CH_2CH_2OC(O)CH=CH_2$ R = C_mH_{2m+1} (m = 1, 2)	-	-	U	(R. E. Banks, Smart, and Tatlow 1994)
1-Propanaminium, 3-[[(perfluoroalkyl)sulfonyl] amino]-*N*,*N*,*N*-trimethyl-, chloride (1:1)[1f]	$Cl^- C_nF_{2n+1}SO_2NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 8	38006-74-5	P	(CAS 2019 (JP04164990))

1a

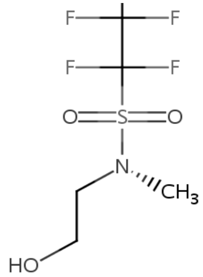


1b

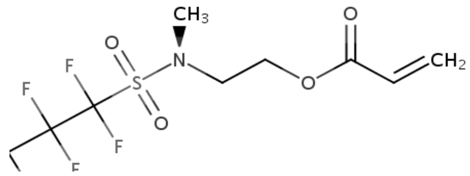
1c



1d



1e



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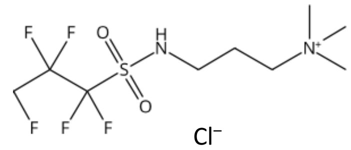
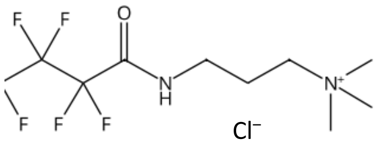
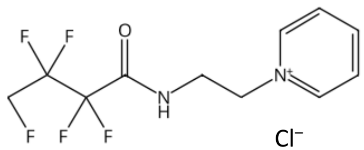


<u>PACF-based substances</u>					
1-Propanaminium, *N*,*N*,*N*-trimethyl-3-[(perfluoro-1-oxoalkyl)amino]-, chloride (1:1)[2a]	$Cl^- C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_3$	n = 7	53517-98-9	P	(CAS 2019 (JP04164990))
Pyridinium, 1-[2-[(perfluoro-1-oxoalkyl)amino]ethyl]-, chloride (1:1)[2b]	$Cl^- C_nF_{2n+1}C(O)NHCH_2CH_2N^+C_5H_5$	n = 7	308-01-0	P	(CAS 2019 (JP04164990))
1-Propanaminium, *N*-(2-carboxyethyl)-3-[(perfluoro-1-oxoalkyl)amino]-*N*,*N*-dimethyl-, inner salt[2c]	$C_nF_{2n+1}C(O)NHCH_2CH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 8	119131-05-4	P	(CAS 2019 (WO9748780))

2a



2b



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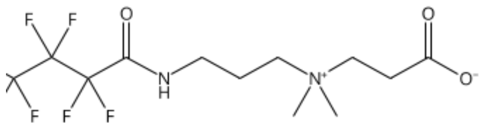
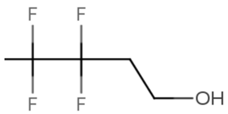


<u>Fluorotelomer-based substances</u>					
(n:2) Fluorotelomer alcohols (FTOHs)[3a]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6, 10	647-42-7, 865-86-1	D	(Herzke, Posner, and Olsson 2009; Norden 2013)
(n:2) Fluorotelomer acrylates (FTACs)[3b]	$C_nF_{2n+1}CH_2CH_2OC(O)CH=CH_2$	n = 8, 10, 12, 14	27905-45-9, 17741-60-5, 34395-24-9, 34362-49-7	P, U	(CAS 2019 (WO9748780); R. E. Banks, Smart, and Tatlow 1994)
(n:2) Fluorotelomer methacrylates (FTMACs)[3c]	$C_nF_{2n+1}CH_2CH_2OC(O)C(CH_3)=CH_2$	-	-	U	(R. E. Banks, Smart, and Tatlow 1994)

Oxirane, 2-[[(perfluoroalkyl)oxy]methyl]-[3d]	$C_nF_{2n+1}CH_2CH_2OCH_2C_2OH_3$	n = 4, 6	384828-82-4, 122193-68-4	P	(CAS 2019 (KR2016012293))

3a



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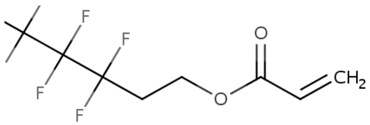

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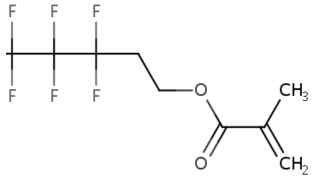

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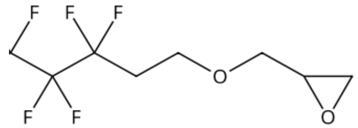
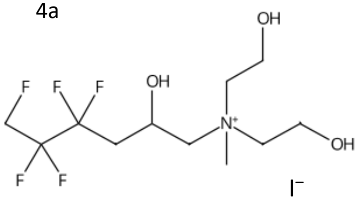
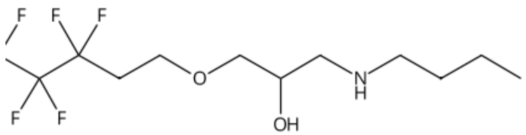


1-Aminium, perfluoroalkyl-2-hydroxy-*N*,*N*-bis(2-hydroxyethyl)-*N*-methyl-, iodide (1:1)[4a]	$I^- C_nF_{2n+1}CH_2CH(OH)CH_2N^+(CH_3)(CH_2CH_2OH)_2$	n = 8	93776-18-2	P	(CAS 2019 (WO9748780))
2-Propanol, 1-(butylamino)-3-[(perfluoroalkyl)oxy]-[4b]	$C_nF_{2n+1}CH_2CH_2OCH_2CH(OH)CH_2NHCH_2CH_2CH_2CH_3$	n = 4	1874268-14-0	P	(CAS 2019 (KR2016012293))
2-Propanol, 1-(octylamino)-3-[(perfluoroalkyl)oxy]-[4c]	$C_nF_{2n+1}CH_2CH_2OCH_2CH(OH)CH_2NHC_8H_{17}$	n = 6	1874268-12-8	P	(CAS 2019 (KR2016012293))

4a



4b



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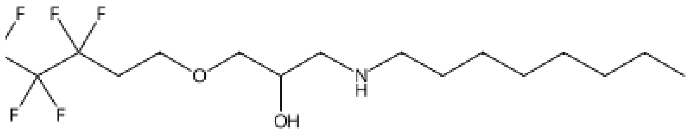
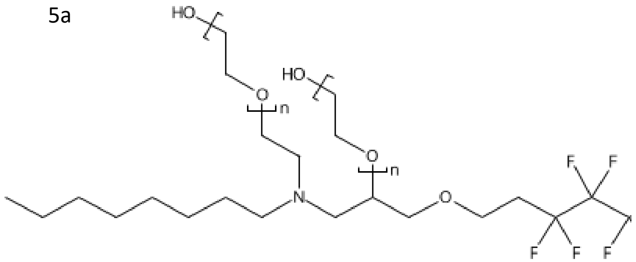
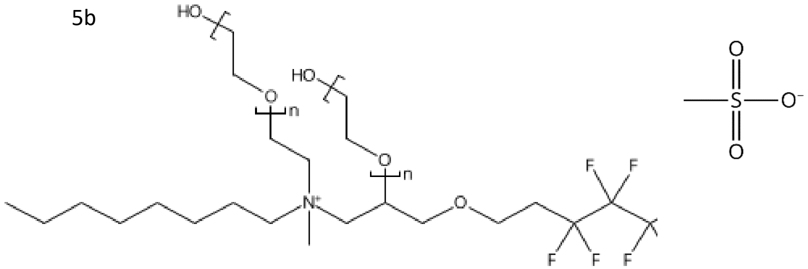


Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with 1-[(2-hydroxyethyl)octylamino]-3-[(perfluoroalkyl)oxy]-2-propanol (2:1)[5a]	$C_nF_{2n+1}CH_2CH_2OCH_2CH[(OCH_2CH_2)_mOH][CH_2N(C_8H_{17})(CH_2CH_2(OCH_2CH_2)_mOH)$	n = 6	1874268-13-9	P	(CAS 2019 (KR2016012293))
Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with *N*-(2-hydroxyethyl)-*N*-[2-hydroxy-3-[(perfluoroalkyl)oxy]pro pyl]-*N*-methyloctanaminium, methanesulfonate (2:1:1)[5b]	$CH_3SO_3^-$ $C_nF_{2n+1}CH_2CH_2OCH_2CH[(OCH_2CH_2)_mOH][CH_2N^+(CH_3)(C_8H_{17})(CH_2CH_2(OCH_2CH_2)_mOH)]$	n = 6	1874268-16-2	P	(CAS 2019 (KR2016012293))

5a

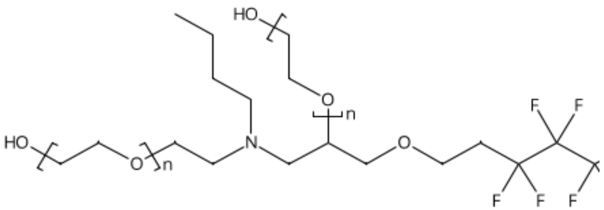


5b

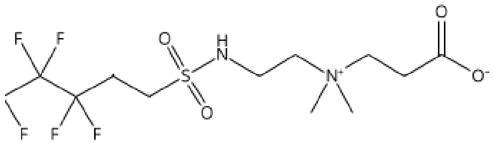


Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with 1-[butyl(2-hydroxyethyl)amino]-3-[(perfluoro alkyl)oxy]-2-propanol (2:1)[6a]	$C_nF_{2n+1}CH_2CH_2OCH_2CH[(OCH_2CH_2)_mOH][CH_2N(C_4H_9)(CH_2CH_2(OCH_2CH_2)_mOH]$	n = 4	1905409-72-4	P	(CAS 2019 (KR2016012293))
Ethanaminium, *N*-(2-carboxyethyl)-2-[[(perfluoroalkyl) sulfonyl]amino]-*N*,*N*-dimethyl-, inner salt[4a]	$C_nF_{2n+1}CH_2CH_2SO_2NHCH_2CH_2N^+(CH_3)_2CH_2CH_2COO^-$	n = 6, 8, 10	34695-30-2, 34695-29-9, 34695-31-3	P	(CAS 2019 (DE2120868))
1-Alkanol, perfluoro-, hydrogen phosphate, ammonium salt[6c]	$NH_4^+\ PO_2^-\ (OCH_2C_nF_{2n}H)_2$	n = 8, 10	7757-53-1, 1765-83-9	P	(CAS 2019 (US3096207))

6a



6b



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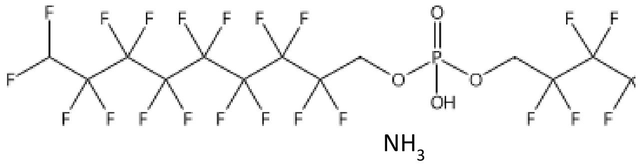
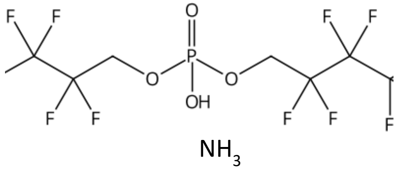


1-Alkanol, perfluoro-, phosphate (2:1), ammonium salt[7a]	$NH_4^+\ PO_2^-\ (OCH_2C_nF_{2n+1})_2$	n = 7	1555-33-5	P	(CAS 2019 (US3096207))
1-Alkanol, perfluoro, phosphate, ammonium salt (2:1)[7b]	$1/2\ NH_4^+\ HC_nF_{2n}CH_2OPO_3^{2-}$	n = 10	100738-12-3	P	(CAS 2019 (US3096207))
Perfluoroalkyltrimethoxysilane[7c]	$C_nF_{2n+1}CH_2CH_2Si(OCH_3)_3$	n = 6, 8	85857-16-5, 83048-65-1	P	(CAS 2019 (WO2012041661))
Disiloxane, 1,1,3,3-tetramethyl-1,3-bis(polyfluoroalkyl)- [7d]	$O[Si(CH_3)_2CH_2CH_2C_nF_{2n+1}]_2$	n = 6	71363-70-7	P	(CAS 2019 (WO2012041661))

7a



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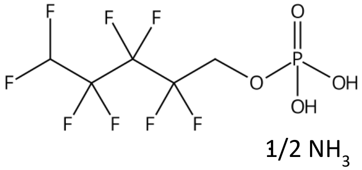

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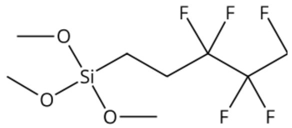

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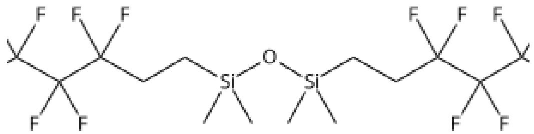
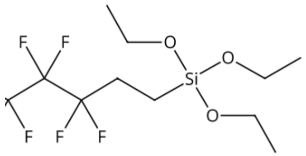


Perfluoroalkyltriethoxysilane[8a]	$C_nF_{2n+1}CH_2CH_2Si(OC_2H_5)_3$	n = 6, 8	51851-37-7, 101947-16-4	P	(CAS 2019 (WO2012041661))
Trisiloxane, 1,1,3,5,5-pentamethyl-1,5-bis(polyfluoroalkyl)-[8b]	$SiH(CH_3)[OSi(CH_3)_2CH_2CH_2C_nF_{2n+1}]_2$	n = 6	521069-00-1	P	(CAS 2019 (WO2012041661))

<u>Others</u>

Pyridinium, 1-[3,3,4,4,5,5-hexafluoro-5-[1,2,2,2-tetra fluoro-1-(trifluoromethyl)ethoxy]pentyl]-, chloride (1:1)[8c]	$Cl^- CF_3CF(CF_3)OCF_2CF_2CF_2CH_2CH_2N^+C_5H_5$	-	144930-59-6	P	(CAS 2019 (JP04164990))

8a



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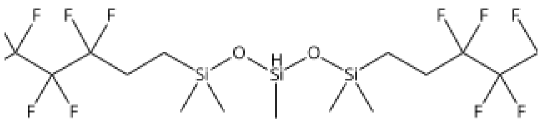

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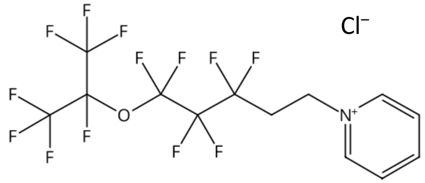
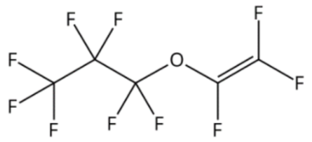
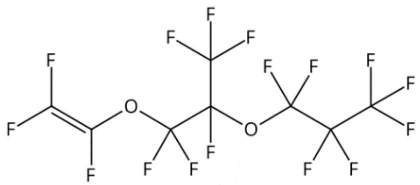
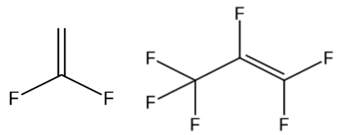
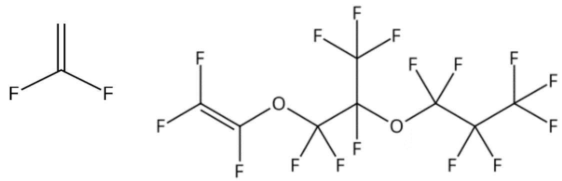
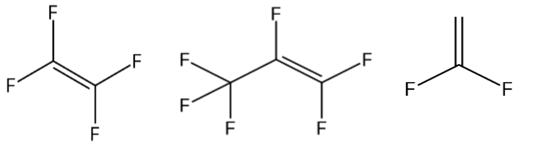
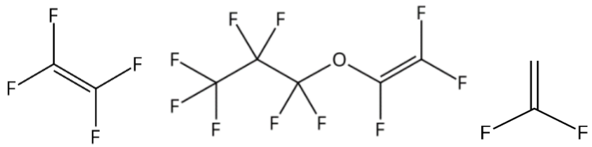
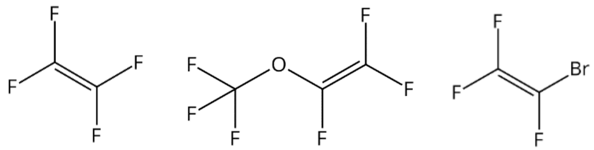


<u>Polymers</u>

Perfluoro(propyl vinyl ether)[9a]	$-[CF_2CF(OC_3F_7)]_x-$	polymer	70087-25-1	P	(CAS 2019 (WO2002095121))
Propane, 1-[1-[difluoro[(1,2,2-trifluoroethenyl) oxy]methyl]-1,2,2,2-tetrafluoroethoxy]-1,1,2,2,3,3,3-heptafluoro-, homopolymer[9b]	$-[CF_2CF(OCF_2CF(CF_3)OC_3F_7)]_x-$	polymer	98973-10-5	P	(CAS 2019 (WO2002095121))
Vinylidenfluorid-Hexafluorpropylen copolymer[9c]	$-(CH_2CF_2)_x-[CF_2CF(CF_3)]_y-$	polymer	9011-17-0	P	(CAS 2019 (WO2002095121))
Propane, 1-[1-[difluoro[(1,2,2-trifluoroethenyl)oxy] methyl]-1,2,2,2-tetrafluoroethoxy]-1,1,2,2,3,3,3-heptafluoro-, polymer with 1,1-difluoroethene[9d]	$-(CH_2CF_2)_x-(CF_2CFOCF_2CF(CF_3)OC_3F_7)_y-$	polymer	80975-16-2	P	(CAS 2019 (WO2002095121))

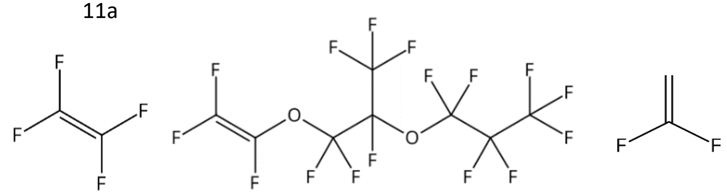
9a  9b  9c  9d 

Hexafluoropropylene-tetrafluoroethylene-vinylidene fluoride copolymer[10a]	$-(CF_2CF_2)_x-[CF_2CF(CF_3)]_y-(CF_2CH_2)_m-$	polymer	25190-89-0	P	(CAS 2019 (WO2002095121))
Propane, 1,1,1,2,2,3,3-heptafluoro-3-[(1,2,2-trifluoroethenyl)oxy]-, polymer with 1,1-difluoro ethene and 1,1,2,2-tetrafluoroethene[10b]	$-(C_5F_{10}O)_x-(C_2H_2F_2)_y-(C_2F_4)_m-$	polymer	74499-68-6	P	(CAS 2019 (WO2002095121))
Ethene, 1-bromo-2,2,2-trifluoro-, polymer with 1,1,2,2-tetrafluoroethene and 1,1,1-trifluoro-2-(trifluoromethoxy)ethene[10c]	$-(C_3F_6O)_x-(C_2BrF_3)_y-(C_2F_4)_m-$	polymer	60917-27-3	P	(CAS 2019 (WO2002095121))

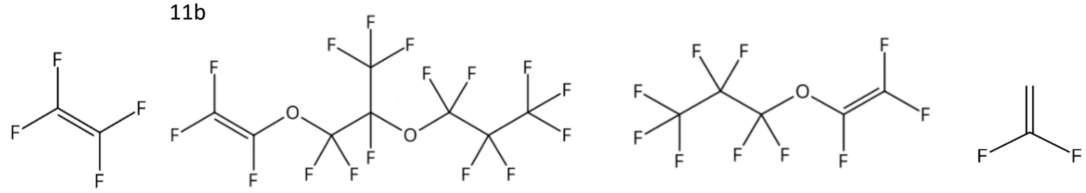
10a  10  10c 

Ethene, tetrafluoro-, polymer with 1,1-difluoroethene and 1-[1-[difluoro[(trifluoroethenyl)oxy]methyl]-1,2,2,2-tetrafluoroethoxy]-1,1,2,2,3,3,3-heptafluoro propane[11a]	$-(C_8F_{16}O_2)_x-(C_2H_2F_2)_y-(C_2F_4)_m-$	polymer	349118-39-4	P	(CAS 2019 (WO2002095121))
Propane, 1-[1-[difluoro[(trifluoroethenyl)oxy]methyl]-1,2,2,2-tetrafluoroethoxy]-1,1,2,2,3,3,3-heptafluoro-, polymer with 1,1-difluoroethene, 1,1,1,2,2,3,3-heptafluoro-3-[(trifluoroethenyl)oxy]propane and tetrafluoroethene[11b]	$-(C_8F_{16}O_2)_x-(C_5F_{10}O)_y-(C_2H_2F_2)_m-(C_2F_4)_n-$	polymer	477198-48-4	P	(CAS 2019 (WO2002095121))

11a

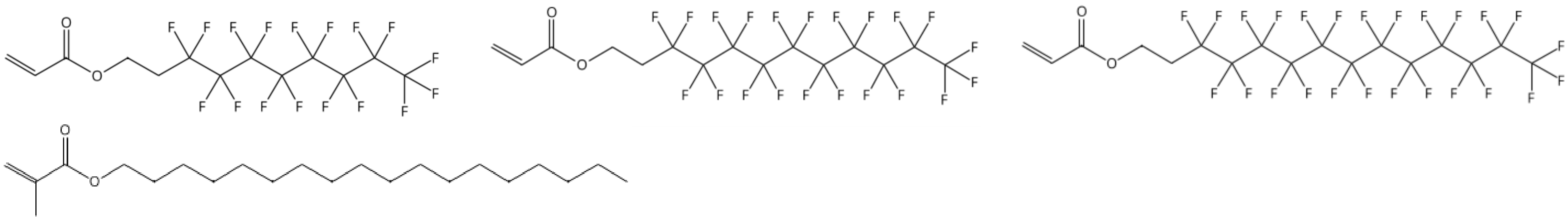


11b



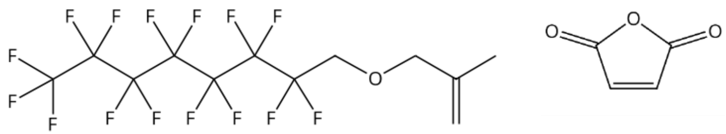
2-Propenoic acid, 2-methyl-, octadecyl ester, polymer with 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10, 11,11,12,12,12-heneicosafluoro dodecyl 2-propenoate, 3,3,4,4,5,5,6, 6,7,7,8,8,9,9,10,10,10-heptadeca fluorodecyl 2-propenoate and 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10, 10,11, 11, 12,12,13,13,14,14,14-pentacosafluorotetradecyl 2-propenoate[12a]	$-(C_{22}H_{42}O_2)_x-(C_{17}H_7F_{25}O_2)_y-(C_{15}H_7F_{21}O_2)_m-(C_{13}H_7F_{17}O_2)_n-$	polymer	142636-88-2	U	(USEPA 2016)

12a

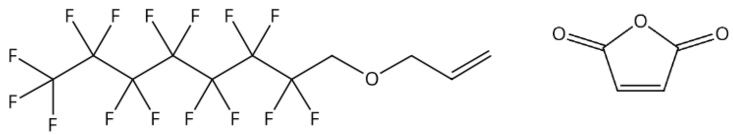


2,5-Furandione, polymer with 1,1,1,2,2,3,3,4,4,5,5,6, 6,7,7-pentadecafluoro-8-[(2-methyl-2-propenyl)oxy] octane[13a]	$-(C_{12}H_9F_{15}O)_x-(C_4H_2O_3)_y-$	polymer	38467-14-0	P	(CAS 2019 (DE2208020))
2,5-Furandione, polymer with 1,1,1,2,2,3,3,4,4,5,5,6, 6,7,7-pentadecafluoro-8-(2-propenyloxy)octane[13b]	$-(C_{11}H_7F_{15}O)_x-(C_4H_2O_3)_y-$	polymer	38467-12-8	P	(CAS 2019 (DE2208020))

13a

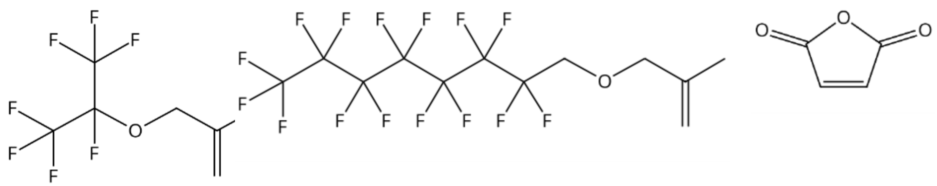


13a

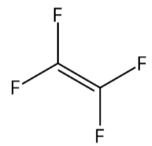


2,5-Furandione, polymer with 2-methyl-3-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethoxy]-1-propene and 1,1,1,2,2,3,3,4,4,5,5,6,6,7,7-pentadecafluoro-8-[(2-methyl-2-propenyl)oxy]octane[14a]	$-(C_{12}H_9F_{15}O)_x-(C_7H_7F_7O)_y-(C_4H_2O_3)_m-$	polymer	38467-13-9	P	(CAS 2019 (DE2208020))
Polytetrafluoroethylene (PTFE)[14b]	$-(CF_2CF_2)_x-$	polymer	9002-84-0	U*	(Norden 2020)

14a

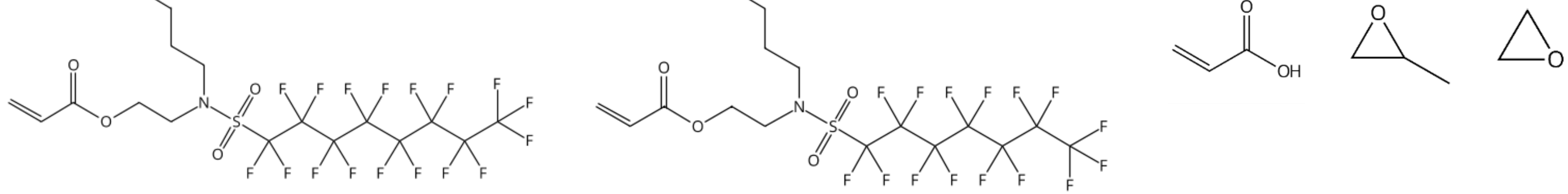


14b



2-Propenoic acid, 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]amino]ethyl ester, telomer with 2-[butyl[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,7-pentadecafluoro heptyl)sulfonyl]amino]ethyl 2-propenoate, 2-methyloxirane polymer with oxirane di-2-pro penoate, 2-methyl oxirane polymer with oxirane mono-2-propenoate and 1-octanethiol[15a]	$-(C_{17}H_{16}F_{17}NO_4S)_x-(C_{16}H_{16}F_{15}NO_4S)_y-(C_3H_6O)_m-(C_2H_4O)_n-(C_8H_{18}S)_w-$	polymer	68298-62-4	U	(Norden 2020)

15a



2-Propenoic acid, $C_{16\text{-}18}$-alkyl esters, polymers with 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadeca fluorodecyl acrylate	-	n = 8	160336-09-4	U*	(Norden 2020)
Siloxanes and Silicones, (3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether	-	n = 8	143372-54-7	U	(Norden 2020)
Acrylate, methacrylate, adipate and urethane polymers of *N*-Ethyl perfluorooctane sulfonamidoethanol	-	n = 8	-	U	(UNEP 2017)
Side-chain fluorinated polymers based on derivatives of PBSF	-	n = 4	949581-65-1, 940891-99-6, 923298-12-8	U	(KEMI Swedish Chemical Agency 2015b)

Side-chain fluorinated polymers based on 3:1 and 5:1 fluorotelomer alcohols	-	n = 3,5	-	U	(KEMI Swedish Chemical Agency 2015b)
Per- and polyfluorinated polyether silanes	-	-	-	U	(Buck, Murphy, and Pabon 2012)

Additionally, polyester yarn containing C_6 – C_8 perfluoroalkanecarboxylic acid, poly(vinyl alcohol), and an acrylic polycarboxylate make yarns easy to weave. When the fluorinated surfactant was replaced by potassium lauryl phospate, the weavability was poor (Kissa 2001).

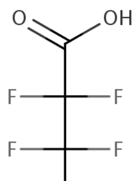
2.40.2 Textile impregnation spray

The substances shown in Table 107 have been detected in impregnation spray for special textile coating (Nørgaard et al. 2014).

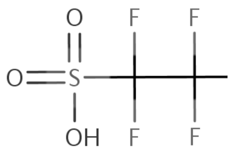
Table 107: PFAS detected in impregnation spray for special textile coatings. D under type stands for detected. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoroalkyl carboxylic acids (PFCAs)[1a]	$C_nF_{2n+1}COOH$	n = 3, 5, 7, 9	375-22-4, 307-24-4, 335-67-1, 335-76-2	D	(Blom and Hanssen 2015; Borg and Ivarsson 2017)
Perfluoroalkane sulfonic acids (PFSAs)[1b]	$C_nF_{2n+1}SO_3H$	n = 10	335-77-3	D	(Vejrup, Kark and Lindblom 2002)
(n:2) Fluorotelomer alcohols (FTOHs)[1c]	$C_nF_{2n+1}CH_2CH_2OH$	n = 6	647-42-7	D	(Borg and Ivarsson 2017)
Silanediol, 1-methoxy-1-(polyfluoroalkyl)-[1d]	$C_nF_{2n+1}CH_2CH_2Si(OH)_2OCH_3$	n = 6	1531633-11-0	D	(Nørgaard et al. 2014)
1,1-Disiloxanediol, 3,3-dimethoxy-1,3-bis(polyfluoroalkyl)-[1e]	$C_nF_{2n+1}CH_2CH_2Si(OH)_2OSi(OCH_3)_2CH_2CH_2C_nF_{2n+1}$	n = 6	1531633-12-1	D	(Nørgaard et al. 2014)

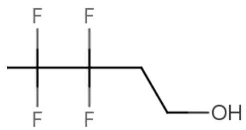
1a



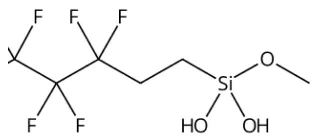
1b



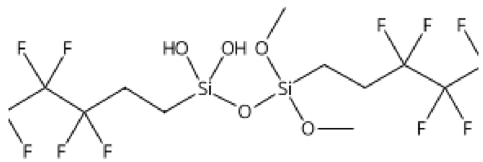
1c



1d

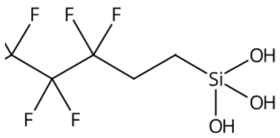


1e



Silanetriol, (polyfluoroalkyl)-[2a]	$C_nF_{2n+1}CH_2CH_2Si(OH)_3$	n = 6	185911-29-9	D	(Nørgaard et al. 2014)

2a



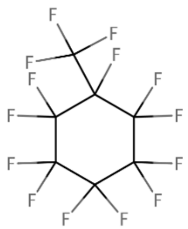
2.41 Tracing and tagging

Perfluorocarbons are used in tracing and tragging applications because they are non-radioactive, are chemically and thermally stable, do not occur naturally and have very low atmospheric background concentrations (F2_Chemicals 2019a). Applications areas include tracking of air-borne pollutants, testing ventilation systems, mapping oil fields, detecting leaks in cables, pipelines, landfill waste and underground storage tanks, tracking of marked items (F2_Chemicals 2019a). Perfluorocarbons that can be used in such tracing and tagging applications are listed in Table 108, the specific applications are described in the subsequent sections.

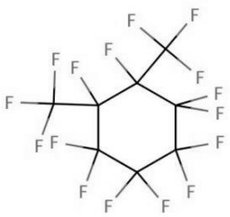
Table 108: PFAS that can be used in tracing and tagging applications. U under type stands for use. Additional explanations to the table are provided on Page 2 and 3 of this document.

Chemical name	Molecular formula	Specification of chemical(s)	CAS No.	Type	Reference
Perfluoromethylcycloalkane[1a]	$c\text{-}C_nF_{2n}$	n = 6 (Flutec TG PMCP), 7 (Flutec PP2)	1805-22-7, 355-02-2	U	(F2_Chemicals 2019a)
Perfluoro-1,2-dimethylcycloalkane[1b]	$c\text{-}C_nF_{2n}$	n = 8 (Flutec TG o-PDMCH)	306-98-9	U	(F2_Chemicals 2019a)
Perfluoro-1,3-dimethylcycloalkane[1c]	$c\text{-}C_nF_{2n}$	n = 8 (Flutec TG m-PDMCH)	355-27-3	U	(F2_Chemicals 2019a)
Perfluoro-1,4-dimethylcycloalkane[1d]	$c\text{-}C_nF_{2n}$	n = 8 (Flutec TG p-PDMCH)	374-77-6	U	(F2_Chemicals 2019a)
Perfluoro-1,3,5-trimethylcycloalkane[1e]	$c\text{-}C_nF_{2n}$	n = 9 (Flutec TG-PTMCH)	374-76-5	U	(F2_Chemicals 2019a)
Perfluoroethylcycloalkane[1f]	$c\text{-}C_nF_{2n}$	n = 8 (Flutec TG-PECH)	335-21-7	U	(F2_Chemicals 2019a)

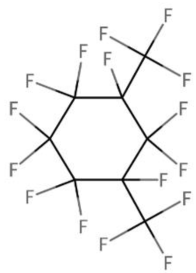
1a



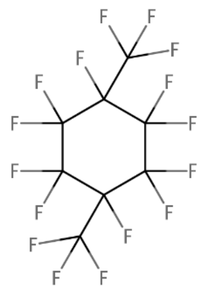
1b



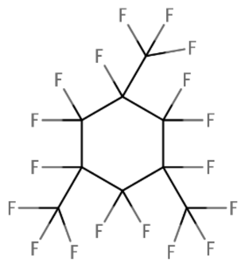
1c



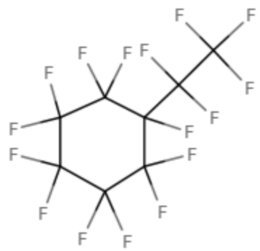
1d



1e

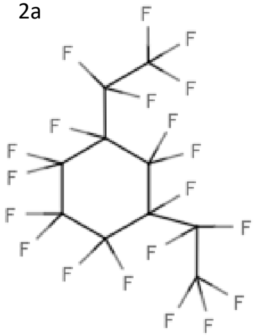


1f

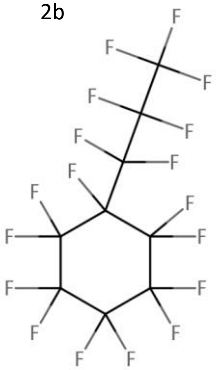


Perfluoro-1,3-diethylcycloalkane[2a]	$c\text{-}C_nF_{2n}$	n = 10 (Flutec TG m-PDECH)	335-23-9	U	(F2_Chemicals 2019a)
Perfluoroproylcycloalkane[2b]	$c\text{-}C_nF_{2n}$	n = 9 (Flutec TG n-PPCH)	374-59-4	U	(F2_Chemicals 2019a)
Perfluoro-iso-propylcycloalkane[2c]	$c\text{-}C_nF_{2n}$	n = 9 (Flutec TG i-PPCH)	423-02-9	U	(F2_Chemicals 2019a)
Perfluoro-1,3-diisopropylcylcoalkane[2d]	$c\text{-}C_nF_{2n}$	n = 12 (Flutec TG m-PDIPCH)	75169-51-6	U	(F2_Chemicals 2019a)
Perfluorodecalin[2e]	$c\text{-}C_nF_{2n-2}$	n = 10 (Flutec TG PFD)	306-94-5	U	(F2_Chemicals 2019a)

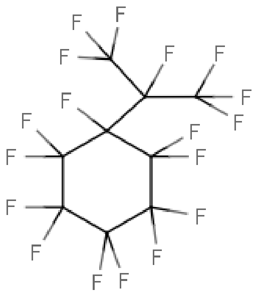
2a



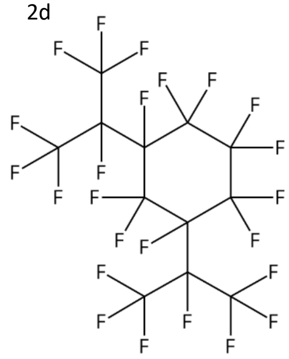
2b



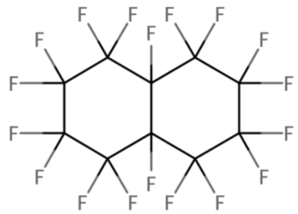
2c



2d

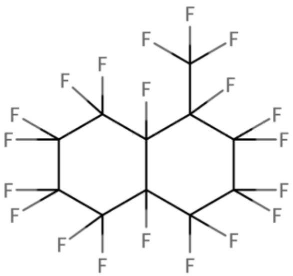


2e



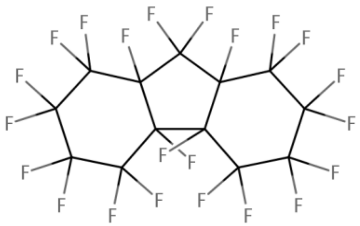
Perfluoromethyldecalin[3a]	$c\text{-}C_nF_{2n-2}$	n = 11 (Flutec TG PFMD)	306-92-3	U	(F2_Chemicals 2019a)
Perfluoroindane[3b]	$c\text{-}C_nF_{n+1}$	n = 9 (Flutec TG-PFIND)	374-80-1	U	(F2_Chemicals 2019a)
Perfluoroperhydrofluorene[3c]	$c\text{-}C_nF_{2n-3}$	n = 13 (Flutec TG PPF)	307-08-4	U	(F2_Chemicals 2019a)
Perfluorotetradecahydrophenanthrene[3d]	$c\text{-}C_nF_{2n-4}$	n = 14 (Flutec TG PPHP)	306-91-2	U	(F2_Chemicals 2019a)
Perfluoroperhydrobenzyl tetralin[3e]	$c\text{-}C_nF_{2n-4}$	n = 17 (Flutec PP25)	116265-66-8	U	(F2_Chemicals 2019a)

3a

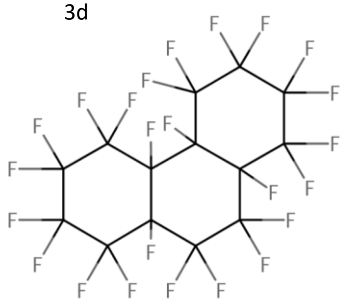


3b

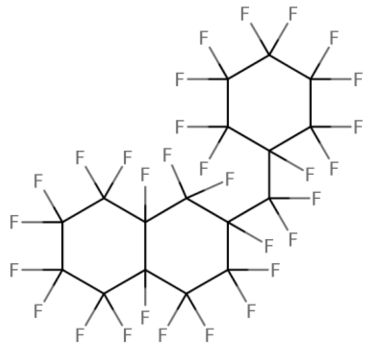
3c



3d

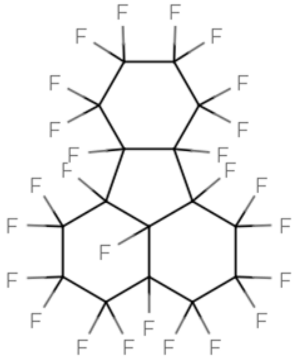


3e

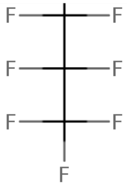


Perfluoroperhydrofluoranthene[4a]	c-C_nF_{2n-6}	n = 16 (Flutec TG PPHF/Flutec PP24)	662-28-2	U	(F2_Chemicals 2019a)
Linear perfluoroalkanes[4b]	C_nF_{2n+2}	n = 5 (Flutec TG PFP), 7 (Flutec TG PFHEP), 8 (Flutec TG PFNO)	678-26-2, 335-57-9, 307-34-6	U	(F2_Chemicals 2019a)
Perfluoro-2-methylpentane[4c]	$CF_3CF(CF_3)CF_2CF_2CF_3$	Flutec TG PFH	355-04-4	U	(F2_Chemicals 2019a)
Perfluoro-3-ethylpentane[4d]	$CF_3CF_2CF(C_2F_5)_2$	Flutec TG PEP	2690-05-3	U	(F2_Chemicals 2019a)
Perfluoro-2-methyl-3-ethylpentane[4e]	$CF_3CF_2CF(C_2F_5)CF(CF_3)_2$	Flutec TG PMEP	354-97-2	U	(F2_Chemicals 2019a)
Perfluoro-2,4-dimethyl-3-ethylpentane[4f]	$CF_3CF_2CF[CF(CF_3)_2]_2$	Flutec TG PDMEP	50285-18-2	U	(F2_Chemicals 2019a)

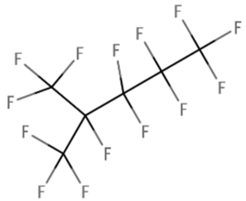
4a



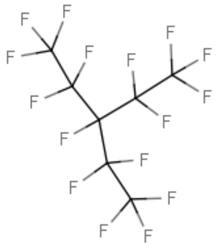
4b



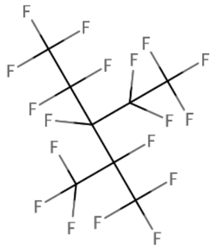
4c



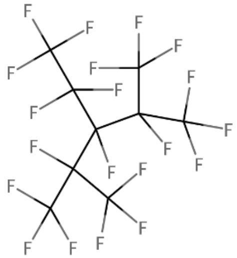
4d



4e



4f



2.41.1 *Tracking air-borne pollutants*

Perfluorocarbons can be used to simulate industrial accidents and terrorism attacks with toxic gas. Numerous experiments have been performed since the 1980s across the world. The most important issues are that the background concentration of the tracer is very low and that the sensitivity is very high. The extremely high stability of perfluorocarbons means that with each experiment the background concentration will rise, and eventually that particular perfluorocarbon will no longer be usable as a tracer (F2_Chemicals 2019a).

2.41.2 *Testing ventilation systems*

Perfluorocarbons are also used to test whether buildings have adequate ventilation, and gases like carbon dioxide and carbon monoxide do not build up (F2_Chemicals 2019a).

2.41.3 *Mapping gas and petroleum reservoirs*

To map oil and petroleum reservoirs, a tracer is introdcued at one site in the reservoir, and its presence in the extracted oil or gas at other sites shows a connected field. Also, information regarding injector/producer communication, partitioning characteristics and cycle times can be obtained. Different kinds of tracers have been used in the past, but perfluorocarbons replace more and more the traditional radioactive tracers (F2_Chemicals 2019a).

2.41.4 Detection of leaks in cables, pipelines, landfill waste and underground storage tanks

Leak detection can be done in different ways. For example on an inventory basis such as noting that the flow at the end of the pipeline is less than that at the start. Lekas can also be detected by using the leaking material itself as a tracer, perhaps with conductivity or other probes, depending on the material. Another option is to use an additional tracer in the liquid medium (F2_Chemicals 2019a). Perfluorocarbons are especially useful in the latter option for leak detection of liquid filled tubings (for example electrical cables that are laid in liquid filled tubing for cooling and insulation). A small amount of a perfluorocarbon is added to the liquid medium, so that a leak can be detected when a portable analyser in a van is driven along the pipeline (F2_Chemicals 2019a).

2.41.5 Tracking of marked items

Small quantities of perfluorocarbons can be incorporated into various items (for example explosives or ransom money) to allow those items to be detected. The technology involves encapsulating the perfluorocarbon in a microcapsule which slowly releases the perfluorocarbon over a long time (up to 30 years, depending on the application) (F2_Chemicals 2019a).

2.42 Water and effluent treatment

Commercial filter membranes for water and effluent treatment can be made out of fluoropolymers, e.g. PVDF (CAS No. 24937-79-9) or PTFE (CAS No. 9002-84-0) (POPRC 2018a).

2.43 Wire and cable insulation, gaskets and hoses

Fluoropolymers provide high-temperature endurance, fire resistance, and high-stress crack resistance to cable and wire insulations and gaskets and hoses (FluoroIndustry 2019; POPRC 2016b). Specific uses are, for example, in power, communication, and control wiring in aircraft and other transport systems (R. E. Banks, Smart, and Tatlow 1994). However, fluropolymers have also been used in communication cables in deep drilling (see Section 1.14.1) The most important fluoropolymer resins in these applications are PVDF, vinylidenfluorid-hexafluoropropylen-copolymer (VDF–HFP copolymer, CAS No. 9011-17-0), FEP, ETFE, ECTFE and PCTFE (R. E. Banks, Smart, and Tatlow 1994; Gardiner 2015; Dohany 2000). FEP is mainly used in plenum cable insulation because it has high durability and fire resistant properties (Gardiner 2015). PVDF is used as a primary insulator in computer cables and industrial control wiring although only in low-frequency applications due to its high dielectric constant (Gardiner 2015). Cross-linked heat-shrinkable PVDF tubings have been used as connector sleeves for wires and cables. Some sleeves incorporate a ring of solder, forming a so-called solder sleeve for power control, electronic, aircraft, and communication wiring (Dohany 2000). Polyethylene copolymers ECTFE and ETFE are also extensively used as flexible and flame resistant insulation for wires and cables in the automotive, train, and air industries, as well as in the aerospace industry as tubing and wiring components of spacecraft and spacesuits (Gardiner 2015).

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