# PFAS-SUSPECTED ACTIVITIES FOR SOIL, GROUNDWATER AND SEDIMENT CONTAMINATION

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADONA | 4,8-dioxa-3H-perfluorononanoate |
| AFFF | Aqueous film forming foam |
| AR-AFFF | Alcohol resistant film forming foams |
| AR-FFFP | Alcohol resistant film forming fluorine protein foams |
| ECF | Electrochemical fluorination |
| EEA | European Economic Area |
| ETFE | Chlorotrifluoroethylene copolymer |
| FEP | Perfluorinated ethylene-propylene resin |
| FFF or F3 | Fluorine-free foams |
| FFFP | Film forming fluorine protein foams |
| FKM | Fluorine Kautschuk Material (fluorine rubbers) |
| FP | Fluorine protein foams |
| FTOH | Fluorotelomer alcohol |
| FTS | Fluorotelomer sulfonic acid |
| FOSA | Fluorinated sulfonamide |
| FOSE | Fluorinated sulfonamido ethanol |
| GenX | Ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy) propanoate |
| HFA | Hexafluoroacetone |
| HFP | Hexafluoropropylene polymer |
| MSDS | Material safety datasheet |
| PAP | Perfluorophosphoric acids |
| PCTFE | Polychlorotrifluoroethylene |
| PFA | Perfluoroalkoxypolymers |
| PFAAs | Perfluoroalkyl acids |
| PFAS | Poly- and perfluoroalkyl compounds |
| PFBA | Perfluorobutanoic acid |
| PFC | Perfluorine components |
| PFCAs | Perfluorocarboxylic acids |
| PFDA | Perfluordecanoic acid |
| PFHpA | Perfluorheptanoic acid |
| PFHxA | Perfluorhexanoic acid |
| PFHxS | Perfluorhexane sulfonic acid |
| PFNA | Perfluornonic acid |
| PFOA | Perfluorooctanoic acid |

| | |
|---|---|
| PFOS | Perfluorooctane sulfonic acid |
| PFPA | Perfluoropropanoic acid |
| PFPeA | Perfluoropentanoic acid |
| PFPrA | Perfluoropropionic acid |
| PFSAs | Perfluorosulfonic acids |
| Ppm | Parts per million |
| PTFE | Polytetrafluoroethylene |
| PVDF | Polyvinylene fluoride |
| POP | Persistent organic pollutants |
| RIVM | National Institute of Public Health and the Environment (the Netherlands) |
| WWTP | Watewater Treatment Plant |
| TDI | Tolerable daily intake |
| TFMS | Trifluoromethanesulfonic acid |
| TM | Telomerization |
| US-EPA | United States environmental protection agency |
| WTP | Water Treatment Plant |

# SUMMARY

The 'Exploratory soil investigation protocol for PFAS contamination by fluorinated firefighting foam and at PFAS-suspected risk sites' (dd. 19/04/2022) contains a list of various activities where PFAS may be present as a possible contaminant. This list is based on a study performed in 2018 (Onderzoek naar aanwezigheid van PFAS in grondwater, bodem en waterbodem ter hoogte van risicoactiviteiten in Vlaanderen). Meanwhile, knowledge about these potential risk activities has further evolved and the list requires an update.

This report provides the most current overview of PFAS-suspected activities based on an extensive literature review. It outlines the processes or applications where PFAS are or were used, helping soil remediation experts to assess whether PFAS should be investigated during a soil study. Of course, this assessment should still consider location-specific conditions such as the type of process, existing (soil) protective measures, expected emissions to soil, water, or air, volumes used, and duration of the activities.

The PFAS family includes 42 subfamilies and several thousand substances. This report focuses on the 3 main families and subfamilies: perfluorinated compounds, polyfluorinated compounds and fluoropolymers.

All identified PFAS-suspected activities were grouped into 4 different main sectors:

- PFAS-producing industry
- PFAS-processing industry
- Use of PFAS-containing products
- Waste processing

Where possible, these PFAS-suspected activities were matched to their corresponding VLAREM and VLAREBO categories (as defined in Flemish legislation). These categories serve as a tool or early warning sign for soil remediation experts in charge of soil investigations. Note that some PFAS-suspected categories are very broad and may include sites where PFAS were never used, so careful interpretation is required.

Where possible, additional information was included for each activity regarding the specific steps in the processes that may lead to PFAS emissions, the time period during which PFAS were used and the most relevant PFAS substances involved. Furthermore, this report includes a qualitative estimate of the likelihood of soil contamination based on (1) the volume of PFAS used in the sector within the EEA (tons/year) and (2) the expected direct or indirect emissions.

This updated list is more comprehensive than the 2018 version. This is due to the availability of more detailed information on PFAS applications and the inclusion of all VLAREM subcategories are listed, whereas the previous list often only mentioned main categories.

# 1 INTRODUCTION

The "Research protocol exploratory soil investigation for PFAS contamination by fluorinated firefighting foam and at PFAS-suspected risk sites" (dd. 19/04/2022) contains a list of activities where PFAS can be considered as a suspect substance. This list is based on a 2018 study (Investigation into the presence of PFAS in groundwater, soil and sediment at high-risk activities in Flanders).

Given the continuing evolution of knowledge about PFAS use, the list is in need of an update. Therefore, the most recent information on PFAS-suspected activities was compiled in this report.

This report serves as a guide for licensed soil remediation experts and provides guidance for evaluating whether or not an activity is suspected of using PFAS.

This report describes the processes in which PFAS are or were used and makes a qualitative estimate of the likelihood of causing soil, groundwater and sediment contamination, taking into account site-specific conditions such as the type of process, protective measures for soil, expected emissions to soil, water or air, volumes used and the history (e.g. period of use) of the activities.

These PFAS-suspected activities have been translated where possible into their corresponding VLAREM and VLAREBO categories. It is important to note that these categories serve only as an aid and a thorough preliminary study is always necessary. Some 'PFAS-suspected' categories are very broad and cover a wide variety of activities. Often, the linked categories need to be nuanced and PFAS was/is not used at all sites with a particular category of activities.

Chapter 2 provides an overview of the different PFAS substace goups.

Chapter 3 describes the methodology used to estimate the probability of soil contamination with PFAS by activity. This was done based on:
- the volume of PFAS used in the sector within the EEA (European Economic Area) and, where possible, supplemented with data for Belgium.
- the anticipated direct emissions to soil and groundwater or indirect emissions via air and/or water.

These are indicative risk estimates because the likelihood of soil contamination is highly dependent on site-specific conditions that must be evaluated in each soil investigation: How was the process conducted? In what time period? What quantities of PFAS were used at the site? Was/is pavement present? What is its condition? How carefully were the waste streams handled? Are soil protection measures in place? Are there air discharges and emissions? What is the condition of the sewers? Have there been any incidents (e.g., fires, spills)? ...

It is important to note that for many PFAS applications, the estimated probability of soil contamination from direct emissions to soil or groundwater is theoretically limited, if activities are carried out carefully and appropriate soil protection measures are in place. However, as this has not always been the case in the past and is still not guaranteed at all sites today, a conservative approach has been taken in estimating the risks for industries with a long operating history (e.g. paper production, textiles, etc.). The estimates refer only to the probability that an activity will lead to PFAS contamination of soil or groundwater, not to the expected concentrations in the different environmental compartments.

For many activities, the presence of PFAS in wastewater or emissions to air cannot be ruled out, so the impact on sediment or soil via deposition can be significant. Treatment technologies for wastewater or air are often not specifically designed to treat PFAS or may not have existed in the past. A well-conducted scoping study, including sufficient attention to discharge points to water and air, is therefore essential to estimate the actual risk.


Figure 1 : Steps to be followed in a preliminary study

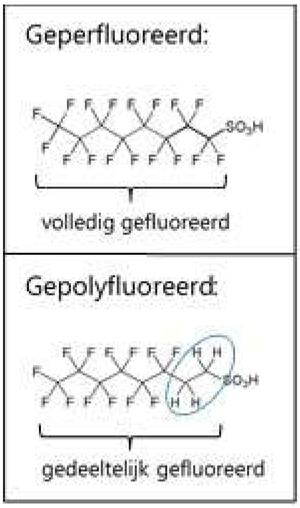
A summary table of PFAS-suspected activities is included in Chapter 4.

Chapter 5 provides a brief description of each PFAS-suspected activity. Where possible, additional information is provided for each activity on which specific steps in particular processes are of primary interest, in which time period, and which PFAS substances are most relevant.

A complete summary of the information collected is provided in Appendix 1.

# 2 OVERVIEW OF THE OF PFAS SUBSTANCE GROUP

The group of poly- and perfluorinated alkyl compounds (PFAS) comprises a high group of more than 6,000 individual substances. Common to all Pfas is that they contain a fully (per-) or partially (poly-) fluorinated carbon chain of varying length, typically 2 to 16 carbon atoms. The best known PFAS are PFOS (perfluorooctane sulfonic acid) and PFOA (perfluorooctanoic acid).
In Buck et al. (2011) (1), PFAS are defined as substances containing the unit $C_nF_{2n+1}$-. More specifically, this means:




- Perfluorinated alkyl compounds: aliphatic substances in which **all** H atoms bound to C atoms in the carbon chain have been replaced by F atoms, except for those H atoms whose replacement would change the nature of the functional groups (e.g. a hydroxyl group -OH).
- Polyfluorinated alkyl compounds: aliphatic substances in which H atoms bound to at least one C atom (but not all) have been replaced by F atoms so that they contain at least the perfluorinated unit $C_nF_{2n+1}$-. Again, the H atoms whose replacement would change the nature of the functional groups are still present.

PFAS are used in part because of their unique surfactant properties. This makes them both water and grease repellent and highly resistant to heat or acids. These substances consist of a backbone of carbon (C) and fluorine (F) atoms to which a specific functional group is added. Chemists have been able to create many different variations, resulting in a substance group with more than 6.000 different compounds. The use of these compounds in industrial or household products is very broad. They have been used to make carpets stain-resistant, to make textiles water-repellent, in metalworking processes, in the production of non-stick materials, or as an additive in certain types of firefighting foams. Since 2000, substances in the PFAS substance group have come under increased scrutiny as research shows that these substances are persistent, bioaccumulative and toxic. In addition, measurements show that these substances are widespread in our environment (2).

This report provides an overview of the different types of PFAS, their uses, and estimates of their likelihood of causing soil contamination.

There are 42 subfamilies in the PFAS substance group . This report focuses on the major families and subfamilies. Three major subfamilies can be distinguished: perfluorinated compounds, polyfluorinated compounds and fluoropolymers.

- Perfluorinated compound
    - Perfluorosulfonic acids (PFSAs).

    - Perfluorocarboxylic acids (PFCAs).
- Polyfluoro compounds
    - Fluorotelomers
    - Precursors
- Fluoropolymers - may also be precursors

For a more comprehensive overview of (some of) the different types of PFAS, see Figure 2.

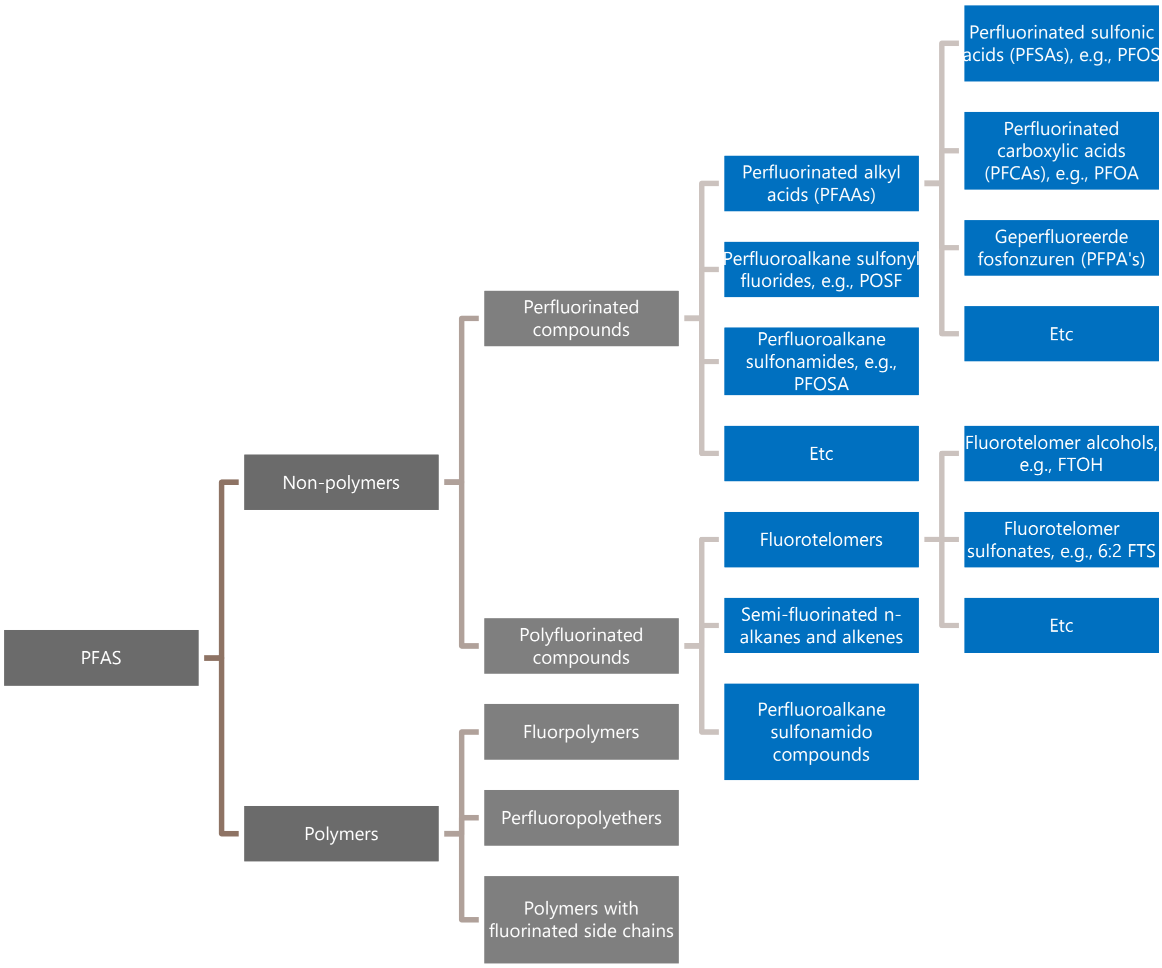



Figure 2: Overview of PFAS compounds classes

## 2.1 PERFLUORINATED COMPOUNDS

Perfluorinated compounds (alkyl acids) are compounds with a fully fluorinated carbon chain of varying length, generally from C2 to C16. The group of perfluorinated alkyl acids (perfluoroalkyl acids; PFAAs) can be further divided into different types of acids (Figure 3), such as e.g. the sulfonic acids (which include PFOS), the carboxylic acids (which include PFOA), and other perfluorinated alkyl acids such as perfluorinated phosphonic acids.

The functional group varies between a sulfonic acid group in the perfluorosulfonic acids (PFSAs) and a carboxylic acid group in the perfluorocarboxylic acids (PFCAs). There are also perfluorinated alkyl acids with other functional groups (such as phosphonic acids, among others) (3).

Figure 3: Chemical structure of PFOS (left) and PFOA (right)

The production of PFAS often produces mixtures of substances, including a mixture of linear and branched isomers. In addition, shorter and longer PFAS are produced as by-products (3).

**Ultra-short chain PFAS compounds**

Ultra-short chain PFAS compounds typically refer to perfluorinated compounds with a carbon chain length of 2 or 3 atoms (Figure 4). Compounds with carbon chains ranging of 4 to 6 atoms are generally classified as short-chain PFAS. Examples of ultra-short chain PFAS include trifluoroacetic acid (TFA), perfluoropropanoic acid (PFPA), trifluoromethane sulfonic acid (TFMS), perfluoroethane sulfonic acid (PFEtS), and perfluoropropane sulfonic acid (PFPS) (4).

TFA is a breakdown product of many chemicals, including pharmaceuticals, pesticides, polymers, and hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs), which were introduced as refrigerants after the phase-out of chlorofluorocarbons (CFCs). Like longer-chain PFAS compounds, ultra-short chain PFAS are also persistent in the environment (5).

Ultra-short-chain PFAS compounds have been detected in snow and surface water in remote regions, including the Arctic. An important pathway for their dispersal is the atmospheric degradation of volatile precursors such as fluorotelomer alcohols, perfluoroalkane sulfonamides, and perfluoroalkane sulfonamide ethanols (4).

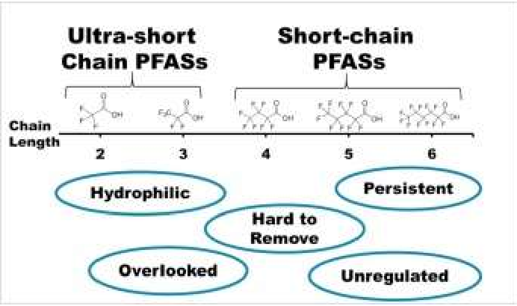



Figure 4: Ultra-short and short chain PFAS (27)

## 2.2 POLYFLUORINATED COMPOUNDS

Polyfluorinated compounds are compounds whose carbon chain is not fully fluorinated, but only partially fluorinated. Polyfluorinated compounds are commonly used as substitutes for PFOS and PFOA.

**Fluorotelomers**

Polyfluorinated compounds include fluorotelomers, which are characterized by the presence of an ethyl group ($CH_2CH_2$) between the fully fluorinated carbon chain and the functional group. The term "fluorotelomer" is derived from the manufacturing process known as fluorotelomerization.

Fluorotelomers are manufactured with a variety of functional groups, including alcohols, sulfonamides, sulfonamido-ethyl acrylates, methyl acrylates and sulfonamido-acetic acids. Most fluorotelomers are used in manufacturing processes such as building blocks for polymers, surfactants and polymers with fluorinated side chains. Many of these products are considered precursors (see below), meaning they can degrade in the environment to perfluoroalkyl sulfonic acids (PFSAs) and perfluoroalkyl carboxylic acids (PFCAs), which are highly persistent and do not degrade further (5).

Two examples are shown in Figure 5: 8:2 fluorotelomer alcohol (FTOH) on the left and 6:2 fluorotelomer sulfonate (6:2 FTS) on the right.

- 8:2 FTOH consists of 8 fully fluorinated carbon atoms, an ethyl group and an alcohol group. It is an example of a PFCA precursor because it can degrade in the environment into compounds such as PFOA (6).
- 6:2 FTS consists of 6 fully fluorinated carbon atoms, an ethyl group and a sulfonate group. Like 8:2 FTOH, it is also an example of a PFCA precursor.

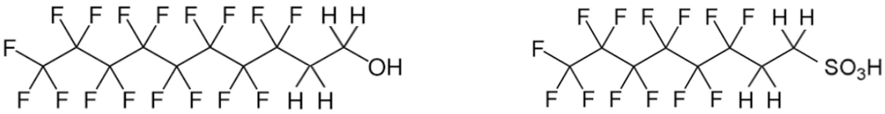


Figure 5: Examples of telomeres, 8:2 FTOH (left) and 6:2 FTS (right)

6:2 FTS is used as a substitute for PFOS in a variety of applications, including class B firefighting foams and as a surfactant in industrial processes. 8:2 FTOH, on the other hand, is widely used to impart water repellency to textiles.

**PFAS precursors**

PFAS precursors are substances that can degrade in the environment to PFSAs and PFCAs, such as PFOS and PFOA. This is a very high group of mostly unknown and impossible or difficult to analyze compounds. It also includes telomeres as described above.  Precursors are important sources of PFAS to the environment. The global production of polyfluorochemicals, most of which are precursors, is many times greater than that of PFOS and PFOA (5).

Commercially available analytical methods for PFAS primarily measure PFCAs and PFSAs and some precursors. Studies of urban runoff water (rain) in which precursors were present in San Francisco Bay have shown that PFSAs and PFCAs make up less than 25% of the total PFAS content (6). Therefore, it is important to understand the presence of precursors.

## 2.3 FLUOROPOLYMERS

Fluorinated polymers may or may not be PFAS, depending on whether or not they contain perfluoroalkyl groups. The fluoropolymer polytetrafluoroethylene (Teflon, PTFE) is a PFAS and is used as a non-stick coating in pans. It is virtually inert at normal temperatures and decomposes at temperatures above 260°C. Teflon resins contain low concentrations (on the order of ppm, parts per million) of hexafluoroacetone (HFA). PFOA was an essential additive in the formulation of these polymers. Since 2012, PFOA has been replaced by another PFAS, GenX, in the DuPont/Chemours PTFE manufacturing process. Part of the nonstick manufacturing process involves a high-temperature sintering process, during which residual PFOA should theoretically evaporate.

In PTFE-coated textiles (jackets, tablecloths, etc.), fluorotelomer alcohols and fluorotelomer carboxylic acids are found in relatively high quantities (7). Other commonly used fluoropolymers include fluoroethylene propylene (FEP), perfluoroalkoxy (PFA) and polyvinylidene fluoride (PVDF).

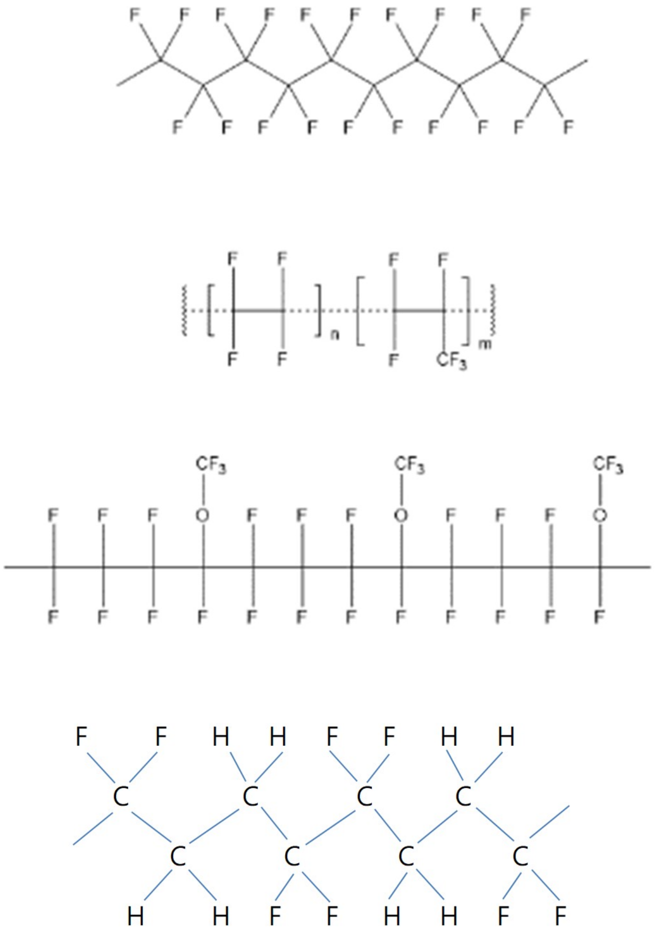



Figure 6 : Structural formulas of some fluoropolymers (32), (47)

There are also polymers with fluorinated side chains. When the polymers degrade, the fluorinated side chains are released and PFAAs can be formed. Thus, these polymers may also be precursors.

## 2.4 GASEOUS/VOLATILE PFAS

Although not all F-gases are considered PFAS, there are certain PFAS components that are volatile or gaseous and are not included in the fluorinated gas regulations, such as fluorotelomer alcohols and perfluorinated trialkylamines. These gases are mainly used as starting materials for fluoropolymers or as refrigerants in refrigeration and air conditioning systems (8).

After CFCs (chlorofluorocarbons, fully halogenated with fluorine and/or chlorine) and HCFCs (hydrochlorofluorocarbons, partially halogenated with fluorine and/or chlorine) were phased out as refrigerants due to their effect on the ozone layer, a switch was made to hydrofluorocarbons (HFCs, which do not contain chlorine). However, HFCs were later found to be a significant contributor to global warming. As a result, there is now a gradual transition to hydrofluoroolefins (HFOs) (unsaturated chains, no chlorine). HFOs do not deplete the ozone layer and have a low global warming potential (GWP), but they degrade into persistent substances (8).

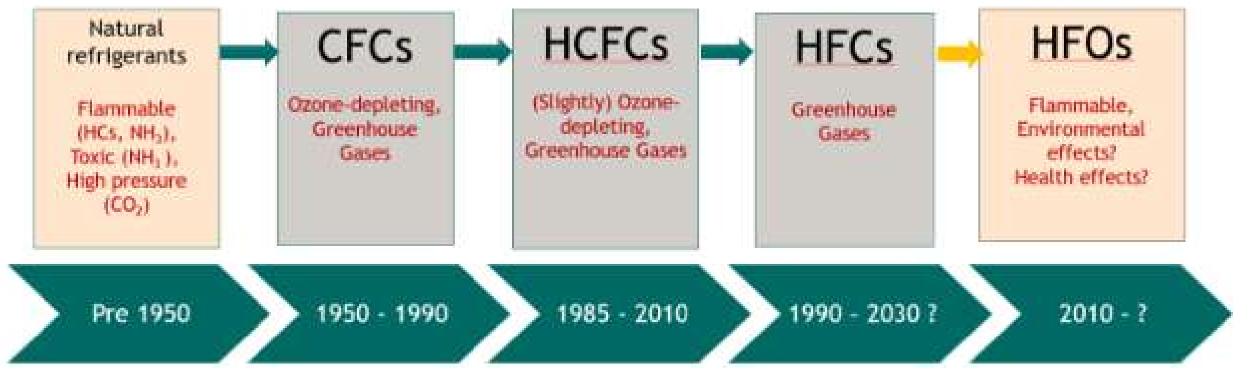



Figure 7: Schematic representation of the use of synthetic refrigerants (9)

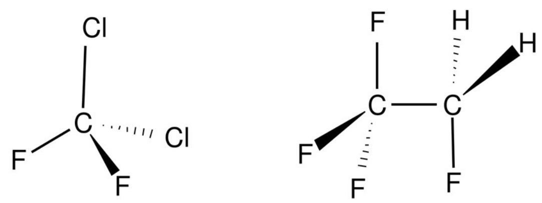


Figure 8: dichlorofluoromethane and tetrafluoroethane, examples of CFCs and HCFCs, respectively

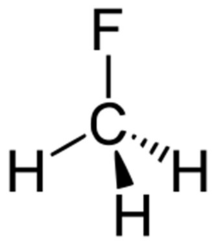


Figure 9: fluoromethane, example of an HFC

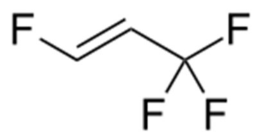


Figure 10: 1,3,3,3-tetrafluoropropene (HFO-1234ze,) example of an HFO

Once released into the atmosphere, fluorinated gases oxidize to a variety of breakdown products. Some degrade readily in the atmosphere, while others are more stable and require more time to degrade. Fluorinated gases have complex atmospheric chemistry, often based on radical oxidation processes via trifluoroacetaldehyde ($CF_3CHO$) or trifluoroacetyl fluoride ($CF_3COF$) as intermediates. The latter of these major intermediates is hydrolyzed with high yield to trifluoroacetic acid (TFA) in water droplets, which are then precipitated with rain and snow. Other important degradation products of fluorinated gases are longer-chain substances such as PFBA, which can be formed, for example, from the fluoroether HFE-7100 ($C_4F_9OCH_3$). (9)

The most important HFOs are HFO-1234yf and HFO-1234ze(E), of which 10.000 to 1.000 t/y and 1.000 to 10.000 t/y, respectively, are registered under REACH. The use of gaseous PFAS is very high, estimated at 520.000 tons/year (production, stockpiles and waste phase combined) for the EEA. (10)

# 3 METHODOLOGY

Since the previous version of this study (2018), more information has become available on the use of PFAS in different applications.

This report attempts update the major uses and PFAS constituents in the context of soil and groundwater contamination, and then link them to the corresponding VLAREM and VLAREBO categories.

PFAS applications were grouped into the following classes:

- PFAS producing industry
- PFAS processing industry – activities using PFAS in processes
- Use of products containing PFAS
    - Use of firefighting foams
    - Industries/activities using products or articles containing PFAS (end uses)
- Waste disposal

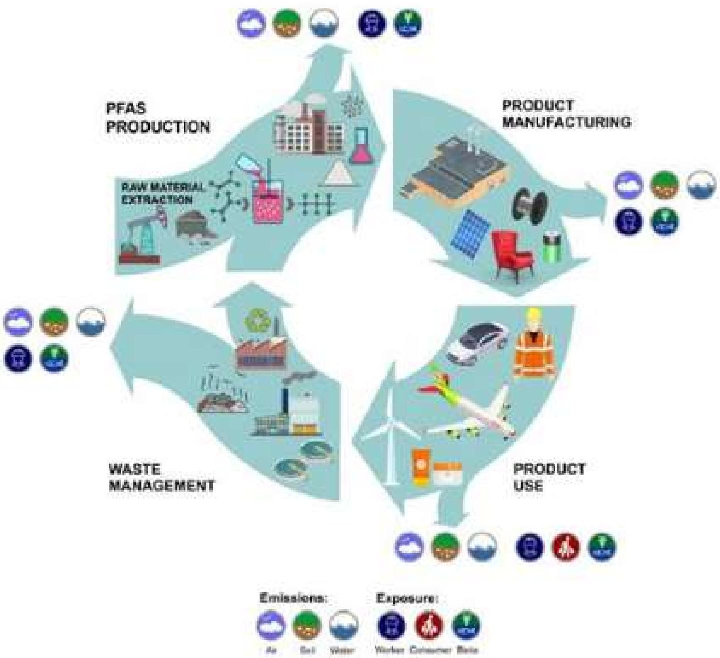



Figure 11: Cycle of PFAS (8)

As a first step, each application where PFAS is potentially a suspected substance was inventoried (based on available literature). These applications were then linked, where possible, to the appropriate VLAREBO or VLAREM category. Relevant activities without a corresponding category were also listed (see section 3.1).

In a second step, the probability of causing soil contamination was estimated for the relevant activities (see section 3.2).

## 3.1 PFAS-SUSPECTED ACTIVITIES AND VLAREBO OR VLAREM CATEGORIES

VLAREM categories are a classification of activities listed in Annex I of Title II of VLAREM (Annex I, VLAREM II). A notification or environmental permit is required to perform these activities.

VLAREBO categories are a selection of VLAREM categories that cover activities that require soil investigation in certain situations. They are identified by the letter O, A, B, or S in column 8 of the classification list and in the VLAREBO appendix (Appendix I, VLAREBO).

To link PFAS-suspected activities to categories, the following approach was used:

- Categories with any link to PFAS-suspected activities were listed (worst case).
- Subcategories under a major category that are not included in the VLAREBO list were not listed. Exceptions to this are discussed in section 4.2.
- the comments column in Appendix 1 provides details on why the category was withheld and in which cases PFAS are used.
- For waste-related categories, all activities related to the processing or storage of waste that may contain PFAS were listed.

## 3.2 ESTIMATED PROBABILITY OF SOIL CONTAMINATION

To estimate the likelihood of soil contamination, the following criteria were considered:

1. the amount of PFAS (order of magnitude) that was/is potentially used in this activity in the EEA (8). Where possible, this was supplemented with figures for Belgium (10).
2. the expected direct emissions to soil and groundwater or indirect emissions via water and air.

The **amounts of PFAS used** have been categorized as follows, based on estimates of annual use in the EEA as described in the REACH restriction document for PFAS (8):

- Very low: order of magnitude < 10 tons/year
- Low: order of magnitude 10 – 100 tons/year
- Medium: order of magnitude 100 – 1.000 tons/year
- High: order of magnitude 1.000 – 10.000 tons/year
- Very high: order of magnitude > 10.000 tons/year

The estimate of the amount used and therefore the potential contribution to the impact on soil contamination is indicative due to, among other things, the following uncertainties:

- Activities – such as waste treatment – that are not included in the REACH restriction document were estimated based on various studies from national and international sources (9), results from a previous study on PFAS-suspected sites (11), and expert judgment.
- When estimating the amount of PFAS based on the REACH restriction document, the type of PFAS used is often not distinguished.
- Estimates of amounts of PFAS used vary over time. Often PFOS or PFOA will have been used in the past while these substances were later replaced by other PFAS compounds. PFAS polymers or polymers with fluorinated side chains also include a whole range of substances for which possible degradation pathways and daughter products are not (well) known.
- The actual amount of PFAS used at a site is highly site-specific and should therefore be investigated during the preliminary study.

**Depending on the type of use and type of production process**, we distinguish the following classes:

- No emissions expected: closed systems with a low risk of PFAS release (soil protection measures, no emissions to air or water)
- Indirect emissions: emissions to air or water are possible. No direct emissions to soil or groundwater expected.
- Direct releases: direct releases of PFAS to soil and/or groundwater are possible, e.g. through application of firefighting foams, spills or leaks, processes with open baths or inadequate soil protection measures, ...

The estimate of the emissions and therefore the potential contribution to the impact on soil contamination is indicative due to, among other things, the following uncertainties

- Site conditions: certain activities may be carried out without emissions at one site and with indirect or direct emissions at another, depending on the presence of a treatment system, the way the process is carried out, and soil protection measures.
- Changes over time: certain activities may have occurred in the past with emissions (e.g., open baths, pavement in poor condition, sewage in poor condition, etc.), whereas newer facilities are closed processes, with e.g. air and water treatment, closed production lines, and liquid-tight floors.
- It is important to note that for closed PFAS applications, the risk of soil contamination due to direct emissions to soil or groundwater is limited. However, for most activities, the presence of PFAS in wastewater or emissions to air cannot be excluded, so the impact on soil or sediment from these indirect emissions can be significant. Wastewater or air treatment technologies are often not specifically designed to treat PFAS. It is therefore prudent to investigate PFAS at the point of discharge, in the sewer system, or to investigate deposition at sites where PFAS-suspected activities are currently taking place or have taken place in the past.

Based on the above criteria, activities are classified according to their likelihood of causing soil contamination. This classification, shown in Table 1, is based on available literature data and expert judgment. The classification serves as a guideline because specific amounts, PFAS substances, application methods, and soil protection measures can vary widely from site to site. For each category/activity in Chapter 5 and Appendix 1, this table was initially used to assess the likelihood of an activity causing soil contamination. However, expert judgment is then used to refine the probability. The rationale for each category is also documented in Appendix 1 and Chapter 5. It is essential that this information is reviewed by a soil expert during the preliminary soil investigation at a specific site.

There is currently insufficient data to make definitive statements about certain activities. For many activities involving the use of PFAS, limited research has been conducted, making it difficult to accurately estimate the likelihood of soil contamination. OVAM will continue to monitor developments and assess whether adjustments are needed as new knowledge becomes available.

Table 1: Soil contamination likelihood classification

| Estimated quantity of PFAS used in the EEA (tons/year) | Assessment based on quantity | Emissions | Likelihood of soil contamination based on quantity and emissions |
|---|---|---|---|
| **< 10** | Very low | No | No |
| | | Indirect | Very limited |
| | | Direct | Limited |
| **10 – 100** | Low | No | Very limited |
| | | Indirect | Very limited |
| | | Direct | Limited |
| **100 – 1.000** | Medium | No | Limited |
| | | Indirect | Limited |
| | | Direct | High |
| **1.000 – 10.000** | High | No | Limited |
| | | Indirect | High |
| | | Direct | Very high |
| **> 10.000** | Very high | No | High |
| | | Indirect | Very high |
| | | Direct | Very high |

# 4 OVERVIEW OF PFAS-SUSPECTED ACTIVITIES

## 4.1 SUMMARY TABLE WITH PFAS-SUSPECTED ACTIVITIES

Table 2 provides a complete overview of all possible PFAS-suspected VLAREM categories. In addition, this table contains a number of relevant activities without a VLAREM category. A more detailed evaluation of the selection of these activities without VLAREBO/VLAREM category can be found in section 4.2. Table 2 also provides an estimate of the likelihood of soil contamination. This estimate specifically refers to the probability that the use of PFAS may result in soil contamination, not to the expected concentrations in soil or groundwater. A detailed description of the various activities, including information on the types of PFAS used, quantities, processes, use history, emissions, and the corresponding probability estimate of soil contamination, is provided in Chapter 5.

It is important to note that the linked categories often require nuance, as PFAS was/is not necessarily used at all sites within a particular category. Some 'PFAS-suspected' (sub)categories are broad and include a wide range of diverse activities. Therefore, the list of (sub)categories should only be used as a guideline. A thorough preliminary investigation is always essential to determine whether PFAS are indeed relevant substances of concern at the specific site under investigation.

Table 2: Summary of PFAS-suspected activities (VLAREBO and non-VLAREBO) with estimated probability of soil contamination with PFAS. Red: very high probability, orange: high probability, yellow: limited probability, green: very limited probability.

| Sector | Activity | VLAREM category | Estimated probability of contamination |
|---|---|---|---|
| ***PFAS producing industry*** | | | |
| PFAS production | Manufacturing | 7.11.1.f, 20.4.2.1, 20.4.2.2 | Very high |
| ***PFAS processing industry*** | | | |
| Production and treatment of plastics and fluorinated rubbers | Production of fluoropolymers and polymers with fluorinated side chains | 7.11.1.h, 20.4.1.1, 20.4.1.2 | Very high |
| | Production and surface treatment of plastics | 23.4*, 23.2.2.a, 23.2.2.b, 23.1.1b, 23.1.1c | Very high |
| | Production of fluorinated rubbers and elastomers | 7.11.1.i, 7.12.2.c, 59.15, 36.1, 36.3.1.b.1, 36.3.1.b.2, 36.3.2 | Very high |
| Textile industry (including leather, furniture and carpets) | Pre-treatment and treatment of textiles, textile finishing | 41.4.1a, 41.4.1b, 41.4.2a, 41.4.2b, 41.4.3a, 41.4.3b, 41.10, 41.3.1a and b, 41.3.2a and b, 41.3.3a and b | High for regular textile<br>Very high for water and dirt repellent textiles and textile finishing |
| | Carpet | 41.6.2a, 41.6.2b, 41.7 | Very high |

| **Sector** | **Activity** | **VLAREM category** | **Estimated probability of contamination** |
|---|---|---|---|
| | | 41.6.1a*, 41.6.1b* | Limited |
| | Leather | 25.1.1, 25.1.2, 25.1.3 | High |
| | Shoes | 59.11 | High |
| Paper and cardboard | Production and handling of paper | 33.1, 33.2.a.1a, 33.2.a.1b 33.2.a.2a, 33.2.a.2b, 33.2.a.3a, 33.2.a.3b, 33.2.b.1a, 33.2.b.1b, 33.2.b.2a, 33.2.b.2b, 33.2.b.3a, 33.2.b.3b, 33.2.c.1a, 33.2.c.1b 33.2.c.2a, 33.2.c.2b, 33.2.c.3a, 33.2.c.3b, 33.2.d.1a, 33.2.d.1b, 33.2.d.2a, 33.2.d.2b, 33.2.d.3a, 33.2.d.3b, 33.2.e, 20.5.1, 20.5.2, 41.9.1, 41.9.2, 41.9.3, 41.11 | Limited for production facilities with no direct emissions |
| | | | High for sites using recycled paper/sites with direct emissions |
| Metal Industry | Metal surface treatment / galvanization | 29.5.5.2a, 29.5.5.2b, 29.5.5.3, 29.5.5.4 | Limited for recent installations with no direct |
| | | | High for sites with direct emissions |
| | | 29.5.5.1a*, 29.5.5.1b* | Limited |
| | Cleaning of metals | 29.5.10.2.a, 29.5.10.2.b | Very limited |
| Lacquer and paint industry | Production of lacquers and paints using PFAS | 4.1.2, 4.1.3, 7.12.2.c | Limited |
| Application of covering materials | Immersion | 4.2 | High to very high |
| | Mechanical, pneumatic or electrostatic | 4.3.a.1.i, 4.3.a.1.ii, 4.3.a.2.i, 4.3.a.2.ii, 4.3.a.2.3, 4.3.b.1.i, 4.3.b.1.ii, 4.3.b.2.i, 4.3.b.2.ii, 4.3.b.2.3, 4.3.c.1.i, 4.3.c.1.ii, 4.3.c.2.i, 4.3.c.2.ii, 4.3.c.2.3 | |
| | Surface treatment | 4.6.a, 4.6.b, 59.2.1.1, 59.2.1.2 | |
| | Coating | 59.3, 59.4.1, 59.5.1.1, 59.5.1.2, 59.5.2.1, 59.5.2.2, 59.6.1, 59.7.1, 59.7.2, 59.9.1, 59.10.1, 59.10.2, 59.14.1, 59.14.2 | |
| | Use of adhesives | 59.12, 59.13 | |
| Glue Production | Manufacturing of adhesives | 26.1.1.a, 26.1.1.b, 26.1.2.a, 26.1.2.b, 26.1.3.a, 26.1.3.b | Limited |
| Electronic industry and semiconductor industry | Production of electronics | 12.4.2.a, 12.4.2.b, 12.4.3.a, 12.4.3.b | High |

| Sector | Activity | VLAREM category | Estimated probability of contamination |
|---|---|---|---|
| Cosmetics | Manufacturing of cosmetics | 22.1.1.a, 22.1.1.b, 22.1.2.a, 22.1.2.b | Very limited |
| Cleaning agents, maintenance agents | Production of cleaning agents | 34.2.1.a, 34.2.1.b, 34.2.2.a, 34.2.2.b, 34.2.3.a, 34.2.3.b | Very limited |
| Lubricants and hydraulic fluids | Manufacturing of lubricants and hydraulic fluids | 44.2.2.a, 44.2.2.b, 44.2.3.a, 44.2.3.b | Limited |
| Firefighting foams | Production of firefighting foams | 7.1.1, 7.1.2, 7.1.3 | High |
| Production site of medical materials | Production of medical products and devices | No specific category, see covering agents, textiles, electronics, plastics, metal, ... | Limited |
| Manufacturing pharmaceuticals | Production of PFAS containing pharmaceuticals | 7.2.5, 7.11.4, 7.12.2.b 13.1, 59.17 | Limited |
| Production site of pesticides and biocides | Production of pesticides | 5.4.1, 5.4.2, 5.5, 7.2.4, 7.12.2.a | High |
| Building materials | Production of building materials such as glass, laminate, tiles, roofing, drywalls, ... | 19.1.2.a, 19.1.2.b, 19.1.3.a, 19.1.3.b, 19.2.2.a, 19.2.2.b, 19.2.3.a, 19.2.3.b, 19.4.1, 19.4.2, 19.4.3, 19.4.4, 19.7, 20.3.4.2, 20.3.8 | High |
| ***Sites where PFAS-containing products are used.*** | | | |
| Printing and graphic industry / photo industry | Print | 59.1.1.1, 59.1.1.2, 59.1.2.1, 59.1.3.1.1, 59.1.3.1.2, 59.1.3.2.1, 59.1.3.2.2, 59.1.3.3.1, 59.1.3.3.2, 59.1.3.4.1, 59.1.3.4.2, 59.1.3.5, 59.1.3.6.1, 59.1.3.6.5, 11.1.2.a, 11.1.2.b, 11.1.3.a, 11.1.3.b | Very limited |
| | Photo industry | 11.2.2.a, 11.2.2.b, 11.2.3.a 11.2.3.b, 14.1.a, 14.1.b, 14.2.a, 14.2.b, 14.3.a, 14.3.b | Very limited |
| Marina and shipyards | Seaport areas and ports | 48.1.1.1a and b, 48.1.1.2 | Limited |
| | Shipyards | 42.2.1a and b, 42.2.2 | Limited for smaller shipyards |
| | | | High for largt shipyards |
| Car and train washes (car wash) | Washing of fire trucks | 15.4.1*, 15.4.2.a*, 15.4.2.b* | High |
| | Other | | Limited, pending further investigation |
| Transport | Garages / body shops | 15.3.1, 15.3.2, 15.2 | Very limited |
| | Transport equipment factories | 42.1, 42.3, 42.4.2, 42.5 | Limited |

| Sector | Activity | VLAREM category | Estimated probability of contamination |
|---|---|---|---|
| Textile | Laundries and dry cleaning | 41.4.1a, 41.4.1b, 41.4.2a, 41.4.2b, 41.4.3a, 41.4.3b, 46.2.a, 46.2.b, 46.3.a, 46.3.b, 59.8 | Very limited for regular textiles<br>Limited for textiles made water and grease repellent |
| Medical materials | Care facilities (outpatient clinics, residential care centers and hospitals) | 49.1*, 49.2* | Limited, and only at discharge point when discharging to surface water |
| Food industry | Wastewater food industry | See categories on wastewater | Limited, and only at discharge point when discharging to surface water |
| Agriculture | Use of pesticides and biocides | / | Limited, further research is needed to better estimate this probability. |
| Use of PFAS containing lubricants. | See aviation, transportation, consumer products | | |
| ***PFAS containing firefighting foam*** | | | |
| Extinguish fire in case of emergency | Emergency | / | Limited for small to medium emergencies<br>High for major emergencies |
| Testing of extinguishing systems (e.g. sprinklers, with fire-extinguishing foam) | Testing | / | Limited |
| Wash stations for fire trucks | Fire department/private and specialist firefighting organizations | 15.4.1*, 15.4.2.a*, 15.4.2.b* | High |
| Storage of fire extinguishing foam | Fire department/industrial sites/airports | / | Limited |
| Fire training sites/training centers/sites for demonstrations and testing (e.g. sprinklers) (incl. military training sites) | Fire drills and demonstrations | / | High |
| Fire extinguishers | Manufacturing, recycling or filling of fire extinguishers | / | High |
| | Testing/demonstrations | / | Limited |
| Airports (civilian/military) | Emergency and/or fire drills | 57.1.1, 57.1.2 | High |
| ***Waste disposal and*** | | | |

| Sector | Activity | VLAREM category | Estimated probability of contamination |
|---|---|---|---|
| Waste collectors and processors | Storage of waste products | 2.1.1 (a.1, a.2, b), 2.1.2. d.1, 2.1.2.d.2 | Limited to high - highly dependent on type of waste, quantities and circumstances |
| | Storage and sorting of waste products for beneficial use | 2.2.1.a,b, 2.2.1.c.1, 2.2.1.c.2, 2.2.1.d.1, 2.2.1.d.2 | |
| | Storage and mechanical treatment of waste products for beneficial use | 2.2.2.a.1, 2.2.2.a.2, 2.2.2.b.1, 2.2.2.b.2, 2.2.2.c.1, 2.2.2.c.2, 2.2.2.c.3, 2.2.2.c.4, 2.2.2.d.1.b, 2.2.2.d.2.b, 2.2.2.d.3, 2.2.2.e, 2.2.2.f.1, 2.2.2.f.2, 2.2.2.g.2 | |
| | Storage and physicochemical treatment for beneficial use | 2.2.5.a.1, 2.2.5.a.2, 2.2.5.a.3, 2.2.5.b.1, 2.2.5.b.2, 2.2.5.c.1, 2.2.5.c.2, 2.2.5.d.1, 2.2.5.d.2, 2.2.5.e.2, 2.2.5.e.3, 2.2.5.f.2, | |
| | Storage and disposal for final storage or destruction | 2.3.1.a, 2.3.1.a | |
| | Storage and physicochemical treatment for final storage or destruction | 2.3.2.a.1, 2.3.2.a.2, 2.3.2.b, 2.3.2.c, 2.3.2.d, 2.3.2.e.1, 2.3.2.e.2, 2.3.2.g | |
| | Storage and biological treatment for final storage or destruction | 2.3.3.c | |
| | | 2.3.3.a.1*, 2.3.3.a.2*, | Limited, pending further investigation |
| | Composting of organic commercial waste | 2.2.3.c.1*, 2.2.3.c.2*, 2.2.3.c.3* | Limited, pending further investigation |
| Landfills | Any type | 2.3.6.a tem 2.3.6.c | Limited for landfills closed before 1960 |
| | | | High for landfills started after 1960 |
| | | | Very high for landfills for waste products that contain PFAS |
| Soil processing, excavated soil and soil landfilling | Soil | 2.1.3.1, 2.1.3.2, 60.2, 61.2.2 | Limited |
| | | 61.2.1*, 60.1* | Limited for older temporary soil storage facilities and landfills where the incoming soil has not been evaluated for PFAS (before 2022) |
| | Dredged material and sludge | 2.2.8.a, 2.2.8.b, 2.3.7.a, 2.3.7.c, 2.3.7.d | Limited |
| | | 63.1*, 63.2* | Limited for older activities where the incoming soil has not been evaluated for PFAS (before 2022) |

| Sector | Activity | VLAREM category | Estimated probability of contamination |
|---|---|---|---|
| Incineration of waste products | Storage and incineration/storage and co-incineration of waste products | 2.3.4.1.a.1*, 2.3.4.2.a.1*, 2.3.4.1.a.2*, 2.3.4.2.a.2*, 2.3.4.1.b, 2.3.4.2.b, 2.3.4.1.c, 2.3.4.2.c, 2.3.4.1.e, 2.3.4.1.f, 2.3.4.1.g*, 2.3.4.1.h, 2.3.4.1.j, 2.3.4.2.d, 2.3.4.1.k, 2.3.4.2.e, 2.3.4.2.g | High for facilities processing PFAS containing waste products (paper industry, medical waste, industrial waste products, textiles...) |
| | | | Limited for other facilities |
| Wastewater | Public waste water treatment plants (WWTP) | 3.6.4.3, 3.6.4.4 | High |
| | WWTP (industrial wastewater) | 3.4.1b*, 3.4.2*, 3.4.3*, 3.6.3.1b*, 3.6.3.2, 3.6.3.3, 3.6.6, 3.6.7 | Very limited to high, if activities from this report are carried out on the site - see probability for these activities |
| | Discharge to groundwater | 52.1.1.2, 52.1.1.3, 52.1.2, 52.2.2, 52.2.3 | Limited |
| Container cleaning companies/barrel rinsers/cleaning tank trucks/ transport companies of waste products | Cleaning empty containers | 2.2.6.a, 2.2.6.b, 2.2.6.c, 2.2.6.d | High |
| | Storage and cleaning of metal containers by thermal cleaning | 2.3.5 | Limited |

* These categories are not included in the VLAREBO

## 4.2 EVALUATION OF PFAS USE IN ACTIVITIES WITHOUT VLAREBO CATEGORY

There are a number of activities that could potentially be considered PFAS-suspected that

- either could not be associated to a VLAREM category (and therefore no VLAREBO category);
- either could be associated to a VLAREM category but not to a VLAREBO category.

They include:

- a selection of PFAS risk activities, whose subcategories with the smallest capacities or volumes are not included in the VLAREBO and where PFAS may still potentially have a (significant) impact on the soil (e.g. intermediate soil storage sites, small-scale carpet production);
- activities that have neither a VLAREBO nor a VLAREM category, e.g. firefighting foams, pesticides/agriculture;
- activities that have a VLAREM but not a VLAREBO category, e.g. packaging of pharmaceutical substances.

For each of these activities, Appendix 1 and Table 3 provide a motivation for why these activities were assigned a probability of causing soil contamination.

**These activities associated with a probability of PFAS contamination are also included in the summary table (section 4.1 ).**

Table 3 : Evaluation of potential PFAS related activities that are **not** included in the VLAREBO or the VLAREM

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| PFAS-suspected activities | | | |
| 2.3.4.1.a.1 and 2.3.4.2.a.1<br>2.3.4.1.a.2 and 2.3.4.2.a.2 | Combustion of biomass waste products - from agriculture and forestry, food industry and fibrous vegetable waste products from raw pulp and from the production of paper from pulp, cork waste products, untreated wood waste products<br>- up to 5 MW<br>- more than 5 MW | PFAS can be added to paper pulp, combustion breaks down mostly longer chains, but short chains require very high temperatures (1.400°C) before they can be broken down | High for facilities receiving a lot of PFAS containing waste products (paper industry) |
| 2.3.4.1.g | Incineration of solid non-hazardous medical waste products | PFAS are used in all kinds of medical equipment | High for facilities receiving a lot of PFAS containing waste products (medical materials) |
| 3.4.1b<br>3.4.2<br>3.4.3 | Discharging commercial wastewater without treatment:<br>- up to 2 $m^3/h$ with hazardous substances<br>- 2 – 100 $m^3/h$<br>- more than 100 $m^3/h$ | The likelihood of contamination depends on the activities carried out at the site | See probability related to activities carried out at the site |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| 3.6.3.1b | WWTP, including discharge of effluent and dewatering of associated sludge:<br>- industrial wastewater – 1 to 5 m³/h (b) with hazardous substances above classification criteria | The likelihood of contamination depends on the activities carried out at the site. | See probability related to activities carried out at the site |
| 23.4 | Surface treatment, including degreasing of plastics by electrolytic or chemical processes, if the capacity of the treatment baths (excluding rinsing baths) exceeds 30.000 liters | PFAS are often used in surface treatment due to their surfactant properties. The category covers high volumes. | Very high |
| 15.4.1<br>15.4.2.a<br>15.4.2.b | Non-domestic establishments for washing motor vehicles and their trailers:<br>- in industrial area<br>- not in industrial area < 10 vehicles per day<br>- not in industrial area > 10 vehicles per day | PFAS are used in hydraulic fluids, lubricants, automotive waxes, and more | For washing fire trucks: high<br>Other washing sites: limited, further research is needed to better estimate this probability. |
| 60.1 | Full or partial backfilling of quarries, mines, excavations and other wells | However, the subcategory with capacity > 10.000 m³ is VLAREBO. In principle, this category only | No soil contamination expected for activities where incoming soils have been assessed for PFAS (as of 2022) |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| | and pits, including lakes and ponds with a capacity of 1.000 – 10.000 $m^3$ | applies to land that can be reused. However, for old activities (before 2022), PFAS (or other emerging contaminants) will not always have been assessed. Current activities will be assessed for the presence of PFAS. | |
| 61.2.1 | Intermediate storage site for excavated soil that meets the requirements for the use of soil materials with a capacity of 1.000 – 10.000 $m^3$ | | Limited for older temporarys soil storage facilities and landfilling where incoming soil was not assessed for PFAS (before 2022). |
| 63.1<br>63.2 | Storage and dewatering of dredged material and sludge in compliance with soil use requirements | For old activities, PFAS (or other emerging contaminants) will not always have been assessed. For current activities, PFAS will be assessed. | For activities where incoming soils have been assessed regarding PFAS (as of 2022), no soil contamination expected |
| | | | Limited for older activities where incoming soil was not assessed regarding PFAS (before 2022). |
| 49.1<br>49.2 | Care facilities (outpatient clinics, residential care centers and hospitals) | Many medical materials contain PFAS, but these typically only enter the environment through waste products (water) and are included in a separate category. Here, PFAS are already incorporated into products and materials, so applications at these sites have been closed. | No soil contamination expected from use of material or from discharge to sewer. |
| | | | Limited probability at point of discharge when discharging to surface water |
| / | Extinguish fire in case of emergency | If PFAS containing firefighting foam was used | Limited for small to medium incidents |
| | | | High for major incidents |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| / | Storage of extinguishing foam, sprinklers with PFAS containing foam | No specific category, may be categorized as a subcategory of category 17.<br>Always a point of attetion at fire training facilities or industrial sites, airports | Limited, not associated to specific category |
| / | Firefighting training sites (including military), demonstration sites, fire department training centers, testing sprinkler systems and other fire extinguishers | If PFAS containing firefighting foam is/was used | High |
| / | Manufacturing, recycling and filling of fire extinguishers for PFAS containing extinguishing foam | Spills during filling, discharge of rinse water and residual liquids. | High |
| / | Testing of extinguishing systems e.g. sprinklers, with extinguishing foam | Disposal of (rinse) water and residual liquids | Limited |
| / | Agriculture: use of pesticides, biocides | Very specific components. | Limited, further research is needed to better estimate this probability. |
| 41.6.1a<br>41.6.1b | Carpet manufacturing plants with an installed motive power of<br>- 5 – 200 kW in industrial area<br>- 5 – 100 kW not in industrial area | A large amount of PFAS is used in carpets. It is expected that the amount of PFAS used in these subcategories can be considered very small, given the limited installed motive power. Consequently, the likelihood of soil contamination in this closed | Limited |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| | | process is considered to be very low. However, subcategories with higher power are VLAREBO. | |
| 29.5.5.1a<br>29.5.5.1b | Surface treatment, including degreasing of metals by an electrolytic or chemical process, if the total volume of the treatment baths and rinsing baths used or of the collection containers for collecting the chemicals used is in the following volumes<br>- 10 – 1.000 l in industrial area<br>- 10 – 300 l not in industrial area | At new sites, this is a closed process, so there is very limited (to no) risk. At old sites, this is an open process, so there is a greater risk of soil contamination. However, these volumes can be considered very small, so the risk of soil contamination from these activities can be considered very low. However, subcategories with higher volumes are VLAREBO. | Limited |
| 2.2.3.c.1<br>2.2.3.c.2<br>2.2.3.c.3 | Composting of organic commercial waste:<br>- max 25 m³ and only commercial material<br>- other, up to 2.000 m³<br>- more than 2.000 m³ | For category 2.2.3.c.1, the volume is limited.<br>For categories 2.2.3.c.1 to c.3: highly dependent on which waste products are composted. The risk is more likely if the compost contains PFAS | Limited |
| 2.3.3.a.1<br>2.3.3.a.2 | Storage and biological treatment for final disposal or destruction, of non- | Biological treatment: composting or fermentation: highly dependent on type of waste product. Risk is | Limited |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| | hazardous waste<br>- max 25 m³<br>- more than 25 m³ | more likely at the site where the composted or fermented material is used. | |
| Other activities | | | |
| 33.3.1a<br>33.3.1b<br>33.3.2a<br>33.3.2b<br>33.3.3a<br>33.3.3b | Plants for the treatment of paper and cardboard for the manufacture of goods from paper or cardboard<br>- 5 – 200 kW in industrial area<br>- 5 – 100 kW not in industrial area<br>- 200 – 100 kW in industrial area<br>- 100 – 500 kW not in industrial area<br>- >1.000 kW in industrial area<br>- >500 kW not in industrial area | This category includes mechanical handling (e.g., folding, rolling), which is less suspicious than paper production itself. It may also include gluing and pasting, which is more suspicious of PFAS, but these activities are usually permitted under another category in the list. Since the PFAS are already in or on the paper when it is mechanically treated, this can be considered a closed process with very little chance of soil contamination. | No soil contamination expected |
| 13.2.1.a<br>13.2.1.b<br>13.2.2.a<br>13.2.2.b | Facilities for the conditioning and packaging pharmaceutical substances with an installed total drive power of:<br>- 5 – 200 kW in industrial area<br>- 5 – 100 kW not in industrial area<br>- 200 – 1.000 kW in industrial area<br>- 100 – 500 kW not in industrial area | Packaging of pharmaceutical substances contains PFAS. However, this category includes packaging of the pharmaceutical substances where the packaging is likely to be supplied and therefore not produced on site. Not retained because the primary production and disposal of the packaging is suspect. | No soil contamination expected |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| 36.2 | Tire production plants | There is no source that links PFAS to tires. There is only mention of PFAS in rubber in general. If PFAS are present, they are more likely to be released into the environment through abrasion. | No soil contamination expected |
| 2.3.2.f | Storage and physicochemical treatment of liquid residues from the filling and cleaning of pesticide application equipment | Strongly dependent on the type of pesticide. Also relevant for other biocides. However, it is expected that the quantities applied are limited and then storage and handling can be considered as a closed process. | No soil contamination expected |
| 2.3.3.b | Storage and biological treatment of liquid residues from the filling and cleaning of pesticide application equipment | | No soil contamination expected |
| 3.6.1<br>3.6.3.1a | WWTP, including discharge of effluent and dewatering of associated sludge production:<br>- domestic wastewater, non-residential - more than 600 m³/year<br>- commercial wastewater – 1 to 5 m³/h<br>a) without hazardous substances above classification criterion | Minor discharges but may affect sediment/surface water. Even if no hazardous substances above classification criterion: PFAS may not always have been assessed in the past. | If discharges from activities are included in this study: see probability for these activities |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
| --- | --- | --- | --- |
| 3.6.4.2 | WWTP, including the discharge of effluent and dewatering of associated sludge production: WWTP -20 – 500 IE | | |
| 3.2.2.a<br>3.2.2.b | Discharge without treatment of domestic wastewater, non-residential - more than 600 m³/year | | |
| 52.1.1.1<br>52.2.1 | Indirect discharge to groundwater within water catchment area and protection zone, indirect discharge of hazardous substances<br>- domestic wastewater<br>Outside water catchment area and protection zone indirect discharge of hazardous substances<br>- domestic wastewater | | |
| 3.4.1a | Discharging commercial wastewater without treatment:<br>- up to 2 m³/h and no hazardous substances | | |
| 34.1.1.a,b | Soap manufacturing plants and establishments producing raw | PFAS are often added to products for their surfactant properties. However, this category | No PFAS contamination expected |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| 34.1.2.a,b<br>34.1.3.a,b | materials for surfactant products or processing for technical purposes<br>- 5 – 200 kW in industrial area<br>- 5 – 100 kW not in industrial area<br>- 200 – 1.000 kW in industrial area<br>- 100 – 500 kW not in industrial area<br>- >1.000 kW in industrial area<br>- >500 kW not in industrial area | covers the production of raw materials, not preparation or blending. As a result, very low to low levels of PFAS are expected in a closed process, so the likelihood of soil contamination is very limited. | |
| 58 | Crematoria | Elevated concentrations of PFAS are measured in human blood (+ textiles, etc.). Combustion mainly breaks down longer chains, but short chains require very high temperatures (1.400°C) before they can be broken down. However, these are very small amounts. Estimation: based on an average PFAS concentration of 5 ng PFAS/ml blood, taking into account the number of cremations in the Netherlands (overestimated compared to the rest of the EU) and extrapolated to the whole EU population, this results in an emission of about 62 g/year for the whole EU. Due to this very small | No PFAS contamination expected |

| VLAREM category | Description | Motivation | Decision probability soil contamination |
|---|---|---|---|
| | | amount, the risk of soil contamination from this activity is considered to be very limited. | |
| 30.8.1.a<br>30.8.1.b<br>30.8.2.a<br>30.8.2.b<br>30.8.3.a<br>30.8.3.b | Manufacture and processing of glass articles with a total installed drive power of:<br>- 5 – 200 kW in industrial area<br>- 5 – 100 kW not in industrial area<br>- 200 – 1.000 kW in industrial area<br>- 100 – 500 kW not in industrial area<br>- >1.000 kW in industrial area<br>- >500 kW not in industrial area | It is unclear at what step(s) PFAS are added in the manufacturing and processing of glass articles. This may already be included in VLAREBO category 20.3.4.2, but it cannot be excluded that PFAS are also used in this category. However, the amount of PFAS used in this process is considered to be very low to low, so the likelihood of soil contamination from these activities is considered to be very low. | No PFAS contamination expected |

# 5 APPLICATIONS PFAS

This chapter briefly describes the major uses of PFAS. As mentioned earlier, these are divided into the following categories:

- PFAS producing industry
- PFAS processing industry – activities using PFAS in processes
- Use of products containing PFAS
  - Use of firefighting foams
  - Industries/activities using products or articles containing PFAS (end uses)
- Waste disposal

This chapter describes each of these activities in more detail and documents the assessment of the risk of soil contamination.

## 5.1 PFAS-PRODUCING INDUSTRY

Historically, two processes have been used to produce PFAS: electrochemical fluorination (ECF) and telomerization (TM). At the two most prominent production sites of PFAS precursors in Europe, 3M in Zwijndrecht (Belgium, since the mid-1970s) and Miteni in Trissino (Italy), PFAS were produced by ECF (2).

Prior to 2001, PFAS production was dominated by 3M's ECF process, which formed perfluorooctane sulfonfluoride (POSF) as the main product (30-45% of production), along with a collection of other PFCAs and PFSAs. POSF can be broken down into long-chain PFCAs or PFSAs (e.g. PFOS) and was the precursor to produce PFOS-related chemicals. ECF was also used at the 3M site in Zwijndrecht. This process was economically interesting because of its low energy costs and relatively cheap starting product. However, the process produced many by-products and waste products (2).

Since 2001, the production of PFAS by ECFs has been greatly reduced due to concerns about the environmental impact of PFOS, and telomerization (TM) has become the primary method of PFAS production. This process does not produce PFOS or PFOS precursors, but fluorinated telomers instead.

The two synthesis routes result in different degrees of product. In general, the ECF process produces even and odd, branched and linear perfluorinated carbon chains. TM produces only even linear chains.

The environment around PFAS production sites is contaminated with PFAS due to years of (permitted) waste discharges into the environment. In the area around Trissino (Italy), this has resulted in a contaminated area of more than 200 km² (WHO, 2016). In the Antwerp port area, the area around the 3M production site is contaminated.

| Activity | Estimated annual production of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| PFOS/PFOA production, telomeres | 53.000-118.000 tons/year | Very high | Indirect | Emissions to air and water, possibility of incidents | Very high | 7.11.1.f, 20.4.2.1, 20.4.2.2 |

## 5.2 PFAS PROCESSING INDUSTRY

### 5.2.1 Production and processing of fluorinated polymers and fluoropolymers

**Application**

The PFAS processing industry includes the production and processing of fluoropolymers (including Teflon and FEP), polymers with fluorinated side chains, fluorinated rubbers and the drying and application of polymers. Teflon and other fluorinated polymers are used as semi-finished products for various industries (plastic (process) pipes, non-stick pans, etc.). The most commonly used types of PFAS for this purpose are PFOA and GenX. PFAS have been used in this way since the 1960s.

In the production of fluoropolymers, fluorinated substances are used not only as raw materials but also as auxiliary agent: as catalysts, suspension media, surfactants or in the finishing of the extrusion process to give the fluoropolymers the desired shape (8).

**Volumes**

The production and processing of fluorinated polymers and fluoropolymers is typically a large-scale chemical industry where very large quantities of PFAS are used over long periods of time.
The PFAS processing industry, such as Teflon® production, uses large quantities of PFAS (12). Therefore, the probability for serious PFAS soil contamination at these sites is high due to the high volumes used.

#### 5.2.1.1 PFAS as a polymerization auxiliary agent

**Type of PFAS components and application**

Substances used in the polymerization process are PFOA, PFNA, PFHxA, 6:2 FTSA, HFPO-DA and dodecafluoro-3H-4,8dioxanoate.

PFOA was used until around 2012 in the production process of fluoropolymers such as polytetrafluoroethylene (PFTE, Teflon). At Chemours (formerly Du Pont) in Dordrecht, the Netherlands, PFOA was used in the production of Teflon, FEP (perfluorinated ethylene-propylene) and Viton (a certain type of rubber). PFOA was also used in the production process of perfluoroalkoxy polymers (PFA polymers).
As of 2013, PFOA has been completely replaced by the GenX process in Dordrecht. The GenX process is based on the perfluorinated compounds FRD-902/903 (ammonium or hydrogen)-2,3,3,3-tetrafluoro-2(heptafluoropropoxy)propanoate) and the conversion product E1 (heptafluoropropyl-1,2,2,2-tetrafluoroethyl ether) (13). There are also production sites in Mechelen and Zwijndrecht where PTFE is manufactured.

**Volumes**

Studies have shown that when PFOA is used as an auxiliary agent in the production of polymers, the final product can contain relatively high levels of PFOA (0,1 – 0,5%). This also means that importing PTFE from countries where PFOA is still used as an auxiliary agent, results in importing significant amounts of PFOA (estimated at 3 - 16 tons of PFOA per year in the EU) (12).

#### 5.2.1.2 PFAS used in extrusion of thermoplastic plastics

**Type of PFAS components and applications**

PFAS are used as additives in the extrusion of plastics, for example in the production of LDPE and HDPE. Typical processes in which this is used are the production of films, pipes, sheets, cables, extrusion dies, tapes and fibres. Typical PFAS used for this purpose are PTFE, FEP and perfluoroalkoxyalkanes (PFA) (8).

| Production and processing of fluorinated polymers and fluoropolymers | Estimated annual consumption of PFAS in EEA | Assessment of quantity of PFAS | Emissions | Additional considerations | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| **Fluoropolymers and polymers with fluorinated side chains** | Fluoropolymers: 49.000 – 102.000 tons/year | Very high | Indirect | Large-scale chemical industry, used very high levels of PFAS for a long time | Very high | 7.11.1.h, 20.4.1.1, 20.4.1.2 |
| **Production and surface treatment of plastics** | Polymers with fluorinated side chains: 54.000-118.000 tons/year | | | Frequent incompletely treated discharges to air and water, atmospheric deposition possible | | 23.4, 23.2.2.a, 23.2.2.b, 23.1.1b, 23.1.1c |
| **Fluor-containing rubbers** | 8.300 tons by 2020, earlier possibly more | High to very high | Indirect | Presumably higher quantities used previously | Very high | 7.11.1.i, 7.12.2.c, 59.15, 36.1, 36.3.1.b.1, 36.3.1.b.2, 36.3.2 |

### 5.2.2 Textile

**Application**
PFAS are used to provide water and dirt repellency in, for example, clothing, shoes, tents, umbrellas, carpets and furniture (e.g. Scotchgard$^{TM}$). The amount of PFAS in these materials ranges from 2-3% by fibre weight to 15% in synthetic carpets. Polymers of PFAS are commonly used. These polymers may contain PFAS residues from the manufacturing process (residues of unreacted monomers and/or auxiliaries) or they may degrade to fluorotelomers such as FTOHs and perfluorocarboxylic acids such as PFOA and PFHxA.

**Type of PFAS components**
To main types of PFAS (polymers) are used to provide water and dirt repellency:
- Polytetrafluoroethylene (PTFE/Teflon) for waterproofing (outdoor) clothing and tents. PTFE is a high molecular weight fluoropolymer and is therefore used in the manufacture of porous fabrics such as Gore-Tex ®. A thin layer of PTFE is added to the fabric to strengthen it and make it breathable. The thin layer of PTFE has 1,4 billion pores per $cm^2$. The pores are smaller than raindrops but larger than water vapor molecules, making the fabric waterproof, yet breathable. The most commonly used fluoropolymers, in addition to Teflon are Polyvinylidene fluoride (PVDF), perfluoropolyethers (PFPE), fluorethylene propylene (FEP) and perfluoroalkoxy PFA (8).
- Polymers with fluorinated side chains, e.g. fluorotelomeric acrylate polymers. These are used in textiles, carpets and leather, for example because of its water and dirt repellent properties. When the polymer degrades, the fluorinated side chains are released. This can happen during use, as well as during washing.

In general, C8-based fluorochemicals (e.g., PFOS, PFOSA, PFOA) were considered the best product in the textile industry (e.g., Scotchgard$^{TM}$). These C8 compounds were later replaced by shorter-chain PFAS. According to the RIVM study "Impregnating agents," the Dutch leather industry uses C4 polymers as an alternative to the C8 compounds. Other sources also refer to C2-C3 and C6 PFAS.

**Information on PFAS contamination for this application**
According to a study conducted by the VMM in 2022, which investigated the dominant PFAS substances in wastewater from different sectors through a large-scale monitoring campaign, PFPeA, PFHxA and PFOA are the main compounds found in textile wastewater (14).

**Volumes and type of process.**
The volumes of PFAS used in the textile sector are high compared to other applications. On an annual basis, it is estimated that about 40.000 – 145.000 tons of PFAS are used in this sector in the EEA, spread over different sub-categories such as home textiles, consumer clothing, professional clothing, technical textiles, medical textiles, leather, ... (8). The Belgian industry is mainly specialised in technical textiles and textiles for interiors (carpets, furniture, mattresses, etc.). The consumption of PFAS in Belgian production is estimated at 200 – 3.500 tonnes (excluding medical textiles) (10).

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Pretreatment and treatment of textiles and wool, textile finishing | 41,000-142.000 tons/year | Very high | Indirect | Depending on type of textile | High for regular textiles | 41.4.1a, 41.4.1b, 41.4.2a, 41.4.2b, 41.4.3a 41.4.3b 41.10, 41.3.1a and b, 41.3.2a and b, 41.3.3a and b |
| | | | | | Very high for textiles made water and grease repellent | |
| Carpet production | | Very high | Indirect | / | Very high | 41.6.2a, 41.6.2b, 41.7 |
| | | Small to moderate | Indirect | Smaller facilities with limited drive power | Limited | 41.6.1a 41.6.1b |
| Leather production | | Rated moderate to high | Indirect | / | High | 25.1.1, 25.1.2, 25.1.3 |
| Shoe Manufacturing | | Rated moderate to high | Indirect | / | High | 59.11 |

### 5.2.3 Paper and packaging industry

**Application**

PFAS are used in the production of greaseproof and waterproof paper or packaging, which is often, but not exclusively, used in the food industry. Perfluorinated surfactants are added to the wet pulp where they are mixed with cellulose fibres before the paper is formed, to increase the wetting and thus also the efficiency of the pulping process (15) (16).

PFAS can be found in the following applications, among others:

- Food/feed packaging: baking paper, heat resistant packaging, milk packaging, films, frozen food packaging, coatings in cans (including beverage cans), disposable plates, cutlery, straws, jars, pet food, animal feed
- Packaging in general: paper and cardboard, wallpaper, tablecloth, carbon paper, plastic jars (coating), coated plastic, glass, metal
- Others: toilet paper, fireworks

**Types of PFAS components**

Water and grease repellent papers are often treated with fluorinated polymers. This group consists of a large number of different substances (6). Some examples are PFOA, PFOS, PFPeA, PFHxA, GENX/HFPO-DA, perfluoroalkyl ethers and perfluoroalkyl phosphonic acids (PAP and diPAP), perfluoropolyethers and fluorotelomer alcohols (6:2, 8:2, 10:2, 12:2, 14:2 and 16:2 FTOH) (8) (10). At a historic paper plant in Willebroek, PAPs and diPAPs and etPFOSAA were detected in addition to PFOS. In the effluent of the paper industry, 6:2 FTS is the main substance found (see also paragraph 5.4.5) (14).

PAPs can migrate from packaging to food and thus be absorbed into the body. Through biotransformation, PAPs can be converted to PFCAs (e.g. PFOA), so despite the lack of toxicological data on PAPs, the health effects of PFCAs may also be related to this group (17). In beverage cans PTFE wax or PTFE micropowder is used often.

The PFAS substances used in non-food packaging have also varied over time. Between 1960 and 2000, mainly long-chain (>C6) PFAS were used, whereas currently mainly C6-fluorotelomers and poly- and perfluoropolyethers are used (15). These PFAS are also used in the manufacture of plastic packaging (see also section 5.2.1). Fluorinated plastics such as fluoroethylene propylene (FEP), perfluoroalkoxy (PFA) and fluoro rubber (FKM - fluoro rubber material) are also used in this process (8).

**Volumes and type of process.**

Approximately 800 to 5.000 tons of PFAS would be used annually by the paper industry in various applications. The largest amounts will be in imported or recycled paper. The paper industry is currently predominantly a closed process, but emissions to air and water are possible. In the past, direct emissions were likely due to limited soil protection measures. Paper sludge has also been used as soil amendment, whether or not in the immediate vicinity of the production site (see also section 5.3.12).

A study in the USA showed that FTOH was present in 90% of the food packaging tested at an average level of about 0,4 mg/kg (18). Research by Kotthoff (19)showed that many PFCAs were present in pre-2010 baking paper (baking paper muffin, PFNA+PFDA=1 mg/kg), but much lower levels were measured in 2015 samples (14 and 18 µg/kg for PFOA and PFPeA, respectively). Low levels of PFAAs were found in baking paper and bread wrapping paper in 2015 (19).

In addition to packaging, PFAS are also used in other forms of paper, including toilet paper. In particular, 6:2 diPAP has been detected in toilet paper and sewage sludge. In addition, toilet paper is often made from recycled paper, which is known to often contain PFAS due to its water and oil repellent properties and as a wetting agent to promote the pulping process as described above (16).

| Activity | Estimated annual use of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Production and treatment of paper | 800 – 5.000 tons/year | High, possibly even higher in recycled material and paper sludge | Indirectly, possibly also directly if soil protection measures are inadequate, or if waste is spread around the plant | Presumably higher quantities used previously | Limited for production facilities with no direct emissions<br>High for sites using recycled paper/sites with direct emissions | 33.1, 33.2.a.1a, 33.2.a.1b 33.2.a.2a, 33.2.a.2b, 33.2.a.3a, 33.2.a.3b, 33.2.b.1a, 33.2.b.1b, 33.2.b.2a, 33.2.b.2b, 33.2.b.3a, 33.2.b.3b, 33.2.c.1a, 33.2.c.1b 33.2.c.2a, 33.2.c.2b, 33.2.c.3a, 33.2.c.3b, 33.2.d.1a, 33.2.d.1b, 33.2.d.2a, 33.2.d.2b, 33.2.d.3a, 33.2.d.3b, 33.2.e, 20.5.1, 20.5.2, 41.9.1, 41.9.2, 41.9.3, 41.11 |

### 5.2.4 Application in electroplating and making metal products

**Application**

In the electroplating industry, PFOS is used primarily in chromium plating. It was (and still is) used to reduce worker exposure to chromium VI. Chromium plating involves passing an electric current through a bath of chromic acid. This creates oxygen and hydrogen gas bubbles that burst on the surface. PFOS is used to reduce the surface tension of the chromic acid bath, which reduces the size of the bubbles and fewer bubbles burst at the interface, thereby reducing the release of carcinogenic chromium VI into the air (20).

PFAS are also used in electroplating with nickel, copper, tin, and zinc as a ‘wetting agent’, also to reduce surface tension and prevent foaming. Fluoropolymer particles are also applied to steel as a protective coating (8).

Figure 12 : Chroming-plating bath (with orange foam) with rinse baths (EPA, 2009)

After the chromium-plating bath, the chrome plated metal is rinsed with water in several rinse baths. Consequently, these rinses are contaminated with PFOS. The main alternative to PFOS currently in use is 6:2 FTS. This substance is similar to PFOS, but the two carbon atoms adjacent to the sulfate atom are not fluorinated. 6:2FTS is a precursor of PFHxA.

Other applications in the metal industry include:

- used as an additive in the application of coatings to metal: PFAS reduces surface tension to promote the flow of the coating and prevent cracking during drying.
- it is also used in aluminum processing during etching to increase the efficiency of alkaline baths and to dissolve the oxide layer in the phosphating process.
- as a corrosion inhibitor (protective coating).
- for electrical insulation of metal.
- cleaning of metal surfaces: fluorinated surfactants promote the removal of dirt from the baths, accelerate the rinsing of acids when metal objects are removed from the baths, and extend the life of the baths.
- and in anti-adhesive coatings e.g. in molds (e.g. in the automotive industry).

**Volumes and type of process**

The amount used in electroplating in the EU is estimated to be much lower (2 – 57 tons/year) than the amount used in the production of metal articles (960 tons/year) (8). Specifically for Belgium, the quantities are estimated to be 1,7 tons/year and 25 tons/year respectively (10). Closed baths and production lines are often used today, but the use of open baths is still possible and was widespread in the past. Consequently, older sites are more likely to contain PFAS.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Metal surface treatment/ electroplating | Estimated about 2 – 57 tons/year for electroplating, 960 tons/year for production | Moderate to high | Indirect and direct (spills, inaccurate use) | Smaller operations with limited content treatment baths | Limited | 29.5.5.1a 29.5.5.1b |
| | | | | Already identified in a few sites in Flanders | Limited at recent plants with no direct emissions | 29.5.5.2a, 29.5.5.2b, 29.5.5.3, 29.5.5.4 |
| | | | | | High at sites with direct emissions/older sites | |
| Cleaning of metals | Unknown | Rated small | Indirect | / | Very limited | 29.5.10.2.a, 29.5.10.2.b |

### 5.2.5 Lacquer, ink and paint industry

**Application**

PFAS are used in the manufacture of paints and varnishes, in part to improve viscosity, but also for their dirt-repellent properties (21). The amounts used are likely to be small because of the specific applications and the availability of cheaper alternatives (12).

**Type of PFAS components**

Fluoropolymers, primarily PTFE, are used. Individual PFAS (including PFSAs and PFCAs) and sulfonamides are also used.

**Volumes and type of process**

In terms of quantity, it is estimated that around 500 t/year of PFAS are used in the EEA in packaging inks alone. As inks are also used in other applications, the total amount of PFAS involved is even higher. In Sweden, Finland, Norway and Denmark alone, about 5.000 tons of PFAS would have been used in this industry between 2000 and 2017, which corresponds to about 300 tons per year. Consequently, the annual production within this industry can be estimated to be more than 1.000 tons/year in the EEA.

| Activity | Estimated annual consumption of PFAS in the EEA | Assessment based on quantity of PFAS | Emissions | Additional considerations | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Production of lacquers and paints using PFAS | 300 tons/year for coatings and paints,<br>500 tons/year for lacquer and ink in packaging | Estimated to be large | Not expected | No specific data on indirect emissions available | Limited | 4.1.2, 4.1.3, 7.12.2.c |

### 5.2.6 Coating agent

**Application**
Because of their surfactant properties, PFAS are often added to coatings to make them more absorbent on surfaces, spread more evenly and repel dirt (22). In addition, PFAS can also provide antistatic properties (15). Coatings containing PFAS are used in numerous applications: food packaging, beverage cans, medical devices, textiles, construction materials, paper... Many of these sectors are also mentioned elsewhere in this document, so there is some overlap. If there are any activities at a site where coatings are applied, this should always be considered in more detail.

Global volumes of PFAS used as coating agents are not available. However, estimates are available for some sectors - these are included in the table of estimated annual consumption. It can be concluded that the volume of PFAS used in coatings is very high.

**Type of PFAS components**
PTFE (as wax or micropowder) or other polymers (PCTFE, HFP, PVDF) are often used in coatings. In anti-adhesive and anti-corrosive applications, PTFE, FEP and ETFE are the most common. Sulfonamides and carboxylates are also used to coat metals. Perfluoroalkylphosphonic acids, fluorotelomers and FTOHs are also possible.

**Volumes**
The estimated annual consumption in these applications varies from about 500 to 100.000 metric tons depending on the sector, resulting in a very large amount of PFAS being used (23).

A study for the FPS Economy (FOD Economie) produced the following estimates of PFAS use in the coatings industry in Belgium. The estimates were provided by the industry itself.

Table4 : Breakdown of the Belgian paint and coatings sector by application with estimated PFAS consumption according to the Belgian IVP coatings federation (10)

| Sub-sector | Description | Size of Belgian industry | PFAS use |
|---|---|---|---|
| **Spray painting of cars** | Body protection coatings and paints for damaged vehicles | ++ | Presumably not |
| **Decorative coatings** | Architectural paints, including anti-graffiti coatings | ++++ | Yes |
| **Waterproofing** | Coatings to protect buildings, roof coatings | + | Presumably not |
| **Protection coatings for industry and transportation** | Coatings for the automotive industry, chemical and food production facilities, boats and offshore structures, bridges and architectural structures, port facilities and wind turbines | +++ | Yes, main application for the Belgian coating industry |
| **Thermal insulation** | Thermal insulation systems for exterior walls containing decorative and/or protective coatings | + | Presumably not |
| **Print ink** | Flexography, screen printing, gravure printing | + | Yes, - PTFE |

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Immersion | Paper and aluminum food packaging: > 500 tons/year<br>Kitchenware: 3.500 - 5.600 tons/year<br>Baking trays for industrial applications: 3.000 - 6.000 tons/year<br>Medical devices: 4.000 - 12.800 tons/year<br>Transportation sector: 1.000 - 10.000 tons/year<br>Textile sector: 41.000 - 142.000 tons/year<br>Building materials: 5.000 - 9.000 tons/year | Very high | Indirect and direct in the case of inadequate soil protection measures | / | High to very high | 4.2 |
| Mechanical, pneumatic/ electrostatic | | | | | | 4.3.a.1.i, 4.3.a.1.ii, 4.3.a.2.i, 4.3.a.2.ii, 4.3.a.2.3, 4.3.b.1.i, 4.3.b.1.ii, 4.3.b.2.i, 4.3.b.2.ii, 4.3.b.2.3, 4.3.c.1.i, 4.3.c.1.ii, 4.3.c.2.i, 4.3.c.2.ii, 4.3.c.2.3 |
| Surface treatment | | | | | | 4.6.a, 4.6.b, 59.2.1.1, 59.2.1.2 |
| Coating | | | | | | 59.3, 59.4.1, 59.5.1.1, 59.5.1.2, 59.5.2.1, 59.5.2.2, 59.6.1, 59.7.1, 59.7.2, 59.9.1, 59.10.1, 59.10.2, 59.14.1, 59.14.2 |
| Application of adhesives | | | | | | 59.12, 59.13 |
| Coating of cans | 4,880 tons/year | High to very high | Not expected | / | Limited to high | / |

### 5.2.7 Glues and adhesives

**Application**
PFAS are used in solvent- and water-based glues and adhesives to increase the contact area between substrates. In addition, they improve the penetration of the adhesive into the pores of the substrate, thereby strengthening the bond (15). Some of the more prominent applications where PFAS-containing adhesives are used include building materials (tiles, ceilings, floors), adhesive tapes, pipe joints, solar panels, and photovoltaic cells (8) (12).

**Type of PFAS Components.**
In aviation, tapes with PTFE-based adhesives are often used to mark aircrafts. PFCAs (e.g. PFOA) are used in stickers, labels, and parts to which stickers and labels are applied (22).

**Volumes and type of process**
The use of PFAS in adhesives is reported in many different industries. Annual production figures are not available but are estimated to be moderate to high. The production of adhesives can be considered as a closed process.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Manufacturing of glues and adhesives | Not available | Estimated to be moderate to high | Not expected | / | Limited | 26.1.1.a, 26.1.1.b, 26.1.2.a, 26.1.2.b, 26.1.3.a, 26.1.3.b |

### 5.2.8 Electronic industry and semiconductors

**Applications**
PFAS are used in electronics and semiconductors to enhance their functionality. These include uses in cables, as a coating for membranes, filters, switches, motherboards, antennas, LCD screens, OLED screens, optical fibers, lenses, as a flame retardant, as a heat transfer fluid, as a sealant, as a solvent, as an aerosol, for cleaning components, as a lubricant, and for packaging semiconductors (8).

A very typical application is the manufacture of semiconductors. In general, a thin layer of a photosensitive polymer is applied to a substrate such as silicon 'wafers'. Light is then used to apply a geometric pattern to the photosensitive polymer. The polymer changes when exposed to light, making it easier or harder to remove. In this way, structures are built up on the substrate.

- Positive photosensitive substances (most common) become soluble in developer (fluid) when exposed to light;
- For negative photosensitive substances, the unexposed area is soluble in developer (fluid).

So-called ‘photoacid’ generators are used to increase the sensitivity of photosensitive substances to light. PFAS can have several functions in this process:

- They can be part of the photosensitive polymer;
- They can function as a photoacid generator or as an adjuvant to enhance the effect of light exposure;
- They can be used to add a thin coating to the polymer to prevent reflection, both on and below the photosensitive polymer;
- They are used as surfactants in developer (fluid) or in other auxiliaries (15).

PFAS also have various applications in the energy sector, e.g. solar panels, photovoltaic cells, heat exchangers, coal-fired power plants, nuclear power plants, lithium-, vanadium-, zinc- and alkaline batteries, fuel cells, transformers and electrical components. They are used there as adhesives, coatings, in filters, in gas scrubbers, as binders for electrodes, in membranes, to prevent corrosion of electrodes, as coolants, as insulators, and as flame retardants (8).

In Belgium, the specific use for the assembly of lithium batteries is estimated at 38,4 tons/year and for cable production at about 40 tons/year (10); the estimate for semiconductors is 66 tons/year.

**Type of PFAS components, volumes and type of process**
The main PFAS used in electronics manufacturing are PTFE, PFA, PVDF, ETFE, FEP and PFBS. Annual production in the EEA is estimated to be between 2.500 and 6.300 ton/year. The production of electronics can be considered as a closed process.
The main PFAS used in the energy sector are PTFE (and PVDF) (65%), PFA (14%), PFSA ionomer (5%). Consumption in the EEA is estimated at 2.800 – 3.200 tons/year. Mainly the production of the materials used in this sector and their waste management can be considered as potential sources of soil contamination, and to a lesser extent, their use.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contaminatio n | Categories |
|---|---|---|---|---|---|---|
| Production of electronics | 2.600 - 6.500 tons/year | High | Indirect | / | High | 12.4.2.a, 12.4.2.b, 12.4.3.a, 12.4.3.b |

### 5.2.9 Manufacturing of cosmetics

**Application**
PFAS are used in the cosmetics industry for a variety of reasons. Thy can be used in sunscreen and body lotions to make the cream water repellent. PFAS are also used in cosmetics as anti-caking agents, solvents, emulsifiers, antistatic agents, stabilizers, surfactants, film formers and viscosity regulators.

**Type of PFAS components.**
The most used substances are PTFE, C9-C15 fluoroalcohol phosphate, perfluordecalin, perfluoroctyl trietoxysilane, perfluornonyl demethicon, polyperfluoromethyl isopropyl ether, octafluorpentyl methacrylate, acetyltrifluoromethylphenyl valylglycine and methyl perfluorobutyl ether (8).

Polyfluoroalkyl phosphoric acids (PAPs/diPAPs) are also used, and analysis of several cosmetic products indicates that PFCAs (including PFOA, PFHxA and PFHpA) may also be present in cosmetics (24).

**Volumes and type of process.**
EU consumption is estimated to be between 0,028 and 64,2 tons/year (8). The manufacture of cosmetics can be considered a closed process.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Manufacturing of cosmetics | 0,03 - 64 tons/year | Small | Not expected | / | Very limited | 22.1.1.a, 22.1.1.b, 22.1.2.a, 22.1.2.b |

### 5.2.10 Manufacture of cleaning and maintenance products

**Applications**
PFAS are also used in the manufacture of cleaning products (degreasers, dishwashing detergents, laundry detergents) and maintenance products (window cleaners, coatings for textiles and laundry, etc.). PFAS are often used in products that clean hard surfaces such as wood, glass, and floors (15).

**Type of PFAS components**
The types of PFAS used are very diverse. They include PAPs and PFCAs, as well as polymers with fluorinated side chains. PFOS has also been used in the past.

There are a number of PFAS-based textile coatings on the market for consumer use. The products usually consist of a mixture of PFAS and solvents, among other ingredients. The impregnating agents are applied to the fabric as a thin layer using an aerosol and form a thin polymer structure of both polyfluoroalkylated and non-fluorinated side chains on the surface. These side chains provide the dirt and water repellency (19). FTOH is primarily found in these impregnants, which can eventually degrade to PFCAs. Median concentrations in the impregnants can reach 146 mg/kg for 8:2 FTOH (precursor of PFOA), with a maximum of 719 mg/kg measured (19).

**Volumes and type of process.**
The annual consumption for the production of home maintenance products is estimated to be about 21-30 tons/year (8). The production can be considered as a closed process.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Production of cleaning agents | Estimated at 21 - 30 tons | Small | Not expected | / | Very limited | 34.2.1.a, 34.2.1.b, 34.2.2.a, 34.2.2.b, 34.2.3.a, 34.2.3.b |

### 5.2.11 Hydraulic fluids and lubricants

**Applications**
PFAS have been used as additives in hydraulic fluids in filling and refilling operations since at least 1970. The main use is in aircraft construction and maintenance (3).

PFAS are also used in low viscosity lubricants, motor oil (rather limited), lubricating greases and oils. PTFE micropowder is often added (8). Lubricants containing PFAS are used when the lubricant must be resistant to high temperatures or outdoor applications, such as aerospace and offshore technology. Lubricants with PFAS are therefore used in many industries where there are high or low temperatures, such as the food industry, civil and military aerospace, military applications, automotive industry, trains, nuclear industry, watches, hearing aid manufacturing, electronics, laboratory equipment, medical equipment, renewable energy industry such as wind turbines and battery cells, offshore oil and gas industry, chemical industry, gas industry, metalworking, steel industry, waste water treatment, diving equipment, prosthetics, wheelchairs, paper production, plastics production, rubber production, textile production, pharmaceutical industry, ... (8).

**Type of PFAS components.**
38 PFAS have been identified for use in lubricants - these are listed in Table A.107 of Annex A of the REACH restriction document for PFAS[1]. PTFE and PFPE are the main ones.

An analysis of 18 different automotive lubricants and hydraulic fluids in the United States found at least 9 of the 13 PFAS detected in all 18 products. The average total concentration was 1.880 ng/g after oxidation in the PFAS TOP assay. Concentrations were much higher after oxidation, indicating that precursors were primarily present (25).

**Volumes and type of process.**
Total consumption in the EEA is estimated at 1.200 – 2.200 tons/year (8). Lubricant production can be considered a closed process.

| Activity | Estimated annual use of PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Production of lubricants and hydraulic fluids | 1.200 – 2.200 tons/year | High | Not expected | / | Limited | 44.2.2.a, 44.2.2.b, 44.2.3.a, 44.2.3.b |

### 5.2.12 Firefighting foam production

**Application**
PFAS are used in fire extinguishing agents, primarily in Class B AFFF (aqueous film forming foam) foams. These AFFF products are made by combining hydrocarbon foaming agents with fluorinated surfactants. Foaming agents consist of a variety of substances that work together to provide effective foam dispersion over the liquid, storage stability, and fire resistance. The foaming agent includes various surfactants (e.g.

[1] d2f7fce1-b089-c4fd-1101-2601f53a07d1

fluorochemicals, proteins, hydrocarbons, silicones), stabilizers, solvents, and specialty ingredients such as corrosion inhibitors and biocides.

There are many types of firefighting foams:

- Class A foams were developed to fight forest fires. It lowers the surface tension of water, allowing it to penetrate deeper into the burning material. It is therefore also used for extinguishing building fires. These foams typically do not contain PFAS unless they are blended with Class B foams (26).
- Class B foams are used to extinguish flammable liquids. There are two main groups:
    - Synthetic foams
        - **Aqueous film forming foam (AFFF):** contain PFAS (27)
        - **Alcohol resistant AFFF (AR-AFFF):** contain PFAS (27)
    - Protein foams - these are biodegradable. Again, there are several subgroups, some of which contain PFAS:
        - Regular protein foams - do not contain PFAS
        - **Fluorinated protein foams (FP)** - contain PFAS
        - **Film forming protein foams (FFFP**) - contain PFAS (27)
        - **Alcohol-resistant fluorinated protein foams (FPAR**) - contain PFAS (27)

There are also fluorine-free foams (FFF, or F3 foams) - these do not contain any fluorinated substances. These include regular protein foams, alcohol-resistant protein foams (AR-P), synthetic fluorine-free foams (FFF), and synthetic alcohol-resistant fluorine-free foams (AR-FFF).

PFAS are suitable for **Class B** foams because of their ability to form a sealing film layer very quickly. The fluorine components are chemically and thermally very stable, even at extremely high temperatures, and under extreme conditions the compounds remain intact and the foam continues to function (e.g. highly aggressive acidic or basic fuels and chemicals). Therefore, due to its unique ability to repel both hydrophilic (water) and hydrophobic (grease, oil, fuel) compounds, there is little risk of fuel being absorbed into the foam when using AFFF.

**Type of PFAS components**

PFOS and its derivatives were used in firefighting foams from the late 1960s until 2001. PFOS production was then phased out due to environmental concerns. Since 2001, firefighting foams have been made with fluorosurfactants based on fluorotelomers, such as 6:2 FTS and 8:2 FTS (fluorotelomer sulfonates). PFHxS has also been produced in higher volumes since 2011 (28).

PFOA has been used in AFFF to a lesser extent than PFOS, but is often present in AFFF, mostly as a byproduct of the production of the PFAS used in AFFF.

AFFF contains a wide range of fluorinated precursors. The composition of AFFF varies from manufacturer to manufacturer and is often confidential. The information provided on a firefighting foam MSDS is often not sufficient to determine which PFAS are present in the particular AFFF (substances used are confidential or concentrations are too low to be listed on the MSDS). The terms PFOS-free and PFOA-free usually indicate that other PFAS are present in the firefighting foam. Only when the term PFAS-free (or PFC-free) is used can it be assumed that no or very low levels of other PFAS are present in the foam. Due to the specific properties of PFAS (strong adhesion and grease/water repellency), pipes, pumps, tanks, etc. in which PFAS-containing foam was present must be specifically cleaned to be PFAS-free. This rinse water is typically collected and recycled. If this cleaning has not been done intensively, even when switching to non-PFAS foams, the occurrence/residues of PFAS cannot be excluded. AFFF typically contains several types of PFAS compounds, and 240 individual PFAS have been detected in AFFF (29).

**Volumes and type of process**

The amount of PFAS-containing foams produced in the EU is estimated at 14.000 to 20.000 tons/year, resulting in a PFAS use of about 500 tons/year (30)- estimated based on data from the period 2018 - 2020 and an average PFAS concentration of 2,5 to 3,5%.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimate probability of pollution | Categories |
|---|---|---|---|---|---|---|
| Production of firefighting foam | 500 tons/year of PFAS (14.000 - 20.000 tons of foam) - previously probably more | Moderate | Indirect and direct in the case of inadequate soil protection measures | Experience with production sites in Belgium indicates significant contaminations | High | 7.1.1, 7.1.2, 7.1.3 |

### 5.2.13 Production of medical materials

**Applications**

PFAS are used in a wide range of medical materials. The most important are listed below (8):

- Gauze and wound dressings - especially for hernia surgery (PTFE or PVDF), surgical staples (PBSF coated) and silicone tape
- Implants (PTFE, also PVDF and FEP)
- Tubing and catheters (PTFE, FEP, PVDF)
- Coatings (PTFE, fluoroelastomers)
- Cleaning and heat transfer - technical fluids: used to coat needles, scalpels, blood bags, filters and PVC tubes
- Sterilization gases: fluorinated gases as a substitute for the CFCs that were phased out
- Packaging: coating the inside of packages of liquid medication (often ETFE or PTFE)
- Electronic equipment (see also section 5.3.3) e.g. scanners, screens, ...

- Diagnostic laboratory testing: refrigerators, ultra-low temperature freezers, cryogenic storage, lyophilization
- Contact lenses: typically fluoromethyl acrylates
- Eyeglass lenses: coated with PFAS to make them easy to keep clean, grease and water resistant and scratch resistant
- Inhalers - often made of aluminum coated with a fluoropolymer (PFA or FEP), the propellant may also be a fluorinated gas
- Additive to HPLC in analysis (trifluoroacetic acid (TFA))
- Medical textiles (mainly fluorotelomers)

For the production of materials containing PFAS in medical clothing, packaging and electronics, see also sections 5.2.2, 5.3.3 and 5.2.15.

**Type of PFAS components and volumes**
Total annual consumption in the EEA is estimated at 25.000 to 61.000 tons, excluding textiles (8). For Belgium, this is estimated at 3.175 tons/year (10).

There is no specific category for the manufacture of products intended for the medical sector. Therefore, see the sections on coating agents, textile, electronics, polymers, metal, …

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Production of medical materials | 25.000 – 61.000 tons/year | High | Indirect | Strictly regulated production sites | Limited | See related categories under coating agents, textile electronics, polymers |

### 5.2.14 Production of pesticides, biocides and medicinal products

**Applications and type of PFAS components.**
Some of the agents used in these applications belong to the PFAS group. These substances are often chemically different from other PFAS subgroups. They often have one or more $CF_3$ groups in their molecular structure. As a result, the metabolites and degradation products of these substances can be very stable. Trifluoroacetic acid (TFA) is one of these possible degradation products and is extremely persistent in the

environment (8). In Belgium, there are currently 32 active substances in pesticides that belong to the PFAS group (31).

PFSAs, perfluoroalkyl phosphinic acids and fluorotelomer alcohols are also used as adjuvants in pesticides. They are listed in patents as antifoaming agents for herbicides, fungicides or insecticide mixtures. Their use as dispersants is also mentioned. Concentrations from 0,01 to 3% by weight of the mixture are mentioned, while other patents mention concentrations from 0,1 to 20 g/l. It is not clear to what extent PFAS have been used for these applications in Europe and Flanders. This use as a dispersant has been banned in the United States since 2008. In Belgium, 3 PFAS substances are still present as adjuvants in 5 pesticides. 1 of these is a propellant (31). PFAS may also be present in fertilizers. One patent relates to coating manure particles with PFAS polymers to reduce dust formation (22).

The use of PFAS as active ingredients in pharmaceuticals in the EEA is estimated to be over 500 tons/year for human use. No data are available for veterinary use. An overview of known substances is given in Tables A.108 and A.110 of Annex A of the PFAS restriction document[2].

The total consumption of active substances for pesticides in the EEA is 5.479 tons/year - 2% of the total use of PFAS. For Belgium this is estimated to be 529 ton (10). Data on use as inactive ingredient are unknown (10). Uses for biocides are not known in the EEA (8). The production of pesticides can be considered as a closed process. The use (see paragraph 5.3.11 ) of pesticides is more of a diffuse problem.

| **Activity** | **Estimated annual consumption of PFAS in EEA** | **Assessment based on quantity of PFAS** | **Emissions** | **Additional consideration** | **Estimated probability of soil contamination** | **Categories** |
|---|---|---|---|---|---|---|
| Production of pesticides | Production: unknown<br>Utilization: 5.500 tons/year | High | Indirect | / | High | 5.4.1, 5.4.2, 5.5, 7.2.4, 7.12.2.a, b and c |
| Production of PFAS containing pharmaceuticals | Active ingredients: 500 tons/year | Moderate | Indirect | / | Limited | 7.2.5, 7.11.4, 7.12.2.a, b and c, 13.1, 59.17 |

[2] d2f7fce1-b089-c4fd-1101-2601f53a07d1

### 5.2.15 Production of building materials

**Applications**

Products containing PFAS are used in many construction materials, such as roofing, cables and pipes, foam insulation, bridges, gaskets, and adhesives, e.g. for tiles, concrete, floors, drywall, ceilings, ceramics, linoleum, laminates. They are also added to many plastics used in construction, incorporated into materials as flame retardants, used in wood preservatives, in paints (see also section 5.2.5), to treat the surface of glass, doors and mirrors, the exterior of buildings, industrial structures, elevators, etc. Textiles that may contain PFAS are also recycled into building materials. For example, carpet flocks are used as fuel and as an additive to cement.

Specifically for glass, PFAS are used for (15):

- Surface treatment to make glass grease and water resistant. For example, lenses in cameras or other optical instruments to make them resistant to fingerprints, but also in the glass surfaces of smartphones and solar cells. PFAS coatings have also been used to prevent the evaporation of glass in humid conditions such as bathroom mirrors, car windows, eyeglass lenses and glass for greenhouses.
- Glass etching and polishing
- Drying of glass during finishing

**Type of PFAS components, volumes and type of process**

The total use of PFAS in the EEA is estimated to be between 5.000 and 13.000 tons/year, the vast majority of which are PFAS polymers (97% are PTFE, ETFE and PVDF).

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Production of building materials | 5.000 – 13.000 tons/year | High | Indirect | / | High | 19.1.2.a,b; 19.1.3.a,b; 19.2.2.a,b; 19.2.3.a,b; 19.4.1, 19.4.2, 19.4.3, 19.4.4, 19.7, 20.3.4.2, 20.3.8 |

## 5.3 USE OF PFAS CONTAINING PRODUCTS

### 5.3.1 Use of fluorinated gases

If PFAS are defined as compounds with at least one fully fluorinated carbon atom, this includes several small, fluorinated molecules that are often found in gaseous form. These are used as heat transfer agents in freezers, heat pumps, air conditioners and other applications.

Other uses of fluorinated gases include:

- Base product to manufacture fluorine chemicals and polymers.
- Use in medical applications (see category 5.3.8)
- Use as a foaming agent (e.g. for polyurethane foam or other insultating foams)
- As a solvent for cleaning metal in industrial applications (electronics manufacturing, fiber optics, aerospace materials, medical devices, ...)
- Aerosol propellant
- Protective gas, used to prevent rapid oxidation of a molten metal surface.
- Fire suppressant/retardant e.g. in archives and museums and in military applications.

Since these are gases, soil contamination with PFAS is not expected.

### 5.3.2 Ink and printing

PFAS are used in toners and inks, printing paper and lithographic circuit boards. PTFE is mainly used in printing inks. PFOS has also been found in the transport belts of color printers and copiers. In the EEA, about 500 tons of PFAS are used annually in paints and inks for packaging. As paints and inks are also used in non-packaging applications, this amount could be higher (8) (15).

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS in EEA | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| printing | Presumably smaller quantities than at production sites (see 5.2.5) | Estimated to be moderate | Not expected | / | Very limited | 59.1.1.1, 59.1.1.2, 59.1.2.1, 59.1.3.1.1, 59.1.3.1.2, 59.1.3.2.1, 59.1.3.2.2, 59.1.3.3.1, 59.1.3.3.2, 59.1.3.4.1, 59.1.3.4.2, 59.1.3.5, 59.1.3.6.1, 59.1.3.6.5, 11.1.2.a, 11.1.2.b, 11.1.3.a, 11.1.3.b |

### 5.3.3 Photo industry

PFAS are used in the photographic industry both in imaging equipment such as films (negatives, color film, etc.), photographic paper and reprographic plates, and in solutions for image processing. They act as anti-foaming products and prevent the formation of air bubbles in solutions to avoid image transfer failures. They are additives to emulsions, stabilizers and antistatic agents. PFOS and lithium perfluorooctane sulfonate were used as anti-reflective agents (15).

The amount of PFAS used in the photographic industry is currently unknown. It is estimated to be small.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Photo industry | Unknown | Estimated to be small | Not expected | / | Very limited | 11.2.2.a, 11.2.2.b, 11.2.3.a 11.2.3.b, 14.1.a, 14.1.b, 14.2.a, 14.2.b, 14.3.a, 14.3.b |

### 5.3.4 Marinas, seaports and shipyards

PFAS are used in some coatings and as anti-fouling agents in marinas and shipyards. The substances used are mainly perfluorinated urethanes, acrylates, PTFE and PVDF (15). The amounts of PFAS at these sites are unknown and depend heavily on the number of incidents that have occurred with foams and the size of the shipyard. The amounts are estimated to be low at seaports and marinas and low to high at shipyards. These sites can be considered as (semi-)open processes where soil protection measures are not always available. They can have an impact mainly on the sediment.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Seaports (area), marinas | Unknown | Small | Direct | Not always soil protection measures | Limited | 48.1.1.1a and b, 48.1.1.2 |
| Shipyards | Unknown | Small to high | Direct | Not always soil protection measures | Limited for smaller shipyards<br>High for great shipyards | 42.2.1, 42.2.2 |

### 5.3.5 Car and train washes (car wash)

Given the possible presence of PFAS in, for example, car waxes and lubricating oils, they could also potentially be released from car and train washes. However, the amount is estimated to be small. A study in the Netherlands found small amounts of PFAS in the effluent from a car wash. The highest concentration measured was for PFOA and was 20,0 ng/l (9). More research is needed to better understand the likelihood of soil contamination.

Sites where fire trucks are washed (e.g. fire stations or car washes at worksites fire departments) are an exception because PFAS-containing firefighting foam is washed off the trucks during the wash.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Wash stations for fire-fighting vehicles | Unknown, presumably limited quantities | Estimated to be very small | Indirect | Higher PFAS levels expected compared to other vehicles | High | 15.4.1, 15.4.2.a, 15.4.2.b |
| Other washing sites | | | | Further research indicated | Limited, pending further investigation | |

### 5.3.6 Garage and body shop

Given the presence of PFAS in many car-related products, they can also be released in auto repair and body shops (paints, lubricants, car waxes, etc.).

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Garages and body shops | Presumably rather small | Estimated to be very small | Indirect | / | Very limited | 15.3.1, 15.3.2, 15.2 |

### 5.3.7 Use in the transportation industry

**Applications**
PFAS are used in the transportation sector, including in the construction of car bodies, lubricants, fuel engines, hydraulic fluids, electronics, textiles, and coatings of transportation vehicles such as automobiles, ships, airplanes, and trains (8). See sections 5.2.2, 5.2.4, **Error! Reference source not found.**, 5.2.11, and 5.3.3 for more details.

**Type of PFAS components, use and type of process**
Given the wide variety of applications in the transport sector, the total amounts of PFAS are significant, estimated at 6.000 – 14.500 tons/year for PFAS polymers. One car would contain about 350 – 800 g of PFAS polymers, which corresponds to a stock of about 222.000 tons of PFAS polymers in all registered cars in the EEA (8).

PFAS are typically incorporated into the solid materials when they arrive at the assembly plant.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Transport equipment factory | 6.000 – 14.500 tons/year | High | Indirect | Typically, PFAS have already been processed by the time they arrive at the vehicle manufacturing facility. | Limited | 42.1, 42.3, 42.4.2, 42.5 |

### 5.3.8 Textile laundries and dry cleaning

Washing or dry cleaning textiles that have been made water and grease-resistant can release PFAS.

In Florida, an exploratory groundwater study was conducted at several dry cleaning sites. PFAS were detected at 14 of the 15 sites sampled. Concentrations for PFOS and PFOA ranged from the detection limit to 3.480 ng/l and 2.640 ng/l, respectively. The highest concentrations were found near dry cleaners and sewers, which were often the sources of VOCl contamination. No strong correlation was found with concentrations of PCE and degradation products, but PFAS and VOCl often occurred in the same zones, although there were differences in the distribution pattern: monitoring wells with the highest VOCl concentrations rarely contained the highest PFAS concentrations. Analyses of the various streams within the still-active dry cleaning sites showed that PFAS were primarily present in waste drums and used solvents, and to a much lesser extent in influent water, raw solvents, detergents, or soaps. Concentrations in the waste streams were 2 to 3 orders of magnitude higher than concentrations in groundwater. For this study, it was concluded that although there may be a contribution from PFAS in influent water or crude solvents and soaps, the main contribution is from leaching of PFAS from textiles during washing (32).

Patents are known for the use of PFAS in dry cleaning applications, although it is not clear to what extent these products were effectively used in Flanders.

Sites where many water and grease resistant textiles are cleaned are more suspect (e.g. hospitals, nursing homes, carpet cleaning...).

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Laundries and dry cleaning | Estimated to be very small | Very small | Indirect, also, directly in case of inadequate soil protection measures | / | Very limited for regular textiles<br>Limited for textiles made water and dirt repellent | 41.4.1a, 41.4.1b, 41.4.2a, 41.4.2b, 41.4.3a, 41.4.3b, 46.2.a, 46.2.b, 46.3.a, 46.3.b, 59.8 |

### 5.3.9 Use of medical devices and materials

**Applications**
PFAS are used in a wide variety of medical materials, see section 5.2.13.

**Type of PFAS components and volumes**
The total annual consumption of PFAS in medical materials in the EEA is estimated at 25.000 – 61.000 tons, excluding textiles (8), but no figures are available on how much of this would be released during use of the materials. If PFAS are released, they usually only enter the environment through sewage and waste (water). (see section 5.4.5). Therefore, the use of these materials is not itself considered a source of soil contamination. If discharged to a watercourse, there is a risk of contamination at the point of discharge.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Use of medical material | / | Estimated to be moderate | Indirect | Use of the materials will not release PFAS to soil or groundwater. However, it may be released to wastewater. | Limited, and only at the point of discharge when discharging to surface water. | 49.1, 49.2 |

### 5.3.10 Consumer products

**Applications**
PFAS may be present in many of the consumer applications discussed above. These include (8):

- Cleaners for glass, metal, ceramics, carpets and upholstery, waxes and polishes for furniture, floors and cars
- Products to remove floor wax
- Rinse aids in dishwashing products
- Products for car windshields and windshield washer fluid; cleaning products for cars
- PTFE sprays for lubricating doors, locks, bicycle chains, motorcycles etc.
- Musical instruments: lubricants, guitar strings, in piano keys
- Anti-fogging spray (22)

PFAS treated paper is also used in fireworks for its water resistant properties. Approximately 1.000 tons of fireworks are imported into Belgium each year. The main substance detected is the short-chain PFAS PFPrA (perfluoropropionic acid) with a C3 structure. This short-chain PFAS is also present in paper pulp but is often not analyzed together with the pulp. Although significant amounts of PFAS are measured in fireworks and their use can be considered an open process, their use is rather localized and very limited, so that fireworks are not considered a significant source of PFAS in soil (23).

**Type of PFAS components.**
A wide variety of products are affected. The inventoried products are listed in Tables A.84 through A.90 of Appendix A of the PFAS Residuals document. These include fluorotelomer alcohols and ethoxylates, PFCAs, perfluoroalkyl ethers, perfluoroalkanesulfonamide acetates, and polymers such as PTFE.

Non-stick coatings are also commonly used in cookware. This includes items such as frying pans, baking pans, the surface of electric cooking appliances such as grills, waffle irons, coffee makers and dishwashers. These applications primarily include copolymers of tetrafluoroethylene (PTFE), but also include ETFE, ECTFE, FEP, hexafluoropropylene, PFA and perfluoroelastomers (8).

The release of PFAS to the environment is primarily through wastewater, see section 5.4.5.

### 5.3.11 Food Industry

**Applications**
In the food industry, in addition to packaging, PFAS are mainly used as coatings on equipment used in the production and processing of food and feed. These are mainly fluoropolymers such as PFTE and PVDF.

Other food industry applications include:

- Piping, gaskets etc. in drinking water and food processing applications
- Filters in the use of steam filtration in food processing

- Valves, conveyor belts, hoppers, slide plates, cutting surfaces of knives and shears, springs, sensor covers, lubricants.

**Type of PFAS components**
The major PFAS are PTFE, ETFE, ECTFE, FEP, hexafluoropropylene variants, PVDF polymers, PFA, perfluoroelastomers, PFMVE.

Risks to soil are primarily associated with the reuse of waste products from the food industry and wastewater. To assess the likelihood of soil contamination, we refer to sections 5.4.5 and 5.3.12.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Food industry | / | Estimate to be limited | Indirectly via wastewater, directly when wastes are used as soil amendments | No contamination expected in production itself | Limited, and only at the point of discharge when discharging to surface water | See sections 5.4.5 and 5.3.12 |

### 5.3.12 PFAS in agriculture

**Pesticides and biocides**
Some pesticides and biocides contain PFAS either as an active ingredient or as an inactive ingredient (defoamer or dispersant) - see also section 5.2.14.

The best known use as a biocide is the use of PFOS against leafcutter ants (sulfluramid or sulfuramid(n-ethyl)perfluorooctane sulfonamide - N-EtPFOSA). This product was not used in Europe (23). Other examples include trifluralin, flursulamid, lithium perfluorooctane sulfonate, novaluron, flufenacet and nifluridide. Fipronil is another well-known insecticide with $CF_3$ groups that was registered for agricultural purposes in Europe until 2017 (now only for veterinary use) (8).

Many of these complex PFAS compounds can degrade to trifluoroacetate (TFA).

In addition, EPA research shows that PFAS can also be released from the packaging of these products. They tested several HDPE packages after PFAS contamination was detected in a mosquito repellent product. The study confirmed that quantifiable amounts of PFAS can be released into water or methanol stored in such packaging. The amount of PFAS released varied by brand. Higher concentrations were found in methanol than in water, and the concentrations increased over time (33).

*Volumes and type of process*
The table below shows sales data for Belgium for the substances listed in Table A.109 of the PFAS restriction document. Not every substance in the restriction document table is included in the Fytoweb sales summary. Quantities are expressed in kg active substance.

Table5 : Sales data of pesticides with PFAS as active ingredient in Belgium (kg active ingredient) (C: confidential) (34)

| SUBSTANCES COMMON NAMES | CAS or CIPAC | Detail | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BIFENTHRIN | 82657043 | BIFENTHRIN | | | | | 1 | | | - | - | - |
| LAMBDA-CYHALOTHRIN | 91465086 | CYHALOTHRIN, LAMBDA- | 1.653 | 2.031 | 1.392 | 1.531 | 1.659 | 1.968 | 2.004 | C | C | C |
| Fipronil | | | - | - | - | - | C | C | | | | |

More than 2.000 kg of the substance lambda-cyhalothrin were still sold in 2017.

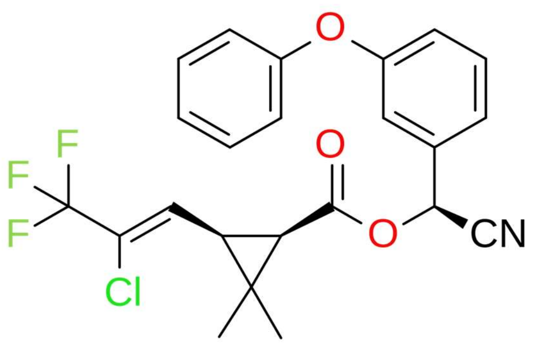



Figure13 : Chemical structure of lambda-cyhalothrin

Based on Fytoweb data, there are currently 32 active substances in pesticides in Belgium that can be considered PFAS. In addition, 3 substances are present in 5 pesticides as adjuvants. These are 2 substances of which approximately 82 kg/year have been released to the environment in the last 5 years. The third substance is a PFAS compound used as a propellant. Of this, an average of 232 kg/year would have been released to the environment in Belgium in the last 5 years (31).

**Soil amendments**
Various waste streams, such as sludge from the paper industry, the food industry or water treatment, are or have been used as soil amendments. For example, in North Rhine-Westphalia, Germany, widespread

contamination of agricultural soils with PFAS has been observed due to the use of PFAS containing paper sludge. Random sampling of soil amendments (before they are applied to land) shows that PFAS have also occasionally been found in Flanders (written question Flemish Parliament No. 240 (2020-2021)). In the United States, elevated levels of PFAS have also been found in so-called 'slow-release' fertilizers. These are made from dried sludge from wastewater treatment plants. In Flanders, sewage sludge has been banned from agricultural use since 2007. Sludge from food companies can still be used in for agricultural purposes. In addition, food companies use equipment coated with PFAS. PFAS, mainly PFBA, have been found in wastewater from this sector (14)(see also section 5.4.5).

**Review**
Diffuse soil contamination cannot be excluded due to the use of PFAS containing products in agriculture.

| Activity | Estimated annual consumption PFAS | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Agriculture | 5.479 tons/year - likely overestimated | Estimated to be moderate | Direct | Very specific components. Additional research is needed to estimate likelihood of contamination | Limited, pending further investigation | / |

### 5.3.13 Use of firefighting foam

PFAS-based Class B firefighting foams (see also 5.2.12) have been widely used since the 1970s to extinguish fires at airports, refineries, chemical bulk storage facilities, and other locations where large quantities of flammable liquid hydrocarbons are handled. Production of these products began in 1965. AFFF is also used in fire extinguisher training at these types of sites and at fire training facilities and may be released during the testing and operation of automatic fire suppression systems (sprinklers) (3).

Depending on the specifications of the foaming agent, it will be proportioned at different concentrations. For example, for a foam forming agent labeled 3% (proportioning rate), the proportioning rate is 3 parts foam forming agent to 97 parts water. Fluorinated foam forming agents contain about 5% PFAS. The amount of foam concentrate used depends on the size and nature of the fire. It can range from tens to thousands of liters of foam concentrate. When foam concentrate is used by the fire department, tens of kilograms of PFAS can be released in large fires.

The proposal to the EC to restrict PFAS in firefighting foams includes more data on sales of PFAS containing foams to various sectors - the most important being the chemical and petrochemical industries, firefighting, airports and defense.

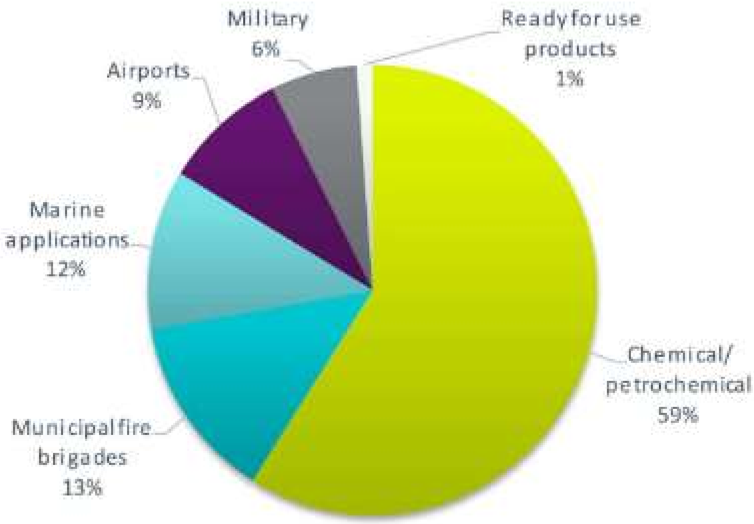



Figure 14 : Distribution of use of PFAS-containing firefighting foams by sector in the EU (31)

Based on this information, the following risk locations can be identified:

- Military training areas and airfields
- Airports (civil aviation)
- Firefighting training areas and industrial training areas
- Wholesale firefighting foam with demonstration room
- All locations where fires have been extinguished - including industrial sites, whether by sprinkler systems or not

In this connection, due attention must also be paid to:

- Sites where firefighting vehicles are washed (see also 5.3.5 )
- Sites where firefighting foams are stored (see also 5.3.14).

| Activity | Estimated annual use of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Extinguish fire in case of an emergency | 500 tons (estimation for Belgium: 16-20 tons ) | Moderate | Direct | Likelihood of contamination based on type and size of fire | Limited for small to medium emergencies | / |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | High for major emergencies | |
| Testing of testing fire extinguishing systems, e.g. sprinklers, with fire extinguishing foam | | | Direct | / | Limited | / |
| Storage of fire extinguishing foam | | | Not expected | Chance of spillage | Limited | / |
| Training sites (fire departments, training centers, demonstration sites, military exercise sites) | | | Direct | / | High | / |
| Airports (civilian and military | | | Direct | / | High | 57.1 |

### 5.3.14 Manufacturing, recycling or filling fire extinguishers

Fire extinguishers may also contain PFAS containing firefighting foams. Based on the REACH restriction document for PFAS in firefighting foams (30), the number of fire extinguishers in the EU containing PFAS containing foams has been estimated at 15 million units. The amount of foam is estimated at 140 – 200 tons (1% of the total amount of PFAS-containing foam – see Figure 14 – "Ready for use products"). Sites where such extinguishers are filled or cleaned and refilled may also release PFAS.

These activities are not specifically mentioned in the VLAREM but may be associated with NACE code 28.293: ‘Manufacture of apparatus for spraying liquids or powders’.

Based on current experience, testing and demonstration of fire extinguishers with PFAS containing fire extinguishing foam may also result in soil contamination.

| Activity | Estimated annual use of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| Manufacturing, recycling and (re)filling of fire extinguishers | 140 – 200 tons of foam (estimated at up to 14 – 20 tons of PFAS) | Small | Indirect and direct | Often small-scale activity, not necessarily requiring a permit - may require fewer soil protection measures - based on known sites, probability adapted to high | High | / |
| Testing and demonstration of fire extinguishers | | | Direct | Often small-scale activity, not necessarily requiring a permit - may require fewer soil protection measures - based on known sites, probability adapted to limited | Limited | / |

## 5.4 WASTE DISPOSAL, CLEANING AND RECYCLING

The use of PFAS and products containing PFAS means that PFAS may also be present in a number of waste streams.
PFAS are expected to be present in waste from the textile, leather and carpet industries, the paper and cardboard industry, wastewater and sludge from wastewater treatment plants. PFAS will also be present in used carpets and textiles that are incinerated or landfilled. Carpets and clothing are regularly recycled; for example, carpets are reused in the cement industry, where the carpet flakes are used as fuel and as an additive to cement. Outdoor furniture and flowerpots can also be made from recycled carpet. Textile flakes can be used as a coating for drainage pipes, in road construction and in the manufacture of clothing.
The different risk areas associated with waste are described in the categories below. The type of PFAS varies from site to site, but it is likely that PFOS and PFOA will be the most prevalent, as they were most commonly used in the past. Sites that were in use after the 1960s are of particular concern.

### 5.4.1 Waste collectors, waste processors, recycling companies

PFAS contamination may also occur at waste collection, processing or recycling sites. For municipal waste, the risk is estimated to be limited. For hazardous waste processing, the risk is estimated to be high (especially oil and foams).

As PFAS are particularly abundant in textiles and paper, sites where paper and textiles are recycled may be potential source sites. This may also include car scrapyards.

Therefore, the likelihood of soil contamination is highly dependent on the type of waste, quantities and conditions at the site.

| Activity | Estimated annual consumptio n of PFAS in EEA | Assessment based on quantity of PFAS | Emission s | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Waste collectors, waste processors, recycling companies | / | / | Both indirect and direct are possible | Strongly dependent on waste type, quantity, circumstances | Limited to high | 2.1.1 (a.1, a.2, b), 2.1.2. d.1, 2.1.2.d.2 2.2.1.a,b, 2.2.1.c.1, 2.2.1.c.2, 2.2.1.d.1, 2.2.1.d.2 2.2.2.a.1, 2.2.2.a.2, 2.2.2.b.1, 2.2.2.b.2, 2.2.2.c.1, 2.2.2.c.2, 2.2.2.c.3, 2.2.2.c.4, 2.2.2.d.1.b, 2.2.2.d.2.b, 2.2.2.d.3, 2.2.2.e, 2.2.2.f.1, 2.2.2.f.2, 2.2.2.g.2 2.2.5.a.1, 2.2.5.a.2, 2.2.5.a.3, 2.2.5.b.1, 2.2.5.b.2, 2.2.5.c.1, 2.2.5.c.2, 2.2.5.d.1, 2.2.5.d.2, 2.2.5.e.2, 2.2.5.e.3, 2.2.5.f.2, 2.3.1.a, 2.3.1.a 2.3.2.a.1, 2.3.2.a.2, 2.3.2.b, 2.3.2.c, 2.3.2.d, 2.3.2.e.1, 2.3.2.e.2, 2.3.2.g 2.3.3.c |
| | | | | Composting, storage and biological treatment of waste products | Limited | 2.2.3.c.1, 2.2.3.c.2, 2.2.3.c.3, 2.3.3.a.1, 2.3.3.a.2 |

### 5.4.2 Landfills

Because PFAS can be found in many household products (including greaseproof paper, Gore-Tex jackets, textiles and furniture with stain resistant coatings), landfills can release PFAS to groundwater. In addition, waste from PFAS manufacturing sites or PFAS processing industries may have been dumped locally. Landfills closed before 1960 are not suspected of containing PFAS. The extent to which other landfills are suspected of containing PFAS depends on the material that was landfilled. A thorough evaluation is required to determine whether or not PFAS should be considered as a compound of intertest for the landfill in question. (35).

The risk of soil contamination at landfills in general is considered to be high, even very high for landfills with PFAS containing waste. For landfills closed before 1960, the risk is limited.

Studies of PFAS at landfills in Dordrecht show that PFAS are indeed present in the groundwater at landfills. In the landfills around Dordrecht, PFOA is mainly found, but this is partly due to the presence of the DuPont/Chemours plant, where a lot of PFOA was used in the past.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Landfills | Unknown | Limited | Indirect and direct | Depending on waste type and time period | Limited for landfills closed before 1960<br>High for landfills started after 1960<br>Very high for landfills containing PFAS containing waste | 2.3.6.a to 2.3.6.c |

### 5.4.3 Soil processing, movement and dumping

Other potential sources of contamination include sites where PFAS-contaminated soil and sludge is processed, disposed of, stored, or reused.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Soil | / | / | Indirect | Depending on origin of soil and soil protection measures | Limited | 2.1.3.1, 2.1.3.2, 60.2, 61.2.2 |
| | | | | By 2022, soil should be tested for PFAS | Limited for older soil storage facilities and landfills for which incoming soil material was not tested for PFAS (before 2022). | 60.1, 61.2.1 |
| Dredged material and sludge | / | / | Indirect | Depending on sludge origin and soil protection measures | Limited | 2.2.8.a, 2.2.8.b, 2.3.7.a, 2.3.7.c, 2.3.7.d |
| | | | | By 2022, dredged material and sludge should have been tested for PFAS | Limited for older activities for which incoming soil material was not tested for PFAS (before 2022). | 63.1, 63.2 |

### 5.4.4 Incinerators

PFAS are degraded in conventional incineration, but probably not completely. Usually, the temperature of the incinerator (about 850 °C) is not sufficient to completely degrade PFAS, in particular short chain PFAS. As a result, PFAS are released via the flue gas, which is usually not treated to remove PFAS. When investigating such sites, the impact of atmospheric deposition on soil should be considered (36) (3). The likelihood of soil contamination is estimated to be limited (3).

A literature review on the presence of PFAS in these flue gases was conducted in the Netherlands (37). They concluded that in practice the formation of gaseous organic fluorinated products would always occur. This would be mainly limited to the smallest members of the PFAS group of perfluorinated carbons, namely perfluoromethane ($CF_4$) and perfluoroethane ($C_2F_6$). Both are potent greenhouse gases, resistant to high temperatures, and most likely to be formed and survive the combustion process (37).

Based on experimental data found in the literature, PTFE is expected to undergo complete thermal degradation at the minimum required combustion temperature of 850°C. However, for solid substances like polymers the conditions in the combustion bed are probably even more important than the temperature in the combustion chamber. The residence time and mixing of the incineration bed on the grate should be sufficient to allow for solid materials to burn out, that is to thermally degrade into smaller volatile components that will subsequently be incinerated in the combustion chamber. PTFE as such will not volatilize and then be burned in the combustion chamber. At the expected temperatures in the incineration bed, between 900 and 1100°C, it is expected that PTFE and other fluorinated polymers will fully degrade into small fluorocarbon molecules (37).

The types of PFASs with the strongest tendency to pass through the flue gas treatment system are iodine-containing PFASs, fluorotelomer olefins (FTOs), the perfluoroalkanes (PFCs), the fluorotelomer alcohols with a short perfluorinated chain of 3 to 5 fluorinated carbon atoms (3-5:2 FTOH) and the fluorotelomer acrylates (FTACs) – assuming that these compounds survive the combustion process. (37).

These conclusions are based largely on published laboratory experiments and qualitative theoretical assessments. Published results from field measurements show that various PFASs have been detected in flue gas and incineration residues such as bottom ash and fly ash. The total PFAS concentration measured in flue gas was about 20 ng/m³ (37).

Based on a review of the scientific literature and the theory about combustion processes and flue gas cleaning techniques, RIVM concludes that (37):

- PFASs present in household, municipal and industrial waste degrade into other substances when this waste is incinerated in compliance with the legal requirements for waste incineration plants in the Netherlands;
- At the same time, a new PFAS group is formed which are strong greenhouse gases such as perfluoromethane and perfluoroethane;
- Some publications about measurements in the chimney of a waste incineration plant do not exclude the possibility that PFASs may still be present in the flue gases and that they can be emitted as a result.

Due to the lack of sufficiently accurate PFAS measurements, it is uncertain what the composition and quantity of PFASs is in the cleaned flue gases.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Waste incinerators | / | Limited | Indirect | Waste type burned will play a role | High for facilities that receive a lot of PFAS-containing waste (paper industry, medical waste, industrial waste), …<br>Limited for the remaining | 2.3.4.1.a.1, 2.3.4.2.a.1, 2.3.4.1.a.2, 2.3.4.2.a.2, 2.3.4.1.b, 2.3.4.2.b, 2.3.4.1.c, 2.3.4.2.c, 2.3.4.1.e, 2.3.4.1.f, 2.3.4.1.g*, 2.3.4.1.h, 2.3.4.1.j, 2.3.4.2.d, 2.3.4.1.k, 2.3.4.2.e, 2.3.4.2.g |

### 5.4.5 Wastewater (industrial and domestic wastewater)

Companies discharge their industrial) wastewater directly into surface waters (treated or untreated) or into the public sewer system. In the latter case, the water eventually ends up in wastewater treatment plants (WWTPs) and/or sewage treatment plants. Both on-site WWTPs and sewage treatment plants are typically not equipped to treat the effluent stream for PFAS. Domestic wastewater can also contain PFAS; for example, toilet paper contributes approximately 6,4 – 80 µg/person/year of 6:2 diPAP to wastewater streams and can therefore be considered a significant source of PFAS (16).
Studies of sewage treatment plants in the Netherlands have found PFAS in influent, effluent and sludge (38). The effluent and sludge normally don't come in contact with the surrounding soil. However, foaming and spreading can release PFAS into the environment. The risk of soil contamination in the vicinity of the treatment plant is estimated to be limited. However, there may be a high to very high risk of contamination in the aquatic (soil) system. A study of effluent concentrations in WWTP in Flanders showed a median concentration of about 50 ng/l for the sum of PFAS (14).

In a monitoring campaign carried out by the VMM in 2022, wastewater from different sectors was monitored. 34 of the 43 PFAS substances investigated were detected. The 9 substances that were not detected are characterized by longer carbon chains that are less soluble in water. In more than half of the sites in Flanders, a total PFAS concentration in wastewater above 100 ng/l is detected and in 10% of the measured sites a concentration above 3.800 ng/l is detected (14).

The PFAS concentrations in the effluents of the different sectors examined by the VMM are in the same order of magnitude (14). The difference between the lowest median (wastewater treatment sector) and the highest median (waste and soil treatment sector) is a factor of 10.

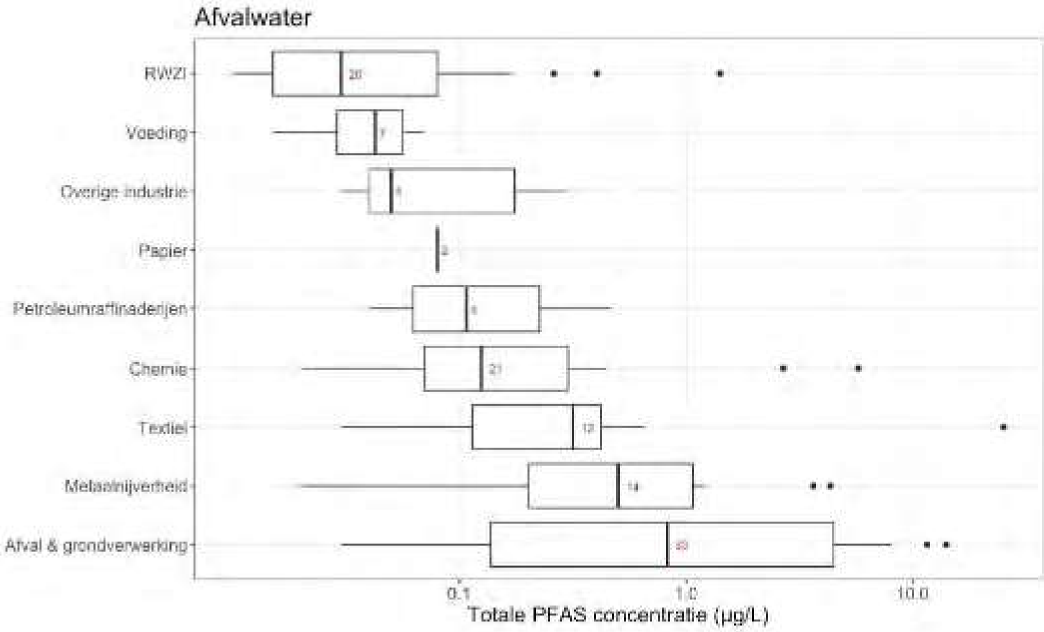



Figure 15 : Boxplot for total PFAS in wastewater in Flanders by sector (red numbers represent the number of monitoring sites). The total PFAS content was determined per site based on the median of the sum of the measured PFAS (15)

PFHxA, PFOA, PFPeA, and PFOS were the dominant PFAS measured near WWTP. The dominant PFAS per sector are listed in the following table (12).

Table 6 : Synthesis of dominant PFAS by sector based on VMM study (2022 measurement data) (16)

| Sector | Dominante PFAS |
|---|---|
| Afval* & grondverwerking | PFBA, PFOA, 8:2 diPAP, HFPO-DA |
| Chemie | PFBA, PFOS |
| Metaalnijverheid | PFOS |
| Papier | 6:2 FTS |
| Petroleum | PFBA, PFOS |
| Textiel | PFPeA, PFHxA,... |
| Voeding | PFBA, PFHxA, PFBS |
| RWZI | PFOA, PFOS, PFHxA, PFPeA |
| Overige industrie | PFPeA, PFBA |

The dominant PFAS by sector can be summarized as follows:

- PFBA is dominant for the food sector and is also strongly present in the 'waste and soil processing' and 'chemical' sector, as well as in 'petroleum sector'. In addition to the dominant presence of PFBA, the 'waste and soil processing' sector also has the highest PFBA concentrations (12)
- PFOS (total) may have particularly strong contributions in metallurgy, chemicals and WWTP
- PFPeA is dominant in textile and other industries
- PFOA (total) is especially dominant in WWTPs
- PFHxA is noticeably present in most sectors (except food)
- 6:2 FTS, PFBS, PFHpA, PFHxS are other PFAS that are noticeably present in different sectors.

A difference was observed between the PFAS fingerprint in the effluent and the fingerprint in the downstream surface water. For example, a higher contribution of PFOS and PFBS, and to a lesser extent PFPeA and PFHxA, was found in surface water downstream of a point of discharge compared to the effluent. PFBA was barely detected in surface water downstream in this monitoring (14).

In the same study, sediments were investigated based on data from different monitoring networks, but not specifically per industrial sector. However, a distinction was made between the regular sediment monitoring network and 'hot spot locations' near a known source inventoried by OVAM. The regular network (sediment monitoring network), has a median concentration of total PFAS of 1,7 µg/kg ds. This is about a factor of 14 lower than the median concentration of total PFAS at the hot spot sites, which is 24,4 µg/kg ds. The highest concentrations were found in the Westerschelde. (12).

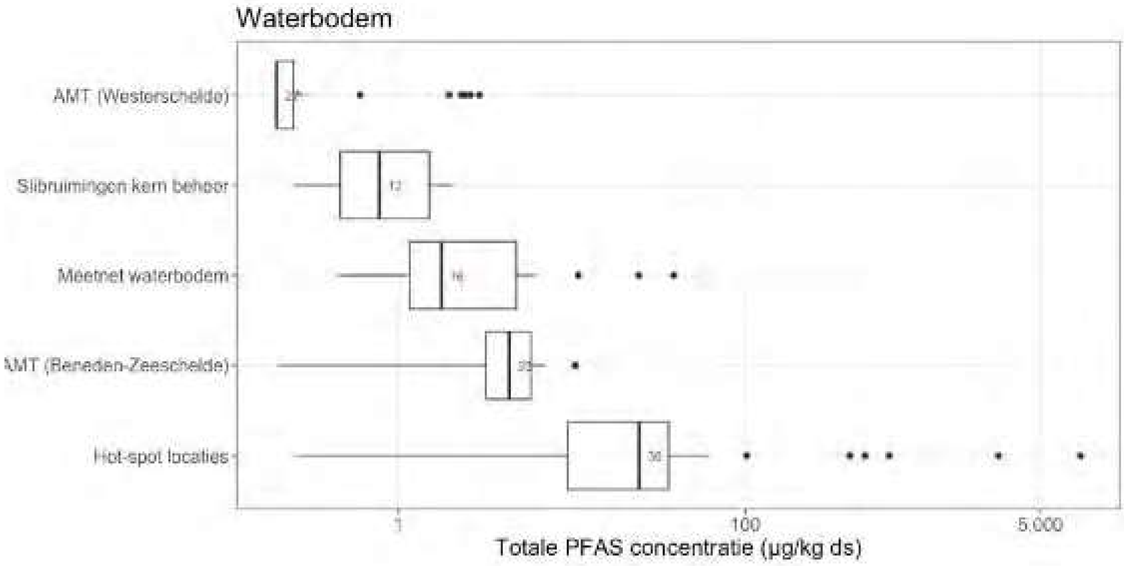



Figure16 : Boxplot for total PFAS in sediment in Flanders by motif (red numbers) (15)

If a PFAS-suspected activity was/is present at the site, the WWTP - both at the level of the treatment itself (e.g. foaming, accidents, sludge dewatering, etc.) and at the sediment around the point of discharge - can be a source of PFAS to the environment. This also applies to domestic WWTP, which may also contain PFAS.

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Sewage treatment plants | / | / | Indirect | Both in the field itself (e.g., foaming treatment) and at the point of discharge | High | 3.6.4.3, 3.6.4.4 |
| Discharge of commercial wastewater, treated of untreated | / | / | Indirect | Commercial wastewater: depending on activities on site - if PFAS-suspected activities: point of discharge and surrounding water treatment plant are also suspected | Very limited to high, if activities on site are mentioned in this study - see opportunity in these activities | 3.4.1b 3.4.2 3.4.3 3.6.3.2, 3.6.3.3, 3.6.6, 3.6.7 |
| Discharge to groundwater | / | / | Direct | Only relevant if this discharged water may contain PFAS | Limited | 52.1.1.2, 52.1.1.3, 52.1.2, 52.2.2, 52.2.3 |

### 5.4.6 Container cleaning companies - drum rinsing/cleaning - tanker trucks - waste transportation companies

Companies that clean containers and tankers are also a potential source of PFAS contamination. This is shown, among other things, by an investigation by the Human Environment and Transport Inspectorate (Inspectie Leefomgeving en Transport, ILT) (39) and an investigation at a drum cleaning facility (11).

| Activity | Estimated annual consumption of PFAS in EEA | Assessment based on quantity of PFAS | Emissions | Additional consideration | Estimated probability of soil contamination | Categories |
|---|---|---|---|---|---|---|
| Cleaning empty containers | / | / | Indirect | Depending on the waste in the containers. Based on 1 investigated site (drum cleaning) and the ILT report on waste transport, the likelihood is considered high. | High | 2.2.6.a, 2.2.6.b, 2.2.6.c, 2.2.6.d |
| Storage and cleaning of metal containers by thermal cleaning | / | / | Indirect | / | Limited | 2.3.5 |

## 5.5 LESS RELEVANT IN FLANDERS

### 5.5.1 Ski wax

PFAS have been used in ski wax to treat skis and snowboards. They are sometimes used in ski boots and other ski equipment. These are mainly partially fluorinated alkanes (SFAs), which are mixed with the regular paraffins in ski waxes . PFCAs are often found in these waxes as impurities ($C_6$-$C_{22}$), PFSAs are also present but in lower concentrations (8). Fluoropolymers are also present.

The peak use of PFAS-containing waxes dates back to 1978. Since 2017 the market for these waxes has shrunk considerably. Use in 2020 is estimated at 1,6 tons for the EU and is expected to decrease further in the coming years.

### 5.5.2 Oil extraction and mining

PFAS are used as surfactants in drilling for the oil industry and in mining (mainly metals - such as copper and gold).

# 6 MORE DETAILS REGARDING PFAS APPLICATIONS

For more detailed information on which PFAS components are used in which applications and in what quantities, e.g. as part of a preliminary soil study, the following documents are recommended:

- Appendix A of the PFAS restriction document (8)
- The study 'An overview of the uses of per- and polyfluoroalkyl substances (PFAS)' (15) and its annexes (pdf and excel). These are comprehensive documents that show both the possible uses for each PFAS component and the PFAS used/patented or measured for each use.
- The PFAS guide developed by ChemSec (40)provides an overview of numerous product categories that can contain PFAS
- The Marketplace developed by ChemSec (41)provides an overview of possible alternatives to PFAS in various applications
- ZeroPM also developed a database listing applications of specific PFAS components and possible (42)

# 7 RESTRICTIONS IN USE

PFAS were invented in the late 1930s and large-scale production and use of PFAS began in the 1960s. Over the years, more and more uses for PFAS were discovered and PFAS compounds were used in an increasing number of industries. From 1966 to 1990, the production and use of PFAS increased due to their unique chemical stability and water and dirt repellent properties. Annual production increased significantly from 500 tons per year in the 1970s to almost 5.000 tons per year in 2000 (43).

**PFOS**

- In 2000, the world's leading producer of PFOS, 3M, began phasing out PFOS production. As a result of this initiative, global production fell significantly between 2000 and 2003.
- The use of PFOS in products and semi-finished products was already restricted in 2006 (Directive 2006/112/EC). In 2009, it was included in the REACH regulation (EC 552/2009, Annex XVII of EC 1907/2006).
- In May 2009, PFOS was listed as a POP (Persistent Organic Pollutant) in Annex B13 of the Stockholm Convention. This means that measures must be taken to phase out the use of PFOS.
- This decision was incorporated into European legislation in 2010 (850/2004/EC, 757/2010). This reduced the maximum allowable content of PFOS to 0,001% by weight or 10 mg/kg.
- Exemptions were reassessed in 2015, resulting in the withdrawal of a few exemptions (including aviation hydraulic fluids, firefighting foam) in April 2017 (EU 2017/758).
- A number of exemptions were again repealed in 2019 (EU 2019/639). Specific exemptions remain for the use of PFOS in firefighting foams to control vapours and fires from liquid fuels (as unintentional trace contaminants up to 10 mg/kg), in closed-system electroplating and in agriculture as ant bait.
- When the restriction on the use of PFAS in firefighting foams (see also below under 'other PFAS') is approved in the EU, this limit will be reduced to 1 mg/kg.

**PFOA**

- In June 2015, PFOA (and salts and PFOA-related components) was added to the list of substances to be evaluated under the Stockholm Convention and will be added to the Convention from July 2020.
- As of June 13, 2017, PFOA and its salts have been added to the list of substances of very high concern under REACH and to Annex XVII of EC 1907/2016, as well as any related substance that has C7H15- as one of its structural elements. Annex XVII includes the following: these substances cannot be placed on the market as a substance by itself after July 4, 2020. In addition, it may no longer be used as a constituent of another substance, article or mixture at concentrations equal to or greater than 25 ppb (25 µg/kg) as PFOA itself or 1.000 ppb (1 mg/kg) as a related substance, although several exemptions are provided (3).

**Other PFAS**

- Since June 2022, PFHxS and related substances have been included in the Stockholm Convention.
- Since August 2023, the substance group has also been included in the EU regulation on persistent organic substances.
- Longer-chain PFCAs are currently being evaluated for inclusion in the Stockholm Convention.
- C9-C14 PFCAs have been restricted under REACH regulations since February 2023.
- On April 19, 2024, it was decided that PFhxA will be regulated more strictly in the EU - after a transition period of from 18 months to 5 years (depending on the application), its use will be banned in textiles, food packaging, consumer goods, cosmetics and fire-fighting foams during training and testing at concentrations above 25 ppb for PFhxA and 1000 ppb for the sum of PFHxA-related substances. Other applications, such as use in semiconductors, are still allowed.
- A restriction proposal for a broad group of PFAS applications was also submitted in January 2023 and is currently under review.
- A restriction proposal specifically for fire-fighting foams was submitted in January 2022, but no decision has yet been taken.

A number of PFAS are on the candidate list of substances of very high concern: HFPO-DA (GenX), PFBS and PFHpA.

Following the phase-out of PFOS and PFOA, these substances have been replaced by other PFAS compounds such as 6:2 FTS, GenX and ADONA. These compounds are also fully or partially fluorinated but often have a slightly different structure compared to the PFAS they replace. GenX and ADONA are perfluoroethers and have one or more ether (-O-) groups in the molecular structure. 6:2 FTS is similar to PFOS, but the two carbon atoms next to the sulphate atom are not fluorinated. 6:2 FTS is a precursor of PFHxA.
Replacement compounds are generally reported to be less bioaccumulative, although this is still under debate. The fluorinated chain makes them persistent.
It is likely that where PFOS and/or PFOA were used in the past, other PFAS compounds are used today. The reverse is also true; where other PFAS compounds are used today, it is likely that PFOS and/or PFOA were used in the past.

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# APPENDIX 1 COMPREHENSIVE OVERVIEW OF PFAS-SUSPECTED ACTIVITIES - SPECIFIC SUBSTANCES AND LIKELIHOOD OF SOIL OR GROUNDWATER CONTAMINATION