Report summary PFAS and PFAS polymer production

Contents

1 Introduction

1.1 Objectives of the study

The scope of the project included fluoropolymers, F-gases and other PFAS. It also included PFAS processors (dryers, powder generators, mixers, etc.). Figure 1 shows the PFAS production process in the wider context of the PFAS lifecycle. PFAS polymer alternatives production and processing are also in scope (i.e., production of fluoropolymers without PFOA, GenX etc. as processing aid).

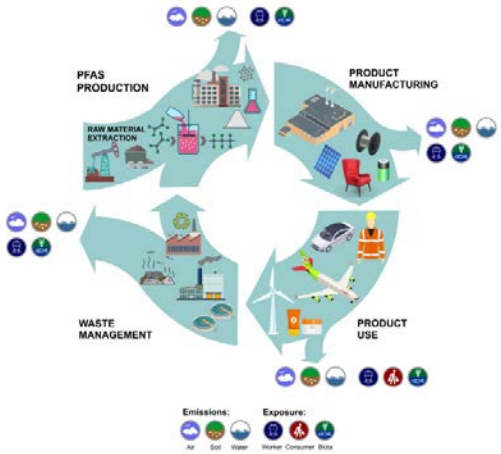

Figure 1: Emission of and exposure to PFAS during their lifecycle
Source: https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf

The following items were out of scope:

- The scope is limited by the REACH scope: production for use on the EU market;
- The scope is limited to current PFAS production (former production is excluded except for historic tonnage reporting);
- PFAS uses are out of scope so downstream use, other than PFAS processing, and use in articles is out of scope; and
- A life cycle analysis of PFAS uses, other than directly linked to PFAS production, is out of scope (waste arising at production is in scope).

The methodology for gathering market information consisted of two main elements:

- A review of relevant literature; and
- Stakeholder consultation and interviews

A systematic literature review was carried out and a questionnaire was designed which was sent to a targeted list of stakeholders with an invitation to participate and provide responses. Information from a previously conducted Call for Evidence (summer 2020) was also made available to the study team.

152 stakeholders were invited by email to participate in the consultation exercise. 27 ultimately provided responses. To clarify their responses and provide an opportunity for the stakeholders to ask questions, 14 follow-up telephone meetings were held. Extensive efforts were made to identify and contact Asian PFAS stakeholders, particularly those in China but no responses were received from China. The level of detail provided by responders to the questionnaire varied, and in some cases did not provide detail especially for economic information (prices and profits). Tonnage and import data was sometimes quite precise, but also (wide) range of tonnage were provided. Survey respondents were asked by the study team to classify their reported substances into one (or more) of 23 groups, which were those groups described in work carried out by the OECD.

2 Market Analysis

Fluoropolymers

The main fluoropolymers produced for commercial and industrial use are polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF), as well as fluoroethylene propylene (FEP), see Figure 2. Ethylene-tetrafluoroethylene (ETFE), perfluoroalkoxy (PFA) and polyvinylfluoride (PVF) follow in terms of volume. Perfluoropolyether (PFPE) is a minor use, used mainly for lubrication.

It was estimated that 51,000 tonnes of fluoropolymers were produced in the EU in 2015, and 21,500 tonnes were imported[1]. Assuming a 2% per year growth rate in line with European GDP during the period[2], it is estimated that production of fluoropolymers in the EU in 2021 will be 57,500 tonnes.

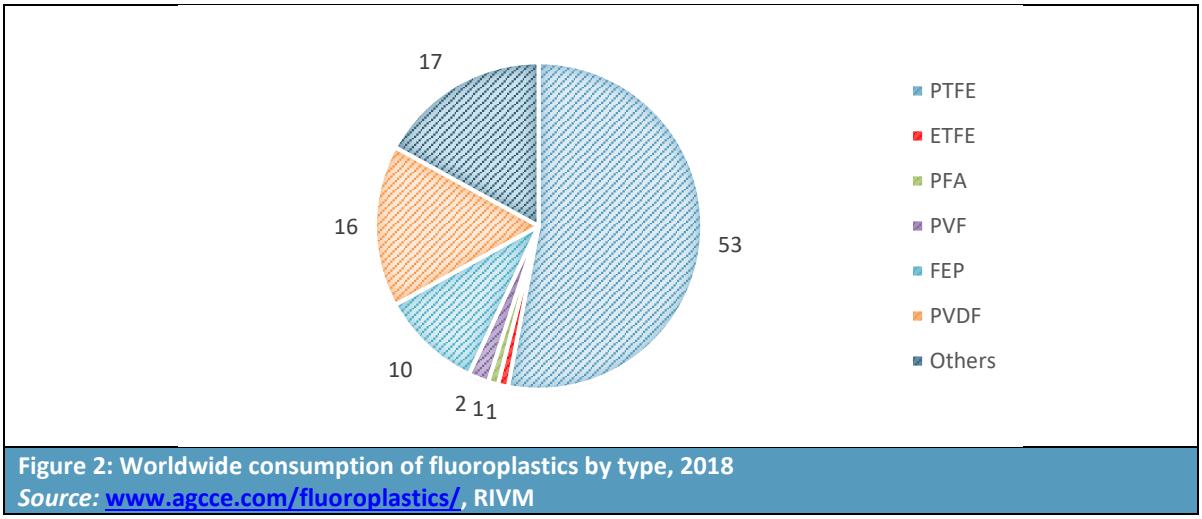

Figure 2: Worldwide consumption of fluoroplastics by type, 2018
***Source:* www.agcce.com/fluoroplastics/, RIVM**

The most important polymers by volume are polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). Perfluoropolyether (PFPE) is a minor use, used mainly for lubrication.

Global PTFE production capacity was reported as 70,000 tonnes in 2002[3], It has not been possible to obtain more recent figures. Global PVDF production capacity identified by Ring (2002)[4] was 27,000 tonnes in 2002 (US, France, and Japan), with overall production at 52% of installed capacity, i.e., 18,600 tonnes. Production capacity at Arkema's Changshu, China site was estimated to be 12,000 tonnes in 2019. With expected capacity expansions, Arkema's production is thought to be 38,000 tonnes globally[5]. Estimates from RIVM indicate that capacity at Solvay is 22,000 tonnes and for remaining producers is around 40,000 tonnes, with about 15,000 tonnes PVDF production located in Europe (RIVM analysis).

Fluoropolymer products can be produced as different grades, for example, Teflon-granulate, Teflon-fine powder, which may contain impurities from the production process. These are often sold to manufacturers for finished articles such as PTFE tape or PTFE-coated cookware.

Traditionally, fluoropolymers such as fine powder PTFE or PVDF are manufactured using emulsion polymerisation using PFAS-based processing aids. However, there are methods of manufacturing

[1] Plastics Europe- Association of Plastics Manufacturers – Fluoropolymers Product Group (2018): The fluoropolymers industry in Europe – A socioeconomic perspective. Available at: http://fluoropolymers.plasticseurope.org/publications
[2] https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2019&locations=EU&start=2008
[3] ICIS, https://www.icis.com/explore/resources/news/2002/02/18/157440/ptfe/
[4] Prevedouros *et al*, "Sources, Fate & Transport of Perfluorocarboxylates", made available to RPA by RIVM
[5] Roskill, 23 December 2019, https://tinyurl.com/4hdyvf3v

fluoropolymers without these PFAS-based processing aids, as with the suspension polymerisation producing granular PTFE. There is no clear demonstration whether fluoropolymers produced using emulsion polymerisation can indeed be produced without the PFAS-based processing aids. There has been development of emulsion polymerisation processes with much reduced PFAS use, or even without PFAS-based aids,[6] but it is not yet clear whether these will be implemented at industry level.

Perfluoropolyethers (PFPEs) are polymers made from perfluoroether monomers. It was reported that there is a lack of information regarding the use of PFPEs in Europe[7]. However, extensive use in lubricants, mainly for the automotive industry, indicates a significant market for these substances, reported as exceeding USD 540 million in 2020.[8] These substances have an extensive range of uses including technologies such as ionomer membranes. Polymers are not required to be registered under REACH, so no substances of that group are found in the REACH registered substance database[9], resulting in limited information publicly available regarding imports, production volumes and exports of specific fluoropolymers.

Another group of substances identified in the Nordic Working Paper are side-chain perfluoroether polymers. These refer to polymers with non-fluorinated polymer backbones and perfluoroalkylether moieties on the side-chains, in line with the side-chain fluorinated polymers. The information regarding the total production volumes of these substances is very limited as they do not appear in any of the EEA databases.

F-gases

A CEMAC report investigated the use of refrigerant chemicals[10]. The whole refrigerant market consists of three major classes of refrigerants: fluorocarbons, inorganic refrigerants, and hydrocarbon-based refrigerants. Hydrochlorofluorocarbons (HCFCs) under investigation include chlorofluoromethane (HCFC-22), 2,2-Dichloro-1,1,1-trifloroethane (HCFC-123). Other HCFCs (such as HCFC-124, HCFC-141b, HCFC-142b) are produced in negligible quantities. Hydrofluorocarbons (HFCs) investigated include 1,1,1,2-tetrafluoroethane (HFC-134a) and blend components (HFC-125, HFC-32, HFC-143a). Other HFCs (such as HFC-152a, HFC-245fa, HFC-365mfc, and HFC-227ea) are produced in negligible quantities.

Remaining PFAS

Another group of substances identified during the review of the Nordic Working Paper, includes perfluoroether non-polymers with unsaturated bonds. These are the monomers for the fluoropolymers found in the previous group. Such substances are registered under the REACH regulation, and it is estimated that they are produced in volumes of up to 1,000 tonnes per year.

The Nordic Working Paper identified another group of substances, consisting of perfluoroether non-polymers with only saturated carbon bonds. Only nine substances of this group are registered under the REACH regulation, and of these, there is very limited information on production volumes. It is estimated that the total tonnage bands are between 212-2120 tonnes/year.

[6] T. Zipplies, K. Hintzer, M. C. Dadalas & G. Loehr, *Aqueous Dispersions of Polytetrafluoroethylene,* Having a Low Amount of Fluorinated Surfactant. US2006/0128872A1 (2006).

[7] Nordic Council of Ministers (2020): Nordic Working Paper – Per and polyfluoroalkylether substances: identity, production and use. Project Number 2019-007

[8] Perfluoropolyether Market Share and Statistics – 2017 (2021). Report ID: GMI1625

[9] Two substances have been found in the Classification and Labelling (C&L) Inventory, four out of the 57 PFAE substances have been identified as fluoropolymers in the SPIN database.

[10] CEMAC (Clean Energy Manufacturing Analysis Center) (2020): Refrigerants: Market Trends and Supply chain Assessment.

2.1 Annual EEA (EU27+NO/IS/LI/UK) production/processing tonnage volumes (last 15-20 years)

Several data sources were investigated to obtain information on production/processing tonnage data:

- Data from responses to questions in our consultation survey;
- Responses to the Call for Evidence;
- The Fluoropolymer Section of Plastics Europe (for data on fluoropolymers);
- REACH-Registered tonnages; and
- Desk study, a.o. the EEA report on F-gases[11].

Survey respondents were asked by the study team to classify their reported substances into one (or more) of 23 groups, which were those groups described by the OECD. Based on the responses, and in the interests of practicality, it was decided to summarise the tonnage data into one of three groups: **fluoropolymer**, **F-gas** or **remaining PFAS**. In some cases, the distinction between production and processing tonnage reported by survey respondents was not clear. These cases represented as significant proportion of the overall volume and so it has not been possible to produce a reliable disaggregated figure. Similarly, it has not always been possible to distinguish between production/processing tonnage and import tonnage. The table 1 below shows production/processing tonnage. Import tonnage is mentioned in table 2.

Table 1: PFAS manufactured/processed in the EEA (in tonnes)

PFAS Group	Minimum (Consultation)	Realistic estimate (lit review)	Maximum (Consultation)
Fluoropolymers	49,458	51,000 (in 2015)	101,763
F-gas	13,600	22,000	52,800
Remaining PFAS	53,902	85,977	118,051
TOTAL	**116,960**	**158,977**	**272,614**

Source: Consultation exercise for this study and literature review

1 The minimum and maximum estimates were based on companies' responses to the survey. Some companies reported exact figures, while others reported ranges. The lower and upper estimates reflect the lower and upper ranges. In some cases, companies reported tonnage data as "greater than x", with no upper bound included (e.g., "> 1,000 tonnes"). Therefore, the "upper estimate" column is not a true maximum value

Conclusion

The production/processing figures for fluoropolymers are broadly in line with those reported by the fluoropolymer section of Plastics Europe, which indicated 51,000 tonnes produced in Europe in 2015 (Plastics Europe commented that they have not published more recent data). Similarly, the figure for F-gases is broadly in line with the production data in the EEA report, which is 21,160 tonnes in 2019. It is more difficult to determine a comparison figure for other PFAS. For both fluoropolymers and F-gases, there were the references documents cited above that allowed a direct comparison to the figures from the survey, but for other PFAS, although there are several sources that provide volume information, the types of PFAS vary widely, and often inconsistent or incomplete volumes are reported. Therefore, it is harder to determine whether volume data gathered from the companies' responses to the questionnaire align with what it is reported in the literature.

[11] EEA Report No 15/2020, Fluorinated greenhouse gases 2020

2.1.1 Literature Review

Fluoropolymers

At a global level, around 320,000 tonnes of fluoropolymers were produced by industry in 2018. In the same year, the industry was worth $ 10 billion per annum.[12] For PVDF, global consumption stood around 46.1 thousand tonnes in 2016, and is projected to reach around 69.2 thousand tonnes by 2022.[13] It was estimated that, in 2018, around 51,000 tonnes per year of fluoropolymers were produced in Europe, not including those PFAS used as processing aids, for which production volumes are unaccounted.[14]

AGC Chemicals is one the world's leading producers of fluorochemicals and fluorochemical materials. They report that in 2018, the worldwide production volume of fluoroplastics was around 316,000 tonnes, while the global consumption of fluoroplastics was approximately 320,300 tonnes (the difference could be due to the use of stockpiled materials). Compared to 2015, where the global consumption was around 270,000 tonnes, this corresponds to an 18.6 % increase, signifying a global increase in demand for these products.

There is very limited information available regarding production volumes of side chain perfluoroether polymers. It was estimated that consumption of UV/EB coating was around 150,000 and 200,000 tonnes for the EMEA region in 2016, most of which was generated by the EEA[15]. Fluoropolymers are not registered in ECHA databases.

F-gases

With regards to the refrigerant market, **HCFC-22** production in EEA is not publicly available but it is estimated that the EU produced 120,000 tonnes of **HCFCs** in 2015, the vast majority of which was used in feedstock. It was not possible to find information on the production of HCFC-123 in the EEA. (Note: ECHA mentions intermediate use only). The same holds for other HCFCs, such as HCFC-124, as they are produced in negligible quantities.

Regarding the production of HFCs, HFC-134a is produced in negligible quantities in EEA, and therefore, these have not been reported. (Note: this is questionable as ECHA registration database mentions: >10.000 to <100.000 t) The same holds for HFCs used as components in refrigerant blends, including HFC-125 (ECHA registration database: > 10.000 to < 100.000 t), HFC-32, and HFC-143a. The EU's capacity for production of HFC-152a is around 5,000 tonnes, and overall, in 2012 the EU consumption was less than 10,000 tonnes. The EU is the only region that produces HFC-365mfc, with 15,000 tonnes produced per year.[16]

Remaining PFAS

The issue in estimating the total volume of PFASs produced in the EEA and globally, is the lack of complete information submitted by manufacturers and producers to authorities as part of REACH.

The Norwegian Environment Agency estimated that global production capacity of **PFHxS** remained constant in the years 2011 to 2016, at approximately 1,000 – 1,500 kg per year. Actual production was estimated around 700 – 750 kg in 2012, and less than 700 kg in 2016.[17] In 2016, consumption of

[12] R. Lohman et al., *Environ. Sci. Technol.*, 2020, 54, 12820-12828.

[13] Polyvinylidene Fluoride – A global market overview (2016).

[14] J. Glüge et al., *Environ. Sci.: Processes Impacts,* 2020

[15] Nordic Working Paper, pp 98

[16] K. Stemmler, D. Folini, S. Ubl, M. Vollmer, S. Reimann, S. O'Doherty, B. Greally, P. Simmonds, & A. Manning (2007). European Emissions of HFC-365mfc, a Chlorine-Free Substitute for the Foam Blowing Agents HCFC-141b and CFC-11. *Env. Sci. & tech*. **41**. *1145-51*.

[17] Norwegian Environment Agency (2018), Investigation of sources to PFHxS in the environment.

PFHxS was around 620 – 640 kg in China, around 40 – 60 kg in Southeast Asia and around 10 – 30 kg in the rest of the world.

2.2 Annual EEA import volumes (last 15-20 years)

The tonnages of individual PFAS categories imported into the EEA (from third countries) have been obtained from consultation for this study as well as from the Call for Evidence responses. These quantities have been compared with data retrieved from Eurostat's International Trade in Goods database. Finally, an overview of imported quantities of fluoropolymers and F-gases has been obtained during the literature review (from the same sources as the production tonnages). A summary of PFAS tonnages imported into the EEA from third countries is presented in table 2 below.

Table 2: PFAS imported in the EEA from third countries (in tonnes)

PFAS Group	Minimum (Consultation)	Maximum (Consultation)	Eurostat (2019)	Literature review
Fluoropolymers	10,419	18,328	36,148	21,500 (in 2015)
F-gas	11,500	51,800	19,198	84,284
Remaining PFAS	4,053	6,120	103,586	n/a
TOTAL	**25,972**	**76,248**	**158,932**	**105,784 (without Remaining PFAS)!**

Source: Consultation exercise for this study and literature review
Note: Grey cells denote figures that have been deemed most realistic and that are used for further assessment of impacts.

Fluoropolymers
The EU is a net importer of **fluoropolymers**, with a sales value of around €310m and an import volume of 21,500 tonnes in 2015.[18]

Statistical data on global manufacture and use of **PFPEs** and therefore information on EEA imports have not been available in the literature review.

PFAEs production volumes are based on estimates for Japan, Western Europe and US, as it is assumed that the aggregated production occurs mainly in these countries, while the amount produced in other countries is considered as negligible[19]. The reported production of PFA in 2015 was around 5,800 tonnes, showing an increase from the 2011 volume of 5,200 tonnes. However, it remains uncertain the extent to which these volumes are shared between exports and imports.

Information on the global production of side-chain perfluoroethers is not publicly available and therefore it is difficult to estimate the volumes of imports to the EEA. However, following the example from the coating industry, it is estimated that the global consumption for UV curable coatings was around 600,000 tonnes in 2016.

[18] Plastics Europe (2017), Socio-economic analysis of the European fluoropolymer industry – executive summary
[19] Wang et al. (2014): Global Emission Inventories for C4–C14 Perfluoroalkyl Carboxylic Acid (PFCA) Homologues from 1951 to 2030. Part I: Production and Emissions from Quantifiable Sources', Environment International, Volume 70, September 2014, pp. 62-75

F-gases

For **fluorinated gases** (F-gases), data from the EEA report shows that total imports have seen a decrease in the years preceding 2017-19. In 2019, amounts imported were 20% less than those in 2017. Specifically, imports of HFCs have decreased by about 30 % since 2017, as imports of unsaturated HFCs and HCFCs have risen by around 40 %. In 2019, HFCs made up about 74 % of total F-gases imports.[20] Illegal trading on the black market of F-gases has been reported within the EU[21], undermining the EU climate goals. New data shows illegal import could be as high as 34 million tonnes carbon dioxide equivalent (CO_2eqT) or 33% of the legal EU HFC market as reported by the European Fluorocarbons Technical Committee (EFTC), a sector group of Cefic.

2.2.1 Eurostat data

Data on imports of certain PFAS chemicals into the EU have been retrieved from Eurostat's International Trade in Goods database[22] and are presented in the table below. The CN corresponds to the HS and provides a further breakdown at eight-digit level and includes around 9,400 eight-digit codes.[23] These have been narrowed down to 98 codes by performing a search for the term "fluoro".

A summary of the volumes of imports retrieved from Eurostat for the period of 2010-2019 as well as their Year-over-Year growth is presented in table 3 below. The relevant CN/HS codes have been summarised into the following three groups: **fluoropolymers**, **F-gas** or **remaining PFAS**.

Table 2: A summary of annual imports of PFAS chemicals from third countries into EU27 (tonnes)

PFAS group	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Fluoropolymers – Volumes (tonnes)	**22,194**	**31,122**	**29,644**	**29,070**	**32,004**	**29,706**	**33,072**	**38,202**	**46,008**	**36,149**
Fluoropolymer – YoY Growth (%)		40%	-5%	-2%	10%	-7%	11%	16%	20%	-21%
F-gas – Volumes (tonnes)	**7,005**	**9,722**	**12,249**	**14,106**	**16,773**	**13,970**	**18,781**	**23,631**	**27,456**	**19,191**
F-gas – YoY Growth (%)		39%	26%	15%	19%	-17%	34%	26%	16%	-30%
Remaining PFAS - Volumes (tonnes)	**87,644**	**79,881**	**85,354**	**75,540**	**77,157**	**77,881**	**83,267**	**105,334**	**110,281**	**103,583**
Other PFAS – YoY Growth (%)		-9%	7%	-11%	2%	1%	7%	27%	5%	-6%

Source: Eurostat's International Trade in Goods database Notes:
CN/HS codes included under the Fluoropolymer group: 39.04.61 and 39.04.69 (based on literature review, these two codes likely cover all legal imports of Fluoropolymers)
CN/HS codes included under the F-gas group: 29.03.39.39; 29.03.49.19; 29.03.77; 29.03.79; 38.24.71; 38.24.74; 38.24.78; and 38.24.87 (these codes do not cover imports of all substances in the F-gas group, based on data obtained from literature review it is estimated that they represent approximately 1/4th of all legal F-gas imports)
CN/HS codes included under the Remaining PFAS group: 28,26; 29.04.31; 29.04.32; 29.04.33; 29.03.34; 29.03.35; 29.03.36; 29.23.30; 29.23.90; 29.35.20; 29.35.40; 39.35.50; 29.35.90 and 39.04.80 (These codes likely include other substances that are not PFAS due to the fact that some HS categories are quite broad. In addition, not all CN/HS codes relevant to the 'Remaining PFAS' category have been identified. Compared to the tonnage of Other PFAS imports obtained during the consultation exercise, the import volumes obtained from Eurostat are more than sixteen times larger.)

[20] EEA (2020), Fluorinated greenhouse gases 2020.
[21] https://stopillegalcooling.eu/data/
[22] Eurostat's International Trade in Goods, 2020, "EU trade since 1988 by HS2,4,6 and CN8 (DS-645593)", available at: https://ec.europa.eu/eurostat/web/main/data/database?p_p_id=NavTreeportletprod_WAR_NavTreeportletprod_INSTANCE_nPqeVbPXRmWQ&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view
[23] Eurostat, 2020, "Methodology - Combined Nomenclature", available at: https://ec.europa.eu/eurostat/web/international-trade-in-goods/methodology/classifications

Data suggest that, in 2019, 27.2% of Fluoropolymer imports, 63.9% of F-gas imports and 42.4% of 'Remaining' PFAS imports into the EU from third countries originated from China. Again, it should be stressed that these figures only relate to a subset of PFAS substances and should be interpreted with caution (see explanation in table 3 above).

A summary of the volumes of exports retrieved from Eurostat for the period of 2010-2019 as well as their Year-over-Year growth is presented in table 4 below. The relevant CN/HS codes have been summarised into the following three groups: **fluoropolymers**, **F-gas** or **remaining PFAS**.

Table 4: A summary of annual exports of PFAS chemicals from EU 27 into third countries (tonnes)

PFAS group	Year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Fluoropolymer – Volumes (tonnes)	**29,535**	**28,469**	**26,595**	**23,323**	**27,360**	**26,546**	**26,107**	**27,068**	**30,167**	**28,718**
Fluoropolymer – YoY Growth (%)		-4%	-7%	-12%	17%	-3%	-2%	4%	11%	-5%
F-gas – Volumes (tonnes)	**9,559**	**7,459**	**7,116**	**7,415**	**8,507**	**12,360**	**18,242**	**16,443**	**13,660**	**10,371**
F-gas – YoY Growth (%)		-22%	-5%	4%	15%	45%	48%	-10%	-17%	-24%
Remaining PFAS - Volumes (tonnes)	**90,728**	**98,378**	**128,659**	**133,519**	**131,424**	**115,358**	**99,810**	**122,130**	**127,711**	**131,866**
Other PFAS – YoY Growth (%)		8%	31%	4%	-2%	-12%	-13%	22%	5%	3%

Source: Eurostat's International Trade in Goods

Notes:

CN/HS codes included under the Fluoropolymer group: 39.04.61 and 39.04.69 (based on literature review, these two codes likely cover all legal exports of Fluoropolymers)

CN/HS codes included under the F-gas group: 29.03.39.39; 29.03.49.19; 29.03.77; 29.03.79; 38.24.71; 38.24.74; 38.24.78; and 38.24.87 (these codes do not cover exports of all substances in the F-gas group)

CN/HS codes included under the Fluoropolymer group: 28,26; 29.04.31; 29.04.32; 29.04.33; 29.03.34; 29.03.35; 29.03.36; 29.23.30; 29.23.90; 29.35.20; 29.35.40; 39.35.50; 29.35.90 and 39.04.80 (These codes likely include other substances that are not PFAS due to the fact that some HS categories are quite broad. In addition, not all CN/HS codes relevant to the 'Other PFAS' category have been identified)

2.3 PFAS production in the market

There are seven manufacturers making up 60 % of the global market for the production of PFAS and fluoroplastics. These are summarised in the table 5 below.

Table 5: Main global manufacturers of Fluoropolymer, F-gas and other PFAS

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

Source: Fluoropolymers, IHS Markit (2019) - https://www.agcce.com/fluoroplastics/

Additional Chinese producers identified by RIVM and the study team include Fuxin Ltd., Juhua Group Corp., and Zhejiang Yonghe Refrigerant Co., Ltd.

2.4 Turnover, profits and market growth rates

Stakeholders were asked to provide their assessment of future growth in the sector.

F-gases

For F-gases there was a mixed picture. On the one hand it was anticipated that there would be downward pressure on volumes due to gradual replacement due to the F-gas regulation. However, one company also noted that there would be an increased demand for refrigeration due to the cold supply chain needed for medicines and vaccines. There would also be increased use of air conditioning units requiring low global warming potential refrigerants.

Unsaturated HFCs and HCFCs experienced a 3 % market growth, with key applications in refrigeration and air conditioning. Meanwhile, HFC supply decreased by 20 % in terms of mass produced. Sulphur hexafluoride (SF_6) saw a 14 % decrease in demand, nitrogen trifluoride (NF_3) decreased by 14 % and PFCs decreased by 21 %.[24]

Fluoropolymers and remaining PFAS

For PFAS other than F-gas (fluoropolymers and remaining PFAS), there was an expectation of growth in the absence of regulatory restrictions. This is driven by growth in demand from key downstream uses related to initiatives such as the Green Deal. Applications driving the anticipated growth include hydrogen fuel cells, coatings for photovoltaic and wind power, REDOX (reduction-oxidation) flow batteries and lithium-ion batteries, and water electrolysis for the hydrogen economy.

<u>Fluoropolymers</u>

The annual sales / turnover for the European fluoropolymer industry was EUR 840 million in 2015. It was estimated that, in the same year, an investment of EUR 43 million was put to research and development of fluoropolymers, equating to 5.5 % of turnover.[25]

[24] EEA (2020), Fluorinated greenhouse gases 2020.

[25] Plastics Europe (2017), Socio-economic analysis of the European fluoropolymer industry – executive summary

Remaining PFAS

The global consumption of PFHxSF was steadily increasing, ranging from about 400 – 700 million USD. Moreover, they foresee a further increase in this demand in the coming years, with an expected maximum in value of 700 – 900 million USD by 2020.[26]

2.5 Market price per tonnage

Fluoropolymers
Based on information obtained during the consultation exercise, prices for fluoropolymers vary widely and can range from €**8,000 per tonne to €5,000,000** per tonne. Noting that this is a very large range (almost three orders of magnitude), the study team were not able to identify an explanation for this range. It should be noted that some prices reported by companies during the consultation exercise most likely referred to the price of a product manufactured using fluoropolymers, which falls out of scope of this assessment. Hence, an average price per tonne of fluoropolymers, €16,471 (in 2015 prices), obtained from the Plastics Europe report[27] will be taken as a representative price per tonne of fluoropolymers sold on the EU market. The price has been converted into 2019/20 prices (**€16,828**) using an appropriate GDP deflator.

F-gases
Regarding the price of **F-gases**, according to a quarterly price monitoring for HFC refrigerants and their alternatives carried by OekoRecherche on behalf of the EU Commission in relation to the EU F-Gas regulation's (517/2014/EU) phase down schedule, the average price of HFC blends in Q3/2019 was between €18,000 and €40,500 per tonne[28]:

Higher prices were reported for F-gases with a relatively high GWP, e.g. R404A. As noted in EC (2020)[29] price increases roughly mirror the climate warming effects of the different HFCs. R404A is currently being phased out in line with the requirements of the F-gas regulation. R134a and R410A are widely used in the EU by the air conditioning servicing and equipment market. Therefore, a price of **€28,000** per tonne (i.e. an average price for one tonne of R2010A or R134a) is taken as representative

Remaining PFAS
A wide variety of prices per tonne of Remaining PFAS substances has been reported during the consultation exercise. The prices reported by companies varied **from €10,000 and €90,000 to several million €** for a specialised application. Due to the absence of other reliable estimates, a midpoint of the interval of €10,000 and €90,000 (i.e. **€50,000**) is taken as a representative price per tonne.

Price of imported PFAS

The prices of PFAS imports in 2019 (latest year for which data are available) have been retrieved from Eurostat. The average **price per tonne of fluoropolymers was calculated as €11,962, the price per tonne of F-gas as €7,777, and finally the average price per tonne of Remaining PFAS substances was calculated as €20,711**.

[26] Norwegian Environment Agency (2018), Investigation of sources to PFHxS in the environment.
[27] Plastics Europe - Association of Plastics Manufacturers – Fluoropolymers Product Group (2018): The fluoropolymers industry in Europe – A socioeconomic perspective. Available at: http://fluoropolymers.plasticseurope.org/publications
[28] OekoRecherche, 2019, "Preise von HFKW-Kältemitteln im dritten Quartal 2019 erneut gesunken", available at: https://www.oekorecherche.de/sites/default/files/publikationen/vdkf_jk_preismonitoring_3-2019.pdf
[29] EC, 2020, "Report From the Commission on on the availability of hydrofluorocarbons on the Union market", available at: https://ec.europa.eu/clima/sites/clima/files/f-gas/docs/20201216_c_2020_8842_en.pdf

2.6 Past, current and expected turnover & profit (before taxes) for (main) producers

Fluoropolymers
Figures from Plastics Europe indicates that that the annual fluoropolymer sales in the EU, in 2015, accounted for €780 million (Plastics Europe 2018).

F-gases and other PFAS
The study did not reveal data on turnover and profit for F-gases and other PFAS.

2.7 Monetised economic benefits of PFAS production

Companies responding to the survey declined to comment in detail on the monetised economic benefit of PFAS production. Companies responding to the survey commented on the complexity of this question, especially given the wide and diverse nature of the downstream supply chain, and producers' limited quantitative insight into the societal and economic value of the downstream uses. They were not able to provide any data.

2.8 Supply chain of PFAS production and supply chain of alternatives

This question was not investigated in detail. Producers commented that it is very difficult to comment on the supply chain of alternatives to PFAS substances, given the limited availability of alternatives. Further it was commented by the responders that the PFAS producers are not necessarily in the best position to identify alternatives or the potential supply chain of such.

2.9 Waste

As an adjunct to the main questionnaire, the study team requested information from the stakeholders on the creation and handling of waste resulting from their PFAS production processes.

Little quantitative information was provided on the volume or composition of waste. Treatment of waste is typically by incineration which may be on-site or off-site at a specialist third party waste treatment company. Transport of waste is via trucks; it was not clear if these are dedicated to PFAS waste alone or combined with other waste streams.

Dams and Hintzer (2016) discuss waste from fluoropolymer processing and compounding operations. They state that waste PTFE resin resulting from moulding, sintering, machining, and cutting operations in making semi-finished parts or final articles are usually in the range of 10–30%. These can be recycled for use in ram extrusion operations, or thermally/radiation-treated to produce low molecular weight PTFE which can be used as additives in plastics, inks, oils, lubricants, and coatings. Overall, the major share of used fluoropolymers ends up in landfills, in incineration plants or in blast furnaces[30].

[30] Dams and Hintzer, "Industrial Aspects of Fluorinated Oligomers and Polymers", in book "Fluorinated Polymers: Volume 2: Applications"

2.10 Identification of alternatives

The study team sought to find information on alternatives to PFAS. The general sentiment from companies responding to the questionnaire was that there are few options, that in turn present their own hazard or performance issues. While in some cases for specific applications (particularly for F-gases) alternatives with adequate performance have been implemented, there are other situations where there are no known suitable alternatives. Companies have made efforts to research and develop alternatives to PFAS substances. Detailed results of these studies were not available to the study team and this type of research tends not to be published, The general sentiment from companies responding to the questionnaire was that there are few options for alternatives to PFAS,

Fluoropolymers
Responses indicate that a difficult class of materials to substitute are fluoropolymers. Several companies and the industry association noted that these substances are expensive and are only used due to their unique combination of functionalities. Applications for fluoropolymers where the survey respondents indicated there are no known alternatives today include lithium-ion battery binders & separator coatings, ultrapure semi-conductor processing, ultra-durable industrial coatings in the construction sector and for industrial pipes/tubing in chemical processing plants, and polymer recycling aids that enable efficient and multiple recycle loops for packaging.

F-gases
There are alternatives for some HFCs, for example ammonia (due to its toxicity, its application is limited to highly controlled industrial environments), hydrocarbons (limited application due to their flammability), and carbon dioxide (which is inefficient at low and medium temperature refrigeration). There has also been a development of lower Global Warming Potential HFCs, HFOs and their blends.

Other PFAS
One survey respondent noted it has spent 20 years successfully developing fluoropolymers without the use of PFAS polymerisation aids (surfactants). It has now scaled up several high-volume fluoropolymers by substituting 100% of the PFAS polymerisation aid with non-fluorinated, non-persistent alternatives.

Fluoropolymers
In terms of environmental and human health impacts of introducing alternatives for fluorpolymers[31,32], there is, according to industry, a potential for higher risk of exposure to hazardous substances in alternatives used to meet the high standards of fluoropolymers in many applications. This brings higher safety risks, increases in emissions resulting from technical regression, and could put Europe's goals for climate and energy at risk.[33]. Alternatives to long-chain PFAS include substances with shorter per- or polyfluorinated carbon chains, non-fluorine-containing substances and non-chemical techniques. Within each of these categories, there are major substance groups that have been developed as alternatives, summarised in table 6 below.

[31] Lohman et al (2020), https://pubmed.ncbi.nlm.nih.gov/33043667/
[32] Henry, B. J., et al: 'A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers' (2018)
[33] Plastics Europe (2017), Socio-economic analysis of the European fluoropolymer industry – executive summary

Table 6: Alternatives to long chain PFAS	
Alternative Group	**Examples**
Shorter chain per- or polyfluorinated carbon chains	• 6:2 fluorotelomer-based chemicals • Perfluorobutane sulfonyl fluoride (PBSF)-based derivatives (to replace chemicals based on PFOS in surface treatment and coatings) • Mono- and polyfluorinated-ether-functionality compounds (e.g. polyfluoroalkyl ether carboxylic acids as alternative processing aids in manufacture of fluoropolymers) • Fluorinated oxetanes • Other fluorinated polymers
Non-fluorine-containing substances	• Propylated naphthalenes or biphenyls (used as water repelling agents for rust protection, marine paints, and coatings, etc.) • Fatty alcohol polyglycol ether sulphate (used as levelling and wetting agents) • Sulfosuccinates (used in surface coatings, paints, and varnishes) • Hydrocarbon surfactants (used in photographs) • Naphthalene derivatives • Siloxanes and silicone polymers (used to impregnate textiles, leather, and carpets or in surface coatings, paints and varnishes). • Stearamidomethyl pyridine chloride (use to impregnate textiles, leather, and carpets) • Polypropylene glycol ether, amines, and sulphates
Non-chemical techniques	• Various biological, physical, or natural control methods have been investigated. • Foam blankets and other barrier materials (used for mist suppression in electrochemical metal plating)
Source: OECD (2018), Synthesis paper on per- and polyfluorinated chemicals	

F-gases

The literature has identified several alternative **F-gases**, that can be used outside the major fluorocarbons currently in use. The most common alternatives include ammonia, carbon dioxide, propane, as well as several fluorocarbons such as HFOs (e.g., HFO-1234YF), or blends of HFOs with other (HFCs) substances[34]. Table 7 below presents these alternatives in detail.

Table 7: Common alternative F-gases		
Category	**Common refrigerants**	**Typical applications**
Inorganic (natural)	Ammonia CO_2	Industrial refrigeration Commercial refrigeration, foam blowing agent, heat pump water heaters
Hydrocarbon (Natural)	Propane Isobutene n-butane cyclopentane	Small commercial refrigerators Residential/ small refrigerators, aerosols Aerosols Foam blowing agent
Hydrofluoroolefin (HFO)	R-1234yf R-1234ze(E) R-1233zd(E) R-1336mzz(Z)	Mobile, stationary (heating, ventilating, and air conditioning) HVAC, refrigeration Refrigeration, HVAC, aerosol, blowing agent Chillers, blowing agent, solvent, waste heat recovery Chillers, blowing agent
Source: CEMAC (2020): Refrigerants: Market trends and supply chain assessment, pp 28		

[34] CEMAC (2020): Refrigerants: Market Trends And Supply Chain Assessment, pp 28

3 Environmental Impact Assessment

3.1 Description of method(s) used to assess impact

The purpose of this Environmental Impact Assessment is to provide an estimate of the total amount of PFAS released to the environment in the EEA per year. The circulated surveys contained information request about PFAS emissions to water and air during production and processing activities. Summing these emission values up would be an easy way to calculate the amount of PFAS entering the environment. However, this would result in an underestimation of the emissions. Even though the surveys were completed by some of the major producers and processors of PFAS present in the EEA, not all emissions have been captured. Hence, an extrapolation step is needed to have a realistic picture of the overall PFAS emissions in the EEA during production and processing.

In order to extrapolate, two values are needed. Firstly, the total volume of PFAS produced and processed per year. Secondly, an emission factor is required to predict the emissions to air and water of the aforementioned activities. The emission factor represents the percentage of PFAS which is released to the environment when a certain amount of PFAS is being manufactured or processed.

The emission factors were derived from the surveys of the companies which have provided information on both volume and emissions. The following formula was used as shown in figure 3 below:

Equation 1:

$$EF_{comp} = E_{comp} / m \times 100,$$

Where:

EF	emission factor of the produced/ processed PFAS	[%]
comp	receiving environmental compartment i.e.: water or air	[-]
E	Tonnes of PFAS emitted per year	[t / year]
m	Tonnes of PFAS produced/ processed per year	[t / year]

Figure 3: Calculation of emission factors
Source: ARCHE Consulting

Direct emissions to soil are not considered to be relevant for industrial settings. Emission factors to air and water were considered relevant and derived when information on amounts of PFAS emitted and amounts of PFAS produced was available in the questionnaires. After deriving the emission factors to air and water for each company, they were aggregated, and average values have been calculated. These average values were then applied to the volume of produced / processed PFAS, which gave the results of the estimated PFAS annually released to the environmental. The derived emission factors are shown in table 8.

Table 8: Emission factors to environmental compartments derived from company questionnaires						
	F-gases		Fluoropolymers		Remaining PFAS	
	Emission factor to water	Emission factor to air	Emission factor to water	Emission factor to air	Emission factor to water	Emission factor to air
Number of datapoints	6	6	7	6	5	5
Standard deviation	0.01 %	1.54 %	0.01 %	0.02 %	0.02 %	0.02 %
Average emission factors	**0.00 %**	**2.06 %**	**0.01 %**	**0.02 %**	**0.04 %**	**0.06 %**
Source: ARCHE analysis						

Certain estimations had to be taken into account when deriving the emission factors. Some companies have provided their annual production volume as a range. In this case, the average values have been used for the calculations, e.g., in case a manufacturer reported 100-1,000 ton/ year, a value of 550 t was considered. The literature information is scattered over different years, categories of PFAS, different geographic scales and life cycle of the PFAS. The advantage of working with the data from the questionnaires is that the emission factors are recent, allocated to PFAS categories and only contain information from production and/or processing of PFAS in Europe. As a result, this is considered to be more reliable.

Table 9: Estimated annual emissions of F-gases to air and water			
	Lower end estimate (t/year)	Midpoint estimate (t/year)	Upper end estimate (t/year)
Tonnages	13,600	33,200	52,800
Emissions to air	279.7	682.8	1,086.0
Emissions to water	0.6	1.4	2.3

Table 10: Estimated annual emissions of fluoropolymers to air and water			
	Lower end estimate (t/year)	Midpoint estimate (t/year)	Upper end estimate (t/year)
Tonnages	49,458	75,610	101,763
Emissions to air	9.9	15.1	20.3
Emissions to water	3.0	4.5	6.1

Table 11: Estimated annual emissions of remaining PFAS to air and water			
	Lower end estimate (t/year)	Midpoint estimate (t/year)	Upper end estimate (t/year)
Tonnages	53,902	85,977	118,051
Emissions to air	10.7	17.1	23.5
Emissions to water	3.2	5.2	7.1

To provide an overall overview of the total amount of PFAS released annually during production and processing to the environment, the emissions of all categories have been summed up and are shown in table 12. The total emissions to air are estimated between 300 t and 1,130 t per year, the range to water is estimated between 6.8 t and 15.5 t per year.

Table 12: Estimated annual emissions of all PFAS categories to air and water			
	Lower end estimate (t/year)	Midpoint estimate (t/year)	Upper end estimate (t/year)
Emissions to air	300.3	715.0	1,129.8
Emissions to water	6.8	11.1	15.5

3.2 Past emissions and expected future emissions in case PFAS production/industrial processing is continued

Information about past and future emissions were also requested in the survey sent to the companies. Out of the 27 answers, 16 provided information on past and future emissions of PFAS. The answers are summarized in table 13.

Table 13: Past emissions and expected future emissions by the survey participants					
Past emissions			Future emissions		
Increased	No change	Decreased	Will increase	No change	Will decrease
1	4	11	0	4	12
Notes: The values indicate the number of sites					

Companies also stated that even though their production might increase further, their PFAS emissions will remain the same or even decrease by implementing the best available technologies.

According to the OECD[35], 2015 there has been a solid increase in the total global annual C_4-C_{14} PFCAs emissions between 1951 and 2002. This period was followed by a deep decrease (approximately 40% reduction in emissions). Emissions further continued to decrease in the US, Western Europe and Japan, while in the rest of the world an increase could be observed. Although this is only a fraction of the PFAS substances this is in line with what the EU producers have reported in the questionnaires.

So, on one hand the volumes of PFAS production and processing could increase while on the other hand the emission controls should improve. The companies feel confident that the increased emission controls will further decrease the PFAS emissions in the future.

[35] https://www.oecd.org/chemicalsafety/risk-management/Working%20Towards%20a%20Global%20Emission%20Inventory%20of%20PFASS.pdf

4 ANNEX: CAS Numbers.

Substances identified as F-gases are indicated in **bold**.

Table 14: REACH Registered PFAS substances from the OEDC database			
CAS No	**PFAS category (OECD)**	**Chemical Name**	**REACH registered tonnage band (tonnes per year)**
19430-93-4	n:2 fluorotelomer olefins	1-hexene, 3,3,4,4,5,5,6,6,6-nonfluoro-	100 – 1,000
80793-17-5	**Hydrofluorocarbons (HFC)**	**Octane, 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-**	**0 – 10**
355-04-4	**perfluoroalkanes**	**Pentane, 1,1,1,2,2,3,3,4,5,5,5-undecafluoro-4-(trifluoromethyl)-**	**100 – 1,000**
2043-57-4	n:2 fluorotelomer iodides	Octane, 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-8-iodo-	Intermediate use only
80806-68-4	other fluorotelomer-based non-polymers	1-nonanol, 4,4,5,5,6,6,7,7,8,8,9,9,9-tridecafluoro-	Intermediate use only
647-42-7	#N/A	1-octanol, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-	Intermediate use only
34451-26-8	n:2 fluorotelomer-thiol derivatives	1-octanethiol, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-	0 – 10
72609-36-6	#N/A	Silane, dichloromethyl(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-	10 – 100 / intermediate use only
85857-16-5	n:2 fluorotelomer silanes	Silane, trimethoxy(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-	10 – 100 / intermediate use only
375-72-4	perfluoroalkyl sulfonyl halides	1-butanesulfonyl fluoride, 1,1,2,2,3,3,4,4,4-nonafluoro-	Intermediate use only
101947-16-4		Silane, triethoxy(3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl)-	Confidential
144317-44-2	Perfluoroalkyl sulfonic acids (PFSAs) + salts	Sulfonium, triphenyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	Confidential
52299-25-9		Phosphinic acid, P,P-bis(1,1,2,2,3,3,4,4,4-nonfluorobutyl)-	0 – 10
38565-52-5	fluorotelomer epoxides	Oxirane, 2-(2,2,3,3,4,4,5,5,6,6,7,7,7-tridecafluoroheptyl)-	Intermediate use only
297730-93-9		Hexane, 3-ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl)-	10 – 100 / confidential
26650-09-9	n:2 fluorotelomer-thiol derivatives	Thiocyanic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester	Intermediate use only
27619-89-2	n:2 fluorotelomer sulfonyl based compounds	1-octanesulfonyl chloride, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-	Intermediate use only
17527-29-6	n:2 fluorotelomer acrylates	2-propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester	100 – 1,000
1228350-17-1	fluorotelomer methacrylates (other)	2-propenoic acid, 2-methyl-, 4,4,5,5,6,6,7,7,8,8,9,9,9-tridecafluorononyl ester	0 – 10
307-35-7	perfluoroalkyl sulfonyl halides	1-octanesulfonyl fluoride, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-	Intermediate use only
2144-53-8	n:2 fluorotelomer methacrylates	2-propenoic acid, 2-methyl-, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester	100 – 1,000
56773-42-3	Perfluoroalkyl sulfonic acids (PFSAs) + salts	Ethanaminium, N,N,N-triethyl-, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonate (1:1)	0 – 10
34454-97-2	Perfluoroalkyl sulfonamidoethanols	1-butanesulfonamid, 1,1,2,2,3,3,4,4,4-nonafluoro-N-(2-hydroxyethyl)-N-methyl-	100 – 1,000
67584-55-8	perfluoroalkyl sulfonyl (meth)acrylates	2-propenoic acid, 2-[methyl[(1,1,2,2,3,3,4,4,4-nonfluorobutyl)sulfonyl]amino]ethyl ester	100 – 1,000
34455-29-3	n:2 fluorotelomer sulfonyl based compounds	1-propanaminium, N-(carboxymethyl)-N,N-dimethyl-3-[[3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-, inner salt	100 – 1,000
42532-60-5	perfluoroalkyl cyanide	Propanenitrile, 2,3,3,3-tetrafluoro-2-(trifluoromethyl)-	≥ 1 to < 10
756-12-7	perfluoroalkyl ketones	2-butanone, 1,1,1,3,4,4,4-heptafluoro-3-(trifluoromethyl)-	1 – 10
756-13-8		**3-pentanone, 1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-**	**100 – 1,000 +**

Table 14: REACH Registered PFAS substances from the OEDC database			
CAS No	**PFAS category (OECD)**	**Chemical Name**	**REACH registered tonnage band (tonnes per year)**
132182-92-4		Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-(trifluoromethyl)-	10 – 100
1187-93-5	perfluoroalkyl ethers / alkenes	Ethene, 1,1,2-trifluoro-2-(trifluoromethoxy)-	100 – 1,000
62037-80-3	Per- and polyfluoroether carboxylic acids (PFECAs)	Propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-, ammonium salt (1:1)	10 – 100
90622-71-2	perfluoroalkyl iodides	Alkyl iodides, C6-18, perfluoro	Intermediate use only
68391-08-2	n:2 fluorotelomer alcohols	Alcohols, C8-14, γ-ω-perfluoro	Intermediate use only
85631-54-5	n:2 fluorotelomer acrylates	2-Propenoic acid, γ-ω-perfluoro-C8-14-alkyl esters	10 – 100
375-50-8	perfluoroalkyl iodides	Butane, 1,1,2,2,3,3,4,4-octafluoro-1,4-diiodo-	Intermediate use only
375-80-4	perfluoroalkyl iodides	Hexane, 1,1,2,2,3,3,4,4,5,5,6,6-dodecafluoro-1,6-diiodo-	Intermediate use only
85995-91-1	n:2 fluorotelomer iodides	Alkyl iodides, C8-14, γ-ω-perfluoro	Intermediate use only
306-94-5	perfluoroalkanes	Naphthalene, 1,1,2,2,3,3,4,4,4a,5,5,6,6,7,7,8,8,8a-octadecafluorodecahydro-	0 – 10
335-27-3	**perfluoroalkanes**	**Cyclohexane, 1,1,2,2,3,3,4,5,5,6-decafluoro-4,6-bis(trifluoromethyl)-**	**0 – 10**
338-83-0	perfluoroalkyl amines	1-Propanamine, 1,1,2,2,3,3,3-heptafluoro-N,N-bis(1,1,2,2,3,3,3-heptafluoropropyl)-	≥ 1 000 to < 10 000
382-26-3	Hydrofluoroethers	Propane, 1,1,1,3,3-pentafluoro-3-methoxy-2-(trifluoromethyl)-	Intermediate use only
382-28-5	other per - and polyfluoroalkyl ether based substances	Morpholine, 2,2,3,3,5,5,6,6-octafluoro-4-(trifluoromethyl)-	100 – 1,000
1800-91-5	**n:2 fluorotelomer olefins**	**1,9-Decadiene, 3,3,4,4,5,5,6,6,7,7,8,8-dodecafluoro-**	**0 – 10**
15290-77-4	**Hydrofluorocarbons (HFC)**	**Cyclopentane, 1,1,2,2,3,3,4-heptafluoro-**	**0 – 10**
19190-61-5	Per- and polyfluoroether carboxylic acids (PFECAs) esters	Butanoic acid, 2,2,3,3,4,4-hexafluoro-4-[(1,2,2-trifluoroethenyl)oxy]-, methyl ester	0 – 10
25628-08-4	Perfluoroalkyl sulfonic acids (PFSAs) + salts	Ethanaminium, N,N,N-triethyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	0 – 10
34455-22-6	n:2 fluorotelomer sulfonyl based compounds	1-Octanesulfonamide, N-[3-(dimethylamino)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-	Intermediate use only
59493-72-0	other per - and polyfluoroalkyl ether based substances	1-Propanaminium, 3-[[4-[(heptadecafluorononen-1-yl)oxy]benzoyl]amino]-N,N,N-trimethyl-, iodide (1:1)	Confidential
96383-55-0	n:2 fluorotelomer-based non-polymers	2-Propenoic acid, 2-chloro-, 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl ester	10 – 100
102061-82-5	Perfluoroalkyl sulfinic acids (PFSAs) + salts	1-Butanesulfinic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, sodium salt (1:1)	Confidential
103055-07-8		Benzamide, N-[[[2,5-dichloro-4-(1,1,2,3,3,3-hexafluoropropoxy)phenyl]amino]carbonyl]-2,6-difluoro-	Confidential
130841-23-5		Benzene, 1,4-dichloro-2-(1,1,2,3,3,3-hexafluoropropoxy)-5-nitro-	Confidential
161075-00-9		1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd., reduced, fluorinated	100 – 1,000
220133-51-7	Perfluoroalkyl sulfonic acids (PFSAs) + salts	Sulfonium, dimethylphenyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	Confidential
220689-12-3	Perfluoroalkyl sulfonic acids (PFSAs) + salts	Phosphonium, tetrabutyl-, 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonate (1:1)	1 + / confidential
332350-93-3	other sulfonyl-based non-polymers	Phosphonium, triphenyl(phenylmethyl)-, salt with 1,1,2,2,3,3,4,4,4-nonafluoro-N-methyl-1-butanesulfonamide (1:1)	Confidential
371771-07-2	Side-chain aromatics	1,2-Benzenedicarboxamide, N1-[1,1-dimethyl-2-(methylsulfinyl)ethyl]-N2-[2-methyl-4-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]phenyl]-	Intermediate use only
874288-98-9	perfluoroalkyl ether halides	Ethane, 1,2-dichloro-1-[difluoro(trifluoromethoxy)methoxy]-1,2,2-trifluoro-	Intermediate use only
908020-52-0	Per- and polyfluoroether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[1,1,2,2-tetrafluoro-2-(1,1,2,2,2-pentafluoroethoxy)ethoxy]-, ammonium salt (1:1)	10 – 100

Table 14: REACH Registered PFAS substances from the OEDC database			
CAS No	**PFAS category (OECD)**	**Chemical Name**	**REACH registered tonnage band (tonnes per year)**
919005-14-4	Per- and polyfluoroether carboxylic acids (PFECAs)	Propanoic acid, 2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy]-	Intermediate use only
958445-54-0	Per- and polyfluoroether carboxylic acids (PFECAs) esters	Propanoic acid, 2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy]-, methyl ester	Intermediate use only
1189052-95-6	n:2 fluorotelomer phosphonic acids	Phosphonic acid, P-(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-, sodium salt (1:1)	0 – 10
1190931-27-1	Per- and polyfluoroether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy]-, ammonium salt (1:1)	10 – 100
1190931-39-5	Per- and polyfluoroether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy]-, potassium salt (1:1)	Intermediate use only
1190931-41-9	Per- and polyfluoroether carboxylic acids (PFECAs)	Acetic acid, 2,2-difluoro-2-[[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy]-	Intermediate use only
13846-22-5	perfluoroalkyl ethers / alkenes	Propane, 1,1,2,2,3,3-hexafluoro-1,3-bis[(1,2,2-trifluoroethenyl)oxy]-	Intermediate use only
203929-12-8	n:2 fluorotelomer olefins	1-Hexene, 3,3,4,4,5,5,6,6-octafluoro-6-iodo-	Intermediate use only
36097-07-1	n:2 fluorotelomer-thiol derivatives	1-Butanethiol, 4-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-	0 – 10
428-59-1	perfluoroalkyl epoxides	Oxirane, 2,2,3-trifluoro-3-(trifluoromethyl)-	100 – 1,000
88992-45-4	n:2 fluorotelomer-thiol derivatives	1-Propanaminium, 2-hydroxy-N,N,N-trimethyl-3-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-, chloride (1:1)	10 – 100
62880-93-7	n:2 fluorotelomer-thiol derivatives	1-Propanesulfonic acid, 2-methyl-2-[[1-oxo-3-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]propyl]amino]-, sodium salt (1:1)	10 – 100
76-19-7	**N/A**	**Propane, 1,1,1,2,2,3,3,3-octafluoro-**	**100 – 1,000**
754-12-1	**N/A**	**Polyhaloalkene and 2,3,3,3-tetrafluoroprop-1-ene**	**≥ 1 000 to < 10 000**
29118-24-9	**N/A**	**(E)-1,3,3,3-tetrafluoroprop-1-ene**	**≥ 1 000 to < 10 000**
102687-65-0	**N/A**	**(1E)-1-chloro-3,3,3-trifluoroprop-1-ene**	**≥ 1 000 to < 10 000**
357409-09-7	**N/A**	**1,1,1,2-tetrafluoroethane;hydrobromide**	**Not registered**
406-58-6	**N/A**	**1,1,1,3,3-pentafluorobutane**	**Confidential**
460-73-1	**N/A**	**1,1,1,3,3-Pentafluoropropane**	**1 000+**
374-27-6	**N/A**	**3,3,4,4,4-pentafluorobut-1-ene**	**1 – 10**
75-37-6	**N/A**	**1,1-difluoroethane**	**100 – 1,000**
75-10-5	**N/A**	**Difluoromethane (HFC-32)**	**≥ 10 000 to < 100 000**
811-97-2	**N/A**	**Norflurane (HFC-134a)**	**≥ 10 000 to < 100 000**
354-33-6	**N/A**	**Pentafluoroethane (HFC-125)**	**≥ 10 000 to < 100 000**
138495-42-8	**N/A**	**(S,S)-1,1,1,2,2,3,4,5,5,5-decafluoropentane; reaction mass of: (R,R)-1,1,1,2,2,3,4,5,5,5-decafluoropentane**	**≥ 10 to < 100 / confidential**
677-56-5	**N/A**	**1,1,1,2,2,3-Hexafluoropropane (HFC-236cb)**	**Not registered**
420-46-2	**N/A**	**1,1,1-trifluoroethane**	**≥ 1 000 to < 10 000**
75-45-6	**N/A**	**Chlorodifluoromethane (HCFC-22)**	**Not registered**
354-14-3	**N/A**	**1,1,2,2-tetrachloro-1-fluoroethane**	**Not registered**
75-46-7	**N/A**	**Trifluoromethane (HFC-23)**	**Not registered**
690-39-1	**N/A**	**1,1,1,3,3,3-hexafluoropropane**	**100 – 1,000**

Source: OECD, ECHA 2020, RIVM analysis

Notes: substances in bold are assessed by RIVM as being F-gases

Table 14: REACH Registered PFAS substances from the OEDC database			
CAS No	**PFAS category (OECD)**	**Chemical Name**	**REACH registered tonnage band (tonnes per year)**
Only the first 72 substances in the table (up to CAS no 76-19-7) appear in the OECD database of PFAS substances			

CAS 75-38-7, 1,1-difluoroethylene, HFC-1132a ≥ 10000 to < 100000 tonnes

In Table 14 above, the first 72 substances (up to CAS no. 76-19-7) were identified by filtering the OECD database for "REACH Registered" substances and obtaining the registered tonnage data from the ECHA database. The remaining 18 substances in this table have been identified by RIVM as F-gases however they do not appear in the OECD database of PFAS substances. As discussed, the figures for total F-gas volumes in this study were obtained from the stakeholder consultation exercise and the total volume data provided in the EEA report. It has been noted in discussions with RIVM that there can be some ambiguity in the definition of "F-gas". From a purely chemical and physical perspective, an F-gas could be considered as any substance that contains at least one fluorine atom and is a gas at standard temperature and pressure. This is a very wide definition and is likely the reason why some substances that meet this description do not appear in the OECD database.

Table 15 below shows the tonnage bands for those substances registered under REACH.

Table 15: Tonnage bands of PFAEs non-polymers with unsaturated bonds		
CAS No	**Name**	**Tonnage band/ (tonnes/ year)**
1187-93-5	Trifluoro(trifluoromethoxy)ethylene	100-1000
1623-05-8	**1,1,1,2,2,3,3-heptafluoro-3-[(trifluorovinyl)oxy]propane**	**100-1000**
1644-11-7	**1,1,1,2,3,3-hexafluoro-2-(heptafluoropropoxy)-3-[(trifluorovinyl)oxy]propane**	**1-10**
10493-43-3	**Trifluoro(pentafluoroethoxy)ethylene**	**1-10**
13846-22-5	1,1,2,2,3,3-hexafluoro-1,3-bis[(trifluorovinyl)oxy]propane	Not available – intermediate use only
19190-61-5	Methyl 2,2,3,3,4,4-hexafluoro-4-[(1,2,2-trifluoroethenyl)oxy]butanoate	0
29514-94-1	**1,1,2,2-tetrafluoro-2-[(trifluorovinyl)oxy]ethanesulfonyl fluoride**	**1-10**
442-390-9 [EC No]	**1,1,2,2,3,3-hexafluoro-1-trifluoromethoxy-3-trifluorovinyloxypropane**	**10-100**
700874-87-9	**1-[Difluoro(trifluoromethoxy)methoxy]-1,2,2-trifluoroethylene**	**10-100**
Sources: Nordic Council of Ministers (2020): Nordic Working Paper- per and polyfluoroalkylether substances: identity, production and use, pp 60, ECHA (2020) Note: substances in bold are in the OECD database but are not listed there as REACH Registered and therefore do not appear in the table.		

The results from the literature review show that there is very limited information publicly available with regards to the production of perfluoroethers non-polymers with saturated bonds. However, Table 16 presents the estimates on the tonnage bands reported for those substances registered under REACH.

Table 16: Tonnage bands of perfluoroethers non-polymers with saturated bonds		
CAS No	**Name**	**Tonnage band/ (tonnes/ year)**
382-28-5	2,2,3,3,5,5,6,6-octafluoro-4-(trifluoromethyl)morpholine	100-1000
62037-80-3	Ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate	10-100

Table 16: Tonnage bands of perfluoroethers non-polymers with saturated bonds		
CAS No	**Name**	**Tonnage band/ (tonnes/ year)**
144728-59-6	**2-(1,2-dichloro-1,2,2-trifluoroethoxy)-1,1,2,2-tetrafluoroethanesulfonyl fluoride**	**N/A**
874288-98-9	1,2-dichloro-1-[difluoro(trifluoromethoxy)methoxy]-1,2,2-trifluoroethane	N/A
919005-14-4	2,2,3-trifluoro-3-[1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy]propanoic acid	N/A
957209-18-6	**2,3,3,4,4-pentafluoro-2,5-bis(1,1,1,2,3,3,3-heptafluoropropan-2-yl)-5-methoxytetrahydrofuran**	**1-10**
1190931-27-1	Ammonium difluoro{[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy}acetate	1-10
1190931-39-5	Potassium difluoro{[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy}acetate	N/A
161075-00-9	Hexafluoropropene, oxidized, oligomers, reduced, fluorinated	100-1000
Total		212-2120

Source: Nordic Council of Ministers (2020): Nordic Working Paper- per and polyfluoroalkylether substances: identity, production and use, pp 76

Note: substances in bold are in the OECD database but are not listed there as REACH Registered and therefore do not appear in the table.