M-2026|2021

Miljødirektoratet / Norwegian Environment Agency

PFAS in mining and petroleum industry – use, emissions and alternatives

Wood Group UK Limited – July 2021

Report for

Angelika Baumbusch
Miljødirektoratet
Brattørkaia 15B
Trondheim
7010
Norway

Main contributors

Ian Keyte (Lead)
Julius Kreißig
Rob Whiting
Liz Nicol
Alex Matulina
Maria Paola Calasso

Issued by

pp

liz.nicol
2021.07.02
13:44:36 +01'00'

....

Ian Keyte

Approved by

....

Caspar Corden

Wood

Floor 23, 25 Canada Square
Canary Wharf
London E14 5LQ
United Kingdom
Tel +44 (0)20 3215 1610

43264-WOOD-XX-XX-RP-OP-0012_S3_P01 - PFAS in petroleum and mining - Final

General Data Protection Regulation (GDPR)

As a global business operating in a transparent and ethical manner, we respect the privacy rights of individuals and are committed to handling personal information responsibly and in accordance with applicable law. The client acknowledges that Wood's proposal may contain the CV's and personal data of individuals. Wood expects the client to use this data for the sole purpose of the evaluation of Wood's proposal and in strict accordance with the requirements of the EU General Data Protection Regulations (GDPR). In particular, the client (i) will not share the personal data received from Wood with any third party, (ii) will take appropriate technical and organisational measures to protect such personal data, which will be accessible only to those client personnel who have a need to see such data for the purposes of evaluating Wood's bid, in order to ensure the necessary level of security and (iii) will immediately destroy any personal data received from Wood in the event that the contract is not awarded to Wood.

Management systems

This document has been produced by Wood Environment & Infrastructure Solutions UK Limited in full compliance with our management systems, which have been certified to ISO 9001, ISO 14001 and ISO 45001 by Lloyd's Register.

Document revisions

No.	Details	Date
1	Draft Report	09/12/2020
2	Draft Final Report	1/07/2021
3	Final report	23/06/2021
4	Final report V2	02/07/2021

Contents

Glossary of abbreviations

Abbreviation	Full expression/term
BAuA	Federal Institute for Occupational Safety and Health
BAT	Best Available Techniques
CAS	Chemical Abstracts Service
CfE	Call for Evidence
ECHA	European Chemicals Agency
ECTFE	Ethylene chlorotrifluoroethylene
EEA	European Economic Area
EGR	Enhanced Gas Recovery
EOR	Enhanced Oil Recovery
EOSCA	European Oilfield Speciality Chemicals Association
EPDM	Ethylene propylene diene monomomer
ERC	Environmental release category
ETFE	Ethylene tetrafluoro-ethylene
EU	European Union
FEP	Fluorinated ethylene propylene
FEPM	Fluorinated ethylene propylene (tetrafluoroethylene-hexafluoropropy lene copolymer)
FFKM	Perfluoroelastomer
FKM	Fluoroelastomer
FP	Fluoropolymer
FVMQ	Fluorosilicone Rubber
IOGP	International Association of Oil & Gas Producers
NEA	Norwegian Environment Agency
HNBR	Hydrogenated Nitrile Rubber
OCNS	Offshore Chemicals Notification Scheme
OPF	Oil phase fluid
OSPAR	Convention for the Protection of the marine Environment of the North-East Atlantic

PAH	Polycyclic Aromatic Hydrocarbon
PBSF	Perfluorobutane sulfonyl fluoride
PCTFE	Polychlorotrifluoroethylene
PDMS	Polydimethylsiloxane
PEC	Predicted environmental concentration
PEAK	Polyaryletherketone
PEEK	Polyether ether ketone
PFA	Perfluoroalkoxy polymer
PFAS	Per- and Polyfluoroalkyl Substances
PFBS	Perfluorobutane sulfonate
PFCA	Perfluoroalkylcarboxylic acid
PFECAs	Per- and polyfluoroalkylether carboxylic acids
PNEC	Predicted no-effect concentration
POP	Persistent Organic Pollutant
PTFE	Polytetrafluoroethylene
PVDF	Poly(vinylidene fluoride)
REACH	Registration, Evaluation, Authorisation & restriction of CHemicals
RMO	Regulatory Management Option
RPM	Revolutions per minute
SPIN	Substances in Preparations in Nordic Countries
STP	Sewage treatment plant

1. Introduction

1.1 Per- and polyfluoroalkyl substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS) are a family of man-made chemicals that have been extensively used in a wide number of different industrial and consumer applications since the 1950s due to their unique physical and chemical properties (such as water-, oil- and grease-repellence and high chemical and thermal stability). The OECD[1] estimates that there are approximately 4,700 known individual chemical substances in the PFAS family, while others estimate that closer to around 6,000 substances belong to this group.[2]

Uses of PFAS include in textiles and leather; cosmetic products; food contact materials; paper and board; firefighting foams; household articles and consumer mixtures; construction products; lubricants and greases; industrial chemicals used in chrome plating; semiconductors; mixtures for treatment of skis; medical devices and apparel; applications within the oil, gas and mining industry; refrigeration and cooling applications; transportation (automotive, aviation etc.); and photographic surface layers.[3]

Some of the unique physicochemical properties of PFAS that have made them so useful and popular in these uses could also result in negative impacts on the environmental and human health.[4] Some PFAS either are, or degrade to, very persistent chemicals that accumulate in humans, animals and the environment.[5] Their resistance to degradation, and high mobility in the environment mean that PFAS are now found everywhere, including remote environments such as the Arctic. PFAS have been observed to contaminate water and soil in most European Union (EU) countries and it is extremely difficult and costly to clean up such contamination[6].

A number of PFAS are known to display toxic and/or bioaccumulative effects. Health effects in humans associated with exposure to certain PFAS include increased cholesterol levels, impact on infant birth weights, effects on the immune system, increased risk for cancer, and thyroid hormone disruption.[7] Some PFAS are classified in the EU as toxic for reproduction, the liver and as suspected carcinogens.[8]

While, within the past decade, several 'longer chain' PFAS compounds (e.g. PFOS, PFOA) have been restricted or banned under EU legislation, more recently, there have been mounting concerns and evidence that 'short chain' PFAS are also very persistent and very mobile in the environment, potentially leading to contamination of the environment in the future. This is a serious concern, particularly where manufacturers and industry may have switched from longer chain to shorter chain PFAS following the previous regulatory actions.

The European Commission has recommended that actions on the EU level to phase out PFAS should be taken to ensure that the use of PFAS is phased out in the EU, unless it is proven essential for society[9].

---

[1] https://www.oecd.org/chemicalsafety/risk-management/synthesis-paper-on-per-and-polyfluorinated-chemicals.htm

[2] https://www.concawe.eu/wp-content/uploads/2016/06/Rpt_16-8.pdf

[3] Juliane Glüge et al. (2020) An overview of the uses of per- and polyfluoroalkyl substances (PFAS), https://pubs.rsc.org/en/content/articlelanding/2020/em/d0em00291g#!divAbstract

[4] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/aboutPFAS/

[5] European Environment Agency (2019), Emerging chemical risks in Europe — 'PFAS', https://www.eea.europa.eu/themes/human/chemicals/emerging-chemical-risks-in-europe

[6] Nordic Council of Ministers (2019). The cost of inaction. A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf

[7] Elements for an EU-strategy for PFASs", 2019, attachment to letter from Ministers of Denmark, Luxembourg, Norway and Sweden to the Executive Vice-President for the European Green Deal & Climate Action and Commissioners calling for an EU action plan for PFAS https://www.regjeringen.no/contentassets/1439a5cc9e82467385ea9f090f3c7bd7/fluor---eu-strategy-for-PFAS---december-19.pdf

[8] https://www.hbm4eu.eu/the-substances/per-polyfluorinated-compounds/

[9] European Commission (2020) Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment, https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

1.2 This report

In May 2020, it was announced that Denmark, Germany, the Netherlands, Norway and Sweden would jointly analyse restriction options for PFAS on the basis of their high persistence in the environment and prepare a restriction proposal over the next two years. [10] The restriction proposal will potentially cover all PFAS rather than specific individual compounds and may include the use of fluoropolymers. It would be taken forward under the EU's regulation on the registration, evaluation, authorisation, and restriction of chemicals (REACH).

A call for evidence to inform about this process and to collect information from stakeholders was held, closing at the end of July 2020. Questions were addressed to the whole supply chain including manufacturers, importers, distributors, and downstream users.

The restriction will consider a range of different uses of PFAS. Along with the inputs from this stakeholder consultation, a number of projects are being conducted to gather and assess the evidence regarding the use of PFAS in specific uses. During these projects targeted stakeholder interviews were performed to further increase the understanding of the different applications.

This report provides an overview of the results from the study investigating the use of PFAS in the petroleum, and mining sector. This includes the following:

- An overview of PFAS in the petroleum and mining industry (Section 2) – detailing the specific uses for PFAS in this sector, and the function they provide that makes them valuable in these applications.
- PFAS in the petroleum and mining industry from the European perspective (Section 3) – looking at which specific substances and applications are most commonly used in Europe and the level of use of PFAS in this sector in Europe
- Emissions and exposure (Section 4) – looking at how PFAS are released, and how humans can be exposed from these uses, and the levels of release to different compartments of the environment.
- Alternatives to PFAS in the petroleum and mining sector (Section 5) – discussing the feasibility of alternatives to PFAS in this sector, and the implications for restricting use of PFAS in terms of the economic and technical aspects.
- Summary and main conclusions (Section 6)

Please note that all tonnages up to and including 2020 include the UK.

---

[10] https://echa.europa.eu/-/five-european-states-call-for-evidence-on-broad-pfas-restriction

2. PFAS in the petroleum and mining industry

2.1 Overview

A wide variety of chemicals are used in the petroleum and mining industries. This includes, for example, acids, antifoams, biocides, clay stabilisers, corrosion inhibitors, demulsifiers or emulsion breakers, foaming agents, friction reducers/lubricants, gas hydrate inhibitors, paraffin inhibitors, proppants, scale inhibitors, surfactants, tracers and water clarifiers.[11]

This assessment has focused on the use of PFAS, covering both 'non-polymeric' PFAS and fluoropolymers for use in petroleum exploration and production[12] and in mining.

The key applications for which PFAS-based chemicals are used in the petroleum and mining industries is summarised in Table 2.1 below.

Table 2.1 Summary of PFAS used in the petroleum and mining industries

Parent Level	Sub – Level[1]	Application
Petroleum exploration and production	Water-based and organic phase drilling fluids	Hydrocarbon foaming agent in drilling fluid
	Production chemicals[2]	Antifoaming agents
	Stimulation chemicals	Surfactants in stimulation fluids for chemically driven oil or gas production
		Hydrocarbon foaming agents
	Water and gas tracers	Tracers used to map oilfields
	Other[3]	Chemicals used in the storage or containment of oil and gas
		Fluoropolymer used in pipeline, valves, gaskets, O-rings, seals, cable and wiring insulation
Mining applications[3]	Extraction of ores and minerals	Acid mist suppressing agent
		Wetting agents
		Hydrocarbon foaming agent (Flotation)
		Fluorinated surfactants used in ore floating (Flotation)
	Equipment	Fluoropolymer used in pipes, cable, hoses, conveyor belts

[1] For petroleum extraction, as defined under the Harmonised Mandatory Control System under OSPAR Decision 2000/2. This does not apply to mining.

---

[11] See OECD (2012) , Emission scenario document on chemicals used in oil well production, http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2012)7&doclanguage=en

[12] The use and discharge of offshore chemicals apply to "chemicals which are used in the actual exploration, exploitation and associated offshore processing of oil, gas and condensate", as defined in the Common Interpretation on which Chemicals are Covered and not Covered by the Harmonised Mandatory Control System under OSPAR Decision 2000/2

[2] Referred to as 'Chemicals used in the actual production and processing of hydrocarbons' under OSPAR

[3] Uses not covered under OSPAR Decision 2000/2

2.2 Non-polymeric PFAS

2.2.1 PFAS in the oil and gas sector

Fluorosurfactants have been used in oil and gas exploration and production for the last 50 years and the increased demand for petroleum has been an important driver towards the use of PFAS in this sector.[13] The use of fluorosurfactants has become increasingly popular in the industry due to:

(i) Their exceptional hydrophobic and oleophobic nature

(ii) Their effectiveness at extremely low concentrations

(iii) Their ability to modify surfaces and interfaces better than conventional hydrocarbon surfactants

The main uses for PFAS in the oil and gas sector are[14]:

- **Drilling and production chemicals** – Fluorinated surfactants are used as hydrocarbon foaming agents in drilling fluids, which help reduce the amount of fluid that gets lost during drilling and reduces potential formation damage.

  PFAS-based products are also used as '**anti-foaming agents**' in drilling fluids. These additives prevent the formation of foam during the preparation of a treatment fluid or slurries at surface to reduce handling and pumping difficulties that interfere with the performance or quality control of the mixed fluid. They can also be used to aid the separation of water and oil during production or refining processes.

- **Stimulation chemicals** – PFAS are used in enhanced oil/gas stimulation fluids due to key desirable properties: chemical and thermal stability, wetting ability, and low aqueous surface tension. Fluorinated surfactants are used to render the surfaces of the oil-bearing reservoirs hydrophobic and oleophobic, which supports the exploration of petroleum reserves through the displacement of the petroleum streams from the underground sand and rock formations.

- **Tracers** – Chemical tracers are important in oil and gas reservoir mapping, e.g. to track the movement of the injected fluid through the oil reservoir, monitoring reservoir performance, investigating unexpected anomalies in flow and verifying suspected geological barriers or flow channels. PFAS-based tracers are used by the oil and gas sector to accurately map flow paths, volumes and the geological structures of oil and gas reservoirs to trace the path of the chemical to a production well in the subsurface environment.

- **Oil and gas storage and containment** – Evaporation of liquid fuels (e.g. gasoline) can be prevented by an aqueous surface film containing anionic surfactants, including PFAS-based chemicals, while oil spills on water can be contained and prevented from spreading by a chemical barrier containing a fluorinated surfactant.

---

[13] Murphy, P.M. and Hewat, T. Fluorosurfactants in Enhanced Oil Recovery, The Open Petroleum Engineering Journal, 2008, 1, 58-61

[14] Glüge, J. et al. (2020), An overview of the uses of per- and polyfluoroalkyl substances (PFAS), Environmental Science: Processes and Impacts, Issue 12, 2020.

2.2.2 PFAS in the mining sector

In the mining sector, fluorinated surfactants have historically been used to increase wetting of the sulfuric acid or cyanide used to leach ore, enhancing the amount of metal recovery, for example to increase the extraction efficiency in copper and gold mining.[15] The specific functions provided by PFAS for the mining sector include:

- Use as an acid mist suppressing agent in mineral recovery;
- Agents to increase wetting of the sulfuric acid or cyanide used to leach ore, enhancing the amount of metal recovery;
- Use in ore floating to create stable aqueous foams to separate the metal salts from soil; and
- Use in the recovery of metal salts from aqueous solutions.

2.3 Fluoropolymers

2.2.1 Fluoropolymers in the oil and gas sector

A wide range of fluoroplastics and fluoroelastomers are identified as being used in the oil and gas industry. The most common use for these materials in this sector is in the components of the equipment and piping used in extraction, transport and storage of petroleum resources. A summary of the key applications and the useful properties of fluoropolymers in the oil and gas industry is shown in Table 2.2 below[16].

Table 2.2 Summary of applications and properties of fluoropolymers in the petroleum industry

Application	Examples	Functional properties
Lining of piping, flowmeters and fittings, fluid-handling components, process vessels, tanks, storage and transport containers	● Polytetrafluoroethylene (PTFE) ● Perfluoroalkyl polymer (PFA) ● Fluorinated ethylene propylene (FEP)	High temperature resistance High mechanical strength Chemical resistance Corrosion resistance Inertness Non-adhesive/low friction resistance Low permeation Flexibility/ductility Light weight Non-flammable
Seals, liners, valves, O-rings, gaskets, packer elements.	● Fluoroelastomer (FKM)	High temperature resistance Rapid gas decompression resistance Resistance to compression fluids

---

[15] Glüge, J. et al. (2020), An overview of the uses of per- and polyfluoroalkyl substances (PFAS), Environmental Science: Processes and Impacts, Issue 12, 2020.

[16] Information presented in this section was gathered from Call for Evidence responses or further direct consultation with manufacturers and suppliers.

Application	Examples	Functional properties
Cable and wiring insulation	● Perfluoroalkyl polymer (PFA) ● Polyvinylidene difluoride (PVDF) ● Fluorinated ethylene propylene (FEP) ● Ethylene tetrafluoro-ethylene (ETFE)	High temperature resistance Flexibility/ductility

Pipes used in the production and transportation of oil are generally large and are manufactured from carbon steel. However, water, steam and chemicals (such as sulphur, sulphur dioxide, and carbon dioxide) present in the oil typically make the oil acidic, causing corrosion. Lining the interior surface of oil well pipes with fluorocarbons such as polytetrafluoroethylene (PTFE) helps prevent this corrosion. The key functional properties that makes fluoropolymers like PTFE important in this sector are durability, mechanical strength and corrosion resistance under the extreme environments found in down hole drilling (e.g. high temperature, high pressure, presence of steam and harsh chemicals). PTFE is also favoured due to its non-adhesive / low friction resistance, meaning pipes coated with PTFE have improved transfer of petroleum resources.[17]

Fluoroelastomers are widely used to produce key components (e.g. seals, liners, valves, O-rings, gaskets, packer elements). The high temperature degradation resistance (up to 200℃) is particularly important, allowing better resistance in deep well exploration. Other key properties include rapid gas decompression resistance (i.e. resistance to cracking due to adsorption of gases such as CO_2, N_2, and CH_4, after removal from high-temperature down-hole environments), extrusion resistance, and resistance to compression fluids.

Polymeric PFAS are used in cable insulation for communication cables in oil and gas drilling. With deep drilling, temperatures of at least 280°C are not uncommon at or near the bottom of the well. Cable insulation made out of Perfluoroalkoxy polymer (PFA), Polyvinylidene difluoride (PVDF), Fluorinated ethylene propylene (FEP) or Ethylene tetrafluoro-ethylene (ETFE) can withstand the extremely high temperatures near the bottom of the well.

2.3.2 Fluoropolymers in the mining sector

It can be expected that there may also be some use of fluoropolymers/ fluoroelastomers in the mining sector (for example, in cables, pipes, conveyor belts etc), given how widely fluoropolymers are used in industrial applications in general and the likely functionality (e.g. heat and chemical resistance and mechanical strength) needed for materials in this application. For example, PTFE rotary lip seals are marketed in Europe. Furthermore, products such as Nafion are known to be used in metal recovery in the mining industry[18] However, the level and type of use has not been confirmed by industry.

---

[17] Information presented in this section was gathered from Call for Evidence responses or further direct consultation with manufacturers and suppliers.

[18] Gardiner, J. (2015) Fluoropolymers: Origin, Production, and Industrial and Commercial Applications, Australian Journal of Chemistry 68(1):13

3. PFAS in the petroleum and mining industry – the European perspective

3.1 Non-polymeric PFAS

3.1.1 Overview of the oil and gas industry

Based on an assessment of the market for PFAS-based products currently sold and used in Europe, three main types of applications and corresponding PFAS substances have been identified in the petroleum industry[19]:

- PFAS used as anti-foaming agents[20];
- PFAS used as tracers; and
- PFAS-based enhanced oil/gas recovery stimulation products.

A summary of the estimated tonnages of PFAS used in these applications is provided in Table 3.1 below. Please note that all tonnages up to and including 2020 include the UK:

Table 3.1 Overview of the key PFAS uses in the oil and gas industry in Europe (2020)[21]

Application	PFAS used	Estimated volume of PFAS-containing products used (2020)	Estimated volume of PFAS used (2020)
Anti-foaming agents	Fluorinated silicones/siloxanes	170 tonnes	3.4-8.5 tonnes[2]
Tracers	Fluorinated alkanes and other (confidential) products	~1 tonne	~1 tonne [3]
Enhanced oil/gas recovery stimulation products	PBSF-based compounds/polymers	Negligible[1]	Negligible[1]

[1] Data collected during the consultation indicated minimal use of these products in Europe, no identified products currently on the market for this application.

[2] based on a PFAS content of 2-5% (derived from Call for Evidence submission, and consultation with national authorities)

[3] based on a PFAS content of 100% (derived from Call for Evidence submission)

---

[19] This assessment is limited to PFAS used in the extraction of petroleum resources. While it is expected that PFAS will be used in refineries of petroleum products, no data was available on current products, or their volumes of use in Europe.

[20] Anti-foaming agents are used in drilling and production (see Section 2.2.)

[21] Data is based on industry input in the (confidential) Call for Evidence Response and national authority data on tonnages of registered products used and discharged (2010-2018)

3.1.2 PFAS used as anti-foaming agents

Several **fluorinated polysiloxanes** are reported to be currently used in anti-foaming agents used the oil and gas industry in Europe. The identity of one specific fluorinated polysiloxane is confirmed, along with several (confidential) other fluorinated polysiloxanes, which are (OCNS) registered for use in this sector and active use and discharge from the oil and gas sector is confirmed through data provided by national authorities.[22]

It is expected that these products are used in a relatively small number of installations in 'severe cases' to provide foam control at small dose levels, where other types of anti-foaming agents are less effective. It has been indicated by one supplier that use of these products is gradually being eliminated where technical function is not compromised. It has also been reported that regulatory authorities in some countries have refused authorisation for use of these substances in the industry.

3.1.3 PFAS used as tracers

A number (>20) of specific **fluorinated alkanes** have been identified as being currently marketed and sold as tracers for the oil and gas industry. Several of these substances have active REACH registrations[23] and several have listings in the SPIN database[24] (although the tonnage information is confidential). Data from national authorities suggest that at least seven of the fluorinated alkanes identified have active (OCNS) registrations and it is confirmed that they have been actively used and discharged from oil and gas facilities in Europe in the last 10 years. Tracer substances generally need to be highly persistent and detectable at some level. Fluorinated alkanes are needed depending on reservoir characteristics and the range of other tracers used. Industry input notes that they are reportedly used sporadically in small (10-15 kg) quantities.

Various other PFAS-based compounds used as tracers in the oil and gas sector have been identified, based on data provided by national authorities with their identity being confidential. This data indicates that these substances represent the main bulk (>90%) of PFAS used for this application.

3.1.4 PFAS used as enhanced oil/gas recovery stimulation products

Very little information on the specific oil/gas well stimulation products currently being marketed and sold in Europe has been obtained in this assessment. A small number of specific products have been identified from the review of publicly available information and review of supplier sites. However, one supplier of a specific product identified as being based on a PBSF-based substances has indicated this product has been discontinued and is no longer sold in Europe. Furthermore, data provided by national authorities suggest that PBSF-based substances are not being actively used in offshore oil installations in Europe.

Data provided by regulators suggests that, in several cases, it has been reported that applications to use PFAS-containing well stimulation products have been rejected by regulators on the grounds of environmental risks posed, based on the expected PFAS degradation products released to the environment (e.g. perfluorobutane sulfonate, PFBS). This could indicate that the use of these products could be minimal as the use of non-fluorinated alternatives[25] is likely to be favoured in most cases.

3.1.5 Overview of mining industry

Based on limited input from the mining industry in this assessment, it is suggested that use of PFAS in the mining sector is minimal.

---

[22] Siloxanes and Silicones, di-Me, Me 3,3,3-trifluoropropyl, vinyl group-terminated (CAS: 68951-98-4)

[23] https://echa.europa.eu/information-on-chemicals/registered-substances

[24] http://www.spin2000.net/spinmyphp/

[25] See Negin, C. et al. (2017) Most common surfactants employed in chemical enhanced oil recovery, Petroleum, doi: 10.1016/j.petlm.2016.11.007.

3.2 Fluoropolymer

3.2.1 Use in the oil and gas sector

There are a large number of companies manufacturing and/or supplying fluoropolymer to the European market, and it is suggested from the input of manufacturers and suppliers in this assessment, the majority of these companies provide fluoropolymers that are ultimately used to formulate products used in the petroleum and mining sector.

The range of specific products and applications using fluoropolymer within the petroleum and mining industry is very wide, therefore the type of applications and specific products used is likely to vary considerably between individual installations. The number of individual components or products containing fluoropolymer in the petroleum and mining sector is expected to number in the thousands. Based on industry input, it is possible to derive an estimate for the percentage of total fluoropolymer contained in the specific products and components used in the oil and gas industry (see Table 3.2).

Table 3.2 Typical composition range for fluoropolymers in petroleum and mining applications

Fluoropolymer	Typical % composition in products for petroleum and mining sector
PTFE	50-100%
PFA	30-100%
FEP	>90%
ET	90%
PVDF	>90%
FKM	50-80%

The overall tonnages of fluoropolymer-containing products manufactured/sold in Europe are not available in the public domain. Only a small number of manufacturers and suppliers of fluoropolymer to the petroleum and mining sector have provided information on the estimated tonnages supplied in this sector.

A very approximate estimate has been derived from this assessment, suggesting the estimated total sales of fluoropolymer in Europe for use in the petroleum and mining sector is 3 500 to 7 500 tonnes per year.[26] It is estimated that this volume of sales to the petroleum and mining sector represents approximately 5% of total fluoropolymer sales in Europe (i.e. sales to all sectors).

It has not been possible to derive unit prices, either for the fluoropolymer sold for use in this sector, or for the products containing fluoropolymer sold to downstream users, due to a lack of information provided by suppliers, and the large number of products on the market for this sector.

Based on the estimated range of the tonnage for fluoropolymer used annually in the petroleum and mining sector in Europe (presented above), a very approximate estimate of €5.25 to €11.25 million of sales per year

---

[26] Based on data from one supplier.

has been derived.[27] It is emphasised that this value is subject to significant uncertainty and is based only on input from one supplier. This estimate is therefore indicative and should be used with caution.

It has not been possible, based on the information provided by industry in this assessment, to disaggregate the information on estimated tonnage or value for different types of fluoropolymer.

3.2.2 Use in the mining sector

See Section 2.3.2.

Due to a lack of data from the mining industry during this assessment, it has not been possible to derive an estimate for the overall tonnage of fluoropolymer used in the mining industry in Europe, or an estimated total value of these products in this sector.

---

[27] Based on Plastics Europe (2017) Socio-economic analysis of the European fluoropolymer industry, https://www.plasticseurope.org/application/files/7315/1708/4052/Final_SEA_Fluoropolymers_summary2017.pdf
Based on an estimated € 780 million total revenue from fluoropolymer across all sectors and an estimated 52 000 tonnes sold (2015 value).

4. Emissions and exposure

4.1 Overview

This section considers the potential environmental release of PFAS from the use of PFAS-based products and fluoropolymers used in the petroleum and mining industry. For this assessment, a basic source-flow model has been developed. Emissions to different environmental compartments (air, water, marine water, land), as well as waste, are estimated for each application, and estimates are also provided for the different key stages of the product lifecycle. It should be noted that the estimates of total tonnages of production and use of PFAS-containing products, and the emissions of PFAS to the environment in Europe presented in this report include the UK.

4.2 Emissions of PFAS to the environment

4.2.1 Approach

Life-cycle stages

The development of this source-flow approach began with a consideration of the key life-cycle stages and what kinds of emissions may occur at each life-cycle stage, which included:

- Production - Manufacture of the PFAS substances and fluoropolymers themselves is not within the scope of the current assessment.
- Formulation - This phase covers the formulation (i.e. blending/mixing of substances) stage to manufacture the mixtures/products that are actively used in this sector.
    - Non-polymeric PFAS products (tracers, antifoaming agents) - formulation of PFAS compounds into aqueous mixtures.
    - Fluoropolymer - 'raw' polymer material undergoes further compounding and processing to form specific products and components to be used in petroleum and mining installations (e.g. O-rings, pipes, linings, cables).
- **In Use** – It is expected that all PFAS- and fluoropolymer- containing products used in this sector, which are covered in this assessment, will be for outdoor use (open applications) so direct release to the environment is expected.
    - Non-polymeric PFAS products (tracers, antifoaming agents) - expected that these products are released into the oil/gas stream as part of their active use.
    - Fluoropolymer - expected that fluoropolymer-based products (typically solid polymer components) and components used in the petroleum and mining sector will be deployed in the (sub-surface) environment and are likely to remain in-situ for relatively long time periods (up to 20+ years)[28].
- **Waste** – The emissions during the waste-cycle are <u>not</u> within the scope of this assessment and are covered by a different use category of the restriction proposal. However, in this assessment,

---

[28] Based on input from manufacturers and suppliers to the Call for Evidence and further consultation.

an attempt is made to indicate the quantity of PFAS consigned to different waste-cycle pathways (landfill, incineration, wastewater treatment plants).

Product categories covered

The approach taken has not tried to develop estimates on a substance-by-substance basis, but rather taken a grouping approach. The emissions assessment has been limited to the three main groups of ongoing use have been identified:

- Water and gas tracers – all monomeric PFAS used as tracers in oil and gas fields (includes both fluoroalkane-based tracers and other confidential PFAS).
- Production chemicals – specifically emissions from the use of fluorinated siloxane-based products as anti-foaming agents for oil and gas processing.
- Fluoropolymers – specifically the emissions of the residual monomeric-PFAS in the fluoropolymer matrix. Note that the emission of fluoropolymer itself (e.g. through abrasion of tubes, linings and joint sealants during use) is not considered in the emissions assessment.

It should be noted, for the emissions assessment, only uses involved in the extraction of resources are considered. It has not been possible to include emissions from use in oil refining process due to a lack of information on this aspect.

Calculations and assumptions

Emissions to different environmental vectors have been estimated based on the estimated tonnage of the products actively used in Europe (see Section 3), and an assessment of the release patterns from each of the three product categories identified. The assessment presented in this section has considered three possible approaches to estimating the emissions to different environmental compartments (see Table 4.1).

Table 4.1 Overview of scenarios covered in the emission assessment

Scenario	Description
1	Application of ECHA worst-case release factors. Applied to estimated annual volume of use of PFAS in each product category.
2	Assumes 0% is recovered (either in the petroleum product or recovered water), 100% reaches the environment. Applied to estimated annual volume of discharge of PFAS in each product category directly.
3	Assumes 100% is recovered (either in the petroleum product or recovered water), 0% reaches the environment. Applied to estimated annual volume of discharge of PFAS in each product category directly.

Unless more detailed specific data were available on the use or release patterns of the products in question, or physical and chemical properties of the PFAS compounds identified, a broad estimate of the emissions via the three key environmental pathways (air, water and soil) has been made using worst case default release factors provided by ECHA.[29]

It should be noted that, for the use phase, the default values in the ECHA (2016) Guidance have been adjusted to take into account the estimated distribution of use between onshore and offshore installations and the assumed impact this has on the emission pattern of chemicals at these facilities, namely:

- 90:10 split between offshore: onshore
- 100% release to marine waters at offshore installations
- 50% release to soil, 50% release to fresh water at onshore installations.

An overview of the ECHA release factors used in this assessment is provided in Table 4-2.

Table 4.2 Overview of ECHA worst-case release factors used in the emissions assessment

Environmental release categories		**Applicable to**	**Default worst-case release factors resulting from the conditions of use described in the ERCs.** **Original values**			**Default worst-case release factors resulting from the conditions of use described in the ERCs.** **Adjusted (use phase)**			
#	**Description**		**To air**	**To water (before STP)**	**To soil**	**To air**	**To fresh water**	**To marine water**	**To soil**
2	Formulation into a mixture	Tracer, anti-foaming agents	2.5%	2%	0.01%	na	na	na	na
3	Formulation into a solid matrix	Fluoropolymers	30%	0.2%	0.1%	na	na	na	na
7	Use of functional fluid at industrial site	Tracer, anti-foaming agents	5%	5%	5%	5%	0.5%	9%	0.5%
10A	Widespread use of articles with low release (outdoor)	Fluoropolymers	0.05%	3.2%	3.2%	0.05%	0.2%	6.1%	0.2%

Where there is more detailed and specific information available, this has allowed a more focussed assessment of the emissions to the environment for PFAS used in these applications. In the case of tracers and anti-foaming agents, data has been provided by national authorities on the levels of use and discharge of specific PFAS-based products authorised and registered for use at oil and gas installations

A summary of key assumptions made in this assessment more generally is provided below.

- The baseline year for this assessment is 2020.

---

[29] ECHA (2016) Guidance on information requirements and Chemical Safety Assessment, Chapter R.16: Environmental exposure assessment, Version 3.0 https://echa.europa.eu/documents/10162/13632/information_requirements_r16_en.pdf (see Appendix A.16-1)

- Based on data provided in the DNV GL (2017) Energy Transition Outlook[30] on projected onshore and offshore oil and gas production volumes, it is assumed the use of PFAS-based products is split 90%:10% for offshore and onshore use respectively.
- It is assumed that, for the 'formulation' phase, all emissions to water will be to waste water (before sewage treatment plant (STP)). For the 'in use' phase, emissions to water are assumed to be to the marine water compartment for offshore use (90%) and to freshwater for onshore installations (10%).
- Where there is release to the environment at onshore installations during the use phase, it is assumed this will be 50% to land, 50% to freshwater.
- For the use of anti-foaming agents, it is expected that the PFAS-containing products will be contained in the injection fluids but, due to the lipophilic nature of the PFAS compounds, they will tend to be retained in the oil/gas stream. A conservative estimate is applied, assuming 80% is retained in the petroleum stream and 20% remains in the recovered water, which is ultimately disposed in marine waters (offshore) or fresh waters onshore).
- For emissions from tracers:
  - It is assumed, based on industry input that the PFAS concentration in the product is 100%. This is considered a worst-case scenario as this is based on supplier input on fluoroalkane products, noting that some other tracer products may have lower PFAS concentrations, but data was not provided by industry for other products.
  - Limited specific data are available on the precise release patterns or exactly how these substances will behave when released to the environment. In particular, the use phase is extremely challenging to characterize accurately and this is subject to considerable uncertainty.
- For emissions from **anti-foaming agents**:
  - It is assumed that the PFAS concentration in the product is 2-5%, based on data provided by manufacturers/supplier and national authorities on the fluorinate polysiloxane products identified as being used and discharged in this sector.
  - Limited specific data are available on the precise release patterns or exactly how these substances will behave when released to the environment (see above discussion on tracers). Produced water is often reinjected in the reservoir, hence the emissions to the environment are probably lower.
  - A range of possible emission scenarios in the use phase have been assumed (see above discussion on tracers).
- For emissions from **fluoropolymers**:
  - Total sales/use of fluoropolymer in this sector is estimated to be 3500-7500 t/a.
  - The level of residual monomeric PFAS in the fluoropolymer matrix is highly uncertain and limited specific data were available in this assessment.
  - Broad 'high' and 'low' [residual concentration] scenarios were used to produce an estimate and wide range of total quantity of monomeric PFAS present in the fluoropolymer used in Europe was presented between these two scenarios, to illustrate this uncertainty.

---

[30] Available from: https://eto.dnv.com/2017/main-report

- The 'high' scenario was informed by the ECHA (2014) Annex XV restriction report on PFOA[31] to derive estimates for the proportion of total fluoropolymer used containing different concentrations of monomeric PFAS. The assumptions made and PFAS concentrations used in deriving an estimate for the residual PFAS content for the 'high' scenario are presented in the table below.

PFAS concentration range (ppm)	PFAS concentration used (ppm)	ECHA (2014) PFOA Annex XV restriction scenario	Proportion of FP market applicable (2020)
0 ppm	0 ppm	Worst case / Refined	67%
20-50 ppm	35 ppm	Worst case / Refined	17%
1000-2000 ppm	1500 ppm	Refined	17%

- The 'low' scenario makes the broad assumption of 1ppm concentration for PFAS (unspecified) in all fluoropolymer.
- Using this approach, an estimate for the residual quantity of monomeric PFAS in the fluoropolymer is 4-8 kg (low scenario) and 900-1900 kg (high scenario).
- The ECHA ERCs for the formulation and use phases were applied to the total PFAS content estimated for the total fluoropolymer (see Table 4.2).
- These estimates only consider the emissions from 'new' fluoropolymer being used in this sector each year. It has not been possible to estimate the tonnage of 'in-situ' fluoropolymer in this sector, which could act as a source of residual monomeric PFAS to the environment.

4.2.2 Estimated emissions

An overview of estimated emissions, separated according to the different life-cycle stages, and the different environmental compartments is presented below in Table 4.3 and Table 4.4 respectively.

Source flow diagrams for the estimated emissions of PFAS from the use of chemical tracer products, anti-foaming agents, and the fluoropolymer low and high scenarios, are presented below in Figures 4-1 to 4-4.

---

[31] ECHA(2014) ANNEX XV Proposal For A Restriction – Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances. https://echa.europa.eu/documents/10162/e9cddee6-3164-473d-b590-8fcf9caa50e7

Table 4.3 Overview of emissions by different environmental compartment for all life-cycle stages (excluding waste) combined (in kg) for 2020

Group	PFAS compound	Quantity of product used (kg)	Quantity of monomeric PFAS (kg)	Emissions to air (kg)	Emissions to water (onshore) (kg)	Emissions to marine water (kg)	Emissions to land (kg)	Total Emissions (kg)	Total quantity entering waste (kg)
Water and gas tracers	Fluoroalkane tracers + other PFAS-containing tracers	1000	1000	25-70	20-25	0-110	0-5	165-185	20-145[1]
Drilling/Production chemicals	Fluorosiloxane antifoaming agents	170 000	3 400 – 8 500	85-635	70-210	20-760	0-45	170-1650	70-360[2]
Fluoropolymers (all) **Low scenario**	Monomeric PFAS (not specified)	3 500 000 – to 7 500 500	4-8	1-2	<1	<1	<1	1-3	<1 (formulation) 1-3 (end of life)[3]
Fluoropolymers (all) **High scenario**	Monomeric PFAS (not specified)	3 500 000 – to 7 500 500	900-1900	270-580	3-6	20-40	20-45 (1-2)	310-670	3-6 (formulation) 310-670 (end of life)[3]

[1] ~20kg from the formulation phase (water (before STP) and soil) ; 0-125kg from the use phase (recaptured at surface)

[2] 70-170kg from the formulation phase (water (before STP) and soil) ; 0-190kg from the use phase (recaptured at surface)

[3] Calculated using the total calculated residual monomeric PFAS content of the fluoropolymer and the total emissions across all use phases

Table 4.4 Overview of emissions by different life-cycle stages (in kg) for 2020

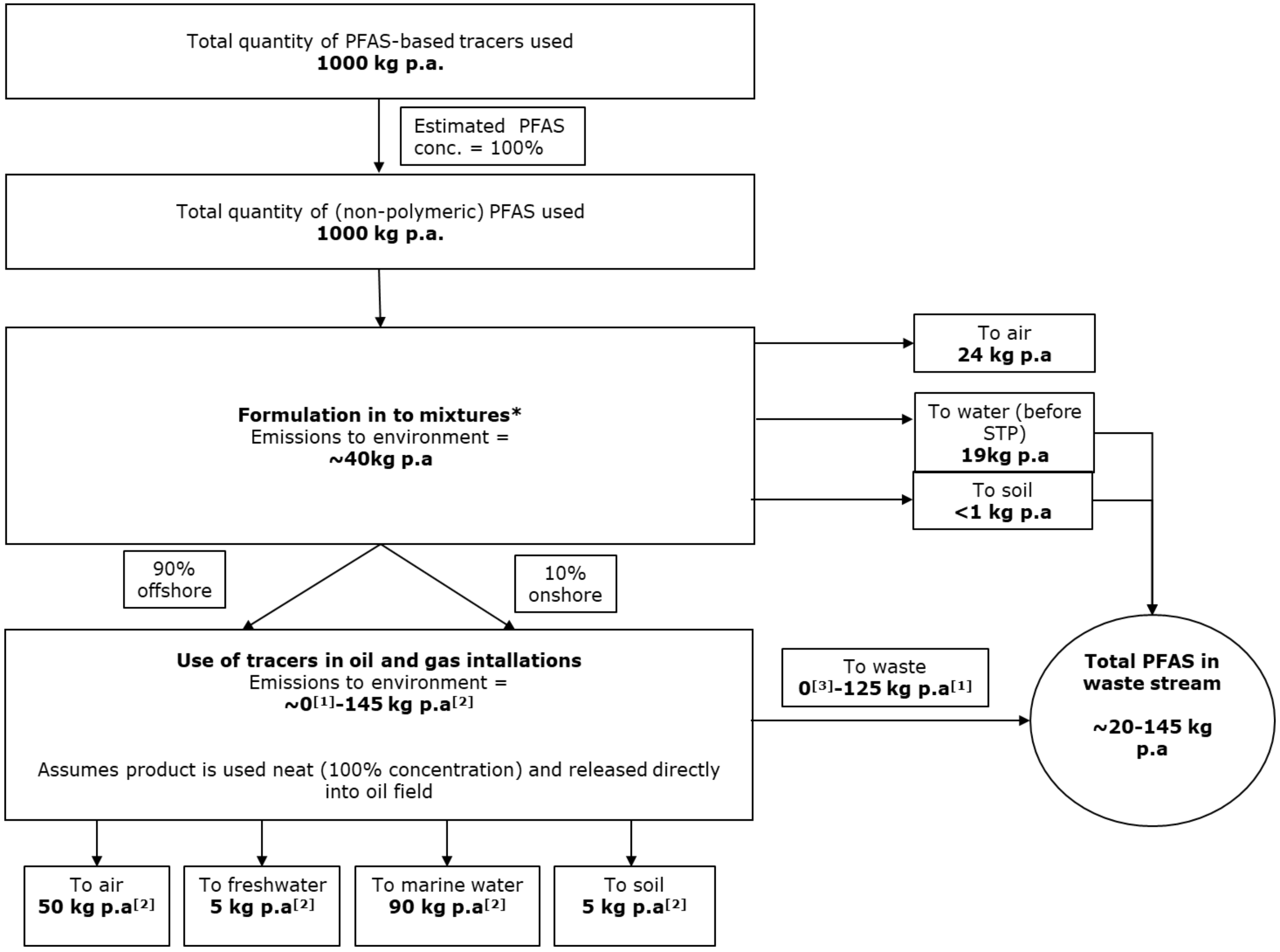
Group	PFAS compound	Quantity of product (kg)	Quantity of monomeric PFAS (kg)	Production Emissions (kg)	Formulation Emissions (kg)	In-use Emissions (kg)	Total Emissions (kg)
Water and gas tracers	Fluoroalkane tracers	1000	1000	na	40	125-145	165-185
Drilling/Production chemicals	Fluorosiloxane antifoaming agents	170 000	3 400 - 8 500	na	150-380	20-1300	170-1650
Fluoropolymers (all) **Low scenario**	Monomeric PFAS (not specified)	3 500 000 to 7 500 500	4-8	na	1-2	<1	1-3
Fluoropolymers (all) **High scenario**	Monomeric PFAS (not specified)	3 500 000 to 7 500 500	900-1900	na	270-580	40-85	310-670

Sources:

Quantity of products and PFAS – see estimates in Section 3 / Table 3-1

Residual content of PFAS in fluoropolymer – see Section 4.2.1

Figure 4-1 Material flow diagram for PFAS (tracers)

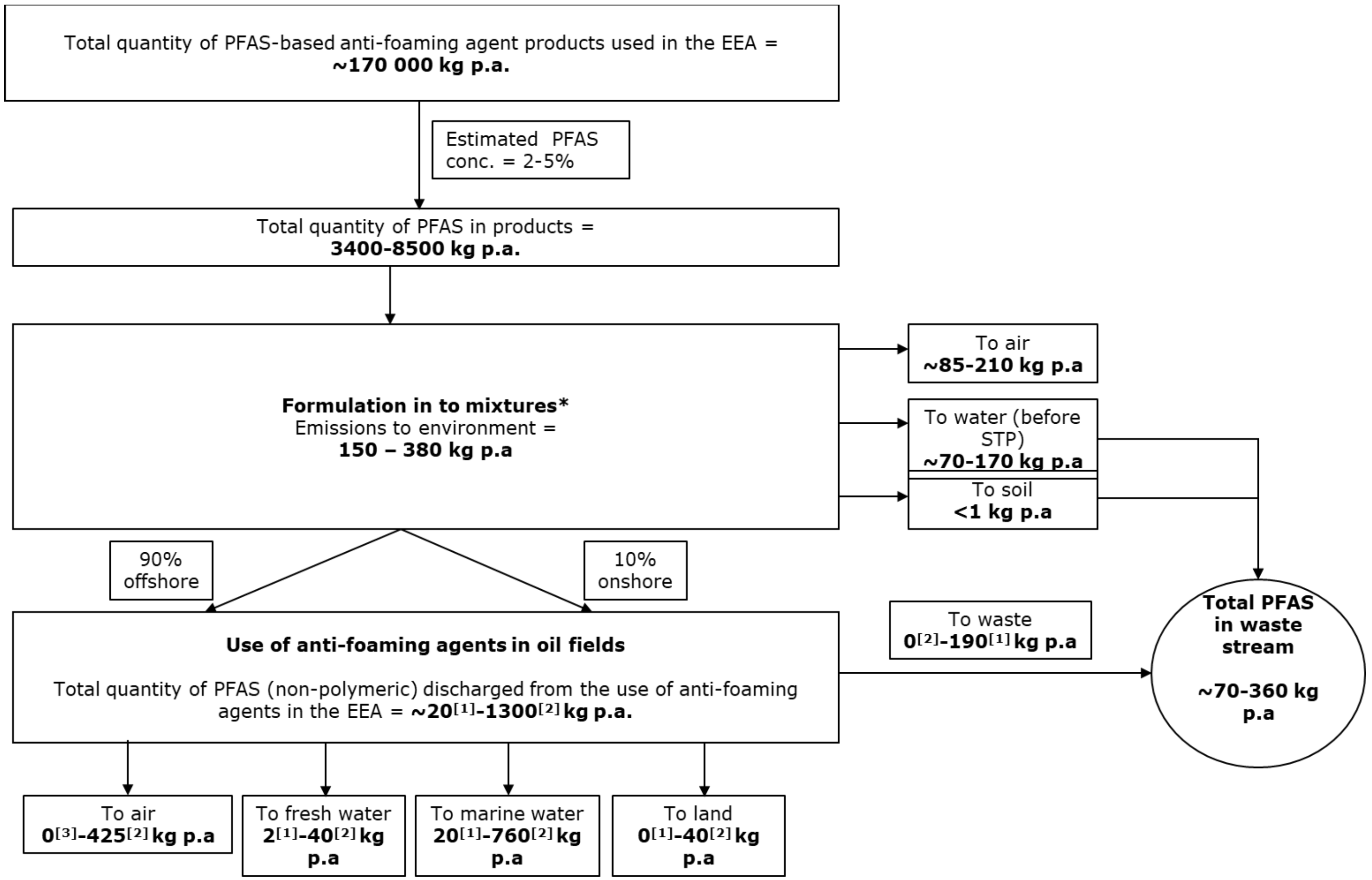


Baseline year: 2020

[1] Scenario 3; [2] Scenario 1; [3] Scenario 1 and 2. For a full description of each scenario see Table 4.1.

* Calculated using Environmental Release Category (ERC) emission scenario no.2 for 'formulation into a mixture' from ECHA (2016) Guidance on information requirements and Chemical Safety Assessment, Chapter R.16: Environmental exposure assessment. 2.5% w.w to air; 2% w.w to water (before STP) and 0.01% w.w to soil.

Figure 4-2 Material flow diagram for PFAS (anti-foaming agents)

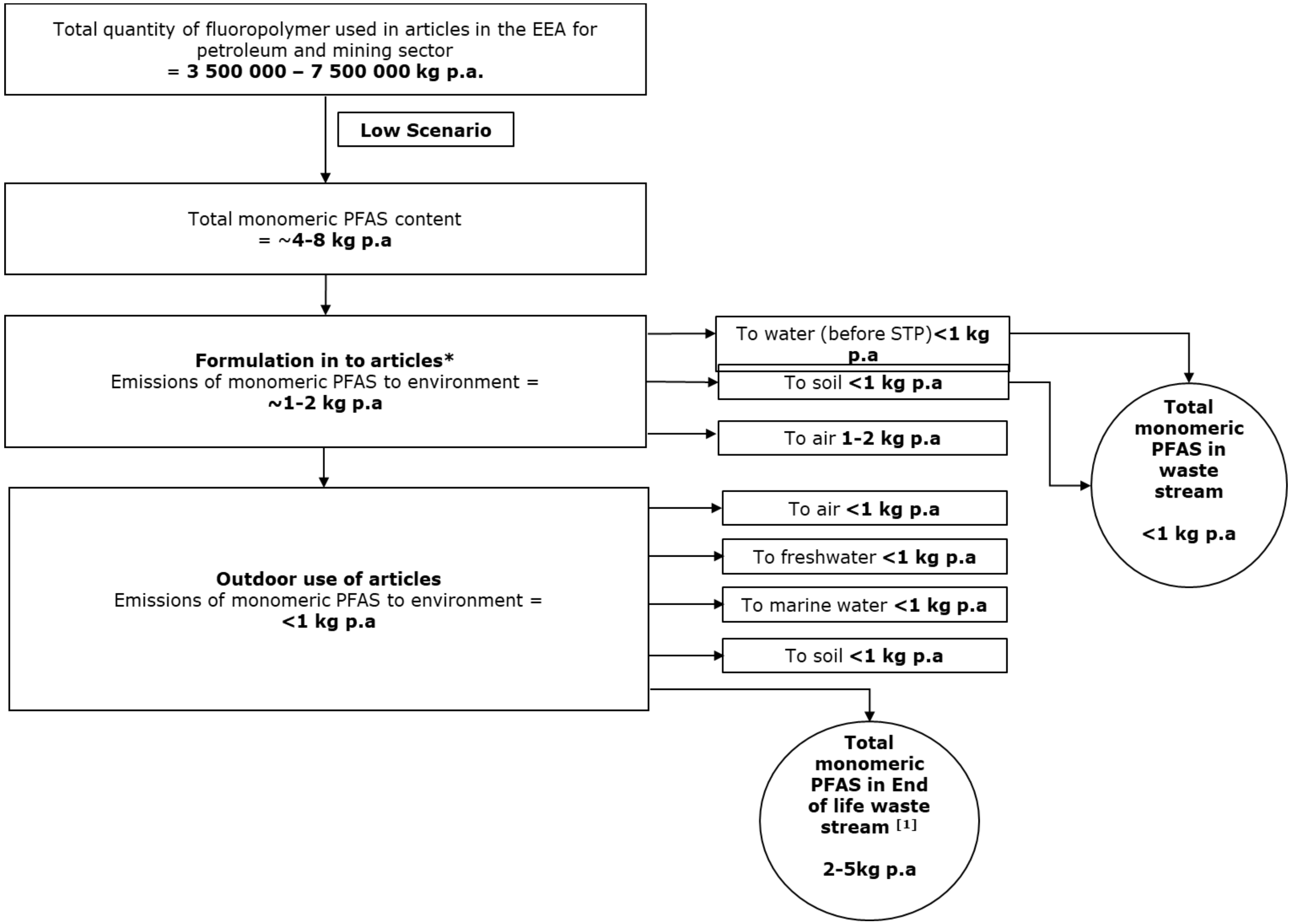


Baseline year: 2020

[1] Scenario 3; [2] Scenario 1; [3] Scenario 2 and 3. For a full description of each scenario see Table 4.1

* Calculated using Environmental Release Category (ERC) emission scenario no.2 for 'formulation into a mixture' from ECHA (2016) Guidance on information requirements and Chemical Safety Assessment, Chapter R.16: Environmental exposure assessment. 2.5% w.w to air; 2% w.w to water (before STP) and 0.01% w.w to soil.

Figure 4-3 Material flow diagram for PFAS (fluoropolymer agents, low scenario)

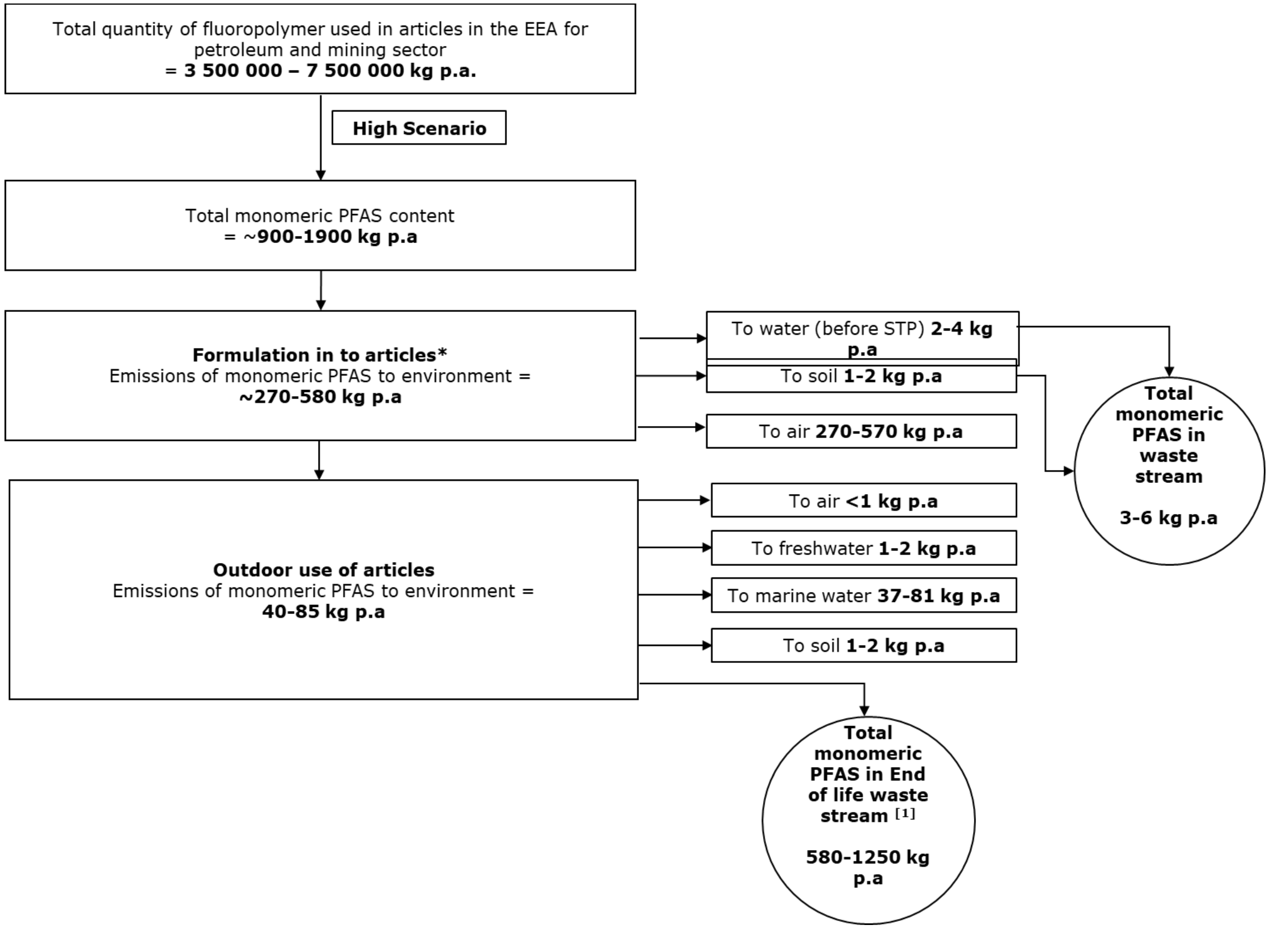


Baseline year: 2020

[1] Calculated using the total calculated residual monomeric PFAS content of the fluoropolymer and the total emissions across all use phases.

* Calculated using Environmental Release Category (ERC) emission scenario no.3 for 'Formulation into a solid matrix' from ECHA (2016) Guidance on information requirements and Chemical Safety Assessment, Chapter R.16: Environmental exposure assessment. 30% w.w to air; 0.2% w.w to water (before STP) and 0.1% w.w to soil.

Figure 4-4 Material flow diagram for PFAS (fluoropolymer agents, high scenario)



Baseline year: 2020

[1] Calculated using the total calculated residual monomeric PFAS content of the fluoropolymer and the total emissions across all use phases.

* Calculated using Environmental Release Category (ERC) emission scenario no.3 for 'Formulation into a solid matrix' from ECHA (2016) Guidance on information requirements and Chemical Safety Assessment, Chapter R.16: Environmental exposure assessment. 30% w.w to air; 0.2% w.w to water (before STP) and 0.1% w.w to soil.

4.3 Emission estimates time-series

4.3.1 Overview of approach

This section provides additional estimates to map production/use trends in PFAS or fluoropolymer-based products in the petroleum and mining sector covering the backward-looking time-series (1990-2020) as well as projections (2020-2050) for a business-as-usual scenario and REACH restriction (assuming no exemption is granted for this sector).

For the past trend, in the absence of more specific data, a broad assumption has been made regarding the past volumes of products sold, compared to the 2020 baseline. It has been assumed that sales of products start at a specific year and the trend in levels of sale have grown from 0 kg up to present volumes in the 2020 baseline, with a linear progression from the start year to the baseline year. The assumed start year for the substances covered in this assessment are as follows:

Category of use	Start year	Source
Tracers	1990	Assumption based on supplier input
Anti-foaming agents	1990	Assumption based on supplier input
Fluoropolymer	1950	Gardiner (2015)[32]; Teng, H. (2012)[33]

For the forward-looking trends (2020-2050), it is noted that petroleum production in Europe is expected to decline significantly over this time period. For example, the volume of offshore oil production in Europe is forecast to decrease by ~50% between 2020 and 2050 (see DNV GL, 2017 Energy Transition Outlook[34]). Similarly, it is also noted that decommissioning of oil and gas infrastructure is expected to become increasingly active, with over 200 platforms forecasted for complete or partial removal, over 2,500 wells to be decommissioned in the North Sea before 2030[35].

However, input from manufacturers and suppliers has indicated that the demand for PFAS-based tracer and anti-foaming agents, is expected to increase in future years, as the industry is likely to explore more ‘challenging’ environments for oil and gas production.

Similarly, suppliers and users have indicated that the demand for fluoropolymer in this sector is also expected to grow as the requirement for materials to sustain increasingly harsh environments (e.g. high temperature, high pressure) in oil and gas exploration. It is therefore expected that the future volumes of sales and use of these products may not be considered to be proportional to the overall volumes of oil and gas production.

In the absence of more detailed information or estimates from industry, a conservative annual growth of 1% has been assumed for the three product categories. This estimate is a best approximation, based on indication from manufacturers and suppliers that sales are likely to increase in future years for these products but the level of demand in a specific year is highly uncertain, and the market is expected to be highly variable year-on-year. This is largely attributed to the volatility in oil prices, which is the key driver in the level of

---

[32] Teng, H. (2012) Overview of the Development of the Fluoropolymer Industry, Appl. Sci. 2012, 2, 496-512.

[33] Gardiner, J. (2015) Fluoropolymers: Origin, Production, and Industrial and Commercial Applications, Australian Journal of Chemistry 68(1):13

[34] Available at: https://eto.dnv.com/2017/main-report.

[35] See Oil and Gas UK. 2019 Decommissioning Insight. Available at: https://oilandgasuk.cld.bz/Decommissioning-Insight-2019/36/

activity in oil and gas exploration and drilling in a given year, hence directly influencing the demand for PFAS-based products in this sector.

Forecasting future usage rates and technologies is very challenging and cannot readily consider emergence of novel technologies or unpredicted sudden world events (with Covid-19 being a good example). Furthermore, the further forward in time the projection is cast the greater the uncertainty in future trends or events. Therefore, any estimate of usage as far forward as 2050 should be treated with a great deal of caution and used only as indicative of possible usage rates and associated emissions.

For the purposes of the future projection estimates, a conservative estimate assumes a full REACH restriction on the production and use of both PFAS and fluoropolymer implemented by the end of 2023, with a three-year transition period for PFAS and a ten-year transition period for fluoropolymer. This has been informed by the input of numerous producers and suppliers, which indicated that the industry would require a minimum of 10+ years to transition towards producing alternative materials for these products.

For tracers and anti-foaming agents, the levels of emissions estimated in past and future scenarios are expected to be directly proportional to volumes of production and use of these products, therefore the pattern of emission levels (relative to the 2020 baseline) applied from 1990 to 2020 period, is expected to follow the same trend as presented in the baseline scenario for expected tonnage of sales for these products.

For fluoropolymers, the emissions of monomeric-PFAS will be dependent on the residual content of PFAS in the polymer matrix. The emission time series has been derived, based on scenarios of estimated PFAS concentrations on fluoropolymer in past and future years. In general, it is expected that pre-2000 fluoropolymer will have much higher concentrations than the 2020 baseline and concentrations would decline after the 2020 baseline.

4.3.2 Time series results

Tracers

Table 4.5 below provides projections for future usage rates and associated emissions for chemical tracers (using the same model and assumptions as the baseline year) to all environmental compartments. Please note that all estimates include the UK.

Table 4.5 Usage rates and emission projections for the baseline and REACH restriction scenario (tracers)

Year	**Baseline scenario**			**Restriction Scenario**		
	Production rates / sales (kg)	**Usage rates / PFAS content[1] (kg)**	**Emissions of PFAS to all compartments (kg)**	**Production rates / sales (kg)**	**Usage rates / PFAS content[1] (kg)**	**Emissions of PFAS to all compartments (kg)**
1990	0	0	0	0	0	0
1995	160	160	28-31	160	160	28-31
2000	320	320	56-62	320	320	56-62
2005	480	480	83-93	480	480	83-93
2010	640	640	110-125	640	640	110-125
2015	800	800	140-155	800	800	140-155
2020	960	960	165-185	960	960	165-185

Year	Baseline scenario			Restriction Scenario		
	Production rates / sales (kg)	Usage rates / PFAS content[1] (kg)	Emissions of PFAS to all compartments (kg)	Production rates / sales (kg)	Usage rates / PFAS content[1] (kg)	Emissions of PFAS to all compartments (kg)
2025	1010	1010	175-200	390	390	35-40
2030	1070	1070	185-205	0	0	0
2035	1100	1100	195-215	0	0	0
2040	1170	1170	205-225	0	0	0
2045	1230	1230	213-240	0	0	0
2050	1290	1290	225-250	0	0	0

[1] PFAS content is assumed to be 100%

Anti-foaming agents

Table 4-6 below provides projections for future usage rates and associated emissions for anti-foaming agents (using the same model and assumptions as the baseline year) to all environmental compartments.

Table 4.6 Usage rates and emission projections for the baseline and REACH restriction scenario (anti-foaming agents)

Year	Baseline scenario			Restriction Scenario		
	Production rates / sales (kg)	Usage rates / PFAS content[1] (kg)	Emissions of PFAS to all compartments (kg)	Production rates / sales (kg)	Usage rates / PFAS content[1] (kg)	Emissions of PFAS to all compartments (kg)
1990	0	0	0	0	0	0
1995	28 000	600-1400	30-275	28 000	600-1400	30-275
2000	56 000	1100-2800	60-550	56 000	1100-2800	60-550
2005	85 000	1700-4200	85-825	85 000	1700-4200	85-825
2010	113 000	2300-5600	115-1100	113 000	2300-5600	115-1100
2015	141 000	2800-7100	145-1375	141 000	2800-7100	145-1375
2020	169 000	3400-8500	170-1650	169 000	3400-8500	170-1650
2025	178 000	3600-8900	180-1740	48 000	1000-2400	40-350
2030	187 000	3700-9400	190-1825	0	0	0
2035	197 000	3900-9800	200-1920	0	0	0
2040	207 000	4100-10300	210-2015	0	0	0
2045	217 000	4300-10900	220-2120	0	0	0

Year	Baseline scenario			Restriction Scenario		
	Production rates / sales (kg)	Usage rates / PFAS content[1] (kg)	Emissions of PFAS to all compartments (kg)	Production rates / sales (kg)	Usage rates / PFAS content[1] (kg)	Emissions of PFAS to all compartments (kg)
2050	228 000	4600-11400	230-2225	0	0	0

[1] PFAS content is assumed to be 2-5%

Fluoropolymer

Table 4-7 and Table 4-8 below provide projections for future usage rates and associated emissions for the low and high scenarios for fluoropolymer respectively (using the same model and assumptions as the baseline year) to all environmental compartments.

Table 4.7 Usage rates and emission projections for the baseline and REACH restriction scenario (fluoropolymer, low scenario)

Year	Baseline scenario			Restriction Scenario		
	Production rates / sales (t)	Monomeric PFAS content[1] (kg)	Emissions of monomeric PFAS to all compartments (kg)	Production rates / sales (kg)	Monomeric PFAS content (kg)	Emissions of monomeric PFAS to all compartments (kg)
1990	2000 - 4300	20-43	7-15	2000 - 4300	20-43	7-15
2000	2500 - 5400	25-54	9-19	2500 - 5400	25-54	9-19
2010	3000-6500	17-35	6-12	3000-6500	17-35	6-12
2020	3500 - 7500	4-8	1-3	3500 - 7500	4-8	1-3
2030	4000-8300	4-8	2-3	800-1700	1-2	0-1
2040	4300-9200	4-9	2-3	0	0	0
2050	4700-10100	5-10	2-4	0	0	0

Table 4.8 Usage rates and emission projections for the baseline and REACH restriction scenario (fluoropolymer, high scenario)

Year	Baseline scenario			Restriction Scenario		
	Production rates / sales (t)	Monomeric PFAS content[1] (kg)	Emissions of monomeric PFAS to all compartments (kg)	Production rates / sales (kg)	Monomeric PFAS content[1] (kg)	Emissions of monomeric PFAS to all compartments (kg)
1990	2000 - 4300	8500-18200	3000-6300	2000 - 4300	8500-18200	3000-6300
2000	2500 - 5400	10600-22800	3700-7900	2500 - 5400	10600-22800	3700-7900

Year	Baseline scenario			Restriction Scenario		
	Production rates / sales (t)	Monomeric PFAS content[1] (kg)	Emissions of monomeric PFAS to all compartments (kg)	Production rates / sales (kg)	Monomeric PFAS content[1] (kg)	Emissions of monomeric PFAS to all compartments (kg)
2010	3000-6500	7500-14000	2600-4800	3000-6500	7500-14000	2600-4800
2020	3500 - 7500	900-1900	310-670	3500 - 7500	900-1900	310-670
2030	3900-8300	700-1400	230-500	800-1700	140-300	60-130
2040	4300-9200	500-1100	180-380	0	0	0
2050	4700-10100	300-650	100-220	0	0	0

Discussion

From the above tables it can be seen that, with a restriction in place, reducing the direct emissions of monomeric PFAS to the environment (0 emissions in 2040), the reduction in total monomeric PFAS emissions across the three product categories (compared to the 2020 baseline) is 500-2500 kg. There is a significant uncertainty range associated with these emission estimates. This is largely due to a lack of data on the precise environmental release and behaviour of chemical products (e.g. anti-foaming agents and tracers) from oil and gas facilities, and the uncertainty regarding the residual PFAS contents of fluoropolymer products used in this sector. This has meant that a broad range of assumptions and scenarios have been used to derive emission estimates. Please note that all tonnages up to and including 2020 include the UK.

5. Alternatives to PFAS in the petroleum and mining sector

5.1 Overview

This section discusses the potential alternatives to PFAS-based products, for the specific applications identified above, and their technical and economic feasibility. We focus on the uses in the petroleum and gas sector only, as the uses in the mining sector are expected to be minimal, or in the case of fluoropolymer, very uncertain.

5.2 Alternatives identified in the oil and gas sector

For each of the main applications identified in Section 3, industry has indicated that non-fluorinated alternatives are available on the market and are used in oil and gas applications in Europe. Specific alternative substances/products have been taken forward for further examination. A brief discussion of the main alternatives identified is provided below:

- Tracers - Input from industry has confirmed that both halogenated and radioactive tracers could possibly be used in the oil and gas industry in Europe as an alternative to the PFAS-based tracers.[36] It is indicated that radioisotopes have been used to study the in-situ placement and flow of various subsurface processes in the oil and gas sector for many decades. In addition to other halogenated substances, industry has also mentioned noble gas isotopic tracer, xenon, radioactive tracers, and radiolabelled compounds (d13C, d18O) as alternatives. The industry has reported loss of functionality for some applications when using alternatives (and loss of information on reservoir outflow if no tracers are used).
- Anti-foaming agents - One specific alternative to fluorinated silicone/siloxane products for use as antifoaming agents are non-fluorinated silicone/siloxane-based products. A specific example to this is poly(dimethylsiloxane) (PDMS) oils, which are the most common chemical foam control agents.[37] It is known that a number of manufacturers are marketing various non-fluorinated silicone-based anti-foaming agents for use in the oil and gas sector. Other alternatives include ethyl siloxanes, polypropylene glycol, naphthalene/1,2,4-trimethylbenzene based products, dipropylene glycol monomethyl ether and 2,6-dimethylheptan-4-one. Industry indicates that alternatives are often less efficient and need to be used in higher quantities/concentrations (which has potential implications for cost and storage).
- Enhanced oil/gas recovery stimulation products - The substances used in chemically-driven oil and gas production will vary considerably between individual locations. There are a range of different types of surfactant (anionic, cationic, non-ionic, mixtures) that could be used for this purpose. It has not been possible to establish if/which of these substances are used in the European oil and gas industry but it has been indicated that for most installations in Europe, PFAS-based substances are probably not used with operators tending to prefer non-fluorinated alternatives[38].

---

[36] Based on submission to the Call for Evidence

[37] See Chen, J. et al. (2019) Foaming of Oils: Effect of Poly(dimethylsiloxanes) and Silica Nanoparticles, ACS Omega., 4(4): 6502–6510. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6648748/

[38] See Negin, C. et al. (2017) Most common surfactants employed in chemical enhanced oil recovery, Petroleum, doi: 10.1016/j.petlm.2016.11.007.

- **Fluoropolymers** – as discussed in Section 3, a wide variety of different fluoropolymer materials (including fluoroplastics and fluoroelastomers) are being used in the oil and gas sector, and the number of individual products/components manufactured from these materials for ongoing use in the oil and gas sector totals in the thousands.

It should also be noted, that manufacturers and suppliers have indicated that in many cases, the most viable alternative to one type of fluoropolymer is considered to be another type of fluoropolymer. For example, the use of newer types of fluoropolymer such as poly(vinylidene fluoride) (PVDF) is becoming a popular option for producing components used in this sector.

It has not been possible to conduct an analysis of potential alternatives for all individual uses or components produced from fluoropolymers in this assessment, and relatively limited information on specific alternative materials was available.[39] In general terms, the potential alternatives for fluoropolymer materials in the oil and gas sector include the following:

- Steel and other metal alloys – e.g. stainless steel, copper Base alloys (with Ni, Fe, Mn) and nickel-based alloys (with Cu, Mo and Cr).
- Non-metal materials – e.g. ceramic-based materials and epoxy-based systems, either using glass fibers or carbon fibers.
    - Alternative polymers such as Poly(vinylidene fluoride) (PVDF)
- Fluorine-free polymers – for example:
    - Crosslinked polyethylene (XL PE) as a possible alternative to ETFE
    - Ethylene propylene diene (EPDM) rubber
    - Hydrogenated Nitrile Rubber (HNBR) as an alternative to fluoroelastomers
    - Polyether ether ketone (PEEK)
- Nylon - reportedly used in a number of engineering applications to replace other materials such as aluminium and steel in a number of uses.

5.3 The feasibility of alternatives

To assess the possible viability of the alternatives identified in the previous section, the tables below provide considerations of both the technical (i.e. ability to provide the required functionality) and economic feasibility (e.g. unit and operational costs associated with its use) of the possible alternatives compared with the PFAS-based products. An overview of the considerations (pros and cons) of different alternatives is provided below in Table 5.1 and Table 5.2 respectively.

Table 5.1 Summary of technical feasibility for alternatives in the oil and gas sector

PFAS compound (application)	Alternative(s) identified	Pros	Cons
Fluorinated silicones/siloxanes (antifoams)	PDMS-based products as antifoams (note various other	Generally comparable performance. Non-PFAS based products are more widely used	Alternatives may be less efficient with some crude oils so would be less feasible for some installations and would

---

[39] i.e. through the Call for Evidence and further consultation

	possibilities mentioned above)	than PFAS-based foams, with the latter used only for a relatively small number of 'niche' locations. No major difference expected in environmental or health effects. PBT behaviour not fully understood.	be needed in greater concentrations/quantities.
Fluorinated alkanes (tracers)	Radioactive tracers	No specific alternative products identified. Indicated to provide adequate level of performance in oil tracing due to widespread use.	PFAS-based substances are favoured from technical perspective as they work at very low levels. It is unclear if there are major differences in dose level required. Industry has reported loss of functionality for some applications when using alternatives.
PBSF-based compounds/polymers (EOR/EGR fluid)	No specific substance identified	No specific alternative products identified. Indicated to provide adequate level of performance in EOR/EGR due to widespread use.	PFAS-based surfactants may be needed in some 'extreme' cases at some installations.
Fluoropolymers e.g. PTFE (pipe linings and other components)	Various, including : Steel, other metal alloys, XL PE, EPDM, HNBR, PEEK)	Some alternatives can meet the required functionality suitable for some applications and conditions. E.g. PEEK has similar heat resistance performance as PTFE ; higher tensile strength, better machinability, better compressive strength.	Alternatives may not be suitable for some applications and may not meet the same functionality in the required conditions. E.g. PEEK has lower chemical resistance (e.g. to sulphuric acid) than PTFE so can be susceptible to corrosion. Not suitable for all applications.

Table 5.2 Summary of economic feasibility for alternatives in the oil and gas sector

PFAS compound (application)	Alternative(s) identified	Pros	Cons
Fluorinated silicones/siloxanes (antifoams)	PDMS-based products as antifoams (note various other	PFAS-based product will probably be slightly more expensive to procure, but	For some users, a much higher dose rate is required and therefore would be more expensive overall as

PFAS compound (application)	Alternative(s) identified	Pros	Cons
	possibilities mentioned above)	no quantitative value provided.	more product will be required to achieve the same result. Also has implications for storage volumes needed.
Fluorinated alkanes (tracers)	Radioactive tracers	PFAS-based tracers are likely to be much more expensive to procure, but no quantitative value provided.	Costs of appropriate handling, storage, PPE, and other safety measures and clean up would need to be considered
PBSF-based compounds/polymers (EOR/EGR fluid)	No specific substance identified	No assessment of cost differences was possible	No assessment of cost differences was possible
Fluoropolymers e.g. in (pipe linings and other components)	Various including: Steel, other metal alloys, XL PE, EPDM, HNBR, PEEK)	In most cases fluoropolymer is expected to be more expensive to procure than alternatives. Use of fluorine-free components could reduce clean-up and waste-handling costs.	For alternatives in some cases (e.g. with PEEK, unit costs can be higher than conventional fluoropolymer. Key additional costs could be incurred through additional maintenance, more frequent replacement of parts or higher quantities of product needed to perform the same function, and disposal and clean-up costs. Transition to alternatives could take many years or decades to implement in the supply chain and requires investment of resources and capital from manufacturers and suppliers. Loss in productivity or revenue at specific installations could have implications for employment in the oil and gas and mining sectors. Loss in function that could lead to greater levels of leakage/loss of pollutants has important implications of the environmental and

PFAS compound (application)	Alternative(s) identified	Pros	Cons
			health performance of a specific installation and the sector as whole.

6. Summary

This report has examined the use of PFAS in the petroleum and mining sector, including fluoropolymers. The main points to consider are:

- PFAS are being used in a number of specific applications in the oil and gas industry but are not expected to be used widely in mining.
- Fluoropolymers are widely used in the oil and gas sectors, and provide a very important function in the equipment/piping used in extraction, transport, and storage of petroleum resources and in various other components. Less is currently known about the use of PFAS and fluoropolymer in the mining sector.
- Three main categories of use for PFAS/fluoropolymer have been identified and an estimate for the tonnages of use, and the emissions of PFAS to the environment from use of these products has been estimated. For tracers and release from fluoropolymer, the main emission source is indicated to be during the formulation stage, whereas for anti-foaming agents it is suggested most of the emission occurs during use.
- It is estimated that a restriction on the use of monomeric PFAS in this sector would reduce the emission of PFAS to the environment (compared to the 2020 baseline) by 200- 2700 kg. This estimate is suggesting to significant uncertainty.
- Alternatives for each of the three main applications of PFAS in this sector have been identified and are available on the market. Alternatives to non-polymeric PFAS are generally more technically and economically viable than fluoropolymer uses.

The table below summarises the overall potential impacts and feasibility of a restriction of PFAS/ fluoropolymer in this sector including possible risks associated with a transition:

Use / application	PFAS compounds / Fluoropolymers	Substitution potential	Potential socio-economic impacts	Risk profile
Anti-foaming agents	Fluorinated silicones/siloxanes	**Medium/high** Alternatives are available and can be used in all but a small number of applications	**Medium** Unit cost of alternatives is lower, but required application rate is higher	**Low** No additional risk expected, more data on PBT properties needed.
Tracers	Fluorinated alkanes and other (confidential) products	**High** Alternatives are available and can be used in all but a small number of applications	**Low** Unit costs of alternatives are likely to be lower	**Medium** Use of radioactive tracers could present possible risk to workers
Fluoropolymer	PTFE, PFA, FEP, ETFE, PVDF, FKM	**Low** Some functionality can be replicated by alternatives in some cases; no identified alternatives that can match all required functionality	**High** While differences in unit costs are uncertain, the main risks are associated with loss of functionality, and more frequent failure, shutdown time and maintenance, and associated impacts on production efficiency and revenue,	**Medium/high** Possible increase in leakage of oil or chemicals could increase risk to health and/or the environment in some installations.