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PFAS and fluorine-free alternatives in lubricants and construction products

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1. Introduction

1.1 This report

WSP (formerly Wood), working in partnership with COWI AS, has been contracted by the Danish Environmental Protection Agency to provide services for a study on:
'Per and polyfluorinated alkyl substances (PFAS) and fluorine-free alternatives in lubricants and construction products – use, emissions and socioeconomic analysis of a REACH restriction'

This is the final report for the project. It provides a summary of the results for each of the tasks of the project:

- Substance identification (Section 2).
- Market analysis (Section 3).
- Assessment of emissions (Section 4).
- Economic impact assessment (Section5); and
- Human/social impact assessment (Section 6).

For each task, results are presented in separate sub-sections for lubricants and construction products, respectively. A third subsection outlining the key uncertainties and data gaps is also provided for each task, to support the interpretation of the results and inform potential areas for further study.

Please note that a lot of the data that was collected for this report was declared confidential by the stakeholders that provided it and cannot be disclosed publicly. This report therefore only presents aggregated results that do not disclose or allow inference of individual stakeholder input.

1.2 Project objectives

As set out in the Terms of Reference the overall objective of this project is to assess the use of PFASs and fluorine-free alternatives in lubricants and construction products. The study has the following aims:

- Assess the use of PFAS-based lubricants and construction products and their fluorine-free alternatives.
- Assess emissions, economic and human/social impacts of a full ban of all PFAS-based lubricants and construction products.
- The assessments will be based on the working definition of PFASs from the ECHA registry of restriction intentions[1] PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group (-CF3) or a perfluorinated methylene group (-CF2-) is consider a PFAS. This is in line with the 2021 OECD terminology[2] that is purely based on chemical structure.
- The outcomes have been used in a broad REACH restriction proposal on PFAS, which was submitted as an Annex XV restriction dossier[3] on the 7th January 2023. It should be noted that there are some differences between this report and the Annex XV restriction dossier. This includes but are not limited to:

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[1] Registry of restriction intentions until outcome - ECHA (europa.eu)

[2] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/terminology-per-and-polyfluoroalkyl-substances.pdf

[3] https://echa.europa.eu/da/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

- Substances in scope of the Annex XV restriction dossier is persistent PFASs that fulfil the OECD, 2021 terminology, meaning that there a few exceptions to the definition used in this report.
- A few uses are mentioned in this report that are not included in the sections on lubricants or construction products in the Annex XV restriction dossier, primarily because these uses are covered by other use sectors in the Annex XV restriction dossier.
- Emission estimates and emission projections are slightly different between this report and the Annex XV restriction dossier.
- Socio-economic analysis is further accessed in the Annex XV restriction dossier in order to identify for uses for which derogations could be warranted.

The key differences between this report and the Annex XV restriction dossier are described in the text or as footnotes in the relevant sections.

This report goes beyond the Annex XV restriction dossier as it provides more granular data on substance identification, technical description of uses and emissions (broken down by multiple environmental compartments). This recognises that the Annex XV dossier covers all potential uses of PFASs and thus through necessity works to a higher level of disaggregation.

2. Task 1: Substance identification

Per- and polyfluoroalkyl substances (PFASs) are a family of chemicals spanning thousands of unique- PFASs. They have been commercialised and used globally since the 1950s as surfactants, wetting agents, and processing aids in fluoroelastomers and polymers in a very wide range of applications (Buck, 2011)[4]. In particular their potent ability to repel both water and oil, along with their thermal stability has been highly desirable in a range of different indoor and outdoor applications (including lubricants and construction applications) (ECHA, 2014; EEA, 2019)[5, 6].

However, the specific PFASs in use have evolved since their commercialisation in the 1950s, driven in part by a series of regulatory interventions related to mounting health and environmental concerns. This has in particular seen a transition away from the C8 perfluoroalkyl acids (PFAAs) to shorter chain substances (Wang, 2014)[7], while the use of fluoropolymers has remained a dominant component of total PFAS use. Given the potential number of PFASs in use and shifting evolution in the development and use of specific species, identification, and quantification of PFAS use against specific activities is very challenging.

Task 1 of the current study therefore aimed to assess which PFASs are in use for what applications and at what concentrations ranges. Task 1 also included consideration of the technical function of PFASs and what alternatives may exist that could form a possible substitution.

Lastly, Task 1 also included the identification of substances that might be present as impurities or degradation products. As a general comment across lubricants and construction products (and indeed any other use of PFASs), all PFASs has been manufactured using one of two production pathways (Electrochemical fluorination (ECF)) and telomerisation)[8]. The latter of these two production pathways uses a base material (perfluoroalkyl iodides (also known as Telomer A)) and a series of substitution reactions to produce a wide range of telomer-based PFASs. It is also possible to use this pathway to produce fluoroacrylate or fluorourethane telomer-based polymers. Where fluorotelomers are produced through a series of substitution reactions it means that within the natural environment they can undergo further reactions and degrade into other forms of PFASs. For example, in the review paper by Butt et al (2013)[9], it is reported that fluorotelomer alcohols (particularly 8:2 FTOH) can act as a ready source of PFOA. Li et al

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[4] Buck, 2011, ‘Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins’, integrated Environmental Assessment and Management – vol7, no.4 pp 513-541

[5] ECHA, 2014, ‘Annex XV Restriction dossier for PFOA, its salts and PFOA-related compounds’

[6] EEA, 2019, ‘Emerging chemical risks in Europe – PFAS’, briefing note from the European Environment Agency.

[7] Wang, 2014, ‘Global emission inventories for C4-C14 perfluoroalkyl carboxylic acid (PFCA) homologues from 1951-2030, Part I: production and emissions from quantifiable sources’. Environmental International vol 70 pp62-75

[8] Buck et al, 2011, ‘Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins’, integrated Environmental Assessment and Management – vol7, no.4 pp 513-541

[9] Butt et al, 2013, ‘Biotransformation pathways of fluorotelomer-based polyfluoroalkyl substances: A review’, Environmental toxicology and chemistry https://doi.org/10.1002/etc.2407

(2017)[10] further comment on fluorotelomer based side-chain polymers as a source of both PFOA and PFHxA. The Stockholm Convention listing of PFOA under Annex A (banned) specifically included the PFOA-related substances[11] due to concerns over degradation products. However, due to the high number of PFASs in use and complexity of environmental fate pathways, it means that comprehensive mapping of degradation products for all PFASs on a one-by-one basis for the PFASs in use is extremely challenging. Also further note that the research for generation of PFASs during thermal destruction (at end of life) for fluoropolymers (such as PTFE, ETFE, and PVDF) is limited, with more research needed.

2.1 Lubricants

2.1.1 Uses

Lubricants have many roles in industrial and consumer applications. They reduce friction and wear of interacting surfaces, cool the hot areas of engines and moving parts, and improve mechanical efficiencies and lifetimes. If the lubricants are circulated, such as in some engines, they may carry away wear debris. They are used in the manufacture of plastic and rubber parts to keep them from sticking to equipment and other parts. They are used in many applications such as electrical wiring and seals where casual contact can cause abrasion or sticking. Nuts and bolts and even electrical connectors are lubricated so that they fit together more easily. Greases are not only used in heavy machinery but are also used to control the resistance of control knobs on radios and other electrical instruments, Ebnesajjad & Morgan (2019)[12].

No unique definition of lubricants is available. In EU 2018/1702 of 8 November 2018 - establishing the EU Ecolabel criteria for lubricants[13], they are defined as:

- Lubricant means a product that is capable of reducing friction, adhesion, heat, wear or corrosion when applied to a surface or introduced between two surfaces in relative motion or is capable of transmitting mechanical power. The most common ingredients are base fluids and additives;
  - base fluid (base oil) means a lubricating fluid which flow, ageing, lubricity and anti-wear properties, as well as its properties regarding contaminant suspension, have not been improved by the inclusion of additive(s);
  - additive means a substance or mixture which primary functions are the improvement of one or several of the following aspects: flow, ageing, lubricity, anti-wear properties and contaminant suspension;
  - grease means a solid or semi-solid lubricant which contains a thickener in order to thicken or modify the rheology of the base fluid.

It should be noted that the EU ecolabel does not cover all types of lubricants. Nevertheless, the EU ecolabel definition is considered useful for the discussion on lubricants in general and as a starting point for the discussion of PFAS-based lubricants in this report.

Uses that have been identified via the Call for Evidence, 2nd stakeholder consultation, the targeted stakeholder consultation and via literature have been summarised in TABLE 1 along

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[10] Li et al, 2017, ‘degradation of fluoro-telomer based polymers contributes to the global occurrence of fluorotelomer alcohol and perfluoroalkyl carboxylates. A combined dynamic substance flow and environmental fate modelling analysis’, Environmental Science and Technology vol 51, pp 4461-4470

[11] PFOA-related substances includes are any substances that degrade to PFOA, including any substances (including salts and polymers) having a linear or branched perfluoroheptyl group with the moiety (C7F15)C as one of the structural elements, for example: a) Polymers with ≥C8 based perfluoroalkyl side chains; b) 8:2 fluorotelomer compounds; and c) 10:2 fluorotelomer compounds.

[12] Ebnesajjad S. & Morgan R (2019): Fluoropolymer Additives. 2nd Edition. William Andrew, Hardcover ISBN: 9780128137840 (Chapter 6).

[13] EU 2018/1702 of 8 November 2018, establishing the EU Ecolabel criteria for lubricants https://www.ecolabel.dk/-/criteriadoc/3790

with some examples of sectors and specific uses. Additionally, recent literature has been summarised in a review by Glüge et al. (2020)[14], and included in the table. Please note that the table is not necessarily exhaustive. As will be further elaborated in Section 3.1.2, PFAS-based lubricants can be applied in almost any sector. Further detail on the specific PFASs, their concentrations, and technical function in these uses is provided in Section 3.1.2.

TABLE 1. Identified uses of PFASs in lubricants

Sector/industry	Examples
Food sector	Chains and bearings (e.g., in ovens)
	Lifetime lubrication in micro-amounts in closed parts. Moving mechanical parts, semi-closed. Lubricants and lubricant Sprays for incidental food contact (NSF-H1[15]).
	As a lubrication additive on the inside coating of metal food and beverages containers - it enables filling without damaging the coating[16].
Aircraft/aerospace	Combustion engines
	Hydraulic systems incl. control valves[17]
	Bearings
	Actuators of jet engines, and landing gears
	Slide wire of potentiometers in space craft.
Military – defence applications	Various military lubrication functions (e.g., aircraft and electronics)
Automotive	Combustion engines
	Friction reduction in various mechanical devices including automotive brake system components.
	Bearings and throttle sensors
	ESP systems in cars to measure turning speed of the wheels and many other applications.
	Automotive Electrical Components and Auxiliary Components
	Mechanisms of the sliding of doors and windows
	Mold release agents, assembly aids, grease for e.g., throttle sensors, bearings, moveable parts, seat rail, door hinge, switch actuation
	Automotive interiors. PFPE lubricants used to reduce noises, itch, or judder where different materials come into contact. Added as a lifetime lubrication at point of manufacture.

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[14] Glüge, Juliane & Scheringer, Martin & Cousins, Ian & DeWitt, Jamie & Goldenman, Gretta & Herzke, Dorte & Lohmann, Rainer & Ng, Carla & Trier, Xenia & Wang, Zhanyun. (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). 10.31224/osf.io/2eqac.

[15] "NSF-H1" is an approval system for food-grade lubricants: See https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=178.3570, and https://www.nsf.org/testing/food/nonfood-compounds-chemical-registration

[16] This use is not considered to be a lubricant se in the Annex XV restriction proposal that was submitted to ECHA on the 7th January 2023.

[17] PFAS additives in aviation hydraulic fluids is covered under the use category 'Transport' in the Annex XV restriction proposal that was submitted to ECHA on the 7th January 2023.

	Window wipers, O-rings, intake manifolds, shafts and seals, EGR valves, overrun clutches, alternator bearings and water pumps.
Trains	Valves in powertrains Train door lubrication
Nuclear	Bearings in pumps Laboratory glassware to prevent locking. Bearings and other moving parts Critical bearings, manipulator greases for nuclear waste handling, fuel manufacturer equipment lubrication, compaction equipment lubrication for example.
Watchmaking	Lubricants, and greases, and epilames[18].
Hearing loss applications	Vacuum pumps and bearings during production. Note that it is not clear whether the PFAS as lubricant also plays a role in the final products, but possibly comparable to epilames[18] in watches (see above).
Electronics	Electric circuit breakers Semiconductors manufacturing: Multiple uses, such as wafer handling mechanisms, linear guides of multibeam inspection stage, source mirror actuators, and several other bearing applications. Emergency smoke ventilation fans in e.g., tunnels. Electric switch and push buttons Top coating lubricant on computer disc drives. Rack and pinion disk drive lubricant, spindle and actuator bearings in disk drives.
Laboratory supplies, equipment, and instrumentation	Diagnostical and optical equipment: Lubrication of moveable parts, for instance ball-bearings in various applications where parts need to be moved without friction. Bearings, jewels, and pivots in many kinds of instruments
Hospital equipment	Lubricants for medical applications. Medical use in O2 breathing equipment (ventilators) Medical injection device (Syringe, pumps, pens) Valves, fittings, O-rings, pressure gauges in oxygen enriched environments.
Renewable energy	Wind power – lubrication of screws, nuts, magnetic anchors, bolts etc. Wind power (bearings) Fuel cell technology – assembly aid e.g., grease for O-rings Energy storage and energy conversion via hydrogen such as PEM – bearings and as lubricant additive in plastics
Off-shore / Oil & gas	Lubrications of screws, nuts, magnetic anchors, bolts etc. Bearings Casing/tubing sealants for high-definition threads in high chrome steel
Chemical industry	Machinery for production of oxidising chemicals

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[18] According to a stakeholder in the response to the CfE: "Strictly speaking, epilames are not lubricants nor greases. Epilames are antispreading coatings involved in the lubrication process". Epilames is not considered to be a lubricant in the Annex XV restriction proposal submitted to ECHA on the 7th January 2023.

	Bursting discs and gaskets for heat exchangers, synthesis units and reactors
Diving equipment	Diving Equipment with O_2 contact
Handicap assistant equipment	Prosthesis, orthosis, wheelchair, exoskeleton etc.; piston and gear wheel applications; Lubricant additive in plastic components
Paper	Roller bearings of corrugated paper machinery
Plastics	Polymer processing industry (injection mould lubrication). Added as lubrication additive to the polymer before processing[19].
Other sectors and industrial applications not specifically mentioned above: Agriculture, base materials, construction, cement/lime/gypsum, drinking water, film stretching, fluid power, laundry/dry cleaning, metal forming, primary metals, rubber/leather, process industries, pharma, cosmetics and biotech, power and energy distribution, industrial gases, district energy and building automation, metallurgy and mining, marine equipment, water and wastewater, wood industry, pulp and paper, machinery sector (e.g., snow blowers, lawn movers, gears and belts of conveyers)	Chains, bearings /ball-bearings, pivots, valves, and self-operated regulators Plain bearings for e.g., hinges, seat recliners, vibration dampers, chain tensioners, shock absorbers, pumps, ropeway suspensions, etc. All kinds of industrial machines with moving parts Valves Assembly of bolts, screws nuts and joints in general Various 'oxygen service' applications, i.e., lubrication in systems with a high risk of contact with high oxygen concentration (e.g. when applying some types of pumps). Mechanisms and devices under high vacuum Offices machines, including heaters and printers. Power tools

2.1.2 PFASs used in lubricants

2.1.2.1 Substances identified

Information on substances has been identified via the two Call for Evidence rounds (CfE and 2nd stakeholder consultation), via subsequent targeted stakeholder consultation and via literature. In terms of defining how PFASs is used (and which substances) in lubricants, it necessary to also consider the different roles that these substances take up in the application. Three recent literature publications have been key to this work, firstly, Ebnesajjad and Morgan (2019) and Rudnick (2020)[20] provide a good oversight of technical function which helps identify key substances. Secondly, the review by Glüge et al. (2020) provides detailed information on uses and substance identity (including where patents are in place). 38 individual substances were identified via these sources, which can be grouped into the following main categories:

- PTFE (Poly(1,1,2,2-tetrafluoroethylene, CAS no 9002-84-0)
- PCTFE (Polychlorotrifluoroethylene, CAS 9002-83-9)
- PFPE (Perfluoropolyether, several individual substances and CAS numbers)

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[19] This is not considered to be a lubricant application in the Annex XV restriction proposal submitted to ECHA on the 7th January 2023.

[20] Rudnick (2020): Synthetics, Mineral Oils, and Bio-Based Lubricants. Chemistry and Technology, Third Edition. https://doi.org/10.1201/9781315158150

- Fluorosilicone oils/fluorinated polysiloxanes (several individual substances and CAS numbers)
- Additives (several individual substances and CAS numbers)
- Solvents (several individual substances and CAS numbers)
- One other substance that could not be associated with any of the above groups.

Stakeholders have suggested that different types of PTFE tailored to specific lubricant formulation and lubricant end-uses are applied. This includes PTFE micro powder and modified PTFE, although often just 'PTFE' is specified in literature and by stakeholders. Each type of PTFE is further supplied in many different grades/compositions. PTFE micro powder for example is provided with varying molecular weight.

The call for evidence responses mainly reported application of PTFE, PCTFE and PFPE in fluorinated lubricants. The further targeted stakeholder consultation and a close look at literature identified a range of other PFASs applied. As shown in section 4.1 however, the largest amounts/volumes applied are micro-powder PTFE and PFPEs.

As a further comment on substance identity, technical function, and role within lubricant applications, Ebnesajjad & Morgan (2019) separates lubricants into five categories: low viscosity, “dry-films”, “release-agents”, engine oils and greases. This separation also seems useful for the discussion of PFAS-based lubricants in this report. It should, however, be noticed that the same commercial products are sometimes used as “low viscosity”, “dry-film,” or “release-agent” lubricants.

- Low viscosity lubricants: The fluid phase for “low viscosity” lubricants is typically either mineral oil or synthetic oil. Low viscosity lubricants often contain solid additives, such as e.g., micro-powder PTFE, graphite, MoS_2, WS_2 or BN. Dispersants or wetting agents can be used to assure particle suspension. Besides this, other additives, like rust inhibitors can be added. The only solid additive that is compatible with synthetic PFPE base oils is micro-powder PTFE. The only solid additives that is compatible with synthetic low-MW (oligomer) PCTFE base oils is micro-powder PTFE and high-MW PCTFE. Fluorosilicone oils can also be used as base oils.

- Engine oil[21]: Engine oil could also be considered to be a low viscosity lubricant but is here a separate category. Mineral oils is the most common base oils in engine/motor/automotive oils, however, synthetic base oils are occasionally also used[22]. Micro-powder PTFE can/may be used as an antiwear additive. However, the use of PTFE in engine oils is rather limited due to its inherent instability in oil, the risk of oil filter clogging, as well as difficulties with recycling[23].

- Grease: Greases is basically a base oil that contains a thickening agent to increase its viscosity. They are typically produced with mineral, synthetic or plant-derived oils. Thickening agents may be a soap or it can be a solid with a high surface area. Micro-powder PTFE can be used as thickener/ solid additive/ "fortifier" alone or in combination with other thickeners, however, most greases based on mineral oils do not use fluoropolymers as thickeners. This is more common for some synthetic oils (PFPEs, oligomer PCTFE, polyalphaolefin oils, polyfluorosiloxane oils). When used alone the

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[21] Engine oil is only mentioned in this report for the sake of completeness. The same goes for the Annex XV restriction proposal submitted to ECHA on the 7th January 2023. It is not discussed further as a use of PFAS-based lubricants.

[22] SOMAYAJI A., 2008: A STUDY OF THE ANTIWEAR BEHAVIOR AND OXIDATION STABILITY OF FLUORINATED ZINC DIALKYL DITHIO PHOSPHATE IN THE PRESENCE OF ANTIOXIDANTS https://rc.library.uta.edu/uta-ir/bitstream/handle/10106/1006/umi-uta-2112.pdf?sequence=1&isAllowed=y

[23] Joint Research Centre (JRC) Revision of European Ecolabel Criteria for Lubricants, *Preliminary report*. December 2016. https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/contentype/product_group_documents/1581683740/Preliminary%20report%20EU%20Ecolabel%20Lubricants.pdf (page 153).

PTFE level ranges from 20-40% and when used together with other thickeners the range is from 3-40%. Micro-powder PTFE is often used as thickener in PFPE-based greases. Silica, micro-powder PTFE and/or high-MW PCTFE is commonly used as thickener in PCTFE-based greases (base oil of oligomer/low-MW PCTFE).

- Dry-films (solid): Easy volatilization of the liquid is usually important for these applications, therefore, the fluid phase for "dry-films" could be oil but is more likely to be water, a very low-MW hydrocarbon, or a polar organic compound such as isopropanol or acetone, as these will evaporate before end use. Solid/dry-film lubricants may be applied multiple times.
- Release-agents: Release-agents can be considered as a special case of solid/dry-film use. Release-agents are also known as anti-blocking agents, surface lubricants, parting agents, or slip-aids. They are used particularly in the manufacture or modification of (thermo)plastics and elastomer shapes, preventing sticking and build-up of resin on process equipment. They are sometimes labelled as "internal" or "external" lubricants. Internal lubricants/release aids are incorporated into the resin before the forming or processing of the plastic or elastomeric part. External lubricants are typically coated from liquid suspension or solution onto a mold or contact surface by spraying or brushing. Most external release aids must be applied multiple times as resin is processed.

In general, the category of “low viscosity” lubricants covers systems wherein the fluorinated additive is dissolved or suspended in a liquid lubricant and the liquid is not removed or expected to be removed during its lifetime as a lubricant. When the additive is a polymer, such as PTFE, its concentration is generally low due to the need to keep the polymer particles suspended. Various suspension aids have been reported to assist suspension stability.

Internal lubricants/release-agents/slip-agents are also a type of fluoropolymer polymer process aids (PPA) as described in more details in chapter 11 of Ebnesajjad & Morgan (2019). A distinction can be made between “dry-films,” “release-agents,” and “coatings”. Coatings are expected to have a relatively long lifetime. “Dry-films” that contain binders (epoxy, polyester) to give the films longer life are considered as coating in Ebnesajjad & Morgan (2019).

2.1.2.2 Substances identified for uses which might or might not be considered lubricant uses

Specific PFASs are reported - by stakeholders (as a lubricant use) and in literature - to be used as anti-erosion / anti-corrosion additives in aircraft hydraulic fluids. The following is a quote from Glüge et al. (2020): "*Hydraulic fluids actuate moving parts of the aircraft such as wing flaps, ailerons, the rudder and landing gear …. There are three main types of hydraulic fluids: a) mineral-based fluids, b) polyalphaolefin-based fluids and c) phosphate ester-based fluids …. Hydraulic fluids based on phosphate esters are used in most commercial aircrafts and are extremely fire-resistant …. However, they can absorb water and the subsequently formed phosphoric acid which can damage metallic parts of the hydraulic system. Fluorinated surfactants in phosphate ester-based hydraulic fluids inhibit the corrosion of mechanical parts of the hydraulic system by altering the electrical potential at the metal surface*"[24].

In addition, the following was found in the CfE (indicated to be 'lubricant uses'), but assessed to be of borderline importance in relation to lubricants:

- PFA (not further specified). This was referred to by one stakeholder (a downstream user of mechanical parts). The information "used for lining" suggests that the stakeholder might use a different understanding of lubricant use than is applied in this report.

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[24] In the Annex XV restriction proposal submitted to ECHA on the 7th January 2023, this use is covered under ‘Transportation’ and not under ‘Lubricants’..

- FEP (not further specified). This was referred to by one stakeholder (a coatings formulator). The use of “FEP” (copolymer of TFE and hexafluoropropylene), and “PAVE” (copolymer of TFE and a perfluoroalkylvinylether) in lubricants have also been mentioned in patents, however, Ebnesajjad & Morgan (2019) states that their commercial use in lubricants is very limited.

As will be further elaborated below, a number of other applications related to establishing smooth and low friction surfaces might be seen as lubrication use or be grouped as e.g., coatings or sealings. The same applied for anti-mould applications.

Some further use sectors/applications listed by stakeholders that are *not* considered 'lubricant use' for the purpose of this report:

- *Inks for improved rub and scuff resistance, reduction of friction, chemical inertness, and temperature resistance*
- *PTFE micropowders are normally used on the external coating of the can (RED: we assume this applies to e.g., food cans) to give improved frictional and rub resistant properties to the coating to facilitate easy sliding and movement of the cans on the production line.*
- *Heat resistant, solid lubricating paints*
- *Coating to improve rub resistance and to impart release characteristics.*

2.1.2.3 Impurities and degradation products

The CfE also included a question to specify potential PFAS-impurities, residues or intended additives and indicate their possible concentrations or concentration ranges. Most respondents did not answer this question or responded with 'not known' (or similar).

However, based on the responses from some manufacturers of PTFE and downstream users, there seems to be a focus on keeping PFOA impurity levels below 25 ppb in PTFE, whereas there is basically no information on other possible production impurities in PFPEs. It should be noted that many stakeholders refer to chemical inertness as a key technical function of fluorinated lubricants. This means that (except perhaps for thermal degradation at higher temperatures) they are chemically stable, which could indicate that degradation is limited, but no solid data on this was provided.

In the targeted stakeholder consultation, a PTFE micro-powder supplier mentioned that the company uses two basic processes for manufacturing the PTFE, one of these requiring a PFAS-based surfactant. This surfactant is present in trace amounts (ppb range) in the marketed products. From both processes, the required grades are obtained via an irradiation or thermal degradation process randomly cleaving the original polymer in smaller entities. This results in some short- and long-chained PFASs present in the PTFE. Impurity levels are stated to be in line with the requirements in Part A of Annex I of the POP regulation, and the C9-C14 PFCA Restriction[25].

Glüge et al. (2020) refers to findings where C4-C12 PFCAs and C4, C6, C8, and C10 PFSAs have been detected in automotive greases. It is however not clear whether these are intentional constituents, impurities, or degradation products.

For the purposes of substance identification, the targeted stakeholder consultations therefore mainly focused on possible degradation products following use of PFAS-based lubricants. All stakeholders interviewed noted that one of the reasons for using PFAS-based lubricants is their stability, inertness, and consequently the fact that they do not create unwanted degradation products during use. This is key for many life-time lubrication applications. It is noted that PFPEs and PTFE will not degrade under normal specified temperature ranges, which are that 250 or 260 degree C shall not be exceeded. This maximum operating temperature is line with

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[25] Entered in to force on the 25th February 2023 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1297&from=EN

literature, see e.g., Améduri (2020) and Ebnesajjad & Morgan (2019). No evidence has been received from stakeholders in relation to whether degradation products might be formed below the maximum temperature, e.g., following prolonged operation close to the maximum of the specified temperature range.

In case of higher temperatures (above 300 degree C - which is generally advised against by the lubricant suppliers), fire or "low temperature" incineration, there is a risk of creation of a wide range of PFASs entities with shorter chain length. The US EPA is planning further work to explore the implications of the degradation products[26]. One industry stakeholder notes that the following degradation products are likely to be formed above 300 degree C: >90 % hexafluoroacetone, trifluoroacetic acid, octafluoropropane, hexafluoroethane and carbonylfluoride.

In case of high-temperature incineration, e.g., at temperatures applied during metal/steel recycling, it is believed by industry stakeholders that the fluorine content in PFAS entities will degrade to inorganic fluorides. No further evidence on this has been found or received.

2.1.2.4 Uses and technical function

Overall grouping/categorisation

Based on feedback from various industry stakeholders, PFAS-based lubricants can be categorised into one of three groups: Lubricant base oils that contain PFAS, multiphase systems where PFASs are used as additives, and PFAS agents that provide a solvent function within lubricants (often where the lubricating function is a secondary part of the application)

Lubricant base oils

Lubricants usually contain a liquid base oil with a low surface tension. Base oils have three sources:

1. Crude oil
    - Available in many fractions. The American Petroleum Institute (API) has divided the resulting mineral oils into three “Groups” designated I, II, and III.
2. Chemical synthesis

- Examples of synthetic base oils: poly-alpha-olefins (PAOs), silicone oils (or polysiloxane), esters of fatty acids with alcohols (including polyols), perfluoropolyethers (PFPEs), oligomeric polychlorotrifluoroethylene (PCTFE) and fluorosilicone oils (polyfluorosiloxane oils).

3. Natural sources (fats, plants, and waxes) other than crude oil.
    - Examples are isopropanol, ethanol, or ethyl acetate, or it could even be water.

For the purpose of the discussion on PFAS-based lubrication, PFPEs, PCTFE and fluorosilicone base oils will be described in more details.

PFPE base oil:
According to Rudnick (2020)[27] (chapter 11) perfluoropolyether (PFPE) (also called perfluoropolyalkylether (PFPA)) oils were first synthesized by DuPont in 1959. Use as lubricant was first disclosed in 1965. Since the initial development, the following four distinct types of PFPE oils

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[26] See https://ehsdailyadvisor.blr.com/2020/09/epa-plans-to-study-incineration-of-pfas-waste/. Here is stated: “Laboratory-scale studies have shown that, when incinerated, PFAS can break down to toxic, volatile chemicals such as carbon tetrafluoride and hexafluoroethane, as well as trifluoroacetic acid and hydrogen fluoride,” according to the Environmental Working Group. “However, there are no peer- reviewed studies on PFAS emissions in commercial incineration facilities that burn different types of waste.”

[27] Rudnick (2020): Synthetics, Mineral Oils, and Bio-Based Lubricants. Chemistry and Technology, Third Edition. https://doi.org/10.1201/9781315158150

have become commercially available. According to Rudnick (2020) and Ebnesajjad & Morgan (2019) they have the chemical structure:

- PFPE K (Chemours Krytox^{TM}): $CF_3CF_2CF_2O\text{-}\{CF(CF_3)CF_2O\}_n\text{-}CF_2CF_3$, with n = 6 to 100 (MW 1 000 – 13 500 Daltons)
- PFPE Y (Solvay Solexis Fromblin^{TM} Y): $CF_3CF_2CF_2O\text{-}\{CF(CF_3)CF_2O\}_x\text{-}[CF_2O]_t\text{-}R_f$, with x = 6 to 100 and x:t 40:1 (estimated) (MW 1 000 – 10 000 Daltons)
- PFPE Z (Solvay Solexis Fromblin^{TM} Z): $CF_3CF_2O\text{-}\{CF_2CF_2O\}_p\text{-}[CF_2O]_p\text{-}R_f$, with p+q = 10 to 50 and p:q 1:1 (estimated) (MW 8 000 – 70 000 Daltons)
- PFPE D (Daikin Demnum^{TM}): $CF_3CF_2CF_2O\text{-}\{CF_2CF_2CF_2O\}_y\text{-}CF_2CF_3$, with y = 6 to 100 (MW 2 000 – 15 000 Daltons)

The PFPEs are fluids known to be chemical inert, have low-outgassing, thermal stabile, they are non-flammable, radiation resistant and have a wide temperature range. The order of thermal-oxidative stability of the four commercially available PFPEs is: PFPE Z << PFPE Y < PFPE K = PFPE D. The vapour pressure and volatility of the PFPE oils vary with average MW so that higher-viscosity (higher MW) oils generally have lower volatility losses (Rudnick, 2020).

PFPE oils can be used directly as lubricants, or they can be used as base oil for greases. Commonly used thickening agents are finely divided silica, 'attapulgus clay', montmorillonite, ammeline, boron nitride, talc, calcium carbonate, zinc oxiden micro-powder PTFE and FEP (Rudnick, 2020). PFPE greases are especially used for applications that require performance over a significant temperature range and wherein oxygen-resistance is needed. For PFPE greases thickened with micro-powder PTFE DuPont (Chemours) and Solvay make a point of saying that special grades of PTFE are used for the thickening (Ebnesajjad & Morgan 2019).

The initial use of PFPE oils was in valve and O-ring lubricants in oxygen service (non-flammability and stability in oxygen atmospheres), lubricants for aircraft instrument bearings (low vapour pressure), seal lubricants in reactive chemical environments (chemical inertness, high-temperature stability, and insolubility) (Rudnick, 2020).

PCTFE base oil:
According to Rudnick (2020) (chapter 12) polychlorotrifluoroethylene (PCTFE) lubricants were first synthesized in the 1940s. Scientists were looking for an inert lubricant for use in handling of the extreme reactive uranium hexafluoride in uranium isotope separation.

The chemical structure of PCTFE oil and wax is:

$(CF_2CFCl)_n$ with n = 2 to 17

They are made by a controlled polymerization technique. After polymerization the product is separated into various fractions from light oil to wax, covering many of the common lubricant grades (Rudnick, 2020).

PCTFE oils can be used directly as lubricants, or they can be used as base oil for greases. PCTFE lubricants are known to have good lubricity, to be chemical inert to a high number of aggressive chemicals, be non-flammable, to have low-outgassing, be thermal stabile, they are, radiation resistant, have high dielectric strength, high density and low compressibility. Recommended long-term operating temperature is 204 °C and recommended short-term operating temperature is 260 °C. Contact with metal affects the thermal stability.

PCTFE-based greases (base oil of oligomer/low-MW PCTFE) thickened with silica, micro-powder PTFE and/or high-MW PCTFE is commercially available.

Fluorosilicone base oil:
Fluorosilicone oils (polyfluorosiloxane oils) can resists oxidation, harsh chemicals, fuels, has a low evaporation and a wide service temperature ranges (-40 to 204°C).

Greases based on fluorosilicone oils can be thickened with amorphous fumed silica, PTFE and organics.

Lubricant additives

A wide variety of additives are incorporated into most lubricants. These include antioxidants, corrosion inhibitors, detergents, friction modifiers, antiwear additives, and viscosity modifiers. Of relevance for the discussion on PFAS-based lubricants are antiwear additives. There are several different types of antiwear additives. They function by either chemically reacting with a metal surface or being physically adsorbed onto it under the shear of boundary lubrication conditions. These additives are usually oil-soluble organo-phosphorus, sulfur, chlorine, or lead compounds. The most used antiwear additive is zinc dialkyl dithiophosphate (or ZDDP or ZDP) which is used in many lubricants and virtually all current car engine oils. In addition to the oil-soluble antiwear additives, there are solid particulate lubricants that may be added to liquid lubricants. The primary types are graphite (including fluorinated graphite), molybdenum disulfide (MoS_2), boron nitride (BN, the hexagonal crystalline form is used as lubricant), and fluorinated polymers such as micro-powder polytetrafluoroethylene (PTFE), Ebnesajjad & Morgan (2019).

According to Ebnesajjad & Morgan (2019) there are a number of possible fluorinated additives that may be added to lubricants. A few of these are low-MW (less than 1000) fluoroadditives (including fluorosurfactants). The fluoropolymer micro-powder PTFE is according to Ebnesajjad & Morgan (2019) by far the most commonly used fluorinated additive, but it has a range of possible forms. “FEP” (copolymer of TFE and hexafluoropropylene), and “PAVE” (copolymer of TFE and a perfluoroalkylvinylether) have also been mentioned in patents.

Micro-powder PTFE as lubricant additive:
The extremely low coefficient of friction of (micro-powder) PTFE in combination with its good thermal stability (325 – 345°C) makes it attractive as a solid lubricant additive. Micro-powder PTFE is compatible with PFPEs and PCTFE. It is therefore used as additive in low viscosity lubricants based PFPEs and PCTFE on and is also used at thickener and additive in PFPE and PCTFE greases.

Micro-powder PTFE is also used as a solid additive in non-PFAS based low viscosity lubricants and greases as well in dry-film lubrication / external release-agents where the solvent can be a PFAS or a non-PFAS.

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

The use of PTFE micro-powders from both suspension and dispersion polymerization has been described in lubricants, however, the dispersion-polymerized powders is now the preferred. A relatively small amount of micro-powder PTFE is produced by direct polymerization. The most important advantage of direct polymerization products is the virtual absence of reactive end groups in the PTFE. Most of the present commercial applications of PTFE in lubricants employ low-MW powders that have been ground to a small particle agglomerate size (less than 10 μm) and have a primary particle size less than 0.5 μm (Ebnesajjad & Morgan, 2019). The term “lower MW” can cover a large range as there is a considerable difference between the MWs described in patents (2,000–1,000,000) Ebnesajjad & Morgan (2019). Micro-powder PTFE is used for other applications than as additives in lubricants. E.g., inks, thermoplastics, paints, coatings and elastomers.

Non-polymeric (Low-MW) fluorinated lubricant additives:
There are many types of low-MW fluorochemicals that may be used as additives for lubricants including fluorosurfactants and fluorinated or partially fluorinated alkanes, ethers, amines, esters, and metal salts of alkyl phosphates. The low-MW fluorochemicals are typically used in specialized applications such as for recording media, hydraulic fluids, firearms, and conveyor chains but recent patents have also described their use in internal combustion engines. Perfluoropolyether and perfluoroalkyl phosphates, phosphonates, and salts thereof have been disclosed as lubricants for magnetic media lubrication. They were applied from solution in a hydrofluoroether solvent. Essentially the same compounds have been disclosed as corrosion inhibitors for perfluoropolyethers oils and grease. Fluorochlorinated oils have been disclosed as part of a lubricant system for the machining of metals, Ebnesajjad & Morgan (2019).

Solvents

Various PFAS-based solvents are applied in relation to lubrication. Generally, these uses can be divided in:

- PFAS solvent as part of a lubricant dispersion, where the solvent evaporates during use, leaving the lubricant (solid or as a grease) on the surface of an article. According to industry, these processes take place in closed system where the evaporated solvent is captured, and VOC regulations complied with.
- As cleaning agents (these might be pure PFAS-based solvents, or such solvents mixed with a lubricant). This can be for cleaning parts/articles to be lubricated (to avoid contamination of the lubricant), or for maintenance of equipment that cannot be shut down, so that cleaning can be performed in full operation.

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

Uses, sectors and concentration ranges

According to industry stakeholders, PFAS-based lubricants are used in situations where they are superior in terms of technical performance compared to other lubricants and/or where other types of lubricants would not be technically feasible. Temperature resilience, chemical inertness and a very low friction coefficient are often referred to as key aspects. In many applications it is the combination of specific tribological properties that make PFAS-based lubricants the preferred choice in high-performance applications.

As evident from the above property descriptions, PFAS-based lubricants can be applied in almost any sector where mechanical friction needs to be reduced and where one or more of the above properties is considered critical for the application. This has also become evident from the responses to the call for evidence, from the sub-sequent targeted stakeholder consultation and 2nd stakeholder consultation.

The use sectors and applications identified via these consultations are discussed in this section and presented in Appendix 2along with data from literature (Glüge et al (2020), Rudnick (2020), and Ebenesajjad & Morgan (2019)).

Given this variety in applications, various lubricant suppliers seem to have specific products for various niches and there is hesitation to share detailed information that is considered very business sensitive. There are also to some extent diverging views among these lubricant suppliers as to what are the main issues and main applications. Linked to this it has not been possible to obtain specific information about the concentration levels of PFASs in various lubricants. The following shall therefore mainly be seen as (generic) examples of where fluorinated lubricants are applied.

It should be noted that the level of detail of the information provided in the CfE and 2nd stakeholder consultation varies widely. Some stakeholders for example only mention a sector in general terms, whereas other specify in which components (e.g., a bearing) the PFAS-based lubricant is applied. Further, some stakeholders carefully list the key technical function, some do not specify any technical function, and some provide very long lists of functions.

In terms of PFAS-based lubricants applied and concentration ranges, these were in the CfE not always specifically related to sectors, uses and applications, and it is not always clear which concentrations are used in lubricants (as the CfE asked also for other non-lubricants uses). Further, many stakeholders do not specify a concentration range and concentration ranges is often not available in literature.

PFASs applied and concentration ranges were in the CfE not always specifically related to sectors, uses and applications, and it is not always clear which concentrations are used in lubricants (as the CfE asked also for other non-lubricants uses). Further, many stakeholders do not specify a concentration range. Appendix 2 provides a non-exhaustive extraction of the information on PFAS-based lubricant uses. Nevertheless, this should be treated with caution given the possible uncertainties attached.

Related to this very diverse use and technical function pattern, the first table in Appendix 2 demonstrates that PTFE (micropowder), PCTFE and PFPEs can be used in many different concentrations depending on the application. The table also shows that some applications are on the border between being a lubricant, polymeric processing aid or being a 'coating'. This is e.g., the case in situations where micro-powder PTFE is added as an additive to an often-continuous phase of an non-fluoropolymer thermoplastics, thermosetting resin or a high-viscosity liquid or wax thereby facilitating 'slideability'/'lower friction'/'reduction in wear'/'improved release properties'/'oil and water repellence.

Coatings and internal lubricants mentioned above is not described as lubricants in Ebnesajjad & Morgan (2019) and not in the scope of this report. However, examples provided in the CfE are included in Appendix 2, for illustration.

In the targeted stakeholder consultation, stakeholders suggest that a very wide range of sectors might be affected by a ban of PFAS-based lubricants. The consultation activities have shown that this type of lubricants are used more or less 'everywhere' where mechanical and electromechanical parts need lubrication under conditions where the tribological properties of PFAS-based lubricants are needed. For example, the Technical Association of the European Lubricants Industry (ATIEL) has provided an overview with more detailed examples of where various types of PFASs are used in lubricants, including additional details about their uses and concentrations in products, as well as the perceived 'essentiality' of their use, see the second table (Table 24) in Appendix 2.

Input received from stakeholders has shown that it is difficult to clearly distinguish between sectors. First of all, sector breakdowns provided by different stakeholders are quite different in terms of choice of how a sector is defined and secondly, some categories such as 'bearings' are unspecific and could potentially go into any sector using bearings.

The industry stakeholders interviewed agreed that PFAS-based lubricants are used by both professional and industrial users. There might also be high-end consumer uses among amateur bike enthusiasts, but such uses are not considered 'essential' by these stakeholders (by the stakeholders ‘definition’ of essentiality as no such definition currently exist under REACH). However, it is also stressed that these lubricants will occur as an integral part of many consumer products such as cars, household appliances, some medical equipment for self-medication, power tools, etc.

2.1.3 Alternatives identified

Most responses to the CfE state that no or no appropriate alternatives are known or available. Several stakeholders note that various alternatives have been researched and tested over the past decades, but without success. This message was generally repeated during the targeted stakeholder consultation. One industry stakeholder noted that micro-powder PTFE can to a limited extent be substituted with other chemistries, which can however not always be considered better from an (eco-)toxicological perspective (some examples are discussed further below). In this context, it shall be noted that no suppliers of possible alternative lubricants responded to the CfE or the 2nd stakeholder consultation and that several trade associations, also representing suppliers of non-fluorinated lubricants, were consulted in the targeted stakeholder consultation. Ebnesajjad & Morgan (2019) describes the use of other additives than micro-powder PTFE in low viscosity lubricants and grease. Often, however, these other additives is used in combination with micro-powder PTFE. Other identified literature discusses various potential alternatives to micro-powder PTFE without clearly stating in which applications such alternatives could in practice substitute micro-powder PTFE.

Many stakeholders also argue that fluorinated lubricants are more expensive than traditional lubricants and that substitution has therefore already taken place where possible, leaving only those applications which depend on the technical function and properties of fluorinated lubricants. This position is countered by Rudnick (2020) who states that the basis of fluorinated lubricants being more expensive and therefore driving substitution to non-fluorinated alternatives where possible (based on economic reasons) is false. This position is claimed, because Rudnick asserts the total cost of lubrication is not often considered, and that PFPE based oils and greases can be used for general-purpose lubrication, especially in the presence of harsh and demanding environments.

Furthermore, it shall be noted that the argument of cost of PFAS-based oils and greases driving substitution for general uses might be challenged to some extent in situations where other lubricants can meet the technical requirements, but 'just' need more relubrication as compared with the more expensive fluorinated lubricants. In these situations, the 'Total Cost of Ownership' (see e.g., Grechin et al., 2018)[28] might be lower applying expensive fluorinated lubricants requiring less relubrication and thereby having lower operating/maintenance costs associated. As noted, this relates to situations where alternatives can meet the technical specifications and where it does not lead to excessive wear on equipment, which would need to be considered in the Total Cost of Ownership considerations.

As background for the following, it is therefore recommended to carefully read the subsection about "Use and *technical function*" in section 2.1.2.4.
That sub-section includes some indications/explanations as to why more traditional lubricants according to interviewed industry stakeholders cannot fulfil the required functionality of PFAS-based lubricants in relevant applications.

Some possible alternative lubricant substance and systems have however been identified and discussed in the CfE and in the targeted stakeholder consultation. In addition, some recent publications discuss various alternative substances in R&D.

2.1.3.1 Alternatives to PFAS-based base oil

In general, stakeholders agree that it is very difficult to substitute PFPE as base oil in many applications, exemplified by the following statement from the 2nd stakeholder consultation: "*There is currently no alternative which has the same properties as PFPE such as low vapor pressure, amphiphilic, resistance against aggressive media, resistance of oxygen, not being flammable, being inert, clean in the usage of high temperature applications, very long service life time behavior and excellent low temperature properties up [down] to -80°C and radiation*

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[28] Grechin AG, Schott V, Kling R (2018). PFPE-Greases: modern trends and perspectives. Paper for ELGI AGM 2018 Conference in London.

resistant." Similar statements were made during CfE and the targeted stakeholder consultation.

The long service life of PFPE lubricants make them useful for electrical equipment with a long lifetime such as electrical switchgear (+40 years). According to stakeholders in the 2nd stakeholder consultation currently no alternatives is available that can ensure stability over the full lifetime.

In line with the statement above, no literature discussing possible alternatives to PFPE in lubricants has been identified.

The service temperature range for the PFPE base oils goes from approx. -80 ºC to approx. 350 ºC (depending on the type of PFPE). The type non-PFAS lubricant base oils mentioned above, that comes closest to this, is silicon oils with a temperature service range of approx. -70 ºC to approx. 200 ºC. Silicone lubricants and greases are used for some specific applications a temperature above 200 ºC is not required. According to the 2nd stakeholder consultation they are compatible with most elastomers (except silicone) but they are more affected by radiations than PFPEs and has the worst lubrication behavior and causes more wear and tend to spread. Breakdown voltage of silicone is pretty poor compared to PFPE formulated lubricants. Silicone oil is not considered as flammable material but can burn when it reaches a certain temperature, which is not the case of PFPE formulated lubricants. Furthermore, it is commented in the 2nd stakeholder consultation that: "*Silicone alternatives can remain on the finished articles surface and will reduce the technical performance. E.g. silicone on tire surface will reduce grip between tire and road which is relevant for road safety*.".

For these reasons, silicon oil is not considered a proper alternative to PFPE base oil – at least not for all applications, and especially not under harsh conditions.

No information was received on alternatives to other PFAS-based base oils like PCTFE or fluorosilicone oils.

2.1.3.2 Alternatives to micro-powder PTFE

Compared to PFPEs, there seems to be more activity related to possibly substituting PTFE, at least in some applications.

Alternatives to micro-powder PTFE identified in the CfE and targeted stakeholder consultation include graphite, amorphous silica, molybdenum disulphide, boron nitride or other inorganics (e.g., layer building zinc phosphates). This is in line with Ebnesajjad & Morgan (2019) that mentions that in addition to fluoropolymers such as micro-powder PTFE, the other solid additives that may typically be used in lubricants are graphite, molybdenum disulphide (MoS_2) and boron nitride (BN). For Low Viscosity Lubricants and dry-film lubrication Ebnesajjad & Morgan (2019) highlights that a mixture pf micro-powder PTFE and boron nitride performs better than micro-powder PTFE and boron nitride on their own and also better than graphite and molybdenum disulphide.

For grease clays such as bentonite may be used in combination with PTFE to thicken synthetic base oils such as polyalphaolefin oils, esters and PFPE oils. Silicon oil (polysiloxane) greases is commonly thickened with a mixture of amorphous fumed silica and PTFE. Molybdenum disulphide, graphite, talc and zinc oxide can also be used as grease additives (Ebnesajjad & Morgan, 2019).

Comments in the 2nd stakeholder consultation confirms that graphite, molybdenum disulphide (MoS_2), boron nitride and talc is used in combination with micro-powder PTFE.

Concerning above possible alternatives to micro-powder PTFE, one stakeholder in the CfE noted: *"The friction reduction level is universal and cannot be matched by fluorine-free solid lubricants like boron nitride, grafite or molybdenum disulfide, as very often their performance is strongly dependent on environmental conditions like relative humidity."*

Molybdenum disulphide is good for high load applications but cannot, according to industry, do the job in applications where rotations and especially 'slideability' is a factor.

It is also argued by industry that use of micro-powder PTFE generally leads to more clean conditions (required in some applications), e.g., the following statement has been received: "*Graphite and molybdenum alternatives are used specifically for their lubricating properties, but PTFE is more chemically resistant and allow for clean conditions. In dry lubricant application, PTFE micropowder replaced graphite for lubrication of lace machinery as PTFE ensured production of clean lace and eliminated lengthy scouring process, to remove residual graphite.*" Similar arguments was also received in the 2nd stakeholder consultation here it was also argued that micro-powder PTFE has a much better plastic/elastomer compatibility than graphite and molybdenum disulphide.

As noted above, it is by stakeholders generally considered difficult to substitute PFPEs as base oil in many applications. These PFPEs base oils are sometimes thickened with micro-powder PTFE (where PTFE might be added to control viscosity and other properties). In relation to whether micro-powder PTFE could be substituted in such base oils, several industry stakeholders note that, the inorganic alternatives (graphite, molybdenum disulphide, etc.) are not an option due to the very poor compatibility with the PFPEs base oil. Such use would lead to loss of lubricant from the system being lubricated and thus need for frequent relubrication and/or system failure. This would also lead to immense challenges for life-time lubrication systems in devices where re-lubrication is not possible, such as in electronics and other devices.

Of the inorganic alternatives to micro-powder PTFE, boron nitride might be the most promising, but not for all applications. Further, to date it is noted that from research, the performance of the lubricants with this alternative do not reach those of lubricants with micro-powder PTFE. Several stakeholders note that boron nitride is considered more toxic as it might be a source of boron acid. Further, the costs for boron nitride is about 3 times higher than micro-powder PTFE.

It is also noted by stakeholders that where possible, micro-powder PTFE containing lubricants have already been substituted with these types of alternatives where possible.

In addition to these alternatives, which were identified in the CfE, targeted consultation and recent literature reviews the potential for other chemistries and dimensions which could potentially substitute micro-powder PTFE. This includes using materials such as those mentioned above (e.g., MoS_2 and boron nitride), as well as Black Phosphorous (BP), WS_2 and (modified) graphene as thin two-dimensional (2D) lubricant additives (see e.g., Nair et al., undated[29]; Liu et al., 2019[30]; Wang et al., 2018[31]). These are typically sheets in nano-scale dimensions, i.e., with mono or multi atomic layer thickness, which can slide easily (Liu et al., 2019). In this respect these 2D lubricants might be interesting as substitutes for micro-powder PTFE, which has a very low coefficient of friction. Most promising of these 2D systems seem to be the graphene chemistry. However, a challenge is that graphene, as other nanomaterials, tends to agglomerate. To avoid this and to be more efficient graphene can be modified via a hydrogenation or fluorination (Liu et al., 2019). The latter, seeming to be advantageous, is however also to be considered a PFAS as they contain CF_2 and CF_3 groups (see e.g., Ahmad et al.,

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[29] Nair RR, Ren WC, Jalil R, Riaz I, Kravets VG, Britnell L, Blake P, Schedin F, Mayorov AS, Yuan S, Katsnelson MI, Cheng HM, Strupinski W, Bulusheva LG, Okotrub AV, Grigorieva IV, Grigorenko AN, Novoselov KS, Geim AK (undated). Fluorographene: a Two Dimensional Counterpart of Teflon. http://www.condmat.physics.manchester.ac.uk/pdf/mesoscopic/publications/graphene/small62010.pdf

[30] Liu L, Zhou M, Jin L, Li L, Mo Y, Su G, Li X, Zhu H, Tian Y (2019). Recent advances in friction and lubrication of graphene and other 2D materials: Mechanisms and applications. Friction 7(3): 199–216. https://doi.org/10.1007/s40544-019-0268-4

[31] Wang W, Xie G, Luo J (2018). Black phosphorus as a new lubricant. Friction 6(1): 116–142. https://doi.org/10.1007/s40544-018-0204-z

2021[32]). Similarly, a TiO_2 Nanoparticle/Fluorinated Reduced Graphene Oxide Nanosheet Composite, which can be used as lubricant shows promising friction reduction and wear resistance (Zhao and Ci, 2020[33]), also contains fluorinated groups. Further, any health and safety issues with nanomaterials should be considered if these described alternatives are applied as substitute for micro-powder PTFE (noting that PTFE can also be produced in nanoform). Finally, it shall be noted that the reviewed literature generally does not explicitly state in which applications these substances might act as substitutes for micro-powder PTFE. In the 2nd stakeholder consultation it was commented that graphene, silica and zinc compounds have a completely different lubrication behavior compared to micro-powder PTFE and that for many applications in the electronic industry it is difficult to use graphene as an alternative to micro-powder PTFE because of its hardness, which can damage the mating material, the higher dosage, and the potential for electrical effects when released due to its electrical conductivity.

Lubrizol is working on a 'water-based phenolic-melamine gold lacquer' alternative to PTFE[34]. This alternative is still in the R&D phase and from the information available, it is not clear to which extent/for which applications this substance might potentially substitute PTFE in lubricants, nor is it obvious whether this alternative possesses other/better environmental persistence characteristics than PTFE.

Chemie-Technik GmbH has developed a silicone oil thickened with polyurea as a substitute for a micro-powder PTFE-thickened silicone oil for specific applications where the PTFE-thickened silicone oil tends to separate in conditions with low velocity/poor flow conditions. This is not the case with the newly developed polyurea-thickened silicone oil, which was developed specifically for application in a progressive distributor on the central filler carousel in a brewery[35]. The extent to which this product can be applied as substitute for micro-powder PTFE thickened silicone oils in general is not clear from the reference. This was commented in the 2nd stakeholder consultation were one stakeholder agreed that "*polyurea is a very good option in bearing with a very high-speed application*" but that micro-powder PTFE-thickened silicone oil can do the same job and has additional applications/benefits as well. It was also stated in the 2nd stakeholder consultation that polyurea thickeners don't perform well in harsh chemical environments and can degrade at elevated temperatures meaning that the lubricant will fail or require more frequent lubrication (if possible). Further it is stated that life span of PFPE-based lubricants much longer than polyurea lubricants.

Overall, there seems to be much on-going activities related to alternatives which might substitute micro-powder PTFE. A few of these alternatives are already in use in certain applications, but most are currently in R&D and attention should be made the possible health and safety issue associated with such alternatives, some of which are PFAS-based themselves.

2.1.3.3 Alternative lubrication systems

Possible alternative lubrication systems identified in the CfE include silicones, silicones greases, and esters. A specific group - ionic lubricants - has been identified via literature.

In terms of alternative lubrication systems, the following considerations were provided as part of the CfE:

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[32] Ahmad Y, Batisse N, Chen X, Dubois M (2021). Preparation and Applications of Fluorinated Graphenes. Journal of Carbon Research, C 2021, 7, 20. https://doi.org/10.3390/c7010020

[33] Zhao W, Ci X (2020). TiO2 Nanoparticle/Fluorinated Reduced Graphene Oxide Nanosheet Composites for Lubrication and Wear Resistance. ACS Appl. Nano Mater. 2020, 3, 9, 8732–8741. https://doi.org/10.1021/acsanm.0c01547

[34] https://www.lubrizol.com/Coatings/Blog/2019/10/PTFE-Alternatives

[35] https://www.elkalub.com/profile/press/press-details/better-without-ptfe-free-silicone-grease-for-the-food-industry.html

- One stakeholder noted that for some bearing applications, premium quality esters might be an alternative, but 15 to 25 times the volume of lubricant would be required (e.g., due to more frequent relubrication needed).

- One stakeholder noted that several alternative lubricants are on the market such as silicones (without further specifying for which applications).

- One stakeholder noted that some customers use silicone greases in applications where others use PFPE greases. Sometimes the silicone greases cause technical problems e.g., that silicones are contaminated, which is not the case with PFPE greases because PFPE is chemically inert.

During the targeted stakeholder consultation, no further benefits of these systems were identified, and it was generally noted that, where possible, substitution to such systems would already have taken place, but that such systems in many cases do not meet the tribological properties of fluorinated lubricants. As described in the section on potential alternatives to PFPE base oils, stakeholders in the 2nd stakeholder consultation does not considered silicon oil as a proper alternative to PFPE base oil – at least not for all applications, and especially not under harsh conditions.

A specific group of lubricants undergoing research and development are ionic lubricants (Somers et al., 2013)[36]. These consist of large, asymmetric organic cations and usually an inorganic anion. The anions can be of PFASs nature such as perfluoroalkylphosphate (FAP), but also e.g., tetrafluoroborate (BF4) and hexafluorophosphate (PF6) or they can be non-fluorinated. Thus, this group of lubricants covers some based on PFASs as well as alternative chemistries. In response to whether such lubricants could substitute fluorinated lubricants, industry stakeholders responded that relevant ionic liquids for these applications very often contain CF_3-groups as well (and would thus likely be PFAS-based lubricants themselves). Further, many of these ionic lubricants are according to industry stakeholder’s toxic, sometimes corrosive, and they are generally quite expensive.

2.1.3.4 Alternatives to PFAS-based solvents and additives

Only limited feedback has been received in relation to how critical the uses of PFAS-based solvents and other additives than micro-powder PTFE are in lubricants and in the lubrication process (cleaning before lubrication). Some considerations of 'essentiality' are however presented in Appendix 2 (Table 24, provided by ATIEL). The general message from follow-up interviews in the targeted stakeholder consultation was that they cannot be substituted. Some supporting arguments received are the following:

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

- *"Fluorinated solvents cannot be substituted as long as PFPE/PTFE is to be dissolved for minimum quantity lubrication. Eventually with other technologies (undiluted spraying of greases and oils) the usage of fluorinated solvents can be minimized. However, such technologies need to be developed from downstream users. Fluorinated additives act as strong adsorbing agents for PFPE/PTFE and therefore reduce leakage of PFPE/PTFE into the environment. As long as PFPE-based lubes have to be used, the function of the fluorinated additives -they are polymers- cannot be substituted."*

2.1.3.5 What would happen if only alternatives were available?

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[36] Somers, Anthony ; Howlett, Patrick ; Macfarlane, Douglas ; Forsyth, Maria (2013). A Review of Ionic Liquid Lubricants. Lubricants (2013); 1: 3-21.

Stakeholders argue that a ban of PFASs containing lubricants would:

- Lead to lower lubrication efficiency (and thereby a higher CO_2 footprint).
- Cause problems for new/renewable energy applications (e.g., they have a key function in connectors in charging systems in electrical cars, fuel cell technology, hydrogen cars, and in proper functioning of bearings and gears in wind turbines).
- Increase wear on machinery/moving parts (up to ten times more wear in some applications, which would need frequent replacement). This would in turn lead to more waste and increased resource consumption for producing new equipment and to the increased amount of lubricant used.
- Potentially lead to the development of alternatives with probably the same persistent characteristics as PTFE and PFPEs (as the non-reactivity/chemical inertness is crucial in many applications).
- In this context, stakeholders point to the fact that fluorinated lubricants are generally considered safe/low toxic and they are therefore applied and approved for food processing, drinking water installation and various medical equipment, as well as the preferred choice for some automotive applications where alternatives might lead to odour and VOC emissions no longer allowed within cars.
- Lead to lower yields due to more downtime of equipment and e.g., for the semiconductor/wafer industry to lower yield and quality due to contamination if other non-inert lubricants are applied.

A stakeholder in the CfE noted that PFAS containing lubricants has substituted lead in some applications. This was further specified in the targeted stakeholder concentration in relation to application of lead-free solders in electronics: "*… PFPE-containing products are used to improve the flow ability of the solder without the use of heavy metals*".

A few stakeholders noted that PFAS-based lubricants might be substituted in a few situations, but that these are probably limited given the price of these lubricants. The most optimistic stakeholder estimated the following: "*… only a minor part of applications can be covered by alternatives <10% without significant performance losses, approx. 30% with significant performance losses and the remaining applications would suffer critical performance losses or get totally lost (60%)*".

It was generally claimed by stakeholders that it would take about ten years to develop alternatives (if possible) and that these would then need to be validated, which would also be time-consuming (e.g., for the car industry, the medical industry and even more so for aviation, aerospace).

In this context industry stakeholders stress that in many situations, fluorinated lubricants are the only products which can meet strict specifications laid down in standards for e.g., the food and aviation sectors.

Further, it was suggested that development of new lubricants and resulting changes in downstream technology would be extremely expensive (hundred thousand of Euros (or more) per application) and that some uses/applications might have to be dis-continued as no alternatives are likely be developed.

2.1.3.6 Alternative technologies

As noted, a consequence of a ban might be to develop new lubricant free technology with tribological restrictions (friction, abrasion). This would require time and cost for the redesign /technology development needed. It is argued by many stakeholders that such technology would have been developed if economically and technically feasible. Also, according to industry, it is very unlikely that such systems would not lead to increased resource and energy consumption. One stakeholder however noted that: "In some cases, surface modifications of the component to be lubricated (coatings) or self-lubricating polymers may be an alternative".

Research is also on-going in relation to whether liquid lubrication could in some situations be substituted with non-liquid lubrication. A recent review of polymer self-lubricating coating systems sees prospect such as (quote from Feng et al., 2020)[37]:

- *Develop nano lubricating filler with excellent performance. The traditional solid lubricants, such as graphene … and MoS2 …, will degrade at high temperature. Recently, a new family of two-dimensional early transition metal carbides and carbonitrides, named mxenes … This kind of material has the characteristics of low shear strength, high mechanical strength and self-lubricating property … The tribological properties of the material as a solid lubricant added to the polymer self-lubricating coating deserve attention.*
- *Study on the modification of solid lubricants. Modification of solid lubricants such as inorganic nanoparticles, graphene and molybdenum disulfide … to enhance their compatibility with polymer matrix is also a hot topic in the future.*
- *Microcapsules are added to the coating, which leads to the development of intelligent coating. Microcapsule … technology can make the composite show the characteristics of fluid lubrication in the friction process, it can avoid the defects of fluid lubrication at the same time, which greatly enriches the further application of polymer matrix composite in the field of tribology.*
- *Different application places have different requirements for polymer self-lubricating coating, so it is necessary to test the performance of the material under specific experimental conditions.*

Also, Sahoo (2020)[38] discusses how two dimensional (2D) materials such as graphene, WS_2 and MoS_2 can be used to reduce friction as an integrated additive in composite materials being applied increasingly in e.g., the automotive, aerospace, marine and defence sectors.
It is not clear from the references whether and to which extent these systems can substitute PFAS-based lubricants.

A specific study investigated an advanced high-bearing aromatic thermosetting polyester (ATSP) coating filled with PTFE and graphene nanoplatelets (GNP), respectively. Both composite coatings showed a significant decrease in friction and improved wear resistance with the GNP-filled coating performing better than the PTFE-filled at extreme temperatures of 300 degree Celsius (Bashandeh et al., 2019[39]).

2.2 Construction products

2.2.1 Uses

The uses, sub-uses and functions of PFASs identified by Glüge et al. (2020) act as a starting point for categorisation of PFAS uses in construction products. These uses have therefore been grouped into three tiers of hierarchy:

- Parent level
- Sub-level

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[37] Feng Q, Zou S, Li H, Dou M, Huang F (2020). Review of Polymer Self-lubricating Coatings. IOP Conf. Ser.: Earth Environ. Sci. 526 012077. doi:10.1088/1755-1315/526/1/012077.

[38] Sahoo S (2020). Self-lubricating composites with 2D materials as reinforcement: A new perspective. Reinforced Plastics. Available online 2 July 2020 (in press). https://doi.org/10.1016/j.repl.2020.06.007

[39] Bashandeh K, Lan P, Meyer JL, Polycarpou AA (2019). Tribological Performance of Graphene and PTFE Solid Lubricants for Polymer Coatings at Elevated Temperatures. Tribol Lett 67, 99 (2019). https://doi.org/10.1007/s11249-019-1212-5.

- Application specific level.

Using a tiered approach such as this allows aggregation of the uses depending on the data available, with the aim to target the application specific level wherever possible but allowing the flexibility to work at the sub-level or even parent level if necessary. Aggregating the uses in this kind of tiered structure also allows comparison of the aggregated data at different levels to understand what the overall sector (i.e., all construction products) may look like compared to other sectors where PFASs are used.

TABLE 2 provides the proposed use categories for the current study (for construction products) using the original uses identified by Glüge et al. (2020) to define the application specific level. Construction products have been disaggregated at the parent level, to reflect that the construction sector in general covers a wide range of applications and therefore for clarity some additional disaggregation was needed. The proposed disaggregation relates to the method of application, which is split as follows:

- Products. This covers the use of PFASs or PFAS containing mixtures used within a complete product. The PFASs in this case is likely added at the time of manufacture and again can serve a range of functions including acting as a surfactant or (polymeric or non-polymeric) processing aid or additive, and to provide the final article with repellence against water, oil, dirt, or stains, as well as potentially heat and chemical resistance.
- Coatings. This covers PFAS containing mixtures applied to a pre-existing article (at the time of use or at the end of production). In these cases, the technical function of PFASs provides water, oil, and dirt repellence, as well as a possible levelling agent or surfactant to reduce surface tension. For some applications PFASs can also provide a secondary function to provide a protective layer against wear/surface abrasion. Also, based on discussions with industry, coatings can include fully PFAS-based thin film technologies (e.g., PTFE) as a protective coating/layer to pre-existing articles.

TABLE 2. Categorisation of PFAS uses for construction products in this study.

Parent level	Sub-level	Application-specific level
Construction Products (products) *Definition: This category covers products that already contain PFASs to provide a specific function. Examples may include PTFE, PVC, other plastics, and cabling. The distinction is that the article comes as a complete item that already contains PFAS.*	Building and construction	Architectural membranes (e.g., fabrics or fiber glass), in e.g., roofs, greenhouses, flexible solar panels
		Windows and window frames (containing e.g. ETFE & PTFE) (e.g., greenhouses)
		Cement additives [1]
		Cable and wire insulation, gasket hoses [2]
		Skidways for constructions (e.g., PTFE)
		Bridge bearings (e.g., PTFE)
		Sealants and adhesives (including tapes for structural glazing)
	Pipes, pumps, fittings, and liners	Pipe linings and tower packings/internals for heat and mass transfer applications [2]
		Working fluid/vacuum pump oils [2]
	Household application	PTFE tape (also PTFE tape for professional applications like for drinking water and compressed air systems)
		DIY sealant and adhesive products as e.g., foam mounting tapes and squares, and damage-free hanging solutions.
	Processing aids (PAs) polymer processing additives (PPAs)	Processing aid in the manufacture of construction products. Both non-polymers (e.g., surfactants or solvents) that are not intended to be a part of the final product and polymeric PFASs (PPAs) (micro-powder PTFE, high-MW PTFE, PVDF, PFPE) used as internal lubricant/additive/processing aid in thermoplastics (e.g., PE and PP) and elastomers
Construction Products (surface coatings) *Definition: This category covers the use of coatings (including sprays, paints, mixtures and fully PFAS based thin film technologies) added to pre-existing articles at the time of use or at the end of production as a finishing process to give the component desired water, oil and dirt repellent properties. It*	Wood industry sector	Coatings-paintings-varnishes – Wood substrate
		Coatings-paintings-varnishes – Resin for particleboard
	Glass industry sector	Surface treatment of glass
	Metal industry sector	Coatings-paint for metal protection
	Construction sector plastics	Professional coatings for finishing step of plastics used in construction
	Outdoor electrical components	Surface coatings for wind turbine blades

also includes the addition of PFASs within other coating mixtures (such as paints) as a surfactant/wetting agent/levelling agent.	Stone, concrete, and tiles – Semi-professional aftercare	Surface coatings for solar panels Surface treatments DIY durable water repellent (DWR) impregnation
	Coatings, paints, and varnishes – Domestic / semi-professional aftercare	Paints Coatings (glass, ceramic, and metal e.g., coil coating of aluminium) Linoleum, laminated plastic floor [3] Aftermarket floor protection

[1] This use was identified by Glüge et al. (2020) but note that the cement industry suggested during the consultation that they are not aware of intentional use of PFASs in their industry.

[2] These uses are not included under the use ‘category building material/construction products’ in the Annex XV restriction proposal submitted to ECHA on the 7th January 2023

[3] This use was identified by Glüge et al. (2020) but note that the flooring industry suggested that the only significant uses of PFASs in their industry have been phased out since the early 2000s.

2.2.2 PFASs used in construction products.

2.2.2.1 Construction products (articles)

TABLE 3 provides the consolidated list of PFASs identified as being used within construction product applications in articles, according to stakeholder input during the CfE, the targeted stakeholder consultation, 2nd Stakeholder consultation as well as literature review. Note that, for most cases, the CfE has yielded sufficient data to identify the substances used at the application-specific level with a few notable exceptions, in particular:

- DIY adhesives and sealants – the data identified suggests that primarily non-polymeric PFASs are used for these applications, but details on which specific substances has not been identified.
- Windows and window frame additives. The Annex XV restriction dossier (2023) notes that fluorosurfactants can be used as coating additives and dispersants to create low resurface energy in window frame manufacturing.

Beyond this, while data has been identified to help guide substance identity at the application specific level, data on quantities of use are sparse. Meaning quantifying PFAS tonnages per application has not been possible.

At the parent level (all construction products – articles), Glüge et al. (2020) estimated by volume approximately an even split between polymeric and non-polymeric PFASs in use (although market volumes are not provided in TABLE 3). The distribution of polymeric and non-polymeric PFASs between uses from the results of the CfE can be summarised as follows:

- For some uses there is a mixture of both polymeric and non-polymeric substances in use. This includes sealants and adhesives which appear to be the other major application (besides windows and window frames) where a range of non-polymeric PFASs is in use.
- In several applications only polymeric PFASs was identified, including architectural membranes, foil/film for greenhouses, cable and wire insulation, gasket hoses, bridge bearings, working fluid/vacuum pump oils, PTFE thread sealing tape and polymeric PFASs used as processing aids for production of non-PFAS polymers/plastics.
- Although they can be considered a type of fluoropolymers, it is worth noting that fluoro-elastomers (FKM, FFKM etc.) appear in a number of applications (architectural membranes, and bridge bearings).

The main identified technical functions provided by PFASs in construction product applications in articles are:

- Water, dirt and oil repellence
- Corrosion/chemical resistance
- UV resistance and UV light transparency
- Heat resistance / temperature range
- Low friction / anti-stick
- Durability and mechanical properties (light weight, strength, impact resistance)
- Non-flammable
- Electric insulation, ductility
- Surfactant
- Process aid

TABLE 3. Overview of PFAS used in construction (products)

Application	PFASs	Products	Technical function
Architectural membranes (composite membranes with fluoropolymer top coating and pure fluoropolymer architectural membranes) and greenhouse foil/film	***Polymeric*** PTFE ePTFE ETFE (including as a matrix polymer or additive in composites) THV PVDF	INOFLON ® & INOLUB™ FLUONOX® & INOLUB™ FLUONOX® INOFLON ® INOFLAR™ 3M™ Dyneon™ PTFE Dispersion	Weatherability (water repellence, dirt repellence) Corrosion/chemical resistance Durability, UV light transparency (crucial in greenhouses), anti-fouling properties, light-

	FKM FFKM FEP PFA FTPV FVMQ ***Non-polymeric*** PBSF Trans-1-chloro-3,3,3- trifluoropropene Fluoroalkene Fluoroalkene Oligomers	3M™ Dyneon™ Fluoroplastic PFA 3M™ Dyneon™ Fluoroplastic FEP 3M™ Dyneon™ Fluoroplastic THV Homopolymer PVDF Kynar® Copolymer PVDF KynarFlex(r) ZONYL® HCFO-1233zd(E); Solstice LBA; FA-188; 3M FA-188 (used as blowing agents)	weight, strength (impact resistance, no breaking/splintering), sound absorption, heat-resistance, ductility Non-flammable (certified B1 in DIN4202 part 1)
Windows and window frames	PVDF	No data	Lamination of PVC and high-pressure laminate (HPL) window frames
Cement additives and sealers	PCTFE PFSA perfluoroelastomers perfluorinated acrylic polymers fluoro-acrylate modified urethane emulsions	3M – SRC-220 3M – SRA -250 3M – SRA270 3M – SRA450 3M – SRA-451 Concrete Sealers USA – PS100	Weatherability (water and dirt repellence) Stain repellence
Skidways for construction (e.g., PTFE)	PTFE	Fluoroglide	Low friction Low moisture absorption, strong weather resistance, chemical inertness, electrical and thermal insulation
Bridge bearings (e.g., PTFE)	***Polymeric*** PTFE PCTFE ETFE PVDF FKM FFKM FEPM FTPV FVMQ	3M™ Dyneon™ PTFE	Water repellence Low friction
Sealants and adhesives	***Polymeric*** PTFE; Perfluoropolyether biscarboxy amidosilane; 2-Propenoic Acid, 2-[Methyl[(Nonafluorobutyl)Sulfonyl]Amino]Ethyl Ester, Telomer With Methyloxirane Polymer with Oxirane Di-2-Propenoate and Methyloxirane Polymer With Oxirane Mono-Propenoate; Partially fluorinated PEG	3M™ Fluorosurfactant FC-4430 3M™ Fluorosurfactant FC-4432 3M™ Fluorosurfactant FC-4434 3M™ Stain Resistant Additive SRC-220 3M™ SRA-250 Stain Resistant Additive and Sealer 3M™ SRA-451 Stain Resistant Additive and Sealer 3M™ SRA-461 Stain Resistant Additive and Sealer 3M™ Easy Clean Coating ECC-4000	Water and oil repellence. Important to maintain seal / degradation of sealant. less item staining and enhanced performing life, improves cleanability and inhibits moisture and mold. process aid for foam tapes surfactant (to improve wetting, help application of the adhesive to bonding surfaces, gap filling ability and ability to be

	Non-polymeric Reaction Mass of 2-(ethoxydifluoromethyl)-1,1,1,2,3,3,3-heptafluoropropane and 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro-butane	3M™ Easy Clean Coating ECC-7000	used on contaminated surfaces) Linkage of substrates Forming a barrier to maintain sealing properties. Resistant to UV light, moisture and temperatures
PTFE thread sealing tape (also for professional applications like for drinking water and compressed air systems)	***Polymeric*** PTFE	PTFE Tape, MidiTape, MaxiTape, Sealrite, Unitape, JumboTape, Multitape, Topseal (all PTFE-based thread seal tapes)	Water, oil, dirt repellence Anti-corrosion properties
DIY sealants and adhesive products	No data (could be the same as professional sealants and adhesives)	No data	No data
Processing aids	***Non-polymeric*** Confidential substances	Confidential product	Lowering melt temperatures and extruder pressures, resulting in overall reductions in energy consumption.
Polymer processing aids (PPAs)[40] used for the processing of thermoplastics[1] and thermosetting plastics[2]	***Polymeric*** PTFE (micro-powder and high-MW) PVDF Fluoroelastomers (VDF/HFP/TFE) PFPE	Fluon® PTFE Polyflon Dyneon™ PTFE Micropowder TF 9205 Kynar Flex® PPA 3M™ Dynamar™ FX 5911 3M™ Dynamar™ FX 5912 3M™ Dynamar™ FX 5914 3M™ Dynamar™ FX 5917 3M™ Dynamar™ FX 9613 3M™ Dynamar™ FX 9614 Technoflon® NM FKM Viton™ A Daikin PPA DA Fluoroguard® PRO Fluorolink® A10-P Fluorolink® E10-H Fluorolink® PEG45	Eliminate of melt fracture (shark-skin effect), improve wear and abrasion resistance, reduce coefficients of friction (COF), make surfaces easier to clean, increase melt tension and strength, and improve processability and mold release, reduce of die build-up, improve of the surface finish with high gloss levels, increase production start-up, reduce pressure, increase output at constant die pressure and temperature, lower energy consumption
Polymer processing aids (PPAs) used for the processing of rubber/elastomers[3]	***Polymeric*** PTFE PFPE	Zonyl MP1000, MP1400, MP1600 Dyneon PA 5952, 5955, 5956 Fluon FL1690, FL1700 Algoflon® L206 Polymist® F5A Polyflon™ L-5 Fluorolink® A10-P	Reduction of wear and friction, to improve barrier properties, improvement of mechanical properties (tear strength), reduction of tackiness or stickiness, to improve release properties
Other polymer additives			

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[40] Ebnesajjad S. & Morgan R (2019): Fluoropolymer Additives. 2nd Edition. William Andrew, Hardcover ISBN: 9780128137840 (Chapter 2, 5, 7, 10 and 11).

[1] E.g.: acrylonitrile butadiene styrene (ABS), Polyoxymethylene (POM, acetal), Polyamides (PA), Polybutylene terephthalate (PBT), Polycarbonates (PC), Polyetheretherketone (PEEK), Polyetherketone (PEK), Polyethylene terephthalate (PET), Polyethylene (PE), Polyimides, Polyphenylene sulfide (PPS), Polyphenylene oxide (PPO), Polysulphone, Thermoplastic polyurethane (TPU).
[2] Typical thermosetting resins includes epoxies, phenolics, certain polyurethanes, and certain acrylic resins.
[3] Natural rubber (NR) and e.g. Styrene-butadiene rubber (SBR), Isoprene rubber (IR), Ethylene-propylidene-diene rubber (EPDM), Butadiene rubber (BR), Chloroprene rubber (CR), Nitrile-butadiene rubber (NBR), Silicone rubber (SI, MQ, VMQ, PMQ), Fluorosilicone rubber (FVMQ), Chlorosulfonated polyethylene (CSM), Acrylic-ethylene rubber (AEM), VF2-type fluoroelastomer (FKM, FKM Type 1 [VF2+HFP], FKM Type 2 [VF2+TFE+HFP], FKM Type 3 [VF2+TFE+PMVE]), Propylene/TFE and propylene/TFE/PMVE (FEPM), TFE/PMVE (FFKM)

2.2.2.2 Construction products (mixtures used as coatings)

TABLE 4 provides an overview of the PFASs identified from the CfE, the targeted stakeholder consultation, 2nd Stakeholder consultation and literature at the sub-level use category, as data on the more detailed application-specific level was less complete. Analysis of the data does identify some key trends in the substances used across the different sub-levels of surface coatings. In particular, PVDF are not reported to be used as surface coatings for wood, stone, cement, or tiles, while they are used for the other sub-levels. The EEA report (2021) commented that PVDF in particular was harder wearing than PTFE with added abrasion protection. It is possible that for applications on glass, metal, and outdoor electrical components this property is more desirable.

A number of responses to the CfE report the use of acrylate-based polymers in various sectors (sub-level uses) without further specific details. It is possible that these could be fluorotelomer based, but specific details are not provided.

The paints sector (sub-level use) has the greatest variety of PFASs reported to be in use, including both polymeric and non-polymeric PFAS. This includes a range of telomer based alcohols, acrylates, and sulfonates as well as longer chain PFCAs (≥C12).

The main identified technical functions provided by PFASs in construction product applications in articles are:

- Water, dirt and oil repellence
- Wetting and levelling agent
- UV resistance, light transparency
- Heat resistance / temperature range
- Improve rub resistance and to impart release characteristics.

TABLE 4. Overview of PFAS used in construction – Surface coatings.

Sub-level	PFASs	Products	Technical function
Wood sector	***Polymeric*** PTFE ETFE PFPE Urethane based fluorinated polymers. Acrylate based fluorinated polymers and co-polymers. Fluoro-organo-functional polysiloxane. 2-Propenoic Acid, 2-[Methyl[(Nonafluorobutyl)Sulfonyl]Amino] Ethyl Ester, Telomer With Methyloxirane Polymer with Oxirane Di-2-Propenoate and Methyloxirane Polymer with Oxirane Mono-Propenoate (CAS 1017237-78-3)	3M™ Fluorosurfactant FC-4430 3M™ Fluorosurfactant FC-4432 3M™ Fluorosurfactant FC-4434 3M™ Stain Resistant Additive SRC-220 3M™ SRA-250 Stain Resistant Additive and Sealer 3M™ SRA-451 Stain Resistant Additive and Sealer 3M™ SRA-461 Stain Resistant Additive and Sealer 3M™ Easy Clean Coating ECC-4000 3M™ Easy Clean Coating ECC-7000 Dynasylan® SIVO 121	Water and dirt repellence. For water repellence note that it protects the wood from rotting or attack by fungi and mould.

	Perfluoropolyether biscarboxy amido silane ***Non-polymeric*** 1-Butanesulfonamide, 1,1,2,2,3,3,4,4,4-Nonafluoro-N-(2-Hydroxyethyl)-N-Methyl (CAS 34454-97-2)		
Glass sector	***Polymeric*** PTFE, ETFE, PVDF, PCTFE, **Non-polymeric** PBSF Triethoxy(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silane Fluoroalkylsilane Potassium nonafluorobutane-1-sulfonate (K-PFBS)	Dynasylan® SIVO CLEAR EC Dynasylan® F 8261 Dynasylan® F 8263 eyrise® s350 RM65 (flame retardant added to polycarbonate) Arkema Kynar ® PVDF resins	Weatherability (repels water, oil, dirt) For water helps repel moisture, preventing water marks as well as ingress of water to property. PTFE micro-powders are used in paints and coating to improve rub resistance and to impart release characteristics Aid in wetting out during the coating step (PBSF)
Metal sector (coating of metal)	***Polymeric*** PTFE ETFE THV PVDF PFA FKM PFPE Acrylate based polymers Perfluoropolyether biscarboxy amido silane FEVE ***Non-polymeric*** Fluorochemical alcohols	3M™ Dyneon™ Fluoroplastic ET 3M™ Dyneon™ PTFE 3M™ Dyneon™ Fluoroplastic THV 3M™ Dyneon™ Fluoroplastic PVDF 3M™ Fluorosurfactant FC-4430 3M™ Fluorosurfactant FC-4432 3M™ Fluorosurfactant FC-4434 3M™ Stain Resistant Additive SRC-220 3M™ SRA-250 Stain Resistant Additive and Sealer 3M™ SRA-451 Stain Resistant Additive and Sealer 3M™ SRA-461 Stain Resistant Additive and Sealer 3M™ Easy Clean Coating ECC-4000 3M™ Easy Clean Coating ECC-7000 Kynar 500® FSF® PVDF Resin ORMOSIL Lumiflon™ Arkema Kynar ® PVDF resins	Water, oil, dirt repellence. For water repellence in particular prevents rust. Corrosion resistance and long durability. UV resistance for colour loss.
Outdoor electrical energy components	***Polymeric*** PTFE, ETFE, PVDF, PCTFE, PVF	No specific products identified	
Stone, concrete, and tiles	***Polymeric*** PTFE, PFPE Acrylate based polymers. (Meth)acrylic polymer FEVE Fluorinated acrylic copolymer.	3M™ Fluorosurfactant FC-4430 3M™ Fluorosurfactant FC-4432 3M™ Fluorosurfactant FC-4434 3M™ Stain Resistant Additive SRC-220 3M™ SRA-250 Stain Resistant Additive and Sealer 3M™ SRA-451 Stain Resistant Additive and Sealer	Water, oil and stain repellence.

	Fluorinated acrylic alkylamino copolymer. Non-ionic polymeric fluorochemical surfactant based on PFBS. ***Non-polymeric*** Fluorochemical alcohols Fluorinated phosphate ester Triethoxy(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silane Mixture including 3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctyl methacrylate. 6:2-PAP (ammonium salt)	3M™ SRA-461 Stain Resistant Additive and Sealer 3M™ Easy Clean Coating ECC-4000 3M™ Easy Clean Coating ECC-7000 Maflon Hexafor® Lumiflon™ Dynasylan® F 8261 Daikin ZEFFLE	
Coatings, paints, and varnishes	***Polymeric:*** PTFE PVDF ePTFE FFKM ETFE THV FEP PFPE Acrylate based polymers. Fluorochemical alcohols FEVE fluoro-organo-functional polysiloxane Partially fluorinated PEG Partially fluorinated acrylic polymer ***Non-polymeric:*** Fluorotelomer alcohols Fluorotelomer acrylates Fluorotelomer methacrylates Fluoroesters Perfluorohexadecane Perfluorododecane Perfluoroalkane - CF3-(CF2)n-CF3 Perfluorohexyl-triacontane “C6 fluorotelomers” 4:2-FTS ethyl ester acrylate PFBS PFBS ethyl ester acrylate 3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluorooctyl methacrylate Polyfluoroalkyl betaine 8:2-PAP/8:2-diPAP	ZONYL® (Chemours) 3M™ Fluorosurfactant FC-4430 3M™ Fluorosurfactant FC-4432 3M™ Fluorosurfactant FC-4434 3M™ Stain Resistant Additive SRC-220 3M™ SRA-250 Stain Resistant Additive and Sealer 3M™ SRA-451 Stain Resistant Additive and Sealer 3M™ SRA-461 Stain Resistant Additive and Sealer 3M™ Easy Clean Coating ECC-4000 3M™ Easy Clean Coating ECC-7000 3M™ Dyneon™ PTFE 3M™ Dyneon™ Fluoroplastic ET 3M™ Dyneon™ Fluoroplastic THV 3M™ Dyneon™ Fluoroplastic PVDF Lumiflon™ Dynasylan® F 8815 Arkema Kynar ® PVDF resins Daikin ZEFFLE Chemours Capstone™ Fluorosurfactants ict ™ Thetawet short-chain fluorosurfactants Fluorolink® P56 PFPE Fluorolink® AD1700 Fluorolink® PEG45 Gemini PFPE UV Curable PU Resin Coating Additive (HCPA-620) Gemini® Fluoro Surfactant BH-10W	Water, oil, and dirt repellence, combination of waterproofing and breathability Note in particular water repellence for outdoor applications helps prevent the growth of mould and moss. UV protection (prevents colour loss) Light transmission Corrosion/chemical resistance, weatherability Wide temperature range Non-stick properties Fire resistance C6 fluorotelomers: High durability, anti-block functionality, anti-orange peel capability, and good open-time and recoatability, wetting and levelling agent. FEVE: hydroxyl functionality and can be cross-linked with poly-isocyanates. Additive to improve the wetting and leveling of the construction paints and coatings to make the coating smooth and eliminate the coating defects.

	Reaction product of partially fluorinated alkyl with P_2O_5 (ammonium salt) Reaction product of 3,3,4,4,5,5,6,6,7,7,8,8,8 – tridecafluorooctan-1-ol and polysubstituted alkane with P_2O_5 (diammonium salt) Ammonium salts of mono and bis[3,3,4,4,5,5,6,6,7,7,8,8, 8-tridecafluorooctyl and/or poly (substituted alkene)] phosphate PFSA FS ((CF2)2) FS (CF2)n; n < 3 PFPE acrylate	Scratch resistance Antifouling

2.2.2.3 Impurities and degradation products

Information on the potential degradation products and impurities from the intentional use of PFASs in construction products is provided within this section. The information provided is intended to act as supplemental to the sections on substance identity (see Section 2.2) and exposure and emissions (see Section 4.3). Information has been identified and collated based on information provided in the CfE and a literature review, based on the understanding that the data presented in this section does not represent a comprehensive analysis of degradation products for PFASs more generally.

As a general comment, all PFASs has been manufactured using one of two production pathways (Electrochemical fluorination (ECF)) and telomerisation)[41]. The latter of these two production pathways uses a base material (perfluoroalkyl iodides (also known as Telomer A)) and a series of substitution reactions to produce a wide range of telomer-based PFASs. It is also possible to use this pathway to produce acrylate or urethane telomer-based side-chain polymers.

Where fluorotelomers are produced through a series of substitution reactions it means that within the natural environment they can undergo further reactions and degrade into other forms of PFAS. For example, in the review paper by Butt et al (2013)[42], it is reported that fluorotelomer alcohols (particularly 8:2 FTOH) can act as a ready source of PFOA. Li et al (2017)[43] further comment on telomer based side-chain fluoropolymers as a source of both PFOA and PFHxA. The Stockholm Convention listing of PFOA under Annex A (banned) specifically included the PFOA-related substances[44] due to concerns over degradation products.

However, due to the high number of PFASs in use and complexity of environmental fate pathways, it means that comprehensive mapping of degradation products for all PFASs on a one-by-one basis for the PFASs in use is extremely challenging. Also further note that the research for generation of PFASs during thermal destruction (at end of life) for fluoropolymers (such as PTFE, ETFE, and PVDF) is limited, with more research needed.

For PFASs used in construction products specifically the following data has been identified:

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[41] Buck et al, 2011, 'Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins', integrated Environmental Assessment and Management – vol7, no.4 pp 513-541

[42] Butt et al, 2013, 'Biotransformation pathways of fluorotelomer-based polyfluoroalkyl substances: A review', Environmental toxicology and chemistry https://doi.org/10.1002/etc.2407

[43] Li et al, 2017, 'degradation of fluoro-telomer based polymers contributes to the global occurrence of fluorotelomer alcohol and perfluoroalkyl carboxylates. A combined dynamic substance flow and environmental fate modelling analysis', Environmental Science and Technology vol 51, pp 4461-4470

[44] PFOA-related substances includes are any substances that degrade to PFOA, including any substances (including salts and polymers) having a linear or branched perfluoroheptyl group with the moiety (C7F15)C as one of the structural elements, for example: a) Polymers with ≥C8 based perfluoroalkyl side chains; b) 8:2 fluorotelomer compounds; and c) 10:2 fluorotelomer compounds.

- UBA (2020)[45] undertook a sampling campaign of 23 building materials and 28 industrial textiles, with analysis spanning a suite of 29 PFASs, with samples collected in 2017 and 2018. The samples included paints and surface coatings, sealants and adhesives, and composite materials. The suite of PFASs included in the analysis spanned PFCAs, PFSAs, FTOHs, perfluoro-telomer sulfonates and sulfon amides. The results provide the following comments:
    - Paints and surface coatings. UBA (2020) comment that based on information from industry a range of PFASs are used in paints and surface coatings including shorter chain PFASs (including PFBS), fluorinated acrylates, esters, and phosphate esters (both mono and di polyfluoroalkyl phosphate esters (mono-PAPs and di-PAPs). The results of the sampling campaign detected a range of perfluoroalkyl acids (PFAAs) (including PFHxA, short chain PFCA and PFOA), and fluorotelomer alcohols, particularly 6:2 FTOH. It is not reported whether these substances were present as likely contaminants of acrylates, esters, or Mono/di-PAPs or as degradation products.

    - Sealants and adhesives. UBA (2020) comment that fluorosurfactants may be used in adhesives and sealants as wetting agents to help the material spread more easily over contact surfaces. However, further details of which PFASs are likely to be used are not provided. The sample results for glues and adhesives only detected two PFASs (from the suite of 29 substances), these were 8:2 FTOH (230µg/kg) and 10:2 FTOH (310µg/kg). It is unclear whether these substances were present as impurities or degradation products but note that both fall within the definition of PFOA-related substances under the Stockholm Convention and REACH Regulation.

    - Composite materials. UBA (2020) comment that use of fluoropolymers, particularly PTFE and ETFE are used within composite building materials such as moulded components for facias and roofing. They are also used as thin film technology for membranes and some coating applications. UBA (2020) notes that the manufacture of PTFE and ETFE can make use of non-polymeric PFASs as processing aids with residual contamination in the final polymer. The sampling campaign included nine fluoropolymer thin film ‘foils’ used in construction. The results detected non-polymeric PFASs in all samples, primarily PFCAs, with perfluorobutanoic acid (PFBA) being detected the most frequently. FTOHs were not detected in these samples, although both PFOA and PFOS were identified. Again, these substances could be either impurities or degradation products of processing aids for fluoropolymer production. It should be noted that this likely refers to fluorinated emulsifier/fluorinated polymerisation aids (PAs) used in the polymerization process of some fluoropolymers and not (polymeric) processing additives (PAAs).

- NEA (2017)[46] comment on the use of fluoro co-polymers within mixtures for paints and coatings. In particular the study report from NEA (2017) refers to the product FC-4430 which includes acrylate-based co-polymers as a major ingredient. NEA (2017) comments that N-methyl perfluorobutanesulfonamido ethanol (MeFBSE) (CAS 34454-97-2), N-Methyl perfluorobutanesulfonamide (MeFBSA) (CAS 68298-12-4), and N-Methyl perfluorobutanesulfonamidoethyl methacrylate (MeFBSAC) (CAS 67584-55-8) may be present at low levels <1% w.w., as residuals or impurities of acrylate-based co-polymer.

- As noted above, PTFE is one of the main polymeric PFAS used in construction products. Historically PFOA has been used as a fluorinated emulsifier/fluorinated polymerisation aid (PA) in the manufacture of some types of PTFE (fine powder and dispersion), with much of the PTFE production taking place outside of the EU (Wang et al, 2014). Wang et al. (2014) estimated that residual concentrations of PFOA could be as much as 2% w.w of PTFE produced (equivalent to 20 g/kg). As the use of PFOA as a PA was phased out due to voluntary agreements and international regulation other fluorinated PAs is now used for polymerisation of fine powder and dispersion PTFE.

- Micro-powder PTFE is used as additives in construction product articles made of thermoplastics, thermosetting plastics and elastomers and also in construction product mixtures such as paints and coatings. Micro-powder PTFE can be manufactured by direct (dispersion) polymerisation (approx. 15%) or it can be produced by thermal or irradiation degradation of high-MW PTFE resin (approx. 85%). The high-MW PTFE resin can be manufactured by both suspension (granular) and dispersion (fine powder and dispersion) polymerisation and the resin can be both virgin and re-cycled PTFE resin. Essentially all commercial irradiation of PTFE for use as an additive is carried out in air.

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[45] UBA, 2020, ‘Potential SVHCs in environment and products: measurements of the presence of potential substances of very high concern in the environment and in products’, Report 114/2020

[46] NEA, (2017), ‘Investigation of sources to PFBS in the environment’, Report number M-759/2017

This process results in the development of carboxylic acid (including PFOA and longer chain PFCAs) and acid fluoride end-groups in the degraded resin. PFOA will subsequently have to be removed as the EU POPs Regulation (EU 2019/1021) does has a time limited derogation for the presence of PFOA within micro-powders PTFE set at 1mg/kg (equivalent to 1ppm).

Beyond literature sources, only very limited data on degradation and impurities has been identified through the stakeholder engagement, which is briefly summarised below:

- Respondents to the CfE comment that PFOA residuals within PTFE are expected to be compliant with the REACH restriction threshold value of 25ppb, with PFOA and longer chain PFCA residuals below the 1,000 ppb threshold (also in the REACH restriction).
- One respondent highlighted that the manufacture of ETFE can contain PFHxA as a residual contaminant with a maximum working concentration of 0.4 mg/kg of ETFE.
- For micro-powder PTFE the following comments were received during CfE:
  - *"PFOA (source PTFE micropowder): Our suppliers specify <25 ppb or <1,000 ppb, depending on material type. A program is running to use only materials purified to < 25 ppb until 2021. No other PFAS impurities known."*
  - *"Perfluoroalkyl acids which are included in PTFE micropowders produced by ionising irradiation or by thermal degradation, less than 1 ppm"*
  - *"PTFE micro powders made by a thermal or ionizing radiation degradation process results in incidental impurities such as PFOA. Such impurities have been subject to safe removal using currently available technology to ensure the PTFE micro powders are in compliance with Commission Delegated Regulation (EU) 2020/784, amending Annex I to Regulation (EU) 2019/1021 of the EU Parliament and of the Council."*

2.2.3 Alternatives identified

Very limited data was provided on alternatives for the construction products (both articles and surface coatings) through the CfE. At the time Perfluorooctanesulfonic acid (PFOS) was added to the Stockholm Convention in 2009 (Under Annex B – restriction) approximately 20 specific exemptions were included with the listing. The Persistent Organic Pollutants Review Committee (POPRC) agreed to undertake a review of alternatives (reported in the information document UNEP/POPS/POPRC.14/INF/8 in 2018), which while largely includes other PFASs, does identify some non-fluorinated alternatives. The dossier from POPRC has been used alongside the Annex XV dossier for PFHxS and PFHxA and a brief literature search to supplement the CfE responses further.

2.2.3.1 Construction products – articles

PFAS-based construction articles covers a wide range of specific components used within infrastructure, such as moulded plastics, as well as membranes, and films with expected service lives of up to 25 years.

For PFASs used as processing aids in the production of construction products, such as architectural membranes, several alternatives have been considered, although they cannot be presented due to confidentiality. These alternatives are all considered to "each have trade-offs in performance" and were deemed during the 20-year development of the process in question as not feasible economically or not feasible due to a lack of chemical stability and flame retardancy. In the 2nd Stakeholder consultation the following comments on alternatives to PFASs in articles were received:

- There might be an alternative, e.g., the siloxanes. Though, silane chemistry is not very environmentally friendly. Currently, the fluoro elastomers can be used in food and non-food applications as these are highly chemically stable. Alternatives to be used are either made in an environmentally unfriendly way (silicones) or can be chemically decompose as the alternatives are not as stable as the fluorinated compounds.
- Fluoroelastomers (FKM, FFKM, FVMQ) are used for extreme chemical stress and/or high temperatures (>180°C). No other elastomer can be used at high temperatures.

- The enlisted alternative materials [for bridge bearings] cannot be used due to high friction of those materials. In this application injection moulded bearings made from other polymers were not successful because the technical requirements could not be met. Competitions is only among PTFE bearings. The only known alternative are steel rollers which are economically on a much higher level and require significantly more space in the constructions.
- Mono-material solutions ETFE foil/film, that is frequently used in membrane applications for roofs and facades, is fully recyclable and have a long service life (>40 years).
- A manufacturer of PFAS containing filaments and tapes responds that alternative products to those products in domestic and industrial natural gas fittings and connections such as hemp sealant will dry out in natural gas service and causes leaks (a safety risk).
- For less demanding applications, one possible alternative for thread sealing tape is tow, which use has been heavily restricted due to microbial development.
- Whilst this is not suitable for all our applications due to the upper temperature limit of the material and the corrosion resistance the use of UHMW-PE as an engineering plastic (with some similar characteristics as PTFE) or as a filler in other plastics may be beneficial to the phase out of PFASs in certain industries. It can also be considered useful in powdered form for use in lubrication and coating applications to increase lubrication and abrasion resistance in lieu of PFAS. Its use as a material in knee and hip replacements may provide evidence of its safety for human absorption. Please note that recent REACH proposals regarding microplastics may render this unsuitable as a replacement long term.
- There is uncertainty on the risk profile of some potential alternatives: to some extent, alternatives would show similar properties to fluoropolymers, mainly in terms of persistence (in order to have the same performance in terms of chemical and temperature resistance, inertness). The use of these potential alternatives could lead to regrettable substitution of existing fluoropolymers. Furthermore, substitution by less-suitable materials may lead to situations of risk to humans and the environment, due to lower performance leading to higher risk of equipment failure and releases of hazardous substances/materials from downstream users processes.
- Any of the alternatives [to PFASs in articles] are based on additives and/or impregnation of less stable polymers and materials. The named alternatives will potentially release more additives and substances to the environment during use than the fluoropolymer films will do. For example UV stabilization additives.
- Most potential alternatives present higher risk of exposure to hazardous substance, as they require the addition of chemical additives like flame retardant (mostly CMR1 or 2), UV and thermal stabilizers to compensate their low durability and flame retardancy in order to equal fluoropolymers.

The draft assessment on alternatives to PFOS under the Stockholm Convention (UNEP/POPS/POPRC.14/INF/8) (dated July 2018) comments on the use of PFOS in the production of moulded plastics and rubbers for a wide-range of applications (including construction products) but conceded the key alternative to PFOS at the time of publication was other shorter chain PFASs compounds, particularly PFBS.

The brief literature review revealed some potential alternatives for some of the main applications of PFAS in construction articles:

- Llorens (2015)[47] describes typically used materials for composite architectural membranes/structural membranes/tensile fabrics and their technical performance:
    - Cotton and other natural fibres: High UV resistance but in general low technical performance, but feasible for light-duty applications (service life of 4-5 years). A responded to the 2nd Stakeholder consultation for evidence informs, however, that this material is very flammable.
    - Polyamid (PA or nylon): High strength, stiffness and tenacity and low weight, but not dimensionally stable when wet, poor UV resistance and stretches considerably, therefore not commonly used for architecture.

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[47] J Llorens (Editor) (2015): Fabric Structures in Architecture, 1st Edition, Woodhead Publishing.

  - Polyester: Very commonly used in architecture. Good tensile strength and elasticity, but mechanical properties degrade with UV light, and it is subject to ageing. Can be coated with PVC to provide UV protection. A top coating is commonly applied on top of polyester/PVC. Both fluoropolymer and non-fluoropolymer based top coatings can be used. Fluoropolymers (e.g. PVDF) provide (further) UV resistance, durability and water/dirt resistance. The technical performance of the non-fluoropolymer top coatings is:
    - Acrylic lacquer: Poor UV resistance
    - PVF[48] film: UV resistance,
    durability and water/dirt resistance
    - Titanium dioxide (TiO2): UV resistance, hydrophobic (self-cleaning) and high light reflectance
  - Fiberglass: Very commonly used in architecture. High tensile strength (although decreasing when wet) and long lifetime, but brittle and low elastic strain. Can be coated with silicone to enhance properties such as UV resistance and water protection (not soil resistance). The translucency for silicone coated fiberglass can be as high as 25%.
  - Aramid (Kevlar, Twaron): High strength (except compressive strength), low weight, good abrasion/chemical/thermal resistance. Can degrade slowly from UV exposure. Can be coated with PVC or silicone to provide UV protection (only used when other materials are inadequate).
  - Carbon fibres: Less detail provided than on the other materials. Used for high-tech products, low expansion coefficient, non-combustible.
- Llorens (2015) also compared the technical performance of some of these materials with fluoropolymers (fiberglass coated with PTFE and pure PVDF fabric). Overall, the lifetime of polyester/PVC membranes with TiO_2 and fiberglass fabric coated with silicone appears to be shorter, than composite architectural membranes with a fluoropolymer based top coating and pure fluoropolymer membranes. Further, fiberglass fabric coated with silicone is considered to be more flexible than fiberglass fabric coated with PTFE, but will be less dirt/soil repellent.

- According to Green Science Policy Institute (2021)[49] liquid/paste pipe thread sealants without PFASs are available as alternatives for PTFE thread sealing tape for permanent seals. The report refers to a product called Hercules® Megaloc®.

- As potential alternatives to polymeric PFASs used as processing additives (PPAs) for production of non-PFAS polymers/plastics the literature review revealed that siloxane-based additives such as the thermoplastics additive series Multibase™ might be used.

2.2.3.2 Construction products – paints and coating mixtures

PFAS-based compounds have been added to paints to reduce surface tension (as a levelling agent for high precision applications) and as a dirt and oil repellent. Furthermore, fluoropolymers can be used as (part of) the binder or protection against harsh (environmental) conditions and provides chemical/corrosion resistance, durability, weather and UV resistance. The responses to the CfE identify some possible fluorine-free alternatives:

- Paints and coatings – possible alternatives to PFAS include polyurethane, polyester powder, wax emulsions, silicones/silanes/polysiloxanes, and hydrocarbon polymer technologies. Further details on technical and economic feasibility and availability were not provided, although some of these alternatives are also discussed in the literature (see below).

- Fluorosurfactants as coating additives (wetting agent): Hydrocarbon and silicone-based surfactants were identified as potential alternatives, although stakeholder input notes that they do not provide the same performance in terms of reducing surface tension and oil repellency.

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[48] Polyvinyl fluoride (PVF) is a polymer that is not covered by the OECD (2021) PFAS terminology

[49] BUILDING A BETTER WORLD, Eliminating Unnecessary PFAS in Building Materials. 2021 report by Green Science Policy Institute https://greensciencepolicy.org/docs/pfas-building-materials-2021.pdf

- Furthermore, OECD (2022)[50] comment that feedback from industry highlighted that with non-fluorinated alternatives, such as silica-based coatings and hydrocarbon polymers, it is necessary to use higher concentrations within the paint mixture compared to Fluorosurfactants. They are also expected to be less effective for certain functionality such as oil and dirt repellence. Although the feedback reported in OECD (2022) did also conceded that the main function of surfactants is to reduce surface tension for wetting and levelling.

The draft assessment on alternatives to PFOS under the Stockholm Convention (UNEP/POPS/POPRC.14/INF/8), further corroborates the possible alternatives identified in the call for evidence and provides some additional options:

- Sulfosuccinates, for example sodium salt of di-(2-ethylhexyl) sulfosuccinate dissolved in ethanol and water, are already used as an alternative in wood primers and inks. Di-(2-ethylhexyl) sulfosuccinate can also be used as an alternative mixed with silicone polymers, ethanol, and water.
- Propylated naphthalenes and propylated biphenyls, which can be used as water repelling agents for applications such as rust protection systems, marine paints, resins, printing inks and coatings in electrical applications.
- Fatty alcohol polyglycol ether sulphate, sometimes together with a sulfosuccinate. Note that this alternative was also identified by the Annex XV dossier for PFHxS under REACH.

Evonik offers a range of non-fluorinated wetting additives for coatings under the trade names TEGO®, SURFYNOL® and DYNOL™ based both on siloxanes (e.g. polyether siloxane copolymers, siloxane-based gemini surfactant or modified polyether siloxane) and hydrocarbon surfactants (e.g. non-ionic organic surfactants). with the following chemistries and technical performances (according to the manufacturer):

- Short chain, polyether-modified siloxanes reduce static surface tension, almost universal aids for difficult to wet and contaminated substrates in diverse areas of application including on capillary substrates such as wood, ability to customize properties such as compatibility, low foam and anti-cratering effects via polyether modification and siloxane chain length. A respondent to the 2nd stakeholder consultation comments that substitution to D4, D5 or D6 might be considered regrettable substitution. However, note that based on the safety data sheet for TEGO, SURFYNOL and DYNOL the D4 content is lower than the suggested maximum limit by ECHA.
- Low molecular weight polyether-modified siloxanes reduce the surface tension in waterborne systems more strongly than hydrocarbon-based surfactants or higher molecular weight polyether siloxanes, anti-cratering properties, can be used to improve wetting of wood substrates, can be used in spray paints, provides optimum atomization during application without affecting the slip characteristics of the dried finish.
- Siloxane multi-functional surfactants: combination of reduction in surface tension and defoaming properties, imparting good recoat properties.
- Alkoxylates (silicone and solvent-free): reduce dynamic surface tension which is particularly advantageous for printing inks (potentially less relevant in the context of construction products), foam inhibiting and degassing in waterborne coatings and printing inks, can be used to act as a deaerator and to wet pigments and promote flow.

Li et al. (2021)[51] describe the ongoing development of non-fluorinated superhydrophobic coatings as alternatives specifically to substitute PFAS components. They find that the addition of a polymeric matrix material (the binder) to hydrophobic nanoparticles (the filler) to produce spray-coated superhydrophobic surfaces can be used to address the challenge of optimising mechanical durability, as the rough asperities required for maintaining superhydrophobicity otherwise tend to be easily removed by abrasion. This technology could be a promising alternative to PFASs in coatings, although it still appears to be in development and its performance is not specifically compared to that of PFAS-based coatings.

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[50] OECD (2022) ‘per- and polyfluoroalkyl substances and alternatives in coatings, paints and varnishes – report on commercial availability and current uses’, Report prepared for the OECD 31 March 2021.

[51] Chao Li, Mathew Boban, Jeremy M. Beebe, Dorab E. Bhagwagar, Junying Liu, and Anish Tuteja (2021). Non-Fluorinated, Superhydrophobic Binder-Filler Coatings on Smooth Surfaces: Controlled Phase Separation of Particles to Enhance Mechanical Durability. Langmuir 2021, 37, 10, 3104–3112 Publication Date: March 5, 2021.

OECD (2022) comments that for architectural paints and powder coatings: The European paints and coatings market is largely dominated by non-fluorinated products (92% market share), with PFAS based paints and coatings holding a more niche role (8% market share). The Annex XV restriction proposal specifically highlights applications in architectural paints (although even here global penetration rate is 1% of the market share). For PFAS based paints and coatings used for these applications, the OECD (2022) comments that the most widely used substances are FEVE and PVDF. The OECD (2022), suggests that potential non-fluorinated alternatives are commercially available, including HDPE-based products that contain nano aluminium oxide and nano ceramic, PU, PVC, polyolefin and epoxy powders – described as cheaper than fluorinated and claimed higher performance in certain parameters (e.g. durability, scratch resistance) – but noted PTFE can still perform well at temperatures >200ºC – important factor for coating chemicals vessels in chemicals industry or for use in cables and wires.

However, despite the alternatives listed above, several stakeholders suggested that feasible of alternatives were not available in their view. Several consulted stakeholders elaborated that PFASs are typically more expensive than their alternatives for construction products, which has provided an incentive for industry to substitute PFASs with non-fluorinated alternatives in all applications where that is possible (although it should be noted that in applications where PFASs currently provide a superior performance for example in terms of durability elasticity and long term high temperature creep behaviour, this likely leads to savings over the full service life of the coated article as it needs to be replaced or maintained less frequently). Further detail on the time and costs to develop, test and implement alternatives, as well as on potential impacts of difference in performance is provided in Section 5.4.

The 2nd stakeholder consultation complements with the following comments on alternatives for PFASs in paints and coatings:

- Gloss retention is an important measureable indicator of weatherability. As the coatings weather, the surface becomes pitted and material is lost, causing the gloss values to be reduced. None of the alternatives have the required durability to meet demanding standards for maintenance of appearance. The best PFAS-free alternative lasts less than ¼ of the time in accelerated weathering tests.
- Alternatives are already used on the market. The Risk profile depends on the polymer class (polyester/polyurethane). The main alternative to PVDF is polymer based on hexahydrophthalic anhydride (HHPA).
- Eastman Chemical Company has commercially developed a polyester resin called Tetrashield. Pre-liminary studies showcase that Tetrashield protective resin systems perform comparably to FEVE regarding weather resistance and exceeds FEVE performance in other properties. Eastman explains that the resin is still undergoing further evaluation and testing to distribute externally. They inform that Tetrashield resins are currently approved in multiple regions, including the EU. Tetrashield is also mentioned in OECD (2022)
- A manufacturer of PFASs containing polymeric coating to gain sustainable long-term protection of buildings responds that the investigated alternatives cannot provide the same long-term effects (UV durability, oil repellency and breathability).
- Without mentioning specific alternatives, it was commented that: "*some alternatives for the PTFE waxes exist; they do not allow for like-for-like substitution. Their performance in forming processes and resistance against scratches will be affected. The use of these alternatives in coil coating paints would require extensive assessments to validate their performance.*". No other information on alternatives for the use of micro-powder PTFE as an additive in coil coating mixtures or other paints or coatings was identified.

2.3 Summary of key uncertainties and data gaps remaining

A wide range of substances have been identified as (potentially) being used in lubricants and construction products. Some substances identified in literature have not been identified by stakeholders (and vice-versa), so there is some uncertainty about whether these are (still) used in the EEA in reality.

On the other hand, there are probably further PFASs used that have not been identified. This could be the case particularly for substances (and their uses) that are considered commercially sensitive and strictly confidential.

In terms of alternatives to PFAS, for lubricants, a major uncertainty is associated with the fact that fluorinated lubricants can be used almost everywhere and the products on the market are rather diverse in order to meet specific requirements (including requirements under harsh conditions). This makes it difficult to assess applicability of alternatives more generally, as this might require a very detailed understanding of all of the underlying applications. In addition, stakeholder input on alternatives stems almost exclusively from industry, which means that the assessment of alternatives and their feasibility largely reflects industry positions. Literature describes a number of other/new lubricant substances/system, but often does not specify whether these alternatives could actually substitute PFASs in lubricants and in which applications.

For alternatives to PFASs in construction products, very limited data was provided from stakeholder consultation, and the input received regarding alternatives stems exclusively from industry. Literature on potential alternatives has been identified for some of the main applications but is not comprehensive. This means that likely not all potential alternatives have been identified and the assessment of their feasibility largely reflects industry positions.

3. Task 2: Market analysis

3.1 Lubricants

3.1.1 Information from literature

When the Joint Research Centre revised the Lubricants EU Ecolabel criteria they performed/ purchased a marked analyses of the total lubricant market (PFAS-based and non-PFAS-based). The results for 2014 and 2022 (forecast) can be seen in TABLE 5 and TABLE 6 below[52]. Increasing demand for engine oils, transmissions fluids, and gear oils in commercial and consumer automotives was expected to drive the global lubricants market growth from 2014 - 2022.

TABLE 5. Global lubricants demand by region in millions of tonnes in 2014 and 2022

	2014	2022
World	36.4	43.9
Europe	7.3	8.3
North America	7.6	8.6
Asia Pacific	15.3	19.4
Central & South America	2.5	3.2
Middle East & Africa	3.6	4.5

TABLE 6. Global lubricants demand in billions of US dollars by region in 2014 and 2022

	2014	2022
World	35.7	68.5
Europe	7.4	13.0
North America	7.6	13.6
Asia Pacific	14.9	30.8
Central & South America	2.6	5.1
Middle East & Africa	3.3	6.0

PFPE base oil

Rudnick (2020)[53] (chapter 11) estimated, based on the global production capacity for the four primary companies that manufacture PFPE oils (Chemours (US), Solvay Solexis (Italy), Daikin (Japan) and NOK (Japan)), that more than 1,000 tons is manufactured per year. Additionally, there are small manufactures of PFPEs, however, the production capacity of these companies are unknown. Most manufactures sell the PFPE oils or greases directly or through partners. In addition, PTFE oils are also sold to specialty lubricant suppliers who formulate their own lubricants and sell them under their own brand name. Rudnick (2020) expect growth in the use of PFPE-based lubricants; however, no percentage is given.

No literature tonnage data of production in or import of PFPE into the EEA have been identified.

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[52] Joint Research Centre (JRC) Revision of European Ecolabel Criteria for Lubricants, *Preliminary report*. December 2016. https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/contentype/product_group_documents/1581683740/Preliminary%20report%20EU%20Ecolabel%20Lubricants.pdf (page 44).

[53] Rudnick, Leslie R. Synthetics, Mineral Oils, and Bio-Based Lubricants: Chemistry and Technology (2020). Taylor & Francis.

Setral Chemie estimates that PFPE lubricants account for less than 0.015% of the total lubricant market. They despite the connection between price and volume for base oils in this way[54]:

PCTFE base oil

According to Rudnick (2020) (chapter 12.4) the active companies in the field of PCTFE-based lubricants are Halocarbon Products Corporation (US), Atochem SA (France), Daikin Industries Ltd. (Japan) and Gabriel Performance Products (US) (since January 2021 Huntsman). These companies all market PCTFE oils and some formulated lubricants (oil, greases and waxes) of which some contain performance-enhancing additives such as rust inhibitors or PTFE. Rudnick (2020) expect growth in the use of PCTFE-based lubricants both in near and long term, however, no percentage is given. No literature tonnage data of production in or import of PCTFE into the EEA have been identified.

Micro-powder PTFE as lubricant additive

Micro-powder PTFE have a number of applications including in inks, thermoplastics, elastomers, coatings and lubricants. According to Ebnesajjad & Morgan (2019) the following fluoropolymer manufactures provides micro-powder/low-MW PTFE powder additives: Asahi Glass, Central Glass, Daikin, Dyneon (part of 3M), Chemours and Solvay Solexis. Additionally, Clariant, Laurel Products, Micropowders Inc., Shamrock Technologies, Heroflon and Maflon obtain fluoropolymers (generally PTFE) from secondary sources and convert them into “micro-powder” products. Other second tier companies purchase micro-powder PTFE and prepare suspensions in liquid media. Besides that there are also many specialty lubricant formulators that uses micro-powder PTFE in their formulations. Important suppliers includes: Nye Lubricants, The Lubrizol Corporation, Castrol, Klueber Lubrication, Magnalube, and Cerflon Technologies (Ebnesajjad & Morgan, 2019).

In 2010, the global market for irradiated micro-powder PTFE was assumed to be approximately 7,000 – 10,000 tonnes per year according to Makuuchi & Cheng (2011). It should, however, be noted that this don’t take micro-powder PTFE produced by direct polymerisation or thermal degradation into account.
The total micro-powder PTFE volume for the EU is estimated to be 4,000 tonnes/year in the analysis of derogations in the PFOA and C9-C14 PFCA restrictions ECHA (2020)[55]. It should, however, be noted that this estimate is based on input from one stakeholder.

PFAS-based lubricant market

Based on data from fluoropolymer producers, Wood (2022)[56] provides quantities and sales values of fluoropolymers used in the EU in 2020, broken down into 9 different sectors. The total quantity of PFAS-based lubricants sold in the EEA for 2020 was estimated at 1,500 tonnes of fluoropolymers, valued at €30 million.

Based on the SPIN database, Glüge et al. (2020)[57] (base oils and additives) estimated that around 1,500 t of PFAS[58] were used in lubricants and greases in Sweden, Finland, Norway, and Denmark between 2000 and 2017. These

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[54] Setral Chemie GmbH: https://ecco-gleittechnik.de/PFPE2/en/#!

[55] ECHA (2020). Analysis of derogations included in the restrictions on the manufacture, placing on the market and use of perfluorocarboxylic acids (PFCAs), their salts and related substances and perfluorocarboxylic acid (PFOA), its salts and related substances https://echa.europa.eu/documents/10162/13555/report_pfcas_additional_derogation_en.pdf/527979b6-87ea-c9b7-a504-4ae2a4da73bf

[56] Wood (2022): Update of market data for the Socio-economic Analysis of the European Fluoropolymer Industry. Report for Plastics Europe. Report available at: https://fluoropolymers.plasticseurope.org/application/files/1216/5485/3500/Fluoropolymers_Market_Data_Update_-_Final_report_-_May_2022.pdf

[57] Glüge, Juliane & Scheringer, Martin & Cousins, Ian & DeWitt, Jamie & Goldenman, Gretta & Herzke, Dorte & Lohmann, Rainer & Ng, Carla & Trier, Xenia & Wang, Zhanyun. (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). 10.31224/osf.io/2eqac.

[58] Note that the definition of PFAS used in Glüge et al (2020) is largely consistent but not identical to the definition used for the present study. This may lead to differences in tonnages of PFAS identified in the uses in question. Glüge et al (2020) focuses on poly-

countries may not be representative of the rest of the EEA and use has likely evolved over the years, but as a high-level estimate of the potential magnitude of PFAS use in lubricant products, this data can be extrapolated to the EEA and an annual average calculated.

The four Nordic countries covered by the SPIN database account for about 5.2% of the EEA by population[59]. The period 2000-2017 covers 18 years. Extrapolating the tonnages estimated by Glüge et al (2020) using 5.2% (of EU population) it is possible calculate EU quantities, which can then further be divided by 18 (years) to yield an estimate of around 1,600 t of PFASs used in lubricants in the EEA per year on average.

Product examples

TABLE 7 lists PFAS-containing lubrication products with defined trade names identified in the CfE. PCTFE-based products has been added based on a quick internet search. The table demonstrates that a range of lubricant products are on the market to meet the various applications identified above. It should be noted that for most of the product series listed below there are 5, 10 or more different versions/grades of the product. In addition, there are likely many more products on the market. Ebnesajjad & Morgen (2019) e.g., mention that also Nye Lubricants, Lubrizol, Castrol, Magnalube and Cerflon supply fluorinated lubricants. It is generally not possible to obtain information about the PFAS concentration in the specific products. Reference is made to concentration ranges specified in Appendix 2 for various types of PFAS containing lubricants.

TABLE 7. Examples of lubricant products that contains PFASs referred to in the CfE (and updated PCTFE based products that was not reffered to in the CfE)

Supplier	Trade name	PFAS
PTFE containing lubricants		
Interflon	Interflon Fin Grease (and various other lubricants) https://interflon.com/products/interflon-fin-grease-aerosol	PTFE
Synco Chemical Corporation (SUPER LUBE)	SUPER LUBE (Multipurpose and Dri-Film) https://www.super-lube.com/super-lube-lock-manufacturer	PTFE
TECCEM	Fluoronox M 50/2 http://www.teccem.de/Teccem_lubricants.htm	PTFE
Kemitura	GLEITMO 985 http://www.kemitura.com/gleitmo-985/	PTFE
Jet-Lube	Seal-Guard™ https://www.jetlube.com/product/seal-guard-ecf-premium-thread-compound	PTFE

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meric PFAS with the –CF2– moiety and non-polymeric PFAS with the–CF2–CF2–moiety. This does not include non-polymeric substances that only contain a –CF3 or –CF2–moiety, with the exception of perfluoroalkylethers and per- and polyfluoroalkylether-based substances. For these two PFAS groups, substances with a –CF2OCF2– or –CF2OCFHCF2– moiety are also included.

[59] Calculated as: [Denmark (5.8 million) + Finland (5.5 million) + Norway (5.4 million) + Sweden (10.3 million)] / total EEA population (520.5 million) = 5.2%. Source for population figures: https://countryeconomy.com/countries/groups/european-economic-area

Chemours	DRYFILM HIGH-PERFORMANCE DRY LUBRICANTS https://www.chemours.com/en/brands-and-products/dryfilm/products	PTFE
Klüber Lubrication	UNISILKON https://www.klueber.com/global/en/products-service/lubricants/	PTFE
Henkel	BONDERITE L-GP OD EU ACHESON https://www.henkel-adhesives.com/uk/en/product/specialty-oils-_-lubricants/bonderite_l-gp_odeuacheson.html	PTFE
TEF-GEL™ PTY LTD	ULTRA TEF-GEL https://www.ultratef-gel.com/tef-gel/	PTFE
DuPont	DuPont™ 851G-214, 851G-221, 851G-224 and 851G-255 PTFE Topcoats https://www.dupont.com/products/molykote-industrial-lubricants.html	PTFE
Klüber Lubrication	Klüberalfa GR Y VAC 3 https://www.klueber.com/global/en/products-service/lubricants/	PTFE
PFPE containing lubricants		
Solvay	Fomblin® PFPE series https://www.solvay.com/en/brands/fomblin-pfpe-lubricants	PFPE
Klüber Lubrication	BARRIERTA series https://www.klueber.com/global/en/products-service/lubricants/	PFPE
Lubcon - LUBRICANT CONSULT GmbH	Ultratherm 2000 https://www.lubcon.com/en/products/vacuum-and-nuclear-industry/secondary-vacuum-pumps/ultratherm-2000/	PFPE
PTFE and/or PFPE containing lubricants		
Costenoble (European distributor)	OSIXO® OILS AND GREASES https://www.costenoble.de/osixo-oils-and-greases/?lang=en	PFPE and/or PFTE
DuPont	MOLYKOTE® series https://www.dupont.com/brands/molykote.html	PFPE and/or PFTE
Chemours (Krytox)	Krytox™ High-Performance Lubricants	PFPE and/or PFTE

	Several grades relevant for several sectors: https://www.krytox.com/en/products	
IKV Tribology	IKV ZAROX and FLUOR Oxygen Greases & Pastes http://www.ikvlubricants.com/grease-oxygen-greases-pastes	PFPE and PFTE
Unspecified PFAS content		
Dörken	DELTA-LUBE® (+ DELTA-SEAL and DELTA-PROTEKT, but unclear whether these are actually lubricants) https://www.doerkenusa.com/us/internal-area/data/product-profiles/product-details/?tx_ccproducts_ccproducts%5BproductProfile%5D=3078&tx_ccproducts_ccproducts%5Baction%5D=show&tx_ccproducts_ccproducts%5Bcontroller%5D=ProductProfile&cHash=f7e64377b84ace593ecc61d62243b8f3	PFAS content unclear
PCTFE lubricants		
Halocarbon	Halocarbon https://halocarbon.com/engineered-fluids/engineered-fluids-product-guide/	Low MW PCTFE as base oil Potential PFAS-based additives/thickener: micro-powder PTFE and high MW PCTFE
ARKEMA	VOLATLEF®	

The automotive sector is by many stakeholders mentioned as one of the main sectors of use. A specific input from the European Automotive Manufactures Association (ACEA) lists the following uses (although noting that more time than available would be needed to create a full overview):

- PFASs are used in the form of grease, to limit the thickness of gold plating on the electrical connectors; high and low temperature applications (turbocharger); bearings parts; greases during both manufacturing (high temperature and vacuum application in manufacturing) and operation; important for components through which air flows because odourless and low evaporation rate.
- Properties targeted: good material compatibility to elastomer, plastics; partially no wetting with capillary active materials (textiles, porous plastics); partly special lubricating effects.
- Used for safety-critical brake systems.
- Used as fill-for-life lubricant in small gearboxes (thermal management) / actuators / hydraulic cylinders (clutch systems) when high compatibility and high media resistance is required.
- Very low evaporation loss in the manufacturing of vacuum and waver and chip production necessary for automotive components

As already noted, and as evident from the above, the consultation activities have shown that this type of lubricants are used more or less 'everywhere' where mechanical and electromechanical parts need lubrication under conditions where the tribological properties of fluorinated lubricants are needed.

3.1.2 Information from stakeholder consultation

A call for evidence (CfE) as part of the Annex XV restriction proposal on PFASs[60] was carried out in the period May to July 2020. Targeted stakeholder consultation was also undertaken between November 2020 and February 2021. A second stakeholder consultation was carried out in the period July to October 2021.

The following represents estimates is based on various input from industry stakeholders during the above mentioned stakeholder consultations. The estimates is largely based on information from some PFAS suppliers and some lubricant producers who have estimated volumes for the EU based on their own volume and assumed share of the market:

- Micropowder PTFE additive: The total micropowder PTFE volume for the EU market by some stakeholder estimated to be 4,000 tonnes/year, see e.g., ECHA (2020)[61]. The fraction of this going to the lubricants market is by one lubricant manufacturer estimated to be in the order of 1,000 tonnes/year. A PTFE supplier estimates approximately 200 – 300 tonnes/year going into greases for automotive, construction machinery and aircraft applications and notes that the total volume going into lubricants is somewhat larger. Based on the above, the authors of this report conclude that the EU lubricants market is most likely between 800 and 1,200 tonnes PTFE/year.
- PFPE base oil: Based on references to market surveys, various stakeholders estimate that the global use of PFPEs for lubricants is in the range of 1,000 – 1,500 tonnes/year. It is also estimated that approximately 1/3 of these lubricants are formulated in the EU, which would give a volume of approximately 300 – 500 tonnes/year used for production in the EU. Two other stakeholders in the CfE estimate that the volume for production of lubricants in the EU is about 750 tonnes/year and 500 – 800 tonnes/year, respectively. One respondent to the 2nd stakeholder consultation estimated that the demand in Europe is less than 1 500 tonnes/year. Two other respondents estimated, based on a market analysis[62], that the 2020 EU market for PFPE lubricants is approximately 600 tonnes. Based on this input, the EU PFPE lubricants market could be between 300 and 800 tonnes PFPE/year.
- PCTFE base oil: No information on the tonnage of PCTFE oil or grease have been received.
- Fluorosilicone base oil: No information on the tonnage of fluorosilicone base oil have been received.
- Solvents and other additives than micro-powder PTFE: As will be evident from the following sections, PFAS-based solvents and additives other than micro-powder PTFE are to a minor extent applied in lubricants, and to some extent also in solvents for cleaning purposes. One lubricant manufacturer estimates the volumes used in the EU to be 85 tonnes/year of PFAS-based solvents and 1 tonne/year of PFAS-based additives other than micro-powder PTFE. Considering these estimates are from only one producer, the numbers given should be considered uncertain. To reflect this uncertainty, the following ranges are assumed: 70 - 150 tonnes/year of PFAS-based solvents and 1-10 tonnes/year of PFAS-based additives other than micro-powder PTFE.
- According to information received from an industry stakeholder, between 1,000 and 5,000 tonnes PFAS-based lubricants are produces in the EU per year. Note that this volume includes other components than PFASs.

No data has been identified to quantify in any detail the share between formulation, import and export of these lubricants, although one estimate is that about 90% of lubricants used in the EU are manufactured in the EU. This estimate has been challenged by one respondent to the second stakeholder consultation based on PFPE manufacturing

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[60] The Annex XV restriction proposal on PFASs was submitted to ECHA on the 7th January 2023.

[61] ECHA (2020). Analysis of derogations included in the restrictions on the manufacture, placing on the market and use of perfluorocarboxylic acids (PFCAs), their salts and related substances and perfluorocarboxylic acid (PFOA), its salts and related substances https://echa.europa.eu/documents/10162/13555/report_pfcas_additional_derogation_en.pdf/527979b6-87ea-c9b7-a504-4ae2a4da73bf

[62] MarketResearch.biz Global Perfluoropolyether Market by Product Type (PFPE Oil and PFPE Grease), by Application (Aerospace, Electronics, Chemicals, Others), By Region/Country – Global Forecast to 2027. https://marketresearch.biz/news/perfluoropolyether-market/

capacity. As can be seen in section 3.1.1. there is one major manufacture of PFPE-oil in EU (Solvay Solexis (Italy)). The stakeholder states that: "*In recent years, there has also been an uptick in the EU importation of PFPE base oils from emerging Chinese producers*".

Further it shall be noted that there is international trade in articles containing these lubricants (in cars, pumps, bearings, etc.). No quantitative data on these trade aspects have identified or received.

Concerning trends in use, limited information has been identified, but the following can be extracted from the stakeholder responses:

- Historically, the use of PFAS-based lubricants has been increasing in line with a general shift to synthetic lubricants.
- The demand for fluorinated lubricants is increasing. Estimates of between 1% and 15% increase per year have been suggested by PFAS suppliers and lubricant producers, with others suggesting a 5% increase between 2021 and 2030. There are obviously differences among the downstream use sectors applying these lubricants. Among sectors with certain increased demand, stakeholders point to applications delivering light-weight, efficient, and long-lasting technologies, including "Power to X" [63] and renewable energy solutions, as well as the automotive and aviation sector.

Some stakeholders note that the long-term effect of COVID-19 is not known but that it might affect future marked demands.

In terms of the relative market share of fluorinated lubricants to the total lubricants market, the following has been provided by stakeholders:

- The amounts/volumes of fluorinated lubricants account for less than 1% (some say <0.1 %) of the overall lubricants market[64]. As described in Section 3.1 one stakeholder estimates that PFPE lubricants account for less than 0.015% of the total lubricant market.
- In terms of turnover the fluorinated lubricants market account for about 20% (about EUR 300 million/year) of the overall EU lubricants market. Note that worldwide the percentage is estimated to be 14% equaling EUR 800-900 million/year of a total global lubricant market of about EUR 6.1 billion/year, according to input from stakeholders to the consultation.

This reflects the difference in price. One lubricant producer states the following: "*Fluorinated lubricants may cost the end-user 300-600 US Dollars/kg. Non-fluorinated lubricants have a purchase price of perhaps 15-40 US Dollars/kg and a little higher if one moves into a basic silicone grease.*"

3.2 Construction products

3.2.1 Information from literature

Based on data from fluoropolymer producers, Wood (2022) provides quantities and sales values of fluoropolymers used in the EU in 2020, broken down into nine different sectors. The main sector of relevance for construction products is "construction", for which 4,500 tonnes worth €90 million of fluoropolymer sales are reported. However, note, these estimates are not further disaggregated into construction products (such as architectural membranes) and coatings (such as paints). Therefore, further detail on how this 4,500 tonnes is distributed across the construction sector is not provided.

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[63] Converting surplus/renewable electrical power to energy containing materials such as ammonia, chemicals, fuels, hydrogen or methane.

[64] However, according to one stakeholder, this depends on whether all hydrocarbon and other organic-based fluids in use as lubricants are counted. For example, huge volumes are used as engine oils in cars and in the aircraft industry. If these are included in the denominator, the relative market share of fluorinated lubricants would only be a fraction of a %.

OECD, (2022)[65] further comment on a market analysis covering coatings, paints, and varnishes, where there is a clear split in usage types. Coatings, which includes cabling, wires, thin-film technologies for solar panels, and anti-reflective coatings are heavily dominated by fluoropolymers, particularly PTFE, PVDF and to a lesser degree FEVE, ETFE, FEP, and PFA. Paints, which included professional products for architecture and automotive applications, which include the use of fluoropolymers (for durability as protection against weathering and abrasion), but additionally include the use of side-chain fluoropolymers and non-polymeric PFASs as Fluorosurfactants for wetting and levelling. The side-chain fluoropolymers identified were largely based on chemistry with side chain lengths of below C6. The non-polymeric PFASs used in paints are commented to include substances based on PFBS as a levelling agent, and C6 fluorotelomer based substances as anti-blocking agents (i.e., they reduce the stickiness of paint mixtures).

The OECD (2022) report further clarifies that for use in cables and wire coatings, comments from their stakeholder consultations noted that Fluoropolymers made up a small percentage of the overall market share for cabling and wires, likely in the order of less than 10%, with approximately 90% of cabling and wires using non-fluorinated alternatives.

The OECD (2022) report also comments on coil coatings of steel or aluminium, often used in the construction industry (e.g., for use on metal roofs or building panels) – these applications are estimated to account for 90% of the coil coatings market – with an estimated worth between €500 – 600 million. Use of fluoropolymers for this market (including primarily PVDF and FEVE) estimated to be 9-12% of the overall coil coatings market in the EU.

Based on the SPIN database, Glüge et al. (2020)[66] estimated that around 1,500 t of PFAS[67] were used in building and construction in Sweden, Finland, Norway, and Denmark between 2000 and 2017. Additionally, a further 3,500 t of PFASs were used in paints and coatings for the same countries and timeframe, which within the current study are also included within the scope of construction.

The SPIN database does not give the full picture of the use of PFASs in these countries and the countries may not be representative of the rest of the EEA and use has likely evolved over the years, but as a high-level estimate of the potential magnitude of PFAS use in construction products, this data can be extrapolated to the EEA and an annual average calculated. The four Nordic countries covered by the SPIN database account for about 5.2% of the EEA population[68]. The period 2000-2017 covers 18 years. Extrapolating the tonnages estimated by Glüge et al (2020) using 5.2% (of EEA population) it is possible calculate EEA quantities, which can then further be divided by 18 (years) to yield an estimate of around 1,600 t of PFASs used in building and construction in the EEA per year on average; with a further 3,700 t of PFASs used in paints and coatings in the EEA per year on average. Total usage is estimated as 5,300 t per annum (1,600 t in construction + 3,700 t in paints and coatings).

It should be noted that official statistics on production and trade (e.g., Eurostat Prodcom or Comext data) are not sufficiently detailed to identify PFAS-based construction products. As polymers are exempt from registration under REACH, and a lot of PFAS-based construction products are based on polymeric PFAS, tonnage bands from ECHA's database of registered substances are also not useful in this case. Additionally, the CfE identifies approximately 20 non-polymeric PFASs in use, but with no tonnage data provided. This makes further analysis challenging. Further details from the literature review on the use of PFAS in construction includes:

Fluoropolymer films (including Architectural membranes etc.)

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[65] OECD (2022) 'per- and polyfluoroalkyl substances and alternatives in coatings, paints and varnishes – report on commercial availability and current uses', Report prepared for the OECD 31 March 2021.

[66] Glüge, Juliane & Scheringer, Martin & Cousins, Ian & DeWitt, Jamie & Goldenman, Gretta & Herzke, Dorte & Lohmann, Rainer & Ng, Carla & Trier, Xenia & Wang, Zhanyun. (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). 10.31224/osf.io/2eqac.

[67] Note that the definition of PFAS used in Glüge et al (2020) is largely consistent but not identical to the definition used for the present study. This may lead to differences in tonnages of PFAS identified in the uses in question. Glüge et al (2020) focuses on polymeric PFAS with the –CF2– moiety and non-polymeric PFAS with the–CF2–CF2–moiety. This does not include non-polymericsubstances that only contain a –CF3 or –CF2–moiety, with the exception of perfluoroalkylethers and per- and polyfluoroalkylether-based substances. For these two PFAS groups, substances with a –CF2OCF2– or –CF2OCFHCF2– moiety are also included.

[68] Calculated as: [Denmark (5.8 million) + Finland (5.5 million) + Norway (5.4 million) + Sweden (10.3 million)] / total EEA population (520.5 million) = 5.2%. Source for population figures: https://countryeconomy.com/countries/groups/european-economic-area

In a 2018 market report by Global Market Insights the total fluoropolymer films market size was over USD 1.5 billion, with projected gains close to 5% CAGR between 2016 and 2024 (construction, transportation, electrical & electronics, industrial processing, etc.). Specifically on fluoropolymer films in the construction products it says: “Construction segment held significant share in global fluorine-based organic polymer film market in 2016 and is likely to grow with CAGR close to 5%. Fluorine-based organic polymer film has been recognized for their applicability in various construction applications such as: water-repellent architectural fabrics, anti-graffiti coverings, fiberglass composite for structures, protection against extreme corrosion, fading, cracking, etc. The product demand will be attributed to their unique characteristics such as: flame retardancy, weatherability, thermal stability, etc. Construction sector will feature significant opportunities for fluoropolymers films in the wake of modernization of architectural practices by 2024”.

Fluoropolymer Additives (including paints and coatings)
In a 2019 market report by Global Market Insights[69] the total fluoropolymer additives market size (lubricants, paints & coatings, printing inks and thermoplastics) exceeded USD 1.2 billion in 2018 projected 6.3% CAGR between 2018 and 2025. Industry expects consumption at over 200 kilo tons by 2025. Specifically, on (micro-powder) PTFE additives it says: “*Polytetrafluoroethylene (PTFE) fluoropolymer additives market from coatings application may surpass USD 360 million by 2025 owing to the increasing investments in infrastructure development and growing demand for weather resistant, protective materials for exterior building parts. They provide superior corrosion and electrical resistance which enhance the exterior maintenance cost and non-reactivity towards several solvents & acids.*”

Fluorosurfactants (including wetting/levelling agents in paints and coatings)
In a market report by Global Market Insights[70] on fluorosurfactants it says: “*Fluorosurfactants market share has widespread applications such as industrial cleaners, paints & coatings, adhesives, electronics, waxes & polishes, firefighting, oilfields and specialty detergents. Paints & coatings is anticipated to be the fastest growing segment of the fluorosurfactants market size due to the huge demand of the product due to its superior wetting and levelling properties compared to other surfactants*”. It further says: “*The global paints & coatings industry is projected to reach USD 150 billion by 2024, growing at a moderate CAGR of nearly 3% in the forecast period. The product is an integral ingredient in paints & coatings manufacturing, hence any trend in this industry will have a direct influence on the product as well*”.

3.2.2 Information from stakeholder consultation

TABLE 8 provides total annual quantities by PFAS for the construction sector with the following strong caveats:

- The data provided through the CfE, supplemented by targeted stakeholder consultation and the 2nd stakeholder consultation likely does not cover all relevant users.
- The data gathered via the CfE is incomplete and structured in a fashion that makes analysis very challenging. Respondents have provided data identifying which PFASs are in use, and further data on specific named products including working concentrations for PFAS. However, it is possible for the same product to be used across multiple specific activities and even across major sectors (e.g., the same product may be used in construction and mining). Total quantities manufactured and imported has been provided by some respondents but as a headline number without disaggregation by use. This means it is not possible to apportion tonnages to uses even at the parent level (lubricants, construction products, surface coatings).
- Where data has been provided as ranges, the upper bounds have been used to quantify a ‘worst-case’ scenario.

Therefore, the data in TABLE 8 should be considered as indicative only; however, the table does provide some additional insight about suppliers, i.e., which companies have been reported to manufacture or import construction products containing specific polymeric / non-polymeric PFAS, or to manufacture or import the specific polymeric / non-polymeric PFASs for use in construction products.

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[69] Global Market Insights (2019): Fluoropolymer Additives Market Size By Product (Polytetrafluoroethylene Micropowders, Fluorinated Ethylene Propylene Micropowders, Perfluoroalkoxy Micropowders), By Application (Printing Inks, Coatings, Lubricants & Grease, Thermoplastics & Elastomers), Industry Analysis Report, Regional Outlook, Application Potential, Price Trends, Competitive Market Share & Forecast, 2019 – 2025. Report ID: GMI3236

[70] Global Market Insights: Fluorosurfactants Market Size, Industry Analysis Report, Regional Outlook, Application Development Potential, Price Trends, Competitive Market Share & Forecast, 2020 – 2026. Report ID: GMI1491

TABLE 8. Total tonnages of PFASs manufactured or imported into the EEA for use in the construction sector, based on the CfE* and targeted stakeholder consultation.

PFAS	PFASs in construction products manufactured in the EEA (tonnes)			PFASs in construction products imported into the EEA (tonnes)			Suppliers reported to manufacture/import PFAS containing construction products or PFASs for use in construction products
	Mid-value of range	Range	Number of respondents providing data	Mid-value of range	Range	Number of respondents providing data	
PTFE	3,950	1,715 – 6,185	9	148	60 - 235	4	Chemours, 3M, Trelleborg, HaloPolymers, AGC
ETFE	2,040	1,950 – 2,135	4	444	398 – 490	4	3M, Membrana, Solvay
PVDF	Confidential	Confidential	2	Confidential	Confidential	1	Chemours, 3M, Arkema, Solvay
PFA	75	65 – 85	3	Confidential	Confidential	1	3M, Solvay
FEP	Confidential	Confidential	2	-	-	-	Chemours, 3M
Acrylate based side chain fluoropolymer	26.6	13 – 40	4	-	-	-	Chemours, Daikin, Maflon, Wacker chemie AG
FKM / FFKM	8	1.2 – 15	5	-	-	-	DuPont, Fluorocarbon,
THV	Confidential	Confidential	1	-	-	-	3M
other non-polymeric PFAS	306	201 - 412	13	1	-	-	Solvay (sulfonic acids), Chemours (sulfonic acids), Gore (sulfonic acids + additives), Delta-seal (unclear – potentially resins), 3M (<C6 chemistry), Moeller (unknown – stone protection product), Confidential stakeholder (“C6 fluorosurfactant”)

In terms of tonnages by sub-use or application within the construction sector, comprehensive data was not available to provide a full breakdown. One fluoropolymer manufacturer provided an estimate of total market size of fluoropolymer-membranes for tents (it is assumed that "tents" in this case refers to applications of membranes for roofing and similar applications where tent-cloth like materials are applied, not only tents in the narrower sense). Some of these membranes, particularly non-woven membranes may be the same as are used in the textile sector, but the tonnages below reflect only those applied in architectural applications.

Additionally, the CfE identifies a set of non-polymeric PFASs in use for construction products, but data on tonnages is lacking. These substances are listed in TABLE 9 (below).

TABLE 9. Additional non-polymeric PFASs included in the substance identity where tonnage data was not provided.

Number	CAS number	Substance	Use identified
1	3709-71-5	1,1,1,2,3,4,5,5,5-Nonafluoro-4-(trifluoromethyl)pent-2-ene	Foam insulation additive used to reduce the foam cell size and thus the thermal conductivity of polyurethane and other rigid foam formulations (approx. 0.5% in final product)
2	1623-05-8	1,1,1,2,2,3,3-heptafluoro-3-[(trifluorovinyl)oxy]propane	Coatings (likely the use of perfluoropropylvinylether (PPVE) co-polymer with TFE to produce Perfluoroalkoxy-polymers (PFA). PFA can be used for e.g., cable & wires and coatings)
3	431-89-0	1,1,1,2,3,3,3-heptafluoropropane	HFC-227ea. Rigid and flexible piping and insulation products
4	406-58-6	1,1,1,3,3-pentafluorobutane	Rigid and flexible piping and insulation products. (HFC-365 can be used as foam blowing agent for e.g., PU foam)
5	EC 944-870-8	1,2-Bis[2-(1,1,2-trifluoro-2-heptafluoropropyloxy-ethylsulfany)-ethoxycarbonyl]-ethanesulfonate sodium salt	Coatings
6	422-05-9	2,2,3,3,3-pentafluoropropanol	Coatings
7	163702-07-6	Butane, 1,1,1,2,2,3,3,4,4-nonafluoro-4-methoxy-	No uses listed other than confirming use in construction products.
8	163702-05-4	Butane, 1-Ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro-	No uses listed other than confirming use in construction products.
9	34455-29-3	Carboxymethyldimethyl-3-[[3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propyl ammonium hydroxide	No uses listed other than confirming use in construction products.
10	402-31-3	1,3-Bis(trifluoromethyl)benzene	No uses listed other than confirming use in construction products.
11	34454-97-2	1-Butanesulfonamide, 1,1,2,2,3,3,4,4,4-nonafluoro-N-(2-hydroxyethyl)-N-methyl-	Coatings and sealants
12	356-24-1	Methyl heptafluorobutyrate	Coatings
13	1224429-82-6-	Phosphoric acid, mixed esters with 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctan-1-ol and polysubstituted alkane, mono and diammonium salt	No uses listed other than confirming use in construction products.
14	29420-49-3	Potassium 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulphonate	No uses listed other than confirming use in construction products.
15	29118-24-9	trans-1,3,3,3-Tetrafluoroprop-1-ene	No uses listed other than confirming use in construction products.
16	1472634-24-4	sulfotricarballylic acid tri[2-(2,2,3,3,3-pentafluoropropoxy)-1-(ethyl)-ethyl ester] sodium salt	Coatings
17	1704390-89-5	sulfotricarballylic acid tri[2-(2,2,3,3,4,4,4-heptafluorobutoxy)-1-(methyl)-ethyl ester] sodium salt	Coatings
18	-	Anionic Fluorinated Surfactant	Architectual coatings as corrosion protection.

19	-	Cationic fluorinated surfactants	Coatings
20	-	Fluorinated surfactants	Coatings

3.3 Summary of key uncertainties and data gaps remaining

The market data gathered via the CfE is incomplete and structured in a fashion that makes analysis very challenging. As an example, two key issues can be highlighted:

- Respondents have provided data identifying which PFASs are in use, and further data on specific named products including working concentrations for PFAS. However, it is possible for the same product to be used across multiple specific activities and even across major sectors (e.g., the same product may be used in construction and mining). Total quantities manufactured and imported has been provided by some respondents but as a headline number without disaggregation by use. This means it is not possible to apportion tonnages to uses even at the parent level (lubricants, construction products, surface coatings; see categorisation in Sections 3.1.1 and 3.2.1).
  One exception is that the confidential attachments to the CfE responses included an estimate of the amount of PTFE used in the EU for lubricants as well as a use share between sectors – however we believe the data was taken from an old market analysis which can probably not be cited.
- Many respondents have provided data as ranges and in some cases these ranges are very broad (e.g., “<1,000 tonnes” = 1 – 999 tonnes). Standard approaches can be applied to help us calculate quantities, but with many respondents using large ranges the estimates would be very uncertain.

Market data from the CfE and the targeted stakeholder consultation likely does not cover all relevant users, and sufficient information to extrapolate from the stakeholders that provided information (e.g., their market share) to the whole EEA market was not available. The market data from stakeholder consultation may also include some double counting (when different supply chain stages report tonnages for the same products), although this is likely less severe than the previous caveat. There are certain limitations in using data from the SPIN database to estimate tonnages of PFASs used:

- The database is based on data from the Product Registries of Norway, Sweden, Denmark and Finland and there are certain limitations to what needs to be notified[71] which means that not all construction products and lubricants (containing PFAS) will be notified. In addition, confidential information may not be included in the market figures derived from the SPIN database.
- Tonnage estimates from the SPIN database are extrapolated from the participating countries to the EEA as a whole, based on the assumption that PFAS use in lubricants and construction products per capita is the same across the EEA.

In general, no specific information on import and export of PFAS-based lubricants and construction products was identified.

For construction products specifically, sufficient data was not available to provide a breakdown of tonnages of PFASs used by sub-use or application.

A further uncertainty is associated with the definition of a 'lubricant use'. PFASs can be used for providing smooth and frictionless surfaces. Whether such applications shall be seen as lubricant use or coating/sealing use will impact the figures. There are some borderline cases between the classical understanding of a 'lubricant' and surfaces/coatings with low friction (where lubricant additives are added to the coating or the article matrix). From the call for evidence, it appears that different stakeholders have different views on this, and it is not clear how many of these types of uses are included in the estimated numbers.

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[71] For instance, Part 3 of the Executive Order setting out the notification duties for the Danish Product Registry (https://at.dk/en/regulations/executive-orders/special-duties-suppliers-1794/).

4. Task 3: Assessment of emissions

4.1 General approach

For this assessment, a basic source-flow model has been developed to make use of the data gathered and collated from the market analysis and substance identification. One key caveat here is that on a more general level a very large number of substances have been identified as being in use or potentially in use (around 40 substances for lubricants and 45-60 for construction products) with the quality of data available varying significantly across all substances identified. Therefore, the approach taken has not tried to develop estimates on a substance-by-substance basis, but rather taken a grouping approach. Where availability of data varies significantly on a substance-by-substance basis a key benefit of using a grouping approach is that impacts of varying specific substance data are lessened. The trade-off of using such an approach is that it means the estimates provided will have a higher uncertainty attached to them overall. However, this approach can still provide useful data to estimate the orders of magnitude for emissions when comparing PFAS groups and different sectors.

Therefore, the emission characterisation used in this section has been developed to answer three key questions:

- What are the magnitude of the estimated emissions by different PFAS groups for lubricants and construction products?
- What are the key life-cycle stages for emissions?
- What are the key receiving environments (air, land, and water) for emissions?

The estimates provided will help answer these questions and act as a guide as to the key groups and points of release (both in terms of life-cycle stage and receiving environment). The key caveat being that the estimates included in this section should be treated as indicative orders of magnitude and not definitive estimates to the nearest tonne.

As discussed previously, this report focuses on the use of PFASs in lubricants and construction products. The manufacturing of PFASs has not been considered.

4.2 Lubricants

4.2.1 PFAS groupings

Based on the data gathered from the CfE, stakeholder engagement, and market research, the identified PFASs and PFAS groups (see Section 3.1.2) have been categorised into five main groups:

- Polytetrafluoroethylene (PTFE) as solid additive
- Perfluoropolyethers (PFPEs) as base oil
- Polychlorotrifluoroethylene (PCTFE) as base oil
- PFAS-based solvents
- Other PFAS-based additives than PTFE

PTFE is the single highest volume use of a PFASs within lubricants. As a more general rule PTFE comes in two primary forms, firstly as a granular (high molecular-weight) product, and secondly as a micro-powder (low molecular-weight) product. The CfE identified the use of granular PTFE in single-phase systems as a coating (e.g., PTFE tape and membranes) to produce low-friction surfaces, particularly important for moving parts. These coatings will be covered under other aspects of the REACH Annex XV dossier (e.g., see construction products). On that basis all PTFE used within lubricants will be the micro-powder form as described in section 2.1. The market data estimated that between 800 and 1,200 tonnes are used per annum in the EEA for lubricants. Where the EU is currently preparing a restriction for intentionally added microplastics[72], it is likely that PTFE micro-powder will fall into the definition for microplastics, and therefore should be further disaggregated within this dossier (particularly for consumer uses). The

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[72] https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366

data provided by the CfE in most cases does not disaggregate between consumer and non-consumer uses of micro-powder PTFE. However, based on the stakeholder interviews, a broad assumption has been applied to partition the use of PTFE micro-powder as 7% in consumer applications (equivalent to 84 tonnes per annum) and 93% non-consumer applications (equivalent to 1,116 tonnes per annum).

PFPEs are a group of polymeric PFASs, with Task 1 identifying 13 known substances in use for lubricants. PFPEs are primarily used as base oils, with secondary use as additives. Based on the market surveys and stakeholder feedback in the CfE, the total estimated quantities in use range from 300 – 800 tonnes per annum in the EEA.

PCTFE. Literature (Rudnick (2020)) identifies the use of PCTFE also within base oils to provide a similar functionality as PFPEs. However, no further data has been reported on tonnages or proportionality of use between PFPEs and PCTFE. It has not been possible to provide calculations for emissions of PCTFE within the dossier, although given their use, it can be postulated that the same key life-cycle stages, and pathways to environment as PFPEs will apply.

PFAS-based solvents (with 12 substances identified in Task 1) covers a range of non-polymeric PFASs of varying chain length and including both linear and cyclic substances. Notably this includes a number of perfluoro alkyl ethers (the non-polymeric form of PFPEs) and perfluoroalkanes covering both shorter chain (butanes, pentanes, hexanes) and longer chains (decane and perfluoro compounds up to C18). The combined use of these substances is in the range of 70-150 tonnes per annum in the EEA. The targeted stakeholder interviews explored the use of PFAS-based solvents further with two primary forms of application. Firstly, non-polymeric PFAS-based solvents can be used within lubricating applications (as carriers/deposition solvents) where the PFASs is intended to evaporate leaving a solid lubricant in place which provides the lubricating properties. In industrial uses these kinds of applications are used in closed systems to capture and re-use the PFAS. Secondly, non-polymeric PFAS-based solvents can be used as a cleaning agent in relation to equipment lubricated with PFAS based lubricants. For this latter application it is less clear whether the non-polymeric PFAS-based solvents should be considered a cleaning agent or lubricant, as potentially both functions are important. In many cases the PFAS used can have more than one technical function which makes disaggregation into discrete uses challenging. For the current study those lubricants which also provide a cleaning function as a secondary technical function (i.e., its main role is to lubricate) are included in scope. Those uses where the primary use is as a cleaning agent or surfactant in cleaning agents (with added lubricating benefits) are out of scope and not included. It should be noted that no data has been identified to help disaggregate, and therefore an equal split has been applied, with the assumption that 35 - 75 tonnes per annum are used for lubricants as described above.

PFAS based additives, are the final category which can be added to other lubricants using PFAS as a base-oil to modify physical properties, or lubricants using non-PFAS base-oils. Task 1 identified a total of 13 individual substancess, covering the most diverse set of substances within the categorisation. This group includes fluorosilicones and silanes, inorganic salts of fluorochemicals, and reaction products of amine based fluorochemicals. Total use of these substances combined is between 1 and 10 tonnes per annum in the EU.

4.2.2 Major life-cycle stages covered

Based on the data gathered and presented in section 3, four basic life-cycle stages are considered for use of PFAS based mixtures in lubricants. Note that the manufacture of PFASs used in lubricants (PFPEs, PCTFE, PTFE and PFAS-based solvents) has not been considered. Manufacture of micro-powder PTFE from PTFE resin by irradiation, thermal or plasma degradation has not been considered either. The four life-cycle stages included here are:

1. Formulation of lubricants (including manufacture of sealed articles). This phase covers the formulation to create lubricant products, and manufacture of articles containing lubricants. The data gathered from the CfE and stakeholder engagement highlighted that lubricants can be provided as single phase (100% PFAS) and multi-phase systems (mixtures containing PFAS). Physically they can be provided as oils, greases or other mixtures (e.g., solid/dry-film lubricant which is a solvent containing a solid additive such as micro-powder PTFE) dependent on the specific application. The data from the CfE highlighted that 95-97% of all PFAS-based lubricants are used within sealed articles, where lubrication is added once (at point of manufacture). Additionally, there are also applications where a total loss is assumed during use and need for re-lubrication at later stages of use (described under 3.). These applications make up a minor use of the overall PFAS application (3-5% of all lubricant use). Formulation will cover the emissions

associated with formulating lubricants (blending/mixing) and losses during filling / injection of lubricants into the manufacture of sealed articles.

2. In-use emissions from sealed articles. This life-cycle stage covers the release of PFASs from sealed articles during service life (e.g., leaks, faulty equipment, accidental releases). The applications from this life-cycle stage have been further disaggregated into:

- ‘outdoor’ applications (such as automotive,, industrial machinery hydraulic systems, diving equipment etc.) and
- ‘indoor’ applications (ovens, belts and chains, gears, industrial machinery used indoors, automotive uses (e.g., inside the body of a car can be considered indoor use), etc.).

This assumes that any release outdoors is lost directly to the environment, while indoors the more likely pathway is to wastewater systems.

3. In-use emissions from open applications. This life-cycle stage covers the smaller set of applications identified previously (3-5% of total use). The applications from this life-cycle stage have been further disaggregated into:

- ‘outdoor’ applications where a total loss to environment as part of the use is assumed (e.g., use of specialist dry-film lubrications for bike chains etc.). Here total loss to the environment is assumed.
- ‘indoor’ applications (mold release agents, re-lubrication of belts and chains etc.)

4. Waste-cycle. Although emissions during the waste-cycle are estimated separately in the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, this life-cycle stage will provide data on the quantity of PFASs consigned to different waste-cycle pathways (landfill, incineration, wastewater treatment plants). Some further commentary has also been provided to help guide what the emissions from these different pathways may look like (see FIGURE 1).

PFAS-based solvents for cleaning before lubrication is not included in the emission estimates. This is different from the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, were cleaning agents is included in the emission estimates even though they are not a part of the lubricants.

4.2.3 Key assumptions

Appendix 3 provides a summary set of tables for all the factors and assumptions applied within the model that manipulates the flow of substances from formulation to waste cycle, including emissions at different life-cycle stages. For the purposes of the emission estimates, the ECHA Environmental Release Category (ERC) has been used and the higher end of the tonnage ranges quoted has been used as a worst-case scenario. This is different from the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, where emissions is estimated as a low to high range in a one-compartment model. Furthermore, ERC9B are used in a slightly different way in the two emission estimates. In this report 5%, 5% and 5% is used for air, water and land respectively (three-compartment model) where as 10% is used in the one-compartment model in the Annex XV restriction proposal.

4.2.4 Emission estimates (baseline year)

The outputs of the source-flow model using the year 2020 as a baseline are provided in TABLE 10 and TABLE 11. Additionally, a material flow diagram for all PFASs combined is provided in FIGURE 1. Based on the assumptions used within the source-flow model total emissions are equivalent to approximately 13% of the total volume of PFASs in use, with the greatest emissions coming from micro-powder PTFE and PFPEs as the highest volume group by weight.

As a key point of interest, while the life-cycle stage with the highest emissions is ‘in-use’ sealed applications (likely from maintenance, faults, leaks, etc.), proportionately ‘in-use’ open applications are far more emissive. The model assumes that 95% of all PFAS use is within seal applications (compared to 5% within open applications). Based on these proportions the releases from ‘in use’ sealed applications make up around 8% of the total quantity in use for sealed articles. As comparison the release from open applications makes up around 70% of the total volume of PFAS used within open applications. The next biggest life-cycle stage for releases is during formulation.

In terms of receiving environmental compartment, the emissions are dominated by releases to air by a factor of four, with secondary importance evenly split between land and water. This recognises that the air compartment receives significantly greater emissions than water and land, likely during in-use.

The source-flow model does however hint at a more significant issue generally. The use of controlled systems during formulation and single application to sealed articles places significant onus on the waste-cycle stage of the life-cycle. As the assumptions highlight a significant proportion of applications are likely linked to electrical or electronic components, including transport applications. This suggests wastes that go via the WEEE Directive[73] or ELV Directive[74] pathway will be important. The sealed articles in question may form smaller components within larger articles / vehicles. Therefore, there may be a concern that such articles will pass through shredders without dismantling or recovery of the lubricant, which could represent a very significant emission source (greater than all other life-cycle components combined). As a further comment, non-electrical metal components lubricated by PFAS-based lubricants are likely to be recovered for recycling, where re-melt / smelting activities could act as an important step for the thermal destruction of PFAS. Estimates for these processes have not been provided as emissions from waste have been covered by a different component of the overall Annex XV dossier.

TABLE 10. Overview of estimated yearly EEA emissions for 2020 (baseline) by receiving environment – based on worst case scenario (high tonnage).

Group	Quantity in use in EEA (tonnes)	Emissions to air (tonnes)	Emissions to water (tonnes)	Emissions to land (tonnes)	Total Emissions (all vectors)[75] (Tonnes)
PTFE (Micro-powder) consumer applications	84	7.6	2.0	1.3	10.9
PTFE (Micro-powder) non-consumer applications	1,116	101.1	26.6	17.5	145.2
PFPEs	800	72.5	19.1	12.6	104.2
PFAS-Solvents (carriers/deposition solvents)	75	5.4	1.1	1.1	7.6
PFAS-additives	10	0.9	0.2	0.2	1.3

TABLE 11. Overview of estimated emissions for 2020 (baseline) by life-cycle stage

Group	Quantity in use EEA (tonnes)	Formulation All vectors (tonnes)	In-use (sealed articles) All vectors (tonnes)	In-use (open applications) All vectors (tonnes)	Total Emissions

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[75] There is a difference between total emission estimates in this report and the emission estimates in the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, since emission from PFAS-based cleaning agents is not in this report and since ERC9B is not used in the same way (see section 4.2.3)

[75] There is a difference between total emission estimates in this report and the emission estimates in the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, since emission from PFAS-based cleaning agents is not in this report and since ERC9B is not used in the same way (see section 4.2.3)

[75] There is a difference between total emission estimates in this report and the emission estimates in the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, since emission from PFAS-based cleaning agents is not in this report and since ERC9B is not used in the same way (see section 4.2.3)

					(all vectors)[76] (Tonnes)
PTFE (Micro-powder) consumer applications	84	2.0	6.1	2.8	10.9
PTFE (Micro-powder) non-consumer applications	1,116	26.6	81.0	37.6	145.2
PFPEs	800	19.1	58.1	27.0	104.2
PFAS-Solvents (carriers/deposition solvents)	75	1.9	5.7	0.0	7.6
PFAS- additives	10	0.3	0.7	0.3	1.3

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[76] There is a difference between total emission estimates in this report and the emission estimates in the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, since emission from PFAS-based cleaning agents is not in this report and since ERC9B is not used in the same way (see section 4.2.3)

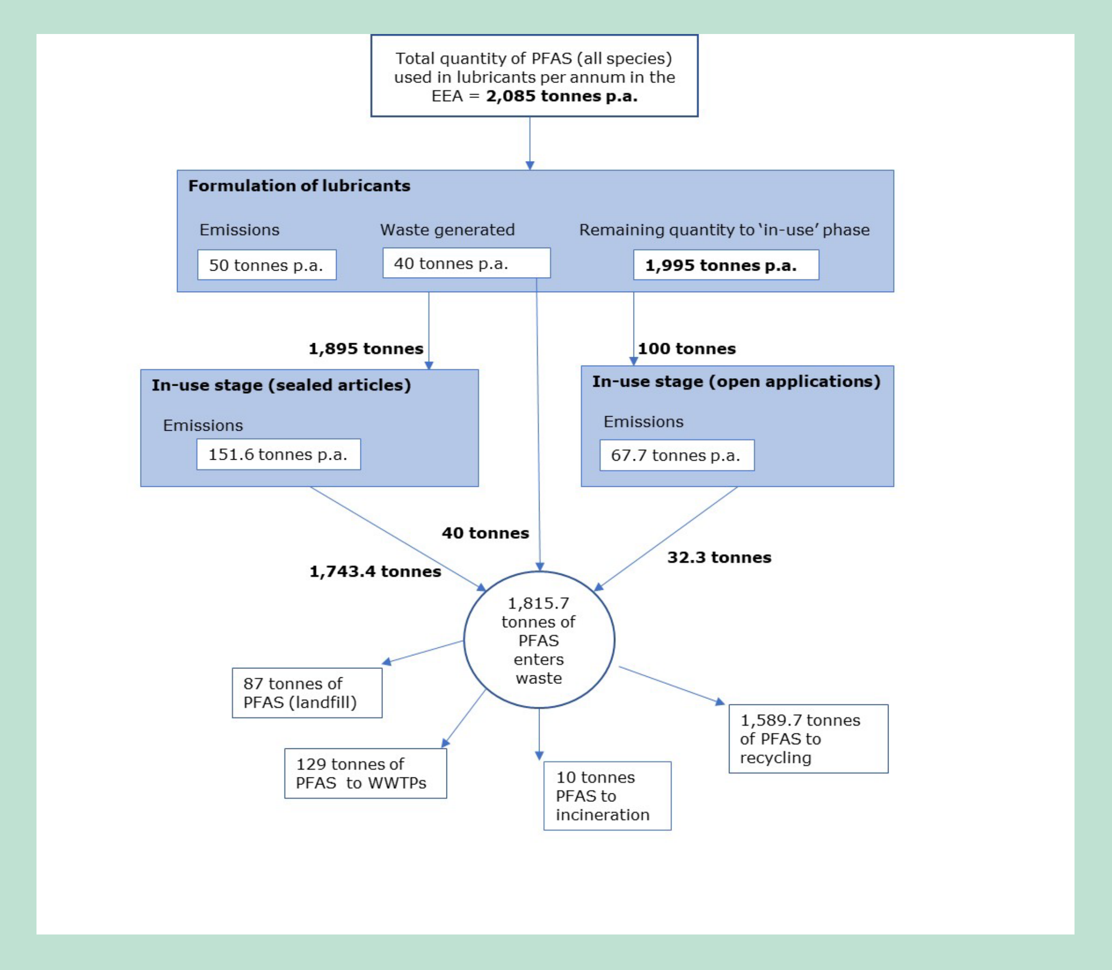

FIGURE 1. Overview of material flow for all PFAS used in lubricant applications.
Note: *) A precise estimates have been used/calculated in the source-flow model, but a wider range is presented here to protect potentially sensitive/confidential market information.

4.2.5 Emission estimates time-series

The previous section provided a set of emission estimates for PFAS based substances used as or in lubricants for the year 2020 using a source-flow approach to provide a baseline. This section further provides additional estimates to map trends covering the backward-looking time-series (1990-2020) as well as projections (2020-2050) for a business-as-usual scenario, assuming no restricted use of PFAS.

4.2.5.1 Approach for backward looking time-series (1990-2020) – Assumptions and caveats

In providing estimates for the historic timeseries some caveats need to be made clear. Firstly, data on previous use of PFASs in the lubricant sector is scarce. The data presented identifies PTFE as the principal PFAS used, in the past the manufacturing process for PFASs did include PFOA as a contaminant. Wang et al, 2014[77] comment that 70-85% of all PFOA use was in the production of PTFE, with residual PFOA present at a maximum of 2% w.w. PFOA has therefore been added as a sub-category to PTFE to make sure these emissions are presented. However, also note, that production processes for PTFE were modified in the mid-2000s, driven partly by the PFOA-stewardship program[78], with PFOA no longer used in PTFE production by the members of the PFOA-stewardship program after 2015. It is possible that PTFE imported into the EU after 2015 still contained trace quantities of PFOA as a contaminant, noting that the Stockholm Convention implemented a global level ban in 2019 (at Conference of the Parties 9). The EU POPs Regulation (EU 2019/1021) does also include an exemption for the presence of PFOA within PTFE

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[77] 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', Environmental international vol 60 pp242-248
[78] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program

micro-powders set at 1mg/kg (equivalent to 1ppm). Applying the 1ppm threshold to PTFE (all types) after 2015 equates to total emissions of PFOA in the orders of grams per annum (≤1kg) for the EEA. It is assumed therefore any emissions of PFOA in the 2020 baseline are negligible.

The transition away from PFOA as a fluorinated emulsifier/fluorinated polymerization aid in PTFE has seen it replaced by a range of other PFASs, as well as non-PFAS alternatives. Wang et al, 2013[79] provides some further comments on the main replacements produced by different manufacturers, this includes ADONA (produced by 3M/Dyneon), HFPO-DA (Chemours tradename Gen-X), cyclic or polymeric functionalized PFPEs (produced by Solvay), ammonium ethoxy perfluoro acetates (CAS 908020-52-0) (produced by Asahi), another PFPE functionalised compound produced by Chenguang in China (specific details retained as confidential), and the use of ammonium perfluorohexanoate (APFHx) by some manufacturers such as Daikin. Furthermore, the ITRC[80] also suggest that some PFBS based alternatives may have been developed and are currently in use. Both ADONA (1-10tonnes) and HFPO-DA (10-100tonnes) are registered under REACH, noting that HFPO-DA was also added to the candidate list of SVHCs in 2019. Further specific data on quantities of use, trace residues, and possible emissions of replacement fluorinated emulsifier/fluorinated polymerization aid has not been identified and therefore estimates have not been possible within the current model.

Secondly, the use of PTFE within lubricants has had two principal applications as a granular (high MW) single phase system for use in low-friction surfaces (which is assumed to be based on PTFE thin-film technologies) and as a micro-powder, which can provide lubricating properties on its own or as a thickening agent within PFAS base-oil to produce greases. PTFE micro-powder was first commercialised in the 1960s, with further evolution in production and growth in use increasing since that time to become the dominant form used within lubricants. Where there is a lack of data to help support the estimates, it is assumed that the starting quantity in use for 1990 was a total of 305tpa, with 20tpa used in consumer applications and 285tpa used for non-consumer applications. These estimated quantities maintain the ratio of consumer to non-consumer use seen in 2020 and are back calculated based on growth trends identified within market data. This assumes a 2% year on year growth between 2013 and 2020, 4% growth in 2012, and 6% growth year on year between 2002 and 2011, and a 5% growth year on year from 1990 to 2010.

Additionally, the EU is currently in the process of implementing a restriction on the intentional use of microplastics[81] with the combined opinion of the RAC and SEAC presented to the Commission in February 2021. The SEAC opinion[82] would suggest that some applications of PTFE micro-powders, that are believed to exist in the 0.25 - 500µm (0.5mm) range, fall well within the scope of the microplastic restriction. Further discussion on this issue is provided in the next sub-section on projections, but for the backward looking element it is assumed that demand for PTFE grew steadily from 1990 onwards without decline from anticipated regulatory actions (which is in line with industry stakeholder input that suggests substitution of PTFE lubricants has not previously been considered, see Section 5).

The EEA (2021) report comments that PFPEs are oily compounds with the inherent water and oil repellence which provides the low surface tension and therefore lubricating property. The oily nature of PFPEs lends itself to the wider application of synthetic oils for lubrication (including base oils), and hence why this family of PFASs in particularly are key to lubricating products.

Feedback from the stakeholder engagement with industry has highlighted a shift from organic based oils to synthetic oils. The market research report from Grand View Research (2020)[83] upholds this position with use of synthetic oils expected to grow by 5% annually between 2019 and 2025. Two respondents to the 2nd stakeholder consultation referred to a market analysis[84], which expects PFPE lubricant demand to grow by 4.1% between 2018 and 2027 (major applications: aerospace, electronics, chemicals and others (including automotive and food industry)). The industry

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[79] Wang et al, 2013, 'Fluorinated alternatives to long-chain perfluoroalkyl carboxylic acids (PFCAs), perfluoroalkane sulfonic acids (PFSAs) and their potential precursors', Environment International vol 60 pp242-248.

[80] https://pfas-1.itrcweb.org/2-4-pfas-reductions-and-alternative-pfas-formulations/

[81] https://echa.europa.eu/hot-topics/microplastics

[82] RAC and SEAC, 2020, 'Opinion on the Annex XV dossier proposing restrictions on intentionally added microplastics', Revision 5 – 10 December 2020. https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366

[83] https://www.grandviewresearch.com/industry-analysis/synthetic-lubricants-market

[84] MarketResearch.biz Global Perfluoropolyether Market by Product Type (PFPE Oil and PFPE Grease), by Application (Aerospace, Electronics, Chemicals, Others), By Region/Country – Global Forecast to 2027. https://marketresearch.biz/news/perfluoropolyether-market/

feedback estimated demand for fluorinated lubricants to increase at 1 – 15% per annum, suggesting that as a sub-set fluorinated lubricants may grow more strongly than synthetic lubricants overall.

For the backward-looking component of the estimates, it is assumed that there has been a more modest growth rate. A 1% growth year on year from 1990 to 2020 for PFPEs, PFAS-based solvents and PFAS-based additives.

4.2.5.2 Approach for projections (2020-2050) – Assumptions and caveats

As a general point regarding the development of emission projections it is important to recognise that prediction of future usage rates and technologies are very challenging and cannot consider 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 care and used only as indicative of possible usage rates and associated emissions.

In current context the usage and emission projections have been based on market trend data, feedback from industry stakeholders, and the impending restriction on microplastics only. The future projections do not include any consideration of changes in usage (increase, decrease or replacement) as a result of changes in technology. Nor do the projections provide any consideration for changes in abatement technology which may affect the emissions.

The previous sub-section highlighted that there is work currently ongoing to implement a restriction for the intentional use of microplastics, with the combined opinion of the RAC and SEAC submitted to the Commission in February 2021. Furthermore, ECHA indicate that a vote on the restriction will likely take place before the end of 2022. However, it is also indicated that there will likely be an exemption for use of micro-plastics at industrial sites, which makes up the largest fraction of current use. Feedback from the 2nd Stakeholder consultation suggested growth rates of 3% year on year for the coming years. Therefore, the projections assume for non-consumer uses of micro-powder a 3% year on year growth up to and including 2025, dropping to 2% year on year after that up to and including 2030, after which growth continues at 1% per annum to 2050. For consumer uses of micro-powder, it is assumed usage rates remain stable until 2023, after which the microplastics restriction sends use into decline, with final use in consumer applications reaching zero by 2030.

For PFPEs feedback from the 2nd stakeholder consultation suggests that there is a single manufacturer in the EU (Solvay Solexis, based in Italy), but in recent years there has been increasing imports from Chinese producers. Based on the CfE it is stated that growth of 5% between 2021 and 2030 is expected. However, the market research report by Grandview (see previous sub-section on backward trends) expects the demand for synthetic oils to grow by 5% annually between 2019 and 2025, suggesting that future growth may be more aggressive. The model therefore assumes a growth rate of 2.5% per annum between 2021 and 2030, after which all future growth falls to 1% per annum.

For non-polymeric PFASs (covering uses as carriers / deposition solvents and additives), less data is available, and therefore in lieu of better data a standard 1% year on year growth is used for all years across the projections.

4.2.5.3 PFAS estimated time-series for lubricants, including projections (1990-2050)

TABLE 12 and TABLE 13 provide the time-series for quantities of PFAS-based lubricants consumed across the EEA and EEA emissions, respectively, based on the assumptions set-out in the previous two sub-sections. FIGURE **1** also provides the aggregated emission estimates (air, land and water combined) as line graph. This illustrates that continued strong growth in synthetic oil-based lubricants and PFAS-based lubricants in particular have the potential to greatly increase emissions (particularly for PFPEs). FIGURE 2 also shows the trends for PTFE micropowders, with emissions growing rapidly in line with use. However, with the restriction on microplastics, the rates of use and consequently emissions begin to curb from the early 2020s, falling significantly after 2026 (the assumed year of implementation for the microplastic restriction) (for consumer uses only).

Again, as a further comment, it is stressed that these projections assume no further restriction of PFASs (beyond those already identified), and do not consider any changes in technology or improvements in emission abatement. Based on the Business as usual (BAU) scenario the aggregated emissions of PFAS for groupings would be expected to double annually by the end of the 2030s. These emission estimates assumes that current strong growth rate in consumption of PFAS-based lubricants (particularly micro-powder PTFE and PFPEs) continues to 2030, before slowing.

TABLE 12. Tonnages used in the EEA including projections for Business as usual (BAU)

Group	1990	2000	2010	2020 (base line)	2030 (BAU)	2040 (BAU)	2050 (BAU)
PTFE (micropowder) (consumer uses)	20	34	62	84	0	0	0
PTFE (micropowder) (non-consumer uses)	285	457	822	1,116	1,428	1,578	1,743
PFPEs	592	654	724	800	1009	1115	1231
PFAS-solvents	55	61	68	75	83	92	101
PFAS-additives	7	8	9	10	11	12	13

TABLE 13. Emissions in the EEA by vector (tonnes) including projections for BAU based on projections.

Group	Vector	1990	2000	2010	2020 (baseline)	2030 (BAU)	2040 (BAU)	2050 (BAU)
PTFE (micro powder) (consumer uses)	Air	2.0	3.1	5.6	7.6	0.0	0.0	0.0
	Land	0.3	0.5	1.0	1.3	0.0	0.0	0.0
	Water	0.5	0.8	1.5	2.0	0.0	0.0	0.0
PTFE (micropowder) (non-consumer uses)	Air	26.1	41.4	74.5	101.1	129.4	143.0	157.9
	Land	4.5	7.2	12.9	17.5	22.4	24.8	27.4
	Water	6.9	10.9	19.6	26.6	34.1	37.6	41.6
PFOA (as by-product of PTFE (all types)	Air	0.6	0.9	1.6	NEG	NEG	NEG	NEG
	Land	0.1	0.2	0.3	NEG	NEG	NEG	NEG
	Water	0.2	0.2	0.4	NEG	NEG	NEG	NEG
PFPEs	Air	53.6	59.3	65.6	72.5	91.4	101.0	111.6
	Land	9.3	10.3	11.4	12.6	15.8	17.5	19.3
	Water	14.1	15.6	17.3	19.1	24.1	26.6	29.4
PFAS-solvents	Air	4.0	4.5	4.9	5.5	6.0	6.7	7.4
	Land	0.8	0.9	1.0	1.1	1.2	1.3	1.5
	Water	0.8	0.9	1.0	1.1	1.2	1.3	1.4
PFAS-additives	Air	0.7	0.7	0.8	0.9	1.0	1.1	1.2
	Land	0.1	0.1	0.1	0.2	0.2	0.2	0.2
	Water	0.2	0.2	0.2	0.2	0.3	0.3	0.3

Note: NEG stands for negligible.

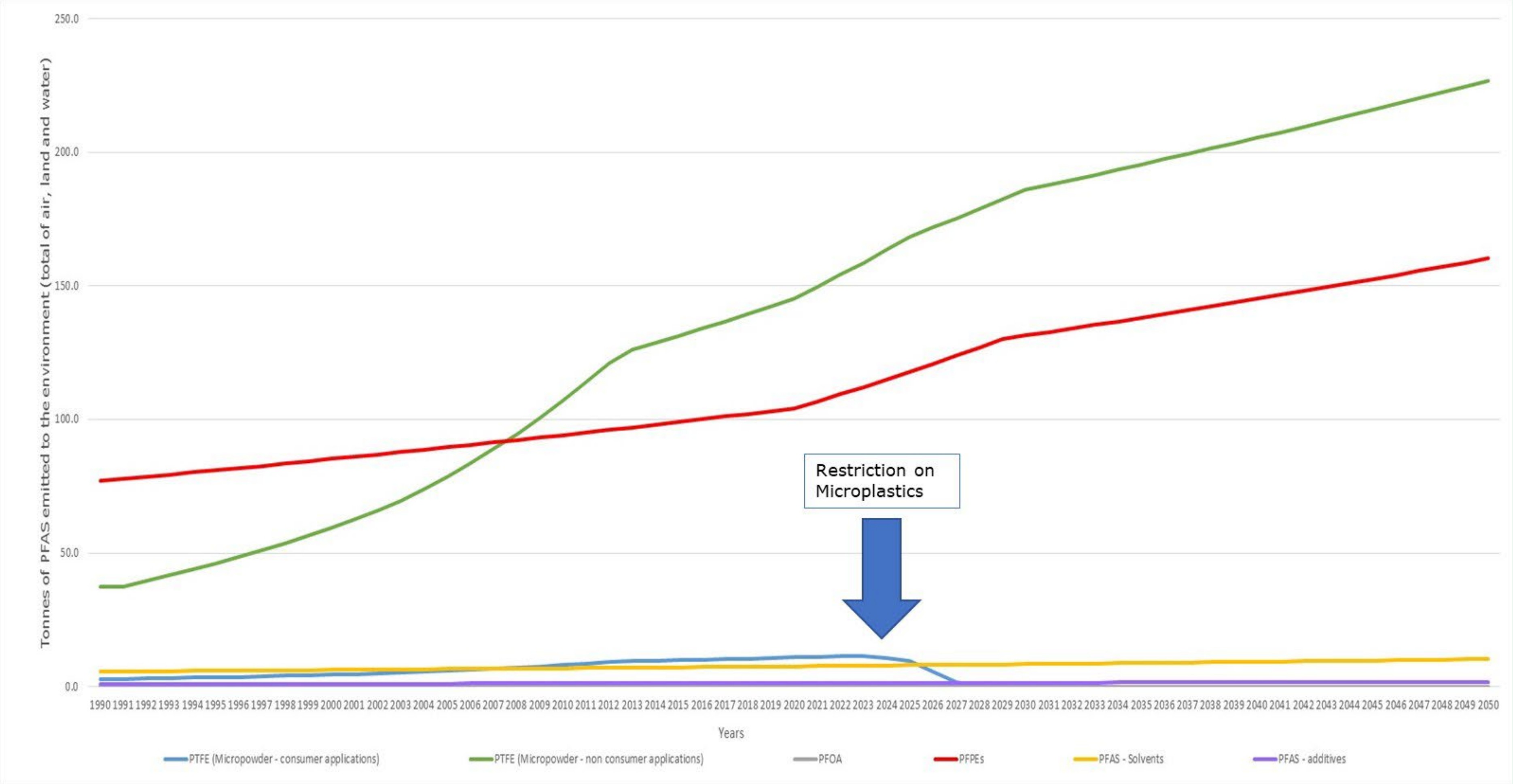

FIGURE 2. Estimated emissions aggregated total (all receiving environments) as time-series and projections (BAU)[85]

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[85] In the Annex XV restriction proposal that was submitted to ECHA on the 7th January 2023 only combined PFAS emission projections is provided (2020-2070).

4.3 Construction products

4.3.1 PFAS groupings

Based on the data gathered from the CfE, stakeholder engagement, and market research, the identified PFASs can broadly be categorised into two major groupings, covering polymeric PFASs and non-polymeric PFASs. However, it is possible to go further based on the CfE feedback in TABLE 3. This identifies the fluoropolymer PTFE as the overall dominant substance in use, something that was further backed-up through stakeholder interviews with industry. Along with PTFE, other major fluoropolymers in use include ETFE and PVDF. These three substances make-up 97% of the reported total usage of fluoropolymers in the construction sector. The remaining 3% covers a range of substances including fluoroelastomers such as FKM, FFKM and THV.

Polymeric PFAS

Within this section the fluoropolymer category has been divided into four major groupings:
- PTFE polytetrafluoroethylene (CAS 9002-84-0)
- ETFE ethylene tetrafluoroethylene (CAS 25038-71-5)
- PVDF polyvinylidene fluoride (CAS 24937-79-9)
- Other fluoropolymer substances

PTFE can be used as a high molecular-weight PTFE (high-MW) (which comes in the form of a granular product, a fine powder and a dispersion) and a low molecular-weight PTFE (low-MW) (which comes in the form of micro-powder only). Based on literature high MW (Jess and Wasserscheid, 2020)[86] and low MW PTFE (Ebnesajjad & Morgaaan, 2019) has the following applications:

- High MW (granular): Articles (45% mechanical applications (such as seals, pistons, rings, bearings, and cylinder tubes), 35% chemical processing (valves, pump linings, gaskets etc.), and 20% electrical applications (cable connectors, circuit breakers, coaxial cores, ribbon cables etc.).
- High MW (fine powder): 30% textile laminates, 28% automotive industry, 16% wires and cabling, and 15% tubing applications.
- High MW (dispersions): 40% film coatings of fabric for architectural purposes, 15% consumer and industrial coatings (cookware, conveyor belts, etc.), 15% PTFE fiber market, and 30% preparation of various items (e.g., metal and graphite parts in heat exchanges).
- Low MW (micro-powder): lubricants, paints, coatings, inks, and processing aids for plastics and rubber.

Mixtures: Further to the bullets above, a further review of publicly available data on the internet (including SDS) suggests that finepowder can also be used as a raw material in ‘melt processes’ to produced moulded products. A respondent to the 2nd stakeholder consultation has identified thermoplastics, elastomers, paints and coatings as main markets for micro-powder PTFE. However, insufficient data has been identified to help provide market splits. The current approach therefore simply refers to PTFE for use in articles (assuming that this covers all high MW forms) and PTFE micro-powder for use in paints and coatings.

Articles: The use of micro-powder within articles is more challenging to estimate. Due to its high molecular weight, PTFE molecules need to be broken down by specific processes.

Review of company websites and SDS have also identified limited data that suggests ETFE could also be used as a fine powder within construction mixtures. One website[87] suggests that coatings of ETFE as a fine powder to form layers (with a thickness of ≤1,000 µm). This means that ETFE fine powders would likely also fall within the range covered by the microplastic restriction. It should be noted, however, the restriction does include a derogation for use of

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[86] Jess and Wasserscheid, Chemical Technology. From Principles to Products. Second edition. 2020. ISBN: 978-3-527-34421-5 (page 802)

[87] https://www.fluorotec.com/materials/etfe/

micropowders at industrial sites under point 4a of the opinion[88]. It is therefore unclear how much of a limiting effect the restriction will have on ETFE directly.

The prevalence of fine powder ETFE use within the market has been challenging to estimate. A respondent to the 2nd stakeholder consultation explains this with ETFE- Fine Powder not used at a commercial grade, rather it is mostly used in sealant tape for water & gas pipes and electrical cables and not in construction as such. Therefore, the emission estimates here have assumed that ETFE used is of a grain size outside of the scope of the microplastics restriction.

Non-polymeric PFAS

For the non-polymeric substances, the picture is more complex with a wide range of substances identified as potentially being in use covering fluorotelomer alcohols, acrylates, methacrylates, alkanes, amines, and silanes. The dominant substances (based on frequency of respondents reporting its use) was a non-ionic PFAS for use as a processing aid. Another substance/group reported is perfluoro-1-butanesulfonyl fluoride (PBSF) and PBSF-related substances, which has applications, primarily as a surfactant and levelling agent for paints, but has also been identified as used in adhesives and sealants (tapes).

The lack of granularity for market data on specific named non-polymeric PFASs, means that in this section they are grouped together and simply referred to as non-polymeric PFASs (the list of non-polymeric PFASs which did not include tonnage data is provided in TABLE 9).

Discussion of estimated volumes of use of polymeric and non-polymeric PFAS:

The PFASs identified also broadly cover one of three major categories of use spanning the applications set-out in Section .2.2.1. This includes the following:

- Articles. This category broadly covers all of the applications under the parent level ‘construction products. In many cases the articles produced (such as pure PFAS architectural membranes or PTFE thread sealing tape) are 100% fluoropolymer manufactured through extrusion as a hot or cold process. Extruded fluoropolymer can also be manipulated or woven to form meshes, tapes, or other thin film technologies for use across a very wide range of applications. This includes the use with non-fluoro articles such as backing materials for foams used within insulation or cladding.
- Processing aids. This category broadly sits under the parent level for ‘construction products. In this case PFAS, primarily as non-polymeric PFASs is used as processing aids in the manufacture of either fluoropolymer articles or non-fluoropolymer articles. PFASs is used as processing aids in the production of these products but is not retained (intentionally) within the final products. Polymer processing additives (PPAs), used for the production of thermoplastics, thermosetting plastics and elastomers, is included in the resin and therefore becomes a part of the final article.
- Commercial construction mixtures. This category broadly covers the parent level for ‘surface coatings. This category covers blended liquid mixtures (including more viscous mixtures such as those covered by adhesives) which are either 100% PFAS or more commonly where PFASs is added to tailor the physical properties of the mixture or the final article to which it is added. A good example here would be paints, where PFASs can be as surfactants to aid spreading and levelling within specialised applications[89].

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[88] https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366

[89] Where PFAS has been reported as having a more substantial cost, the use of PFAS is expected to form a smaller specialised sub-section of the overall paints sector.

Summary for use in emission estimates

The use of polymeric and non-polymeric PFASs covers all three categories, although based on the data provided in the CfE there are some clear distinctions which are further outlined in Table 14 below. Note that in the case of processing aids this refers to use of PFASs to produce non-PFAS related articles, where the (non-polymeric) PFAS processing aid is used at one key stage of production and is not intentionally incorporated into the finished article. These use patterns have been used to help develop the source-flow approach appropriately.

Table 14 Summary of broad patterns of use for PFAS groupings and usage categories.

	Articles	Processing aids	Commercial construction mixtures
Polymeric PFAS	✓		✓
Non-polymeric PFAS	✓	✓	✓

Note that Glüge et al (2020) broadly estimates that the use of polymeric and non-polymeric PFASs in construction products (assumed to cover articles and processing aids) is broadly even by volume. However, for paints and coatings (covered by commercial construction mixtures) that approximately 95% by volume is made up of polymeric PFAS.

The data from the CfE and Glüge et al (2020) provide different estimates for volumes of use with a paucity of good market data making emission estimation challenging. The CfE (see TABLE 8) provides an upper estimate of PFAS consumption in the construction sector of around 7,000 tonnes per annum, largely dominated by PTFE (3,950 tonnes per annum). Noting that the estimates for non-polymeric PFASs are 200-400 tonnes per annum, despite Glüge et al (2020) commenting on broadly even usage of polymer and non-polymeric for construction and paints dominated by polymeric (estimated at 95% of the market), note the approximately 20 non-polymeric PFASs identified in the CfE where no tonnage data was provided (see TABLE 9).

Glüge et al (2020) goes on to estimate that the use of PFASs in construction was around 1,500 tonnes in total between 2000 – 2017 based on the SPIN database for Nordic countries (extrapolated as 1,600 tonnes per annum based on EEA population), a further 3,500 tonnes were used in paints and coatings between 2000 and 2017 (extrapolated as 3,700 tonnes per annum based on EEA population). This would equate to a total of 5,300 tonnes per annum (construction + paints).

In lieu of better data, the information provided by stakeholders has been used to estimate quantities of PTFE, ETFE, PVDF, other fluoropolymer, side chain fluorinated polymers and non-polymeric PFAS, which equates to approximately 7,000 tonnes per annum for construction products. However, Glüge et al (2020) highlights the importance of non-polymeric PFASs for construction (broadly, ratios of 50:50% for construction articles, and 95:5% for coatings in favour of polymeric PFAS). The response from stakeholders identified 200-400 tonnes of non-polymeric PFASs in use annually for construction and paints which represents a very significant gap.

To maintain continuity with the ratios identified by Glüge et al (2020), the quantities of polymeric PFASs in articles and paints from the CfE has been used to calculate the potential volume of non-polymeric PFASs which may be in use but has not been reported to the CfE. These calculations would equate to:

- PTFE assumed to be 4,098 tonnes consumed annually in the EEA (3,950 tonnes manufactured and 148 tonnes imported).
- ETFE assumed to be 2,484 tonnes consumed annually in the EEA (2,040 tonnes manufactured and 444 tonnes imported).
- PVDF assumed to be 554 tonnes consumed annually in the EEA (500 tonnes manufactured and 54 tonnes imported).
- Other fluoropolymer substances assumed to be 150 tonnes consumed annually in the EEA (manufacture only).

- Side chain fluorinated polymers assumed to be 30 tonnes consumed annually in the EEA (manufacture only).
- Non-polymeric PFASs assumed to be 1,670 tonnes consumed annually in the EEA

4.3.2 Major life-cycle stages covered

Based on the major use categories identified in the previous section, the following major life-cycle stages have been identified (covering production, use, and waste):

- Formulation. (Articles and commercial construction mixtures only). This life-cycle stage covers the first step for production of articles and commercial construction mixtures. Note that the manufacture of PFASs themselves are covered and the source-flow approach here assumes that PFASs have already been manufactured and supplied as a raw material in the next set of processes. The formulation stage (Type 1) will cover the extrusion and/or manipulation of fluoropolymers to form articles in form of meshes, membranes, tapes, thin film technologies, or other solid forms for use in construction. As a process this stage also covers the blending/mixing and formulation (Type 2) of commercial construction mixtures assuming that PFASs is introduced additively to achieve desired technical functions and physical properties.
- Processing aids. (Processing aids only). This stage covers the use of PFAS based processing aids in the manufacture of other articles, which may be either fluoropolymer based themselves or non-fluoropolymer. The processing aid is expected to be expended within this step to aid the formation of final articles but is not included (intentionally) in the final article. Those applications where PFASs is intended to still be present in the final article are covered by the formulation step above. Feedback from industry stakeholders as part of the CfE commented that capture systems are in place to retain and re-use the PFAS processing aid as many times as possible, with final spent processing aid sent for thermal destruction. As part of the production process, it is also possible for trace residues of PFASs to remain within finished articles. Further details on working concentrations for final articles has not been provided.
- Application. (Commercial construction mixtures only). This life-cycle stage covers the application of commercial construction mixtures. These applications can take place both indoors and outdoors, with the emission estimates apportioned accordingly. The mechanism of application for commercial construction mixtures can also vary widely (e.g., by spray, roller, cloth, brush, ‘dipping’, etc.). One stakeholder commented that mixtures containing PBFS or PBFS-related substances are used to treat glass panes and window-sills as a ‘dipping’ process. This provides the windowpane with water and dirt repellence which may have key specialist applications (e.g., high-rise buildings where cleaning the outside surface is challenging). Moreover, the OECD (2022) comments that PFAS-based surfactants are not commonly used in household paints, with uses limited to professional applications. Aside from paints (applied to surface layers), commercial construction mixtures will also include coatings as impregnation applications (e.g., on large public buildings for construction concrete, or domestic flooring to provide specific physical properties in the finishing step), and other uses such as adhesives and sealants which may be applied in a controlled and targeted fashion using small quantities (e.g., professional and DIY use) both indoors and outdoors. For consumer use of adhesives and sealants it is likely that the frequency of use annually is low, meaning that the greater concern for repeat exposure may lie within the professional user group.
- In-use phase (articles and commercial construction mixtures only). This stage covers the emissions from the in-use service life. Again, these uses can be split between outdoor and indoor applications. Primary emission for outdoor applications is likely to be through a combination of weathering and abrasion depending on the specific application. For emissions associated with indoor applications, the rate of emission is likely heavily influenced by the specific application. For example, architectural membranes used in roof spaces may lie undisturbed many months or years, with a single significant release during maintenance / removal. Conversely, coatings used on flooring may emit on a steady basis over the service life due to abrasion from footfall and cleaning activities. This makes applying emission factors at a high-level (i.e., all indoor articles) extremely challenging.

  For articles, this may include both use by professionals and DIY products used by consumers. It also means that use itself can be both within public buildings and domestic properties, which also affects the potential rates of emission, pathways, and exposure. No further efforts have been made to try and disaggregate between articles used in public and private buildings.

- Waste. (All categories). Although emissions during the waste-cycle are estimated separately in the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, this life-cycle stage will provide data on the quantity of PFAS consigned to different waste-cycle pathways (landfill, incineration, wastewater treatment plants). Some further commentary has also been provided to help guide what the emissions from these different pathways may look like.

4.3.3 Key assumptions

Appendix 3 provides tables of assumptions and factors used as a summary of all data within the model that manipulates the flow of substances from formulation to waste cycle, including emissions at different life-cycle stages. For the purposes of the emission estimates, the ECHA Environmental Release Category (ERC) has been used and the mean of the tonnage ranges quoted has been used. This is different from the Annex XV restriction proposal, that was submitted to ECHA on the 7th January 2023, where emissions is estimated as a low to high range in a one-compartment model.

4.3.4 Emission estimates (baseline year)

The outputs of the source-flow model using the year 2020 as a baseline are provided in TABLE 15 to TABLE 20. The first three tables (TABLE 15 to TABLE 17) provide the emission estimates by receiving environment for PFAS-based articles, processing aids, and commercial construction mixtures, respectively. For the processing aids and commercial construction mixtures the key receiving environment is the air compartment, although water and land are also significant secondary environments. For PFAS-based articles the key receiving environment is soil, likely linked to their use outdoors during service-life.

Emissions of PFASs are dominated by PTFE for articles, while non-polymeric PFAS emissions dominate the other two use categories. Further disaggregation of non-polymeric PFASs has not been attempted.

The second set of three tables (TABLE 18 to TABLE 20) provide details of the estimated emissions to environment (aggregated) by life-cycle stage for articles, processing aids, and commercial construction mixtures, respectively. The estimates show that for articles and processing aids emissions during manufacture are key, although the outdoor use of articles made from or containing PFASs are a key secondary stage. For commercial construction mixtures the single biggest emission stage is during the application of the mixture. As a caveat, the assumptions (see Appendix 3) make clear that the application stage in reality covers a very broad range of activities with the risk of release to environment varying by the specific type of application. However, uses that involve the application of mixtures (such as paints, adhesives, and sealants) outdoors in a wide or dispersive fashion are the greatest concern.

One further point that can be noted is that despite the high assumed tonnage for the use of non-polymeric PFAS based substances as processing aids (678 tonnes per annum), the overall emissions are comparatively low. This reflects the assumptions and feedback from industry stakeholders regarding how processing aids are used. This includes the assumption that the process does not (intentionally) form part of the finished article and capture systems or closed systems are in use to retain and re-use the PFASs as far as possible.

TABLE 15. Overview of estimated yearly EEA emissions for 2020 (baseline) by receiving environment for articles (based on mean tonnage values)

Group	Quantity in use in EEA (tonnes)	Emissions to air (tonnes)	Emissions to water (tonnes)	Emissions to land (tonnes)	Total Emissions (all vectors) (Tonnes)
PTFE (high MW)	760	7.7	6.0	6.7	20.4
ETFE	460	4.0	3.6	4.0	11.7
PVDF	103	1.0	0.8	0.9	2.7
All other fluoropolymers	28	0.3	0.2	0.3	0.8
All non-polymeric PFASs	678	7.1	5.4	6.0	18.5

TABLE 16. Overview of estimated yearly EEA emissions for 2020 (baseline) by receiving environment for processing aids (based on mean tonnage values)

Group	Quantity in use in EU (tonnes)	Emissions to air (tonnes)	Emissions to water (tonnes)	Emissions to land (tonnes)	Total Emissions (All vectors) (Tonnes)
All non-polymeric PFASs	678	0.3	0.0	0.02	0.32

TABLE 17. Overview of estimated yearly EEA emissions for 2020 (baseline) by receiving environment commercial construction mixtures (based on mean tonnage values)

Group	Quantity in use in EEA (tonnes)	Emissions to air (tonnes)	Emissions to water (tonnes)	Emissions to land (tonnes)	Total Emissions (all vectors) (Tonnes)
PTFE (low MW)	3,338	875.5	409.9	17.1	1,302.5
ETFE	2,024	526.7	250.1	10.4	787.3
PVDF	451	118.0	55.6	2.3	175.9
Side-chain polymer	30	7.9	3.6	0.0	11.5
All other fluoropolymers	122	32.1	15.0	0.6	47.7
All non-polymeric PFASs	314	82.4	38.5	1.6	122.5

TABLE 18. Overview of estimated yearly EEA emissions for 2020 (baseline) by life-cycle stage for articles (based on mean tonnage values)

Group	Quantity in use EEA (tonnes)	Formulation All vectors (tonnes)	In-use (Outdoors) All vectors (tonnes)	In-use (Indoors) All vectors (tonnes)	Total Emissions (all vectors) (Tonnes)
PTFE (high MW)	760	8.0	12.2	0.2	20.4
ETFE	460	4.2	7.4	0.1	11.7
PVDF	103	1.0	1.67	0.03	2.7
All other fluoropolymers	28	0.3	0.5	0.0	0.8
All non-polymeric PFASs	678	7.4	10.9	0.2	18.5

TABLE 19. Overview of estimated yearly EEA emissions for 2020 (baseline) by life-cycle stage for processing aids (based on mean tonnage values)

Group	Quantity in use EU (tonnes)	Use of processing aids (in manufacturing) (tonnes)	Total Emissions (All vectors) (Tonnes)
All non-polymeric PFASs	678	0.32	0.32

TABLE 20. Overview of estimated yearly EEA emissions for 2020 (baseline) by life-cycle stage commercial construction mixtures

Group	Quantity in use EEA (tonnes)	Formulation All vectors (tonnes)	Application All vectors	In-use (Outdoors) All vectors	In-use (Indoors) All vectors (tonnes)	Total Emissions (all vectors)

			(tonnes)	(tonnes)		(Tonnes)
PTFE (low MW)	3,338	80.8	1195.4	25.9	0.4	1,302.5
ETFE	2,024	41.7	729.5	15.9	0.2	787.3
PVDF	451	10.2	162.1	3.5	0.1	175.9
Side-chain polymers	30	0.8	10.7	0.00	0.00	11.5
All other fluoropolymers	122	3.0	43.7	1.0	NEG	47.7
All non-polymeric PFASs	314	7.9	112.1	2.4	0.1	122.5

FIGURE 3 and FIGURE 4 provide two further sets of illustrative diagrams to help present the emission estimates from the source-flow approach. FIGURE 3 provides a source-flow of emissions over across the life cycle for all fluoropolymer based PFASs (aggregated) and FIGURE 4 provides the counter-point flow chart for the non-polymeric PFASs used within construction products.

The two figures are intended to help further highlight the key points of release, which are during formulation for fluoropolymer substances and during application for non-polymeric PFASs. Again, this reflects the issues raised by Glüge et al (2020) in that non-polymeric PFASs are used much more heavily within paints and surface coatings, where the application stage represents a key risk for release.

The other key point to recognise from both Figures is the significant quantities of material that enter the waste phase. This includes both quantities committed to sewer and treated at wastewater treatment plants (based on the assumptions in the approach used), but also at the waste stage.

This is likely dominated by the articles that are either made of or include PFASs within their structure. Much of this material is likely to go via the construction waste pathway.

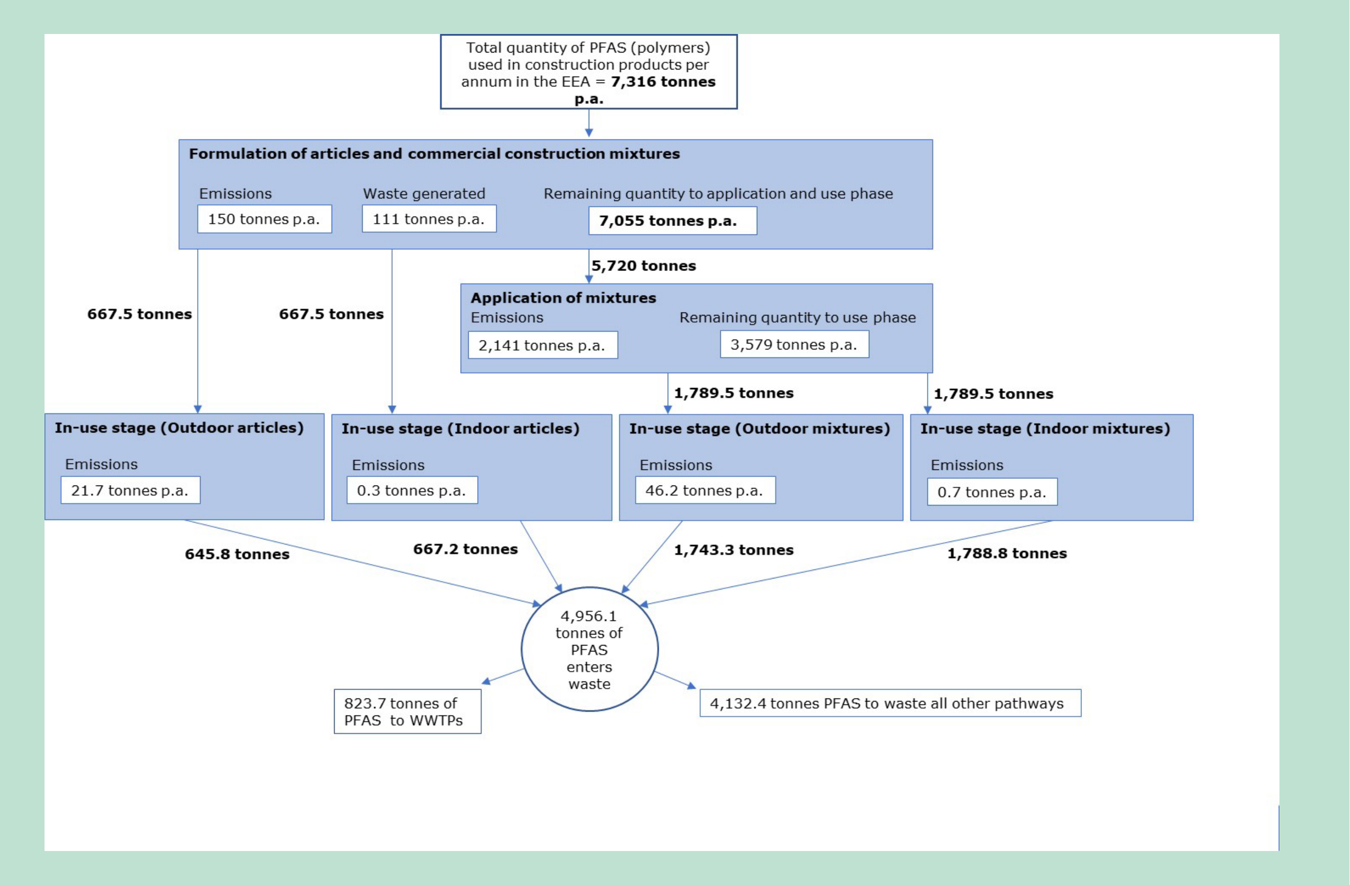

FIGURE 3. Overview of yearly EEA material flow for all polymeric PFASs used in construction products

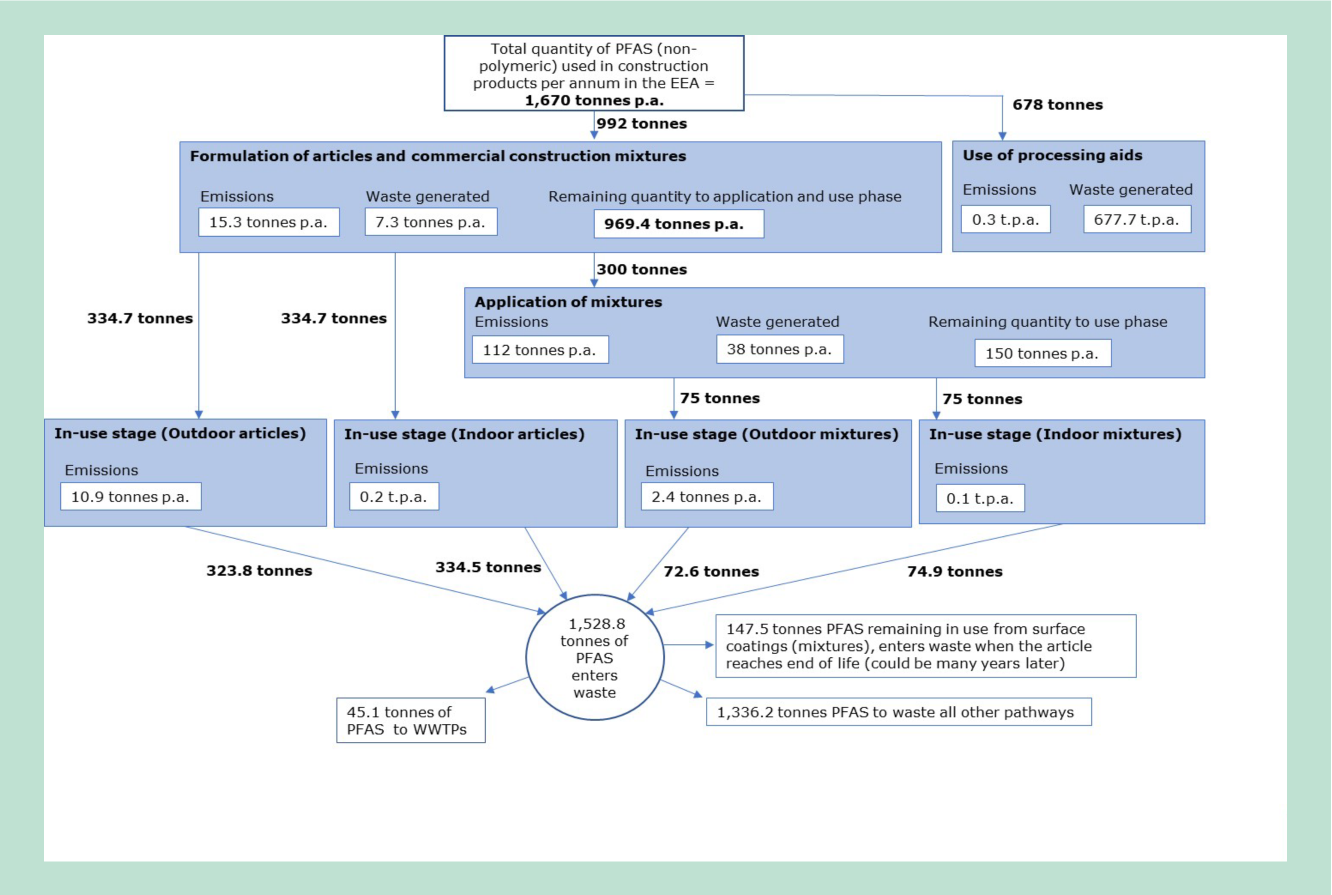

FIGURE 4. Overview of material flow for all non-polymeric PFASs used in construction products

4.3.5 Emission estimates time-series

The previous section provided a set of emission estimates for PFASs used in construction products for the year 2020 using a source-flow approach to provide a baseline. This section further provides additional estimates to map trends covering the backward-looking time-series (1990-2020) as well as projections (2020-2050) for a business-as-usual scenario, assuming no restricted use of PFAS.

4.3.5.1 Approach for backward looking time-series (1990-2020) – Assumptions and caveats

Firstly, developing estimates of historic use is challenging for PFASs given the high number of substances and broad range of specific applications (even when confined to building materials used within construction).

Data from Statista (2020)[90] suggests a strong growth in the demand for ETFE between 2014 and 2019, calculated at 8% per annum growth. This broadly mirrors the data for PTFE which suggests between 2019 and 2025 a growth of 5% per annum for both PTFE and PVDF, as quoted with Grand View Research (2020)[91]. Data for the other fluoropolymers has been more challenging to identify, while Wang et al (2014) comment the growth in PFOA and related Perfluorocarboxylic acids (PFCAs) was strong from the 1950s up until 2002, after which tighter regulations first on PFOS and then PFOA (and more recently PFHxS) suppressed the market between 2002 and the mid-2010s as industry look to transition away from C8 PFASs to alternative forms. Therefore, the backward-looking time-series makes the following assumptions:

- PTFE, growth 1990-2005 increases at 1% per annum. From 2005 – 2020, growth accelerates to 5% per annum, as the advent of PTFE micropowder accelerates potential use, particularly in mixtures.
- ETFE, growth 1990 – 2010 increases at 2% per annum as ETFE. 2010 – 2014 growth at 5% per annum. 2014 – 2020 growth at 8% per annum as indicated by the Statista (2020) reference.
- PVDF, growth 1990 – 2010 increases at 2% per annum as PVDF becomes a strong alternative to PTFE. 2010 to 2020 growth at 5%. The EEA (2020) report suggests that PVDF is one of the most rapidly growing fluoropolymers due to its hard wearing anti-abrasion properties.
- Other fluoropolymers, growth 1990 – 2020. In lieu of data assume growth of 1% per annum.
- Non-polymeric PFASs. Note that this covers a very wide range of substances. 1990 – 2002, assume growth of 3% broadly in line with inflation. Assume growth between 2002 and 2020 is 1% per annum as tighter regulation suppresses the market.

4.3.5.2 Approach for projections (2020-2050) – Assumptions and caveats

The projections aspect of the calculations assumes growth in use translates to growth in emissions. No considerations of changes in technology, abatement, or unpredicted events (such as Covid-19) are included within the estimates.

As with the backward-looking estimates the following growth assumptions have been applied:

- PTFE assumes continued growth at 5% per annum until 2030, after which growth slows to 2.5% between 2030 and 2040 and slows further to 1% per annum between 2040-2050. This mirrors the approach for lubricants. This is confirmed by a respondent to the 2nd stakeholder consultation who refers to BCC research that states that the compounded annual growth rate of fluoropolymers in building and construction from 2020 to 2025 is 4.9%. This excludes PVDF, PCTFE, PVF.
- ETFE assumes growth of 8% per annum until 2025, after which growth slows to 5% (in line with PTFE) until 2030. The growth pattern then mirrors PTFE as growth of 2.5% annually between 2030 and 2040 and 1% per annum thereafter between 2040-2050.

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[90] https://www.statista.com/statistics/732029/ethylene-tetrafluoroethylene-market-volume-worldwide/

[91] https://www.grandviewresearch.com/press-release/ptfe-market

- PVDF mirrors the growth pattern for PTFE (5% annually between 2020 and 2030, then 2.5% between 2030 and 2040, and 1% between 2040 and 2050). This is confirmed by a respondent to the 2nd stakeholder consultation who claims that PVDF-paint consumption is estimated rather stable and that a strong increase is unlikely.

- Other fluoropolymers assumes a growth of 2.5% per annum between 2020 and 2040, after which it falls in line with the other fluoropolymers as a rate of 1% per annum between 2040 and 2050.

- Non-polymeric PFASs is assumed to have a flat increase of 1% per annum from 2020 to 2050, assuming the market continues to be suppressed by the existing restrictions on a number of PFASs.

- Other contaminants. The production of PTFE using processing aids can contain PFOA as a trace contaminant (Wang et al, 2014). Equally, the first CfE highlighted the possible presence of PFHxA as a contaminant in ETFE. These have been managed in the projections as follows:

    - Based on the production and use of PTFE, associated PFOA emissions are calculated at 2% w.w based on the work by Wang et al (2014) from 1990 – 2015, at which time the PFOA stewardship program phased-out the use of PFOA amongst the largest eight global producers. As the PFOA stewardship program did not cover all PTFE production globally, and Wang et al (2014) highlight new producers after 2015, it is assumed that PFOA may still be released from imported PTFE. However, PFOA is also covered by a global ban under the Stockholm Convention (decision SC-9/12) as of 2019, and at European level under the POP Regulation. Therefore, the projections assume that after 2015, remaining sources of PFOA in PTFE fall to 1,000 ppb (which covers the restriction for PFOA and its related compounds). Note that following the transition away from PFOA as a processing aid in PTFE, other PFASs/families of substance have likely replaced it. Specific details of seven possible options were identified by Wang et al (2013) and ITRC, but no market data identified to help apportion use. Furthermore, data on residual concentrations and potential release rates are also missing meaning estimates have not been possible for PFOA replacements used as processing aids for PTFE.

    - PFHxA is currently subject to a REACH restriction process which commenced in late 2019. The consultation process for the restriction concluded in the autumn of 2020, with the opinion of SEAC adopted in December 2021. The projections therefore assume the REACH restriction will be completed and implemented sometime in 20/23, with a potential transitional window of 2-5 years. For the projections, the middle value of three years has been adopted, assuming that the transitional period under the REACH restriction will have concluded by the 1 January 2026. After this date it is assumed any further emissions would be negligible and therefore are assumed to be close to zero.

4.3.5.3 PFAS estimated time-series for construction products, including projections (2020-2050)

TABLE 21 and TABLE 22 provide the time-series for quantities of PFASs (both as fluoropolymers and non-polymeric PFASs) are projected to be consumed across the EU and EU emissions, respectively. FIGURE 5 also provides the aggregated emission estimates (air, land and water combined) as line graph. This illustrates that continued strong growth in the construction sector and demand for fluoropolymer, particularly PTFE and ETFE grows usage and resultant emissions. Noting that these projections assume no further restriction of PFAS, and do not take into account any changes in technology or improvements in emission abatement. Based on the BAU assumptions the demand for fluoropolymer is expected to double by the end of the 2030s, however, usage of non-polymeric PFASs progresses at a slower rate, with usage (and resultant emissions) increasing by 50% at the 2050 year. This is largely based on the assumption that growth in non-polymeric PFASs remains supressed due to concerns over further restrictions for PFAS.

TABLE 21. Tonnages used in the EU for construction products from 1990-2020 and to 2050 for business as usual projections

Group	1990	2000	2010	2020 (baseline)	2030 (BAU)	2040 (BAU)	2050 (BAU)
PTFE (high MW)	303	335	455	760	1,238	1,584	1,750
PTFE (low MW)	96	346	1,243	3,338	2,787	3,079	3,401
ETFE	819	1,002	1,227	2,484	4,658	5,963	6,587
PVDF	221	271	332	554	902	1,155	1,276
Side-chain polymer	12	15	18	30	38	49	54
Other Fluoropolymers	111	123	136	150	192	246	272
Non-polymeric PFASs (all substances)	967	1,311	1,510	1,670	1,845	2,038	2,251

TABLE 22. Emissions (tonnes) in the EU by vector from 1990-2020 and to 2050 for business as usual projections

Group	Vector	1990	2000	2010	2020 (baseline)	2030 (BAU)	2040 (BAU)	2050 (BAU)
PTFE (Granular)	Air	38	42	57	**96**	156	199	220
	Land	60	67	91	**152**	247	316	349
	Water	23	26	35	**58**	94	121	133
PTFE (Micropowder)	Air	0	0	5.5	**15**	0.6	0.7	0.7
	Land	0	0	2.8	**7.5**	0.3	0.3	0.4
	Water	0	0	2.8	**7.5**	0.3	0.3	0.4
ETFE	Air	19	24	29	**59**	109	140	154
	Land	29	36	44	**89**	166	213	235
	Water	13	16	20	**40**	75	96	106
PVDF	Air	6	7	8	**14**	23	29	32
	Land	8	10	12	**21**	34	43	48
	Water	4	4	5	**9**	15	19	20
Other fluoropolymers	Air	5	6	7	**7**	9	12	13
	Land	8	8	9	**11**	13	17	19
	Water	3	3	4	**5**	5	7	7
PFOA (as by-product of PTFE (all types) (in kg)	Air	760	830	1,260	**0.1**	0.1	0.2	0.2
	Land	1,200	1,320	1,870	**0.2**	0.3	0.3	0.3
	Water	460	500	750	**0.07**	0.09	0.1	0.1
PFHxA (as by-product of ETFE) (in kg)	Air	7.2	9	11	**22**	0	0	0
	Land	11	13	17	**32**	0	0	0
	Water	4	5	7	**13**	0	0	0
Non-polymeric PFASs	Air	203	275	317	**350**	387	427	472
	Land	160	211	250	**277**	305	337	373
	Water	106	140	166	**184**	203	224	248

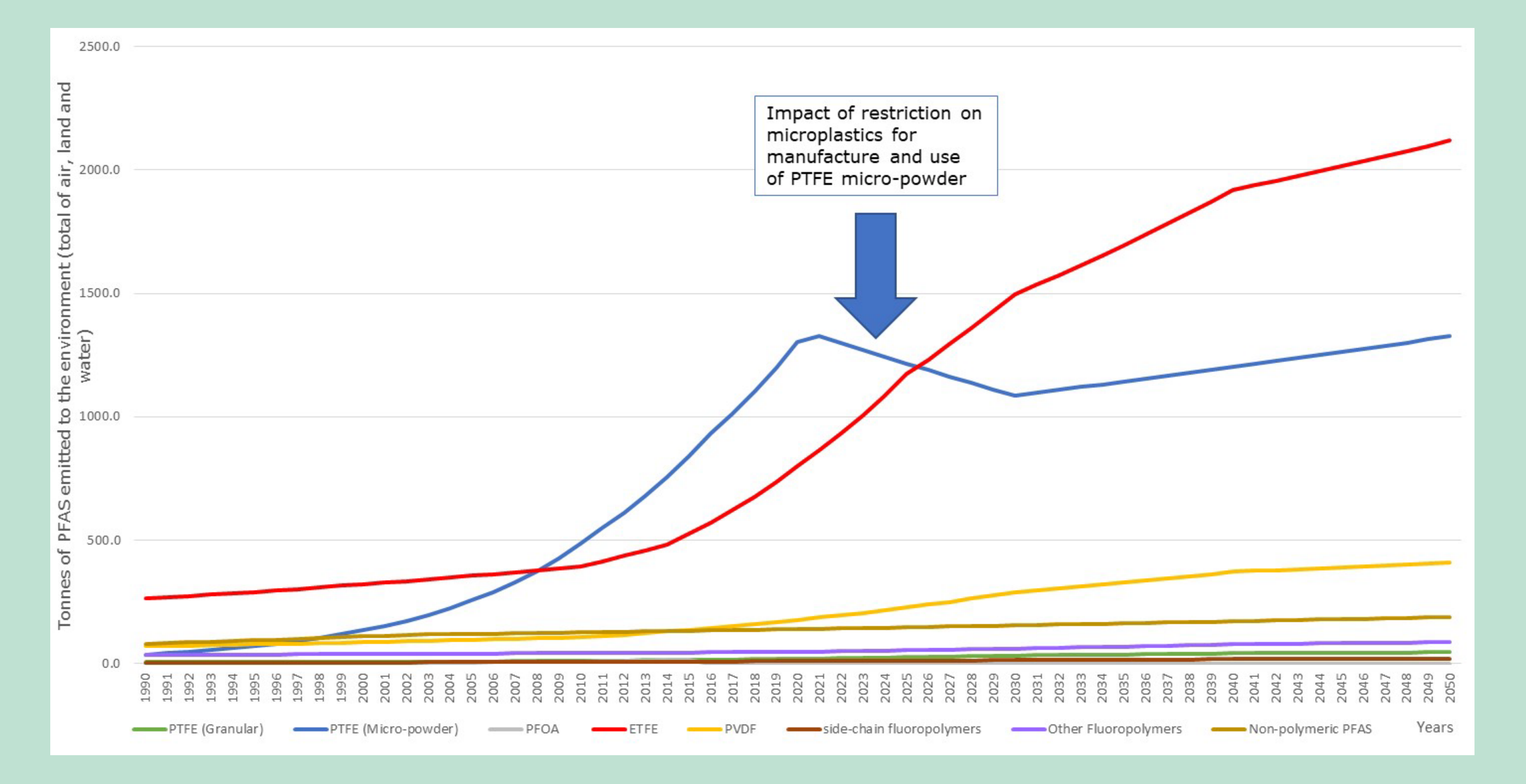

FIGURE 5. Estimated emissions aggregated total (all receiving environments) as time-series and projections (BAU)[92] *excluding PFHxA[93]

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[92] In the Annex XV restriction proposal that was submitted to ECHA on the 7th January 2023 only combined PFAS emission projections is provided (2020-2070).

[93] Emissions of PFHxA range in the low kg per annum (total emission to all vectors in 2020 is estimated as 69kg). All other PFAS substances have emissions in the order of tonnes. Therefore, PFHxA has been excluded from the chart.

4.4 Summary of key uncertainties and data gaps remaining

The approach uses a basic source-flow model, which involves some degree of simplification and generalisation of the life-cycles of the different products.

A very large number of substances have been identified as being in use or potentially in use (with varying quality of data available on each), so the approach taken has not tried to develop estimates on a substance-by-substance basis, but grouped the main substances used and types of uses (based on emission-relevant considerations such as way of application of PFASs to product, indoor/outdoor use, professional/consumer use, etc.).

Specific data on releases was not available for all substances, products and life-cycle stages. Assumptions based on expert judgement and Environmental Release Category (ERC) emission scenarios have been used to fill the gaps.

In addition, the uncertainties around market data (see Section 4.3) cascade into the emission estimates.

Therefore, the estimates included in this section should be treated as indicative orders of magnitude and not definitive estimates to the nearest tonne.

5. Task 4: Economic impact assessment

The relevant data on potential economic impacts gathered from the CfE, 2nd stakeholder consultation and targeted stakeholder consultation is summarised below as the primary basis of analysis. Note that the information is based on statements from industry stakeholders. Where the statements explicitly relate to specific applications, these are specified. The responses have been grouped by type of cost to identify the main cost drivers and compare different stakeholders' views on each type of cost. As opposed to some other uses of PFASs (e.g., fire-fighting foams, textiles, food contact materials), for lubricants no literature on the potential costs of substituting PFASs has been identified.

5.1 Lubricants

During the targeted industry stakeholder consultation, industry noted that substitution of these types of lubricants has not previously been considered, as they meet specifications that cannot be met by alternatives and as they are considered toxicologically safe in many applications (see above under alternatives, Section 3.1.3). It should be noted that some of the PFAS-based lubricants, namely those based on micropowder fluoroplastics such as PTFE in consumer and professional uses where they are not contained, could potentially be covered under the REACH restriction on microplastics[94]. Nevertheless, industry states that they have not carried out any impact assessment addressing the consequences of a possible ban or restriction. Therefore, it has been difficult to receive estimates for cost/impacts.

Industry finds it very important to carry out an in-dept assessment of consequences and impacts before a possible ban or restriction is introduced. Due to the complexity with the array of downstream sectors affected this would be a considerable effort and take time. It also have societal impacts, for example respondents to the CfE in the nuclear energy sector highlight the loss of PFAS-based lubricants without suitable alternatives would impact function of power generation plants.

Stakeholders claim for instance that: "*In our point of view no manufacturing of comparable products [is] possible. No alternative ingredient [is] available due to the unique physical-chemical properties of the C-F bond. We expect a non-calculable risk at critical applications due to the non-comparable properties of the alternatives.*"

There is however consensus among these industry stakeholders that costs of a ban would be extremely high and by far the main economic impacts would not be on the lubricant sector itself, but on the many downstream sectors, some of which might have to redevelop the technologies used or even discontinue operation in case of a ban. As an example of the latter aviation is mentioned.

Further, these stakeholder state, that if 'drop-in' alternatives were to be developed (for some applications), this would take time, be costly and the alternative would not necessary be safer. In some sectors (food, medical, aviation, aerospace) the subsequent approval would take long time and be very costly.

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[94] At the time of writing, RAC/SEAC opinions were completed (https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366), but the restriction was not yet agreed by the REACH committee.

More detail on the stakeholder input received is provided below, organised into different types of costs:

- Substitution costs, which for the purpose of this assessment refers to costs of using alternatives relative to using PFASs (e.g., cost difference to the end product consumers due to more costly materials or higher quantities required).
- Technical costs for developing and implementing alternatives (e.g., for additional testing, technical installations etc.).
- Organisational costs for developing and implementing alternatives (e.g., training of workers, occupational safety measures, regulator costs).
- Costs associated with a potential functionality loss when PFASs can no longer be used in the applications in question.
- Note that in some cases, total costs to develop, implement and use alternatives could not be broken down or distinguished based on the input received. Therefore, for lubricants, these general or total costs have been included in substitution costs, while for construction products, substitution costs, technical costs and organisational costs have been grouped together.

5.1.1 Substitution costs

For the purpose of this assessment, substitution costs refers to costs of using alternatives relative to using PFASs (e.g., cost difference to the end product consumers due to more costly materials or higher quantities required). Note that in some cases, total costs to develop, implement and use alternatives could not be broken down or distinguished based on the input received. Therefore, for lubricants, these general or total costs have been included in substitution costs.

Stakeholders seem to agree that significantly larger quantities of alternatives are required to substitute PFAS-based lubricants. Although no information on the price difference between these products was provided, the higher volume required could imply higher total costs. A few stakeholder provided suggestions of substitution costs per application in the range of €50,000 to €5 million, without providing further detail of what these would entail. The bullets below outline the individual stakeholder responses that were received on the matter:

- 15-25 times higher quantities of premium quality ester-based lubricants would be required to adequately substitute PFPE-based lubricants.
- Another consultee also suggested that in harsh environments, re-lubrication periods are much shorter for alternatives compared to PFPE, i.e., higher quantities of alternatives are required.
- Estimated cost of alternative technologies (this was not further specified, so it is not clear if these are one-off costs of developing and implementing alternatives or recurring costs of using alternatives):
  - €50,000 to 200,000 per industrial application,
  - €200,000-500,000 per automotive application,
  - €500,000 to 1,000,000 per aerospace application.
- One stakeholder estimated total substitution costs: average project durations of 3-5 years per product with an estimated cost of €500,000-1,000,000 per product. At least 3 raw materials would be affected for this particular stakeholder, so the costs for them would be in the order of €1.5-3 million.
- New technology adaptation: More than €5 million. (not further specified)

5.1.2 Technical costs

For the purpose of this assessment, technical costs refer to costs for developing and implementing alternatives (e.g., for additional testing, technical installations etc.).

Development of alternatives: Stakeholders seem to agree that around 10 years is a realistic order of magnitude for the time it would take to develop alternatives. Little information on the associated costs was received. Individual stakeholder responses state:

- At least 10 years would be needed to develop alternatives (suggested by 2 separate stakeholders).
- As an estimate, it would take a minimum of eight years of global research to develop and qualify non-PFASs for use in aviation hydraulic lubricants, with a roughly estimated programme cost of €5-10 million. Some stakeholders note that it would take decade to develop and qualify lubricants for the aviation sector.
- For safety critical applications such as nuclear energy, extensive testing would be needed to ensure that alternative met compliance standards. These costs would be in the order of hundreds of thousands of euros per company.
- About 10 years of entirely new development in material and construction / design of components and equipment.

According to stakeholder input, reformulation costs (i.e., costs covering the effort to change the chemical formulation of products when PFASs is replaced with an alternative in that product) could range between some €50,000 and €3 million per lubricant and/or per application. The following estimates have been provided in individual stakeholder responses:

- €100,000-500,000 per application for reformulation and testing
- Significantly higher than €100,000 per lubricant per company (based on the statement that approval costs of over €100,000 would be only a small part of the reformulation cost).
- “Reformulation costs are not calculable, since there are no alternative materials available for PFPE oils and PTFE micropowders.” Reformulation does very likely require change of design (if possible) of the downstream uses in all industries. According to the stakeholders’ experience, such a change of technology in cooperation with downstream users can take up to more than 10 years. In this time cost of R&D reach up to 10% of sales per year.
- Other reformulation cost estimates (not further specified, assumed to be for one product or one company):
  - €2-3 million “based upon today's costs”
  - €50,000 and 1.5 years of development
  - >€1,000,000

Stakeholders also raised the importance of testing and approval costs, although there was wide divergence (possibly reflecting the diversity of end user markets for which testing and approval would need to be undertaken), ranging from €20,000 per new lubricant to several hundred million Euros. Individual stakeholder responses state:

- Costs for the approval process of new alternatives could be over €100,000 per lubricant per company.
- Time-consuming and costly laboratory and field tests would be many times the development/reformulation costs (which were estimated by this stakeholder as up to 10% of sales per year for 10 years).
- Screening and testing costs of €20,000 per new grease.

- Reapproval costs for the French market estimated at several hundred million Euros.
- “It is generally understood in the semiconductor manufacturing supply chain that any transition of a material, particularly one that may be present ‘close to the process’ (i.e., close to the wafer or the processing chemicals used on the wafer – which would be the case for lubricants used on O-rings used to seal low pressure process chambers, and bearing surfaces with that low pressure environment) can require test runs of 10s of thousands of wafers (both test wafers and real productions pieces) in order to establish with sufficient statistical certainty that the transition towards or away from a particular substance has no significant negative impact on production yields, and if it does, what alternate steps are effective in mitigating the impact. The costs of these requalification investigations should be understood as part of the reformulation costs and can easily extend into the hundreds of thousands of Euros. Impacts on semiconductor yield can be as high as millions of Euros per day, per factory.”
- “For automotive applications [substitution] would block the[ir] test capacities for innovations, would take many years and may cost per product in total more than 1 Million EUR because they have to test and receive approvals per application and per automotive customer. Approval Cost of their customers are not included.”

5.1.3 Costs associated with a potential functionality loss

In general, impacts of a potential functionality loss in lubricants due to the substitution of PFASs could involve significantly reduced technical performance, durability and safety according to some stakeholders. The following input was received with respect to functionality loss in a few specific applications:

- Aviation: Stakeholders stated that alternatives do not currently meet the required performance and safety requirements and their use would result in (and has in the past resulted in) reduced lifetime of lubricated parts and ultimately systems failure. One particular issue noted was valve erosion but note that a patent for a PFAS-free alternative exists to avoid valve erosion[95].
- Hydraulic and pneumatic systems: Without changes to the design of the system, the use of fluorine-free alternative lubricants could result in a reduction of the system lifetime by a factor of 10 or more.
- Load roller bearings: A stakeholder suggests that using PFAS-based lubricant can expand the re-lubrication interval, which avoids the need to change roller bearings and reduces the total maintenance cost even though the PFAS lubricant is more expansive than alternatives.
- A paper by Grechin et al. 2018[96] suggests PFPE greases provide performance advantages and a lower total cost of ownership (purchase price + the costs of operation) compared to alternatives, highlighting the following case studies:
  - “operating costs savings can achieve more than 40% or $6 million for a pulp and paper manufacturer with PFPE grease lubricated pulp dryer and electric motors over a six-year lifetime period”
  - “A metal plates manufacturer has successfully replaced a mineral oil lithium thickened grease used in transport line bearings with a standard PTFE/PFPE grease. […] Switching to PFPE grease reduced the re-lubrication frequency from 210 (every day) to 16 times p.a.

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[95] https://patents.google.com/patent/US6599866B2/en

[96] Alexander Grechin, Verena Schott, Rachel Kling: PFPE-Greases: modern trends and perspectives. Paper for ELGI AGM 2018 Conference in London.

> and completely eliminated the bearing failures. Maintenance costs, parts costs, and production downtime have been reduced accordingly. Despite a large difference in the grease prices, TCO savings with a best performing PFPE grease are far beyond any savings related to the purchasing price of the grease itself."

5.1.4 Other impacts

According to industry stakeholders a ban of PFASs in lubricants would have very significant effects on the economy. One stakeholder from the 2nd stakeholder consultation highlighted the use of PFASs within digital applications, particularly relating to storage of data. Where the EU is increasingly founded on a digital economy, the stakeholder claims that loss of PFAS-based lubricants would have significant societal impacts, on the basis that no viable alternative exists. More generally, the feedback from the CfE and 2nd stakeholder consultation suggests that given a lack of alternatives, a ban would lead to the following:

- It will have a significant impact on the economics and employment in the EU region.
- Production of lubricants containing PFASs will potentially be moved to non-EEA countries (Asia, Russia, South America). (Note however that in case of a REACH restriction on the placing on the market and/or use of lubricants containing PFASs in the EEA, they could also not be imported back into the EEA.)
- However, by far the main impacts would be on the downstream sectors where impacts could be 100-1,000 times more costly than for the lubricant sector itself if access to such lubricants or parts with these lubricants are no longer available.
- Many downstream sectors would be at risk of significantly reducing efficiency, productivity and competitiveness and perhaps even would have to discontinue – automotive industry, aviation, medical industry, chemical industry, renewable energy sectors etc. – see uses described elsewhere.
- CO_2 footprint would increase.

In conclusion, there seems to be a certain degree of agreement between the consulted stakeholders that at least in some applications, alternatives would need much more frequent replacement and/or would lead to reduced reliability of lifetime of the systems in which they are applied, that reformulation costs per company per lubricant would be of the order of €100,000 or more (even if alternatives were identified, which is not the case at present), that the identification or development of alternatives could take in the order of 10 years and that costs and time associated with testing and the approvals process could be significant (e.g. in the aerospace and semiconductor industries).

It should be noted that all stakeholder responses received related to economic impacts came from industry and so the results reflect exclusively an industry position. Respondents included mainly suppliers and users of PFAS-based lubricants, but also included industry associations that cover suppliers or users of both PFAS-bases lubricants and their alternatives.

5.2 Construction products

Very little specific information to quantify costs of a restriction on the use of PFASs in construction products was available. Information on the main types of costs was patchy covering only some of the many applications of PFASs in construction products, but for most identified impacts it seems likely that they are similar across the different applications. The specific input received from stakeholders on the different types of costs is presented below.

5.2.1 Substitution, technical and organisational costs

Aggregated costs for impacts of a restriction on substitution have not been possible (due in part to the complexity of the uses and market). Many stakeholders did not provide cost estimates for substitution (costs of using alternatives relative to using PFAS) but instead suggested that no alternatives were available and/or that reformulation was not possible in their view. Other stakeholders have suggested (that because there to their knowledge are no viable alternatives) loss of business would likely equate into the 10s of millions of euros with job losses in the low hundreds of personnel per respondent. Some respondents to the 2nd stakeholder consultation highlighted that as an international business they may be required to remove all manufacturing outside of the EU to continue servicing non-EU clients. This would result in a full loss of revenue and jobs, further impacting competitiveness of the EU with other geographic regions.

Some respondents highlighted that a lack of alternatives that can provide a similar combination of properties would potentially require significant changes to applications in the construction sector, but further detail on the affected products and associated costs could not be provided. One stakeholder elaborated that "since there are no [drop in] alternat[iv]es for fluoropolymers with [a] similar combination of properties, in a lot of cases this would not require a reformulation, but a redesign of the whole construction system", One respondent (gaskets and hoses) from the 2nd stakeholder consultation posed the question around transition times and whether existing processes could continue to be allowed for at least five years, to avoid impacts on continuity of service. but further detail on the affected products and associated costs could not be provided.

Another potential cost identified by one stakeholder was that "prices of raw materials and energy would rise massively". This was mentioned specifically in the case of a ban of PFAS polymers and elastomers for use in manufacturing of seals, bearings, and many other products, due to a lack of alternatives. Further details on the reasons and expected order of magnitude were not provided.

Regarding PFASs used as processing aids in the production of construction products, one producer indicated that fundamental research is required to find alternatives that deliver the required performance and are subject to lower environmental concerns than PFAS. The stakeholder claims this process would be complex, expensive and take over a decade to develop the process, plus additional time for complex market qualifications. Due to the uncertainties involved, substitution cost could not be assessed at this point. One major source for uncertainty is whether current assets could be used or if they would need to be replaced.

No specific input was received to provide a separate estimate for technical and organisational costs for developing and implementing alternatives (e.g., for additional testing, technical installations, training of workers, occupational safety measures, regulator costs, etc.).

5.2.2 Costs associated with a potential functionality loss

In many cases, PFASs are used in construction products to improve durability and reduce maintenance/cleaning. If this functionality is lost/reduced, this would lead to higher maintenance costs, as well as costs and waste associated with more frequent replacement.

Most detail was available for the performance benefits of PFASs in architectural membranes which would be lost when using alternatives. Stakeholders highlighted the following benefits:

- "*1. Reduction of CO2 emissions and air-conditioning and lighting costs, noting that membrane materials are more translucent than other metals and slates, so they can maintain the brightness of the room during the day.*
- *2. Longer durability than other tent membranes, Since the roof film using fluoropolymer is strong, it is durable enough to be used even in harsh environmental conditions*

such as salt damage and typhoons. In addition, due to its strong chemical resistance, it is less susceptible to salt damage and other effects.

One respondent commented that an example of non-PFAS tent membranes is PVC, which they believed would have greatly reduced durability. This is because with PVC, roofing materials are considered to require more frequent maintenance/replacement, it is assumed that the amount and cost of waste and maintenance cost would increase.

- *3. Excellent fire resistance. Roof membranes for fire-resistant buildings are mainly composed of fluoropolymer and glass cloth.*
- *4. Lighter weight, weatherability and translucent properties, compared to metal materials. Since the weight of the roof can be reduced with fluoropolymers, it is assumed that application of fluoropolymers can reduce the amount of building materials and subsequently the material costs. In addition, it is suitable to create wide spaces in buildings.*

On the other hand, other respondents commented on what they saw as certain disadvantages of using fluoropolymers membrane as roofing materials. Fluoropolymers are expensive generally and the film processing is difficult. Advanced technologies and special equipment are required. Despite the disadvantage above, PTFE and ETFE are widely used as tent membranes in Europe, and we are not aware of alternative substances which own equivalent performance and advantages to PFAS."

This was supported by another respondent who states that "they provide resistance to UV radiation, water, oil, dirt and corrosion, which makes them excellent for outdoor applications, especially in roofs in large infrastructure such as airports, stadia and skyscrapers. The decreased weight of PFAS materials used in construction allow for a reduction in weight of the structures supporting elements which can lead to a reduction in material and construction costs."

Another respondent added that fluoroplastic coated membranes in architecture also enable "novel architectural designs requiring flexibility and thin materials", which may not be feasible without PFAS.

Other impacts stated by stakeholders for specific applications were:

- One stakeholder suggested that ETFE agricultural films in greenhouses save over 30% energy compared to a single layer glass roof.
- According to the producer of a confidential construction product dependent on PFASs as processing aid, alternatives would not match its performance in terms of being "circular economy ready", durability, environmental footprint per quantity installed and disposed of, cost effectiveness and vapour permeability. The same producer further commented that the architectural membrane-like product performs a niche role in the market dominated by alternatives. In terms of technical feasibility the stakeholder states that all alternatives have their trade-offs in performance, but that they are able to meet building regulations. It must, therefore, be assumed that downstream users see the alternatives as technically feasible.

5.2.3 Other impacts

Stakeholders' stated that a restriction on the use of PFASs in construction products would lead to a significant loss of business for certain suppliers and therefore potential closures of particularly effected businesses. However, no information was available to quantify the loss of business.

A potential loss of competitiveness of the European construction product industry was also identified by one stakeholder.

In conclusion, the identified types of impacts by stakeholders can be summarised as follows: Substitution costs and time required for identification of alternatives, reformulation, obtaining market qualifications could not be quantified at this stage but could be substantial. In some cases, the current equipment used, or the construction design may need to be changed in addition or instead of reformulation, which would lead to substantial additional costs. A loss of functionality due to inferior performance of alternatives in construction products could lead to higher maintenance costs, costs and waste associated with more frequent replacement, increased energy costs and emissions, increased material, and construction costs due to higher weight, a loss of the feasibility of novel architectural designs, and in some applications increased health and safety risks (pipe linings, seals/bearings). Other potential costs identified by stakeholdes are a potential loss of business for some businesses (due to failure of substitution), and a potential loss of competitiveness of the European construction product industry (as a result of the loss of functionality).

As noted above, information on the main types of costs was patchy covering only some of the many applications of PFASs in construction products. Hence, it is not clear whether they apply to PFAS-based construction products in general, although it seems likely that the general conclusions outlined by stakeholders above are probably similarly applicable across most applications. It should also be noted that all stakeholder responses received related to economic impacts came from industry and so the results reflect exclusively an industry position. Respondents included mainly suppliers and users of PFAS-based construction products, although many of them likely also supply and use products that are not based on PFAS.

OECD report (2022) provides a case study of paints for bridges. In this example, the fluoropolymer-based paints were considered to have better weatherability and durability to non-fluorinated alternatives (e.g., polyurethane/PU). University of Wisconsin-Milwaukee in 2013 analysed costs over time of painting a bridge with FEVE versus PU. The study concluded that it would cost approximately 26% more for the fluoropolymer-based paint initially, however, after 30 year the total cost for PU would cost 16% more. This was attributed to faster degradation of the PU and need for more frequent recoating – costs associated with the labour and resources needed for this. In particular with bridges exposed to harsh weather conditions (e.g., near the sea) where high salt content can be problematic for corrosion – high performance FP is desired here.

As further comment on this the OECD (2022) notes that within the case study it was assumed that painting a bridge with fluoropolymer-based paint (FEVE) is assumed to have a service life of 20-25 years. The polyurethane alternative by comparison was assumed to have a service life of 5 – 10 years. The OECD (2022) report states that epoxy coatings degrade in sunlight. It should be noted that the Hempadur Avantguard epoxy primers mentioned above are used in a coating system (often 3-coat system) and that the topcoat is often based on polyurethane. According to Hempel different qualities of polyurethane exist (Hempel, 2022b). Hempel offers paint systems that do not contain fluoropolymers, with a very high estimated service life (>25 years) even at high humidity, aggressive atmosphere, and inshore areas of high salinity (Hempel, 2020).

5.3 Summary of key uncertainties and data gaps remaining

Uncertainties about the feasibility of alternatives (see Section 3.3) cascade into the economic assessments.

Information on the main types of costs was patchy covering only some of the many applications of PFASs in construction products and lubricants. In addition, some of the input received from stakeholders was not very clear regarding the costs and applications covered by the estimates of economic impacts.

All stakeholder responses received related to economic impacts came from industry and so the results reflect exclusively an industry position. Respondents included mainly suppliers and users of PFAS-based construction products or lubricants, although many of them likely also supply and use products that are not based on PFAS.

6. Task 5: Human/social impact assessment

6.1 Lubricants

6.1.1 Potential for human exposure

In terms of human exposure, it was repeatedly stated by the consulted industry stakeholders that PTFE and PFPEs are not considered toxic to humans, which is one of the reasons why these substances are approved for use in e.g., drinking water installations, medical equipment, oxygen supply apparatus and food manufacturing (such as oven applications).

In terms of releases of PFAS-based lubricants from different applications and lifecycle stages, industry stakeholders generally state that:

- Very limited emissions of PTFE and PFPEs are expected during production/formulation of the lubricants (material is expensive, low vapour pressure and low water solubility). Less than 1% loss can be assumed[97], but this will most likely go to a (hazardous) waste fraction due to low vapour pressure and lack of mobility and water solubility.
- Between 3-5% of these lubricants are used in 'open'/'total loss' applications (i.e., applications where the lubricant is not contained within the product for the duration of its lifetime) where a 100% re-lubrication is needed at intervals. The 'lost' amount can go to recycling or be lost indoors or outdoors. Stakeholders were generally not able to point to where spent lubricant ends up – how much goes to waste/recycling and how much is lost to the environment (and via which routes)? Further assumptions about this could be developed based on emission scenarios from relevant previous REACH restrictions or environmental release categories from relevant ECHA guidance[98].
- Consequently 95-97% of the lubricant volume in the use-phase end up in life-time lubrication applications, i.e., they remain in the articles until end of service life of those articles, e.g., in a bearing or in an electromechanical device.
    - Due to the need for lifetime lubrication, very limited loss of the lubricant is expected during service life for these applications – less than 1% is estimated by industry stakeholders[99]. If much more is lost, the parts/articles will no longer function.
    - In general, the amounts applied in each part/article are rather low and they are contained in closed parts/articles. It is therefore not practicable to extract/separate the lubricants from the articles prior to disposal. An exemption is the lubricants used in vacuum pumps, which are regularly recycled.
    - Thus, it is assumed that overall, the main quantity of PFAS-based lubricants end-up in the metal waste fractions (e.g., as part of a bearing), where the PFASs are assumed to be degraded to fluorides at high temperature during metal recovery or (in some countries) go to

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[97] Note that the emmission assessment in Task 3 (Section 5) has conservatively assumed higher values based on Specific Environmental Release Categories (SPERCs).

[98] https://echa.europa.eu/documents/10162/13632/information_requirements_r16_en.pdf

[99] Note that the emmission assessment in Task 3 (Section 5) has conservatively assumed higher values based on Environmental Release Categories. ECHA (2016) Guidance on information requirements and Chemical Safety Assessment – Chapter R.16 Environmental exposure assessment, V3.0.

landfill where little loss is expected given the low mobility and water solubility of PFPE and PTFE. No information was received about whether there will be any losses during dismantling of equipment.

- Several stakeholders speculate as to whether more controlled collection and disposal of such parts/articles containing PFAS-based lubricants should be considered, e.g., via somehow labelling such articles. One stakeholder suggested that it should first be investigated whether current regulation – such as the RoHS, WEEE and, ELV directives – and related administrative practices can be adjusted to address the issue before introducing new regulation to specify requirements for collection or take-back systems for worn out articles containing PFAS-based lubricants (in bearing, pumps, tools, cars, etc).
- Between 1% and 10% (probably closer to 1%) of the PFAS-based lubricant volume is recycled one way or the other. No information on the techniques used for recycling the lubricants has been obtained.

Information was received about the use of other PFAS-substances than PTFE and PFPE in relation to lubrication, namely various PFAS additives and PFAS-based solvents, see Section 3). No human exposure nor environmental release data for those substances have consequently been found or received. However, especially for the solvents, a greater loss than those which can be expected for PTFE and PFPEs appear likely, including releases to air.

It should be noted however that there is a difference between PFAS-based solvents used for cleaning and PFAS-based solvents used as part of a lubricant formulation. In the latter case, the solvents will evaporate when lubricant is applied to various articles/parts. It is advised by the lubricant suppliers that the latter should take place in closed processes where the evaporated solvent is recycled/collected to avoid/reduce exposure of workers and emissions to the environment.

6.1.1.1 Workers exposure

Lubricant formulation/production

It is estimated by various stakeholders that fewer than 1,000 workers are involved in the formulation of PFAS-based lubricants in the EU/EEA. Generally, it is stated by industry stakeholders that worker exposure is very low due to strict controls, closed systems or encapsulation and the low volatility of PTFE and PFPEs. No exposure data have been received or identified. The same applies for formulation of lubricant dispersion with PFAS-based solvents where some inhalation exposure must be assumed.

Immediate downstream users

The immediate downstream users are those typically incorporating the PFAS-based lubricants into parts/articles such as bearings. As appears from the use descriptions there are many different types of parts and equipment incorporating these and firm estimates are therefore not possible. Various stakeholders estimated that 10,000 – 100,000 workers are involved. Stakeholders note that many processes involving these lubricants have been or are being automated (estimated for applications covering 30 – 70% of the lubricant volume applied), which would reduce worker exposure. Further, it is stated that many applications take place in working environments which are or can be compared to 'clean-room' facilities and/or sectors where there is a strong focus on OHS compliance (though clearly some other applications may not take place in such environments).

About 3-5% of the PFAS-based lubricants are estimated by industry to be used in 'open'/'total loss' applications. In these situations, there might be a higher potential for worker exposure than for the above-mentioned more automated processes incorporating the lubricant into fully sealed articles.

As noted above, also PFAS-based solvents are used to some extent and it is assumed that this could lead to some inhalation exposure, unless used under very controlled and closed conditions. No exposure data for PTFE, PFPE, and other PFASs including solvents have been received or identified.

Equipment end-users

Stakeholders believe that workers using equipment containing PFAS-based lubricants are generally not exposed or the potential for exposure is very limited, due to the low potential for releases in lifetime lubrication applications as described above.

Cleaning before lubrication

PFAS-based solvents are used to clean mass-manufactured parts (such as electronic components). This is commonly done in specialist sealed equipment where solvents can recovered and reused. For these type of applications exposure is expected to be low.

Cleaning of articles that have previously been lubricated with PFAS-based lubricants with PFAS-based solvents (cleaning of parts/articles prior to adding lubricants, cleaning of production machinery or during maintenance of e.g., wind power installations) may in theory take place during the entire lubricant life cycle. Possible worker exposure during these type of cleaning activities are thought to be the most critical as these solvents are volatile and sometimes even applied as aerosols, and finally these work situations might be less strictly controlled as they are only carried out occasionally and sometimes not in industrial settings. This could lead to elevated inhalation as well as dermal exposures. No exposure data on this type of exposure have been identified or received from stakeholders.

Note on professional uses

Most of the above-described worker exposure situations can be seen as industrial uses, but some of the re-lubrication ('open'/'total loss' applications) and cleaning uses might be seen as professional uses. Further, some of the uses described below for consumers might also be relevant for some professionals (e.g., bike repair).

6.1.1.2 Consumer exposure

Use of lubricants

Consumer exposure is expected by industry stakeholders to be very limited as consumers generally do not use this type of lubricants because of the expense. One exemption from this are speciality products for bicycle chains.

Consumer PTFE lubricants for bicycle lubrication have been seen on the web at a cost of DKK 70 (equaling around EUR 9.4) for 100 ml and 400 ml, respectively. The PTFE concentration for these products are not clear from the web advertisement. Also, other multiple purpose PTFE lubricants, which can be acquired via websites have been identified[100]. These latter lubricants can be bought by consumers but might be intended for professional users. While no evidence of widespread use of PFAS-based lubricants by consumers has been found, the

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[100] E.g. https://www.sanistaal.com/da/produkter/kemi-og-forbrugsvarer/kemi-og-vedligeholdelse/sprayprodukter/smoeremidler-paa-spray/smoereoliespray/c-90.10.30.50.50/503847/kema-tri-17-teflon-olie-smoeremiddel-transparent?variantId=503847

price quoted above does not support the claim that PFAS-based lubricant is too expensive for consumers, considering more expensive fluorine-free lubricants are also being sold.

In any case, all industry stakeholders interviewed do not consider fluorinated lubricants for consumers use as critical or essential.

Consumer use of equipment

Similarly, as for worker end-users, industry stakeholders consider consumer exposure to PFAS-based lubricants in consumer articles to be very limited, due to the low potential for releases in these lifetime lubrication applications.

It is stressed by the industry stakeholders that these uses, where the lubricants are incorporated in various consumer articles such as in cars, household appliances, power tools etc., are considered critical/'essential'.

6.1.1.3 Indirect exposure of humans via the environment

No specific data has been identified. Further conclusions on the likelihood of indirect exposure to be drawn for the final report based on the available information about releases to the environment.

6.1.2 Potential effects on employment

As discussed above, it is estimated by various stakeholders that fewer than 1,000 workers are involved in the formulation of fluorinated lubricants in the EU. Hence, even if a ban on PFASs in lubricants would completely eliminate the current employment in their production, the employment impacts in the lubricant industry in the EEA would likely not more than in the order of 1,000 employees.

However, as discussed in Section 4.4, consensus among industry stakeholders that the main economic impacts of a ban of PFASs in lubricants by far would not be on the lubricant sector itself, but on the many downstream sectors. Some stakeholders even go as far as to caution that whole downstream sectors, such as aviation, would have to stop operation, but this is probably speculative at the moment. Nevertheless, it is conceivable that adverse economic impacts on downstream user sectors would lead to some loss of employment in the EEA, for instance when European products lose competitiveness due to a loss of functionality as a result of substitution. However, sufficient information was not available to make a reasonable estimate of what share of employees of each of the wide range of diverse downstream user sectors might be affected. Note that generally speaking, a share of any employment losses would likely be temporary, as workers typically eventually find a new job, but sufficient information was not available to judge the time of the employment losses and any potential salary implications (if the new job pays a lower salary).

Specific stakeholder responses included lubricant suppliers stating they would likely loose part of their employment and other stakeholders noting there could be employment impacts resulting from value chains connected to lubrication applications moving away from the EEA.

6.2 Construction products

6.2.1 Potential for human exposure

6.2.1.1 Workers exposure

16 companies provided data in the CfE or the targeted consultation (all in confidential attachments to the CfE or in confidential input to the consultation protected under non-disclosure agreements that allow only use in aggregated figures) on the number of workers employed in

the production and handling of well over 100 different PFAS-based construction products. The sum of these workers for all products of the 16 companies amounts to approximately 12,000 workers (rounded to closest 1,000).

This number is uncertain for the following reasons and should therefore be considered only a rough indication of the number of magnitude of workers involved with the products of those 16 companies. As most companies provided the number of workers per product and some of the products may be produced/used in the same installations, there is likely a degree of overlap that leads to double counting of some workers. On the other hand, some companies included their own workers and those in the downstream supply chain (i.e., their customers), whereas others stated they could not reliably estimate the number of downstream workers and stated this could be in the thousands.

Considering the uncertainty of the estimate of the overall market for PFASs in construction products (see Section 4) and given that many of the stakeholders who provided their number of workers did not specify the related tonnage of PFASs in construction products, extrapolation to the whole market has not been deemed appropriate based on the available data. However, for illustration of the potential order of magnitude, the following hypothetical can be considered. The construction sector as a whole employs some 18 million people in the EU[101]. Given the diverse uses of PFASs in construction products (see Section 3.2.1), it stands to reason that the share of construction workers that handle PFAS-based products at least occasionally is not insignificant. If only 1% of construction workers handled PFAS-based products, this would equate to 180,000 workers. If 10% of construction workers handled PFAS-based products every year, this would equate to 1.8 million workers.

The emission estimates provided for the construction sector (see Section 4.3) broadly identified three major categories: Articles, processing aids and mixtures. Manufacture of articles that contain PFASs or are fully made from PFASs (such as PTFE and ETFE). Discussion with industry stakeholders suggested that the manufacture of articles can occur as both hot and cold processes, for example the manufacture of PTFE mesh membranes can be produced through cold extrusion processes. Exposure during production of articles could occur through inhalation of vapours or generation of dusts from mechanical manipulation of materials. Feedback from industry stated that many product plants would make use of abatement equipment as well as personal protection equipment to manage both vapours and dust (how many plants and which abatement equipment was not further specified). Some respondents to the 2nd stakeholders consultation also states that only trained professionals are handling installation and decommissioning of PFAS containing articles. It must be expected that these trained professional workers have personal protection equipment available.

For the manufacture of articles using PFAS processing aids, the feedback from industry was that these processes are largely automated and use closed systems to capture and re-use PFASs as far as possible. It is possible to envisage there will be some atmospheric releases and worker exposure, particularly during maintenance windows, but overall exposure could be expected to be low.

For mixtures used as paints and surface coatings, it can be expected that PFASs will be introduced to mixtures additively during blending and mixing. These processes are more likely to be at elevated temperature, with generation of vapours. Industry feedback was keen to highlight that fluoropolymers such as PTFE, ETFE and PVDF are highly stable with low vapour pressure, but note that as discussed in Section 3, also non-polymeric PFASs are used in paints and coatings.

The highest worker exposure will likely occur during the application phase of paints and coatings (and potentially adhesives). Feedback from industry in the CfE and stakeholder interviews, stated that PFAS based mixtures can be added as coatings/impregnation by spraying,

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[101] https://ec.europa.eu/growth/sectors/construction_en

rolling, or brushing onto finished articles, this may occur both indoors and/or outdoors. Glüge et al (2020) estimates 3,500 tonnes of PFAS, of which 95% is polymeric, are used in paints and coatings. For the emission estimates of non-polymeric PFASs as an example formulation (assumed to cover blending and/or mixing of final mixtures) is estimated to emit approximately 7.9 tonnes per annum to all vectors, while application of mixtures as paints and coatings is estimated to emit approximately 112.1 tonnes per annum. This potential includes much greater risk for direct worker exposure, depending on the specific settings.

6.2.1.2 Consumer exposure

Most construction products are not generally used by consumers. Uses of PFASs in construction products that have been identified where consumer use is more likely to include DIY sealant and adhesive products, DIY durable water repellent (DWR) impregnation and aftermarket floor protection (and potentially paint, as discussed further below). A breakdown of tonnages for these specific applications was not available, and so it was not possible to estimate a number of consumers using these products. It is important to make clear the very wide range of specific applications that the construction products sector may cover, even if limited only to articles.

One point that can be made is that firstly fluoropolymers (such as PTFE, ETFE, and PVDF) are largely stable from degradation, while non-polymeric PFASs may be bound within the matrix of the article. The greater potential for release and exposure may occur where articles are abraided during use (i.e., moving parts) or where maintenance involves cutting, which would generate dust.

A significant share of all consumers will likely come into contact with buildings that have been constructed using PFAS-based construction products. However, if undisturbed and not subject to direct weathering or washing, the potential release is likely low. Even for paints and coatings containing PFASs the major risk of exposure comes during application (although note that the OECD, 2022 comments use in household paints is unlikely), which given the specialist nature of PFAS containing paints is more likely to affect professional workers. The emission estimates for indoor use of paints and coatings are relatively low (4 tonnes per annum from the 3,848 tonnes of PFASs (both polymeric and non-polymeric consumed in paints and coatings across the EEA).

DIY DWR impregnation of e.g., stone, glass, tiles and aftermarket floor protection can contain between 0.5% and 2% PFASs (usually side chain fluorinated polymers). If applied by aerosol spray, high exposure can occur and cases of acute intoxication has been observed (both consumers and professional workers)[102].

It is possible that PFAS-based mixtures are likely to be used within DIY adhesives and sealants, but likely within small quantities. This would suggest the potential risk of exposure is limited, and likely from one-off exposures, given the fact that DIY adhesives and sealants are unlikely to be used on a regular basis by the domestic consumer market.

6.2.1.3 Indirect exposure of humans via the environment

Providing further comment on the potential human exposure to PFASs via the environment from uses in construction products (including paints and coatings) is extremely challenging. The sector as a whole is widely diverse and includes 45 -60 unique PFASs (potentially significantly more), including both polymeric and non-polymeric substances. Uses span both indoor

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[102] https://echa.europa.eu/documents/10162/429fb5c5-ed20-2631-999a-04d32b0fba5a (Table 6, page 50 and Appendix 1)

and outdoor applications, applications where mechanical chafing or abrasion may occur, potentially elevated temperatures, and materials bound within the matrix of articles, or mixtures applied by spraying, rolling, or brushing.

Both the categories covered by articles and coatings include potential outdoor use. It is possible for major construction projects this could include sites near water or agricultural land. Furthermore, the estimated wastewater emissions from the formulation stage have a high potential to end up in sewage sludge, which is applied to agricultural land in some (but not all) EEA states. This would likely give rise to the potential for contamination of food (and potential soil/ground water depending on tillage).

6.2.2 Potential effects on employment

Current employment associated with the production and use of PFAS containing construction products is highly uncertain. As discussed above, evidence of around 12,000 workers associated with the production of PFAS-based construction products was received in the CfE. However, sufficient data was not available to reliably extrapolate this to the whole EEA market. Stakeholder input suggested that employment in downstream user sectors could be much larger, potentially by several orders of magnitude. The construction sector as a whole employs some 18 million people in the EU[103]. While no specific data was available to estimate the share of this that is currently dependent on the use of PFAS containing construction products, the following hypothetical can illustrate the potential orders of magnitude involved. If only 1% of construction employees used PFAS-based products, this would equate to 180,000 employees. If 10% of construction employees used handled PFAS-based products every year, this would equate to 1.8 million employees.

As discussed in Section 4.4, stakeholders claim that a restriction on the use of PFASs in construction products would lead to a significant loss of business for certain suppliers and therefore potential loss of employment for particularly effected businesses, although sufficient data was not provided to quantify this on an EEA and sector-wide level. Stakeholder input was received from some suppliers of construction products dependent on PFAS, employing some 1,000 people in sum, of which at least a share if expected to be lost. It was also suggested that job losses “in the thousands” could occur in the wider construction industry, although no further detail was provided as to how and why this employment would be lost.

A potential loss of competitiveness of the European construction product industry was also identified by stakeholders. It appears likely that this potential loss in competitiveness would also affect employment, and it is also likely that this would affect other sectors than the example mentioned above, considering the potential losses of functionality across many applications of PFAS-based construction products.

Note that generally speaking, a share of any employment losses would likely be temporary, as workers typically eventually find a new job, but sufficient information was not available to judge the time of the employment losses and any potential salary implications (if the new job pays a lower salary).

6.3 Summary of key uncertainties and data gaps remaining

Similar uncertainties as for the market data (see Section 4.3) apply to the use of information from the CfE on workers associated with PFAS-based lubricants and construction products.

In addition, downstream user sectors and applications are very wide-ranging and diverse. Any estimates provided should therefore be considered only a rough indication of the number of magnitude of workers/users involved.

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[103] https://ec.europa.eu/growth/sectors/construction_en

There is also some uncertainty about the degree to which certain applications are used by consumers (as opposed to only professional and industrial uses).

The same uncertainties as for number of workers exposed apply to the number of employees potentially at risk of (temporary) employment impacts, and uncertainties about the overall economic impacts (see Section 5.3) cascade into the potential impacts on employment.

It is also worth noting that all stakeholder responses received relating to economic impacts came from industry and so the results reflect exclusively an industry position. Respondents included mainly suppliers and users of PFAS-based construction products or lubricants, although many of them likely also supply and use products that are not based on PFAS.

Glossary

Annex XV report / dossier / restriction proposal	Document according to Annex XV of the REACH Regulation (see REACH in this glossary) to propose a restriction of a (group of) chemicals.
BAU	Business as usual
C3, C4,…, C14	Denominates the chain length of PFAS in number of carbon atoms
CfE	Call for Evidence
DEHP	Di(2- ethylhexyl) phthalate
DIY	Do-it-yourself (building, modifying, or repairing things without the direct aid of experts or professionals, or products for doing so)
ECTFE	Ethylene chlorotrifluoroethylene
EEA	European Economic Area, except when citing publications from the European Environment Agency (e.g., “EEA (2020)”)
ETFE	Ethylene tetrafluoroethylene
ELV	End-of-life vehicles (see also End-of-Life Vehicles directive (ELV) 2000/53/EC)
ePTFE	Expanded polytetrafluoroethylene
ERC	Environmental Release Category
FEP	Fluorinated ethylene propylene
FEPM	Tetrafluoroethylene propylene
FEVE	Resins consisting of fluoro-olefin units [namely CTFE (chlorotrifluoroethylene) or TFE (tetrafluoroethylene)
FFKM	Perfluoroelastomeric compounds containing an even higher amount of fluorine than FKM fluoroelastomers
FKM	A family of fluorocarbon-based fluoroelastomer materials
FTPV	Fluorothermoplastic vulcanizates
FVMQ	Fluorovinylmethylsiloxane rubber
HFP	Hexafluoropropylene
HFV	Hexafluorovaline
K-PSBF	PFAS mentioned by a stakeholder (not further specified)
OHS	Occupational health and safety
PBSF	perfluorobutane sulfonyl fluoride
PCTFE	Polychlorotrifluoroethylene
PEM	Proton exchange membrane
PFA	Perfluoroalkoxy alkane
PFAS	Per and polyfluorinated alkyl substances
PFCAs	Perfluorocarboyxlic acids
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexanesulphonic acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctanesulfonic acid
PFPE	Perfluoropolyether
PFSA	Perfluorosulfonic acid
POP Regulation	Persistent Organic Pollutants Regulation (EU) 2019/1021
PCTFE	Polychlorotrifluoroethylene
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
PVDF	Polyvinylidene difluoride
PVF	Polyvinylidene fluoride

REACH	Regulation (EC) No 1907/2006 on the Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS Directive	Restriction of Hazardous Substances Directive 2002/95/EC
SPERC	Specific Environmental Release Category
SPIN database	Database on the use of Substances in Products in the Nordic Countries
TCO	Total cost of ownership
TFE	Tetrafluoroethylene
THV	Polymer of tetrafluoroethylene, hexafluoropropylene and vinylidene fluoride
tpa	Tonnes per annum (tonnes per year)
UV	Ultraviolet light
VOC regulation	Volatile Organic Compounds Directive 2004/42/EC
WEEE	Waste electrical and electronic equipment (see also Waste Electrical and Electronic Equipment Directive (WEEE) 2012/19/EU)

Appendix 1. Approach to data collection

This section describes the approach taken in this project for the collection of data required for the population of relevant sections of the REACH Annex XV dossier according to the project objectives (as set out in the previous section).

The collection of data comprised four main aspects:

- A review and collation of information from a first call for evidence, launched by the German, Dutch, Norwegian, Swedish and Danish authorities in Summer 2020.
- A review and collation of information from a second call for evidence, launched in Autumn of 2021 and completed in the winter of 2021.
- A review of relevant grey and scientific literature; and
- Direct consultation with key stakeholders

The approach to each of these three components to the data collection process is discussed below.

Review and collation of information from the call for evidence

A call for evidence (CfE) and a 2nd stakeholder consultation as part of the ongoing REACH Annex XV restriction proposal was carried out by the national authorities of Germany, the Netherlands, Norway, Sweden and Denmark in the period May to July 2020 (1. CfE) and a follow-up call for evidence between July to October 2021. The responses received were made available to the project team by the Danish EPA in two parts:

- The responses to the CfE questionnaire were provided in spreadsheet format. These responses were generally considered non-confidential on the basis that the questionnaire specified the purpose for which the submitted information would be used and potentially made public. However, several responses specified that the information provided was to be considered confidential.
- Respondents to the CfE were given the opportunity to provide attachments which were generally considered confidential. These were provided as individual files using a secure password protected online file storage platform (“Filkassen”).

All responses relating to the sections of the call for evidence that are relevant to the uses in scope of this project were reviewed in detail, and the responses logged in a spreadsheet according to categories of information required for this project (based on the list of information requirements from the tender specifications). In addition, all attachments provided by all respondents who indicated their response is relevant to the uses in scope of this project were reviewed and relevant information logged in the same way. Altogether, 136 responses and several hundred attachments were reviewed.

Literature review

The information from the call for evidence was complemented with a rapid review of key information from the existing grey and scientific literature. The ultimate aim of this process was to efficiently target suitable sources of information and identify knowledge gaps. The identification of sources of information was based on the pre-existing knowledge of the project team and the Danish EPA regarding key sources, recommendations by stakeholders, and a systematic web search was carried out with the use of search tools like google and google scholar.

Targeted stakeholder consultation

Based on the assessment of the data gathered from the 1.CfE and literature (see previous sections), the project team developed a short list of key stakeholders and two sets of questions (one for lubricants and one for construction products) to address the remaining data gaps. These were agreed with the Danish EPA before use and coordinated with other studies contributing to the joint restriction proposal on PFAS.

For lubricants, 14 stakeholders were contacted (or pro-actively contacted by the project team to offer participation in the consultation). Interviews were conducted with eight stakeholders in November and December 2020, several of which provided further input in follow-up correspondence in January and February 2021. Additionally, three stakeholders preferred to provide comments in writing only, with written input received in December 2020 – January 2021. The remaining three stakeholders (out of 14) with which the team were in contact did not provide any input.

For construction products, 18 stakeholders were contacted (or pro-actively contacted the project team to offer participation in the consultation). Interviews were conducted with five stakeholders in December 2020, some of which provided further input in follow-up correspondence in January 2021. Additionally, five stakeholders preferred to provide comments in writing only, with written input received in December 2020 – January 2021, although several of the responses were very brief, stating that use of PFASs in the respondents' applications was limited. The remaining eight (out of 18 stakeholders) with which the team were in contact did not provide any input.

For stakeholders that did not provide input or explicitly denied the request, at least one attempt by phone (where a number was available) and at least one attempt by email was made to follow up on the initial consultation request.

Appendix 2. Further detailed examples of PFAS applications in lubricants

This section provides two tables to further help provide examples of how and where PFAS-based lubricants are used and working concentrations. The first table has been compiled based on a combination of the stakeholder feedback in the two rounds of call for evidence, and further supplemented by literature. It provides a breakdown of sectors, types of use, types of PFASs and working concentrations. The examples in this table should be considered as non-exhaustive and treated with caution based on the potential uncertainties.

The second table included in this section was provided by the Technical Association of the European Lubricants Industry (ATIEL) during the targeted stakeholder consultation to illustrate the wide range of PFASs and their uses in lubricants for various sectors, as well as to comment on the perceived 'essentiality'[104] of those uses. The information in the table should be considered as examples and not a comprehensive list of the full range of relevant PFASs and applications.

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[104] Industry response/assessment on 'essentiality' was based on the following question (as part of targeted stakeholder consultation): "Of the many current uses, which would you consider as essential uses in line with the principles suggest by Cousins et al. (https://pubs.rsc.org/en/content/articlelanding/2019/em/c9em00163h#!divAbstract) ?"

TABLE 23. non-exhaustive list of PFAS uses in lubricants based on literature and information from stakeholders

Branch / sector	Application	Key technical function (those listed as most important by the stakeholder or in literature)	PFAS and concentration (examples were indicated in the CfE)
Food sector	Chains and bearings (e.g., in ovens)	High temperature applications (e.g., ovens)	PFTE (90-99%; 30-70%) PFPE (60-75%; 30-70%)
	Lifetime lubrication in micro-amounts in closed parts. Moving mechanical parts, semi-closed. Lubricants and lubricant Sprays for incidental food contact (NSF-H1[1]).	"Unique tribological function", chemical stability, temperature resilience	PTFE (1-10%) PFPE (80-90%)
	As a lubrication additive on the inside coating of metal food and beverages containers - it enables filling without damaging the coating[105].	'Slideability'	PTFE (2.5 – 100%)
Civil/military aircrafts and aerospace	Combustion engines	High temperature	PTFE (5-50%)
	Hydraulic systems incl. control valves[106]	Anti-erosion, temperature resilience, chemical stability	Potassium decafluoro(pentafluoroethyl)cyclohexanesulphonate ('low concentration' in ppm range) 'PFAS' (another stakeholder refers to 'a PFAS' without further specification (50 ppm)
	Bearings	Thermooxidative stability, low vapour pressure, low flammability, chemically inert	PTFE (30-70%) PFPE (30–70%)
	Actuators of jet engines, and landing gears	Temperature, wear resistance, chemically inert, high pressure stability, minimal oil bleed	PTFE (10-30%)
	Engine starter spline shafts, hydraulic pumps splines and fuel pump splines in aircraft engines.	High/low temperature, low volatility	PFPE (grease)
	Brake and hydraulic fluids	High temperature	PFPE
	Bearings, gears and ball screws in electro-mechanical actuator. PFPE greases used due to wide operating window (-70 to 180), low starting torque and anti-fretting properties.	High/low temperature	PFPE (grease)

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[105] This use is not considered to be a lubricant use in the Annex XV restriction proposal that was submitted to ECHA on the 7th January 2023.

[106] PFAS additives in aviation hydraulic fluids is covered under the use category ‘Transport’ in the Annex XV restriction proposal that was submitted to ECHA on the 7th January 2023.

	Couplings, valves, regulators and seals (PFPE greases) in oxygen systems in space and aviation applications.	Contact with reactive, corrosive or explosive liquids and gases (oxygen compatibility and long time stability)	PFPE
	Moving parts of astronauts pressure suits.	Non-flammability	PFPE (oil)
	Bearings of antenna arrays on spacecraft's	Minimise ware and does not migrate to other parts of the system.	PFPE (oil)
	Bearings that permit extension of the paddle arms supporting solar cells on spacecraft's	Minimise ware and does not migrate to other parts of the system.	PFPE (oil)
	Slide wire of potentiometers in spacecraft's	Minimise ware and does not migrate to other parts of the system.	PFPE (oil)
	O-ring lubrication in spacecraft's	Contact with reactive, corrosive or explosive liquids and gases (inertness to fuels and oxidants)	PFPE (oil & grease)
	Flotation fluids in gyroscopes in aircrafts and missiles	Damping/reducing frictional loss	PCTFE (oil)
	Hydraulic oil and heat transfer fluids for aircrafts	Non-flammable, high temperature	PCTFE (oil)
	Oxygen delivery system to spacecraft oxidizer tanks	Contact with reactive, corrosive or explosive liquids and gases	PCTFE (oil)
	Breathing systems in airplanes and submarines	Low outgassing, Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE
Military – defence applications	Various military lubrication functions (e.g., aircraft and electronics)	Not specified	PTFE
Automotive	Combustion engines	High temperature	PTFE (5-50%)
	Friction reduction in various mechanical devices including automotive brake system components.	Low friction, chemical stability, compatibility with seals, noise reduction	PFPE (base oils) PFTE (lubricating aid and thickener)
	Bearings and throttle sensors	Temperature resistance, non-stick properties, good slide-ability	PTFE PFPE
	ESP systems in cars to measure turning speed of the wheels and many other applications.	Viscosity regulation, temperature resilience, water repellence, chemically resistant	PTFE
	Automotive Electrical Components and Auxiliary Components	Temperature resilience, chemical stability, arc-resistant, low vapour pressure/little outgassing	PTFE PFPE
	Mechanisms of the sliding of doors and windows	Temperature resilience	PTFE (10-30%)

	Mold release agents, assembly aids, grease for e.g., throttle sensors, bearings, moveable parts, seat rail, door hinge, switch actuation. NB! Unclear whether 'mold release' shall be seen a 'lubricant use'.	Non-stick, chemical stability, slidability, temperature, water repellence	PTFE (1-100%)
	Automotive interior. PFPE lubricants used to reduce noises, itch or judder were different materials comes into contact. Lifetime lubrication.	Various	PFPE
	Window wiper motors, electronic waste gate actuators, O-rings in fuel connectors (combustion engines), intake manifolds shaft and seals, EGR valves, overrun clutches, alternator bearings and water pumps. PFPE lubricants used for these applications due to high-temperature stability, chemical resistance and material compatibility.	High temperature	PFPE
		Several stakeholders refer to "Lifetime lubrication" of 'various car parts', which would otherwise need to be re-lubricated every year if more mainstream lubricants were used	
Trains	Valves in powertrains	High temperature resilience; chemical resistance	PTFE PFPE
	Train door lubrication	Temperature resilience	PTFE (10-30%)
Nuclear	Bearings in pumps	Resistance to degradation caused by radiation, no-sludge and gum formation	PFPE
	Laboratory glassware to prevent locking	Temperature reliance and chemical inertness	PTFE
	Bearings and other moving parts	Low friction	PTFE
	Critical bearings, manipulator greases for nuclear waste handling, fuel manufacturer equipment lubrication, compaction equipment lubrication for example.	Chemically inert, temperature resilience, low friction	Fluoropolymer (not further specified)
	Anti-galling thread lubricant for stainless steel assemblies	Contact with reactive, corrosive or explosive liquids and gases	PCTFE
	Lubricant for processing uranium hexafluoride	Resistance to degradation caused by radiation	PCTFE
	Oil for use in nuclear service	Hydrogen-free oil	PCTFE (oil)
	Lubrication of controls for nuclear applications		PCTFE (grease)

Watchmaking	Lubricants, greases, and epilames. Note from a stakeholder in the response to the CfE: "*Strictly speaking, epilames are not lubricants nor greases. Epilames are antispreading coatings involved in the lubrication process.*"	Very high stability, extremely low pour point, anti-wear additives, excellent water demixion, extremely low surface tension, etc.	Fluorinated polymers + From C3 to C6 fluorinated chains (not further specified)
Hearing loss applications	Vacuum pumps and bearings during production. Note that it is not clear whether the PFAS as lubricant also plays a role in the final products, but possibly comparable to epilames in watches (see above).	Temperature resilience and low degradation/chemical stability, UV-resistance	PFPE PTFE
Electronics (including semi-conductor)	Electric circuit breakers	Temperature resilience, chemical stability, arc-resistant, low vapour pressure/little outgassing	PTFE
	Semi-conductors manufacturing: Multiple uses, such as wafer handling mechanisms, vacuum grease, linear guides of multibeam inspection stage, source mirror actuators, and several other bearing applications.	Low friction	PFPE PTFE
	Working fluid and seals in vacuum pumps exposed to aggressive environment	Contact with reactive, corrosive or explosive liquids and gases	PFPE (oil)
	Emergency smoke ventilation fans in e.g., tunnels.	Temperature resilience (the fans needs to function at 400°C for 2h)	PFPE (grease)
	Grease for sliding contacts in electric switch and for push-buttons	Non-oxidizable, non-flammable, lifetime lubrication	PFPE
	Rack and pinion disk drive lubricant	Temperature resilience	PFPE
	Spindle and actuator bearings in disk drives	Temperature resilience	PFPE
	Top coating lubricant on computer disc drives	Low outgassing	PFPE
	Vacuum pump oil for semi-conductor manufacturing equipment	Temperature resilience, low outgassing	PCTFE (oil)
	Vacuum pump oil for equipment used to plasmadesmear multi-layer printed circuit boards	Temperature resilience, low outgassing	PCTFE (oil)
	Inert grease for semi-conductor processing equipment	Chemically inert	PCTFE (grease)
	Vacuum pump oil for equipment used to plasma clean electronics and medical devices	Temperature resilience, low outgassing	PCTFE (oil)
	Instrument fill fluids where strong oxidizing agents prelude the use of glycerine or silicon oil fill fluids e.g.: Diaphragm seals, pressure gauges, manometers, dead weigh testers and sensors.	Chemical stability in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oil)

Laboratory supplies, equipment, and instrumentation	Diagnostically and optical equipment: Lubrication of moveable parts, for instance ball-bearings in various applications where parts need to be moved without friction	Low outgassing	PTFE PFPE
	Bearings, jewels, and pivots in many kinds of instruments	Not specified	PFPE
	Optical instruments and light housings where lubricant condensate needs to be minimised.	Low outgassing	PFPE
	Wax coating to protect glass from attack by aggressive compounds	Chemical stability in contact with reactive, corrosive or explosive liquids and gases	PCTFE (grease/wax)
	Vacuum pump oil for mass spectrometers		PCTFE (oil)
Hospital equipment	Valves, fittings, O-rings, pressure gauges in oxygen enriched environments (ventilators)	Very low vapour pressure. Long-term stability and functionality.	PFPE/PFTE
	Medical injection device (Syringe, pumps, pens)	Low friction	Fluorocarbon gel (not further specified)
	Hospital (and home oxygen systems/units). Hyperbaric oxygen chambers. Anaesthesia machines. Nitrous oxide systems.	Life-supporting systems where an oxygen-enriched atmosphere (>23% O2) or high-pressure air is required	PCTFE (oils and greases)
Renewable energy	Wind power – lubrication of screws, nuts, magnetic anchors, bolts etc.	Low friction; very good wear-resistant and tribologically irreplaceable properties	PTFE (0.25 – 25%)
	Wind power (bearings)	High temperature resilience; chemical resistance	PTFE PFPE
	Fuel cell technology – assembly aid e.g., grease for O-rings	Excellent tribological properties, very good friction properties, eliminate noise, easy assembly	PTFE PFPE
	Energy storage and energy conversion via hydrogen such as PEM – bearings and as lubricant additive in plastics	Temperature, low outgassing (vacuum, applications)	Fluoropolymer (not further specified)
Off-shore / Oil & gas	Lubrications of screws, nuts, magnetic anchors, bolts etc.	Low friction; very good wear-resistant and tribological properties	PTFE (0.25 – 25%)
	Casing/tubing sealants for high-definition threads in high chrome steel	Not specified	PTFE
	Bearings	Thermooxidative stability, low vapour pressure, low flammability, chemically inert	PTFE (30-70%) PFPE (30–70%)
	Sealing systems for centrifugal and rotary pumps	Chemically stable in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oils)
	Antiseize lubricant for drilling tools in hydrogen sulphide environments		PCTFE

	Alkylation lubricant (compatible with HF and sulphuric acids)		PCTFE
	Instrument fill fluid for oil exploration equipment		PCTFE
Chemical industry	Machinery for production of oxidising chemicals	PFAS-based lubricants do not react with oxygen and thereby lower/prevent the risk of fire, auto ignition and explosion compared to other types of lubricants	PTFE
	Bursting discs and gaskets for heat exchangers, synthesis units and reactors	Chemical inertness	PTFE
	Valves, fittings, couplings, O-rings and seals exposed to reactive and corrosive chemicals.	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PFPE
	Chlorine (and bromine) industry: Vacuum pump oils, compressor oil, valve and plug cock grease, lubrication for chlorine vaporiser, valve stem lubricant, assembly and repair of chlorine cylinder valves, tank car maintenance (valves), thread lubricant	Chemical resistance in aggressive environment	PCTFE (Oils and greases)
	Sealing systems for centrifugal and rotary pumps. Sealing systems for rotary agitators and mixers in reactive chemical processes. Sealants for flange faces.	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (Oils)
	Lubricants for equipment used in the fluorination process for blow-molding polyethylene bottles and gasoline tanks	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE
	Sulphur trioxide spill control mixture	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (oil slurried with hollow glass beads)
Bulk gas industry	Oxygen service - lubricants for remote control solenoid valves, thread lubricant, instrument fill fluid, rotary meter lubricant, diaphragm compressor oil, vacuum pump oils for evacuating oxygen cylinders and bulk (cryogenic) storage tanks, vacuum pump oils for oxygen plasma cleaning, bearing grease for liquid oxygen (LOX) pumps and lubricant for compressors in portable oxygen plants	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (Oils and greases)
	Welding gases - lubricants for bearings in LOX pumps and vacuum pump oils for evacuating oxygen cylinders	Low outgassing, Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (Oils)

	Helium service - oil for helium compressors and lubricants for helium regulators	Low outgassing, Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (Oils)
	Carbon dioxide pump oil	Low outgassing	PCTFE (Oils)
Metalworking industry	Cutting/drawing/forming oil for processing refractory metals such as tantalum, molybdenum, tungsten, rhenium, titanium and niobium		PCTFE
	Manufacture of woven wire and cable for safe use in aggressive applications	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE
	Additive to other cutting oils for enhanced tool life		PCTFE
	Machining of high nickel alloys		PCTFE
Steel industry	Grease for swivel joints in oxygen delivery systems and oxygen heating systems	Chemical inertness in contact with reactive, corrosive or explosive liquids and gases	PCTFE (grease)
Water and wastewater treatment	Wastewater chemicals - lubricants that are compatible with water treatment chemicals that are used in chlorinators, pumps valves etc.	PCTFE lubricants are compatible with e.g.: oxygen, ozone, hydrogen peroxide, chlorine, calcium hypochlorite, sodium hypochlorite and chlorinated cyanurates	PCTFE
	Swimming pool chemicals - lubricants compatible with compacting equipment for tableting swimming pool chemicals	PCTFE lubricants are compatible with e.g.: calcium hypochlorite and chlorinated cyanurates	PCTFE
	Lubricant encased within peristaltic pumps which are used in applications of the potable water industry for chemical dosing	Chemical inertness	Not specified
Diving equipment	Diving Equipment with O_2 contact	PFAS-based lubricants do not react with oxygen and thereby lower/prevent the risk of fire, autoignition and explosion compared to other types of lubricants	PTFE
	Valves, fittings, O-rings, pressure gauges in oxygen enriched environments	Long-term stability and functionality is crucial	PFPE
	Diving gear	Life-supporting systems where an oxygen-enriched atmosphere (>23% O_2) or high-pressure air is required	PCTFE (oil and grease)
Handicap assistant equipment (medical devices)	Prosthesis, orthosis, wheelchair, exoskeleton etc.; piston and gear wheel applications; Lubricant additive in plastic components	Temperature resilience, chemically resistant, non-stick, not flammable, noise reduction	PTFE

Paper	Roller bearings of corrugated paper machinery	High temperature resilience	PTFE (3-100%) PFPE (3-100%)
	Lubrication processes in relation to pulp-bleaching chlorine, sodium chlorate, chlorine dioxide, oxygen and hydrogen peroxide.	Chemical compatible with: chlorine, sodium chlorate, chlorine dioxide, oxygen and hydrogen peroxide	PCTFE
Plastics	Polymer processing industry (injection mould lubrication). Often micro-powder PTFE is added as lubrication/polymer processing additive to the polymer before processing (internal lubrication). Lubrication of ejector pins, sliders, folding units and sliding surfaces in plastic injection molding tools (external lubrication).	Temperature resilience, low friction	PTFE (5-30%) PFPE (5-30%)
	Lubrication on silicone cable accessories	PFPE is compatible with silicone	PFPE
	Bearings that support chains that runs through an oven. Plastic film are generally heat-treated in continuous ovens at high temperatures (> 200°C)	High temperature resilience	PFPE
Rubber/tire industry	Lubrication of tire molds to reduce galling, roughing or warping at movable joints.	High temperature resilience	PFPE (grease)
Textile	Bearings that support chains that runs through an oven. Textile are generally heat-treated in continuous ovens at high temperatures (> 200°C).	High temperature resilience	PFPE
Pharmaceutical industry	Clean room applications (including robots in clean room)	Low outgassing	PFPE
Consumer	Dry-film lubrication of bike chains		PTFE
	Dry-film lubrication of Waterproof zippers		PTFE
Other sectors and industrial applications not specifically mentioned above: Agriculture, construction, fluid power, process industries, robots and robotics, 3-D printing at industrial scale, power and energy distribution, district energy and building automation, metallurgy	Chains, bearings/ball-bearings/sliding bearings, pivots, valves, and self-operated regulators	Various	PFTE PFPE Various PTFE and PFPE combinations
	Plain bearings for e.g., hinges, seat recliners, vibration dampers, chain tensioners, shock absorbers, pumps, ropeway suspensions, etc.		
	All kinds of industrial machines with moving parts		
	Valves		
	Dry lubrication for assembly of bolts, screws nuts and joints in general		

and mining, marine equipment, pulp and paper, machinery sector (e.g., snow blowers, lawn movers, gears and belts of conveyers)	Various 'oxygen service' applications, i.e., lubrication in systems with a high risk of contact with high oxygen concentration (e.g., when applying some types of pumps).
	Mechanisms and devices under high vacuum
	Offices machines, including heaters and printers
	Power tools
	Lifts and escalators

TABLE 24. Overview of examples of PFASs and examples of their uses in lubricants, according to ATIEL (The Technical Association of the European Lubricants Industry)

CAS No	CAS Name	Concentration [%]	Product Type	Sector Use	Applications and associated key properties (as stated by ATIEL)	Essentiality (as stated by ATIEL)	End use
161075-14-5	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymerized, reduced hydrolyzed	>=0.1-<1	AEROSOL	Various Industries with approval	Open or closed, high temperature	Essential	Industrial / Professional
161075-14-5	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymerized, reduced hydrolyzed	>=1-<5	SOLID LUBRICANT	Various Industries with approval	Open or closed, high temperature	Essential	Industrial / Professional
163702-05-4	Ethylnonafluorbutylether	<0.1	CLEANING AGENT (Liquid, Aerosols)	Switch cabinets, fuse boxes, transformers in electric power plants and wind power under high voltage	Open process	Essential	Industrial
163702-06-5	Ethylnonafluorisoylether	<0.1	CLEANING AGENT (Liquid, Aerosols)	Switch cabinets, fuse boxes, transformers in electric power plants and wind power under high voltage	Open process	Essential	Industrial
163702-07-6	methyl nonafluorobutyle ether	>=20-<50	CLEANING AGENT (Liquid, Aerosols)	Switch cabinets, fuse boxes, transformers in electric power plants and wind power under high voltage	Open process	Essential	Industrial
163702-07-6	methyl nonafluorobutyle ether	>=20-<50	LUBRICATING GREASE	Automotive	closed, High temperature	Essential	Industrial
163702-08-7	Propane, 2-(difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro-	>=20-<50	CLEANING AGENT (Liquid, Aerosols)	Switch cabinets, fuse boxes, transformers in electric power plants and	Open process	Essential	Industrial

				wind power under high voltage			
163702-08-7	Propane, 2-(difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro-	>=20-<50	LUBRICATING GREASE	Automotive	closed, High temperature	Essential	Industrial
355-42-0	Tetradecafluorhexan	>=10-<20	CLEANING AGENT	Various Industries	closed	Essential	Industrial
406-58-6	1,1,1,3,3-pentafluorobutane	>=50-100	CLEANING AGENT	Various Industries	closed	Essential	Industrial
60164-51-4	Perfluoroalkylether	<0.2	Transmission Oils; Hydraulic Oils, Shock Absorber Oils	Automotive with Approval	Closed applications, Lifetime Lubrications	Essential	Industrial
60164-51-4	Perfluoroalkylether	>=50-100	LUBRICATING GREASES	Food Industry	Closed, High Temperature; Non-Toxic	Essential	Industrial
60164-51-4	Perfluoroalkylether	>=50-100	LUBRICATING OIL	Food Industry	Closed, High Temperature; Non-Toxic	Essential	Industrial
63148-56-1	Siloxanes and Silicones, Me 3,3,3-trifluoropropyl	<0.01	Hydraulic Oil	Automotive with Approval	Closed, High Pressure	Essential	Industrial
65530-69-0	Poly(difluoromethylene), α-[2-[(2-carboxyethyl)thio]ethyl]-ω-fluoro-, lithium salt (1:1)	<0.1	SOLID LUBRICANT	Construction	open	Substitutable	Professional
65545-80-4	Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly(difluoromethylene) (1:1)	>=0.1-<1	SOLID LUBRICANT	Chemical Industry, Aggressive chemicals	Closed	Essential	Industrial
68134-22-5	N-(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxo-2-[[2-(trifluormethyl)phenyl]azo]butyramid	>=0.1-<1	SOLID LUBRICANT	Chemical Industry, Aggressive chemicals	Closed	Essential	Industrial
69991-61-3	Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd.	up to 100	LUBRICATING GREASES	Automotive with Approval; Food Industry; Chemical Industry	Closed, High Temperature; Non-Toxic; Aggressive Chemicals	Essential	Industrial

69991-67-9	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.	up to 100	LUBRICATING GREASE, also as AEROSOL	Automotive with Approval; Food Industry; Chemical Industry	Closed, High Temperature; Non-Toxic; Aggressive Chemicals	Essential	Industrial
69991-67-9	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.	>=1-<5	CLEANING AGENT	various Industries	closed	Essential	Industrial
69991-67-9	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.	<0.1	Shock Absorber Oil	Automotive with Approval	Closed, High Pressure	Essential	Industrial
69991-67-9	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.	>=50-100	LUBRICATING OIL	Automotive with Approval; Food Industry; Chemical Industry	Closed, High Temperature; Non-Toxic; Aggressive Chemicals	Essential	Industrial
9002-84-0	Poly(1,1,2,2-tetrafluoroethylene); PTFE	Up to 50	LUBRICATING GREASES	Drinking Water Applications with approval; Automotive Industry with Approval; Food Industry; Chemical Industry	closed, High temperature; Lifetime Lubrication; Non-Toxic, Aggressive Chemicals, Safety Relevance	Essential	Industrial / Professional
9002-84-0	Poly(1,1,2,2-tetrafluoroethylene); PTFE	up to 100	SOLID LUBRICANT	Drinking Water Applications with approval; Automotive Industry with Approval; Food Industry; Chemical Industry	closed, High temperature; Lifetime Lubrication; Non-Toxic, Aggressive Chemicals, Safety Relevance	Essential	Industrial / Professional
9002-84-0	Poly(1,1,2,2-tetrafluoroethylene); PTFE	>=1-<10	LUBRICATING OIL	Chemical Industry, High Temperature / Aggressive chemicals	Closed applications, Lifetime Lubrications	Essential	Industrial
9002-84-0	Poly(1,1,2,2-tetrafluoroethylene); PTFE	up to 5	-	Drinking Water Applications with approval; Automotive Industry with Approval; Food Industry; Chemical Industry	closed, High temperature; Lifetime Lubrication; Electro Engines; Non-Toxic, Aggressive Chemicals, Safety Relevance	Essential	Industrial / Professional

1187440-14-7	Tetrafluoroethylene,oxidized,oligomers,reduced,fluorinated	up to 100	PFPE Oil	Automotive, Semiconductor	Closed, high temperature lifetime lubrications. Non-toxic	Essential	Industrial
370097-12-4	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd., reduced, hydrolysed reaction products with ammonia	up to 100	PFPE Oil	Automotive, Semiconductor	Closed, high temperature lifetime lubrications. Non-toxic	Essential	Industrial
661476-68-2	Tetrafluoroethene, oxidized, polymd., reduced, Me esters, reduced, 2,4-dinitrophenyl ethers	up to 100	PFPE Oil	Automotive, Semiconductor	Closed, high temperature lifetime lubrications. Non-toxic	Essential	Industrial
86508-42-1	Perfluoro compounds, C5-18	up to 50	Lubricating fluid	Solvent used for diluting grease for application for connector greases in the automotive and electronic industries	Open, low temp	Essential	Industrial

Appendix 3. Assumptions used for emission estimates

This section provides the tables of assumptions used to help develop the emission estimates under Task 3. Which is covered by Chapter 4 of the current report.

TABLE 25. Summary of assumptions and factors applied to data (Lubricants)

Component	Value	Assumption and justification
Formulation of lubricants within the EU. Includes the filling of sealed articles for manufacture.	Quantities of PFASs (by group) used. PTFE (low MW) Micro powder = 1,200 tpa (split between consumer uses 84tpa and non-consumer uses 1,116tpa) PFPEs = 800 tpa PFAS-based additives (other than micro-powder PTFE) = 10tpa	**Assumption**: The market data provides usage rates for different PFAS groupings as a range. In each case the upper limit of the range has been used. **Justification**: Assumes a worst-case scenario and utilises the maximum amount of PFAS for each grouping.
Formulation of lubricants within the EU. Includes the filling of sealed articles for manufacture.	Total use of PFAS-solvents in lubricating applications 70 – 150tpa. However, this includes products where primary function is cleaning and secondary function is lubrication. The total quantity is split in two, with 50% used on cleaning products (out of scope), and 50% used within applications where the PFAS is used as a carrier/deposition solvent to leave final lubricating material. PFAS-solvents (carriers and deposition solvents) = 75tpa	**Assumption**: Total quantity is split evenly between cleaning products and carriers / deposition solvents in lieu of better data. The former category is out of scope. No data on split so assume 50:50. **Justification**: In the absence of any other data, an even split is used to avoid double counting.
Formulations used for sealed articles. One-time application at point of manufacture.	The following shares of total use of each substance group is assumed to be used in sealed articles: PTFE (consumer): 95% (80tpa) PTFE (non-consumer): 95% (1,060tpa) PFPEs: 95% (760tpa) PFAS-solvents (carriers/deposition solvents): 100% (75tpa) PFAS-based additives: 95% (9.5 tpa)	**Assumption**: The range provided by industry is 95-97%. Assume a worst-case scenario where the higher amount (5%) is used in open applications. **Justification**: Industry provides a range for use in sealed applications. We would assume emissions from sealed units are lower than open applications. Therefore, to adopt the worst-case position assume the higher amount (5%) is used in open applications.

Emission factors during formulation and filling of lubricants in sealed articles.	Use Environmental Release Category (ERC) emission scenario no.2 for 'formulation into a mixture' 2.5% w.w to air 2% w.w to wastewater and 0.01% w.w to soil.	**Assumption**: Data on emissions during formulation and filling of articles is very limited. In lieu of presentative data ERC emission factors have been used as standard defaults to help guide the estimates.
		Justification: Formulation of lubricants is likely to happen at elevated temperature, meaning that while volatility of PFAS varies by species there may be air emissions. Equally, it is possible during filling of articles that there may be spillages/leaks which would further contribute to emissions.
In-use (sealed articles) Quantities split between outdoor and indoor applications.	Assume by quantity: 30% used in outdoor applications. 70% used in indoor applications.	**Assumptions**: Based on the major sectors of use listed in Section A.2, which provides a breakdown for quantities of PFASs by sector, an expert judgement has been applied to aggregate sectors into outdoor or indoor categories. For example, it is assumed that automotive uses would be outdoor applications, while food processing industry (equipment) would be indoor
		Justification: The pathway to environment is likely different for outdoor and indoor applications. Therefore, it is important that the quantities in use are disaggregated accordingly. A combination of market data and expert judgement has been applied to assign sectors to outdoor/indoor categories.
In-use (sealed articles) Emission factors Outdoor applications.	Use ERC emission scenario no. 9b for 'widespread use of functional fluid (outdoor)' 5% w.w to air 5% w.w to water and 5% w.w to soil.	**Assumption**: There is very little data on this aspect other than assertions by industry that leaks / accidental release from sealed applications are very low. As the estimates here are presented as a high-level set of estimates spanning potentially a large number of specific applications a more general approach is needed. The ERC emission factors have therefore been applied.
		Justification: The emissions identified here cover leaks, accidental release from faulty equipment, possible release during maintenance (e.g., roadside assistance for automotive). The specific release on an article by article basis is likely to vary significantly for a range of factors (including type of equipment, fill-size, accessibility of the article in larger components, and external pressures). Assertions from industry are that losses during service are very low (<1% w.w) therefore these estimates should be assumed as worst-case.
In-use (sealed articles) Emission factors Indoor applications	Use ERC emission scenario no.9a for 'widespread use of functional fluid (indoor)' 5% w.w to air 5% w.w to wastewater 0% w.w to soil Emissions to soil are not applicable.	**Assumption**: see previous row for emissions outdoor. The same logic has been applied for indoor.
		Justification: see above.

In-use (open applications) Quantities split between outdoor and indoor applications.	No data on where this takes place, given the nature of this activity it could readily be indoors or outdoors. In lieu of better data assume a 50% split to each compartment.	**Assumption**: Open applications use includes activities where re-lubrication is applied to e.g., gears, chains etc. This could be done in the open environment, or within closed environments. **Justification**: see above.
In-use (open applications) Emission factors Outdoor applications	Use ERC emission scenario no.8d for 'widespread use of non-reactive processing aid (no inclusion into or onto article) (outdoor)' 41% w.w to air 41% w.w to water and 8% w.w to soil. *Note amendment to ERC. See assumptions.	**Assumption**: The market data identifies a second set of applications where PFAS based lubricants are used in open applications (e.g., specialist products for bike chains) where full release is likely and re-lubrication will be needed periodically. The ERC 8d covers this type of application but assumes that there will be a 100% release. In reality it is likely that a small quantity of lubricant will remain – either as residue on the applied surface or as left-over quantities within the product bottle. No data has been identified to quantify this aspect. **Justification**: a minor use identified during the stakeholder engagement covers uses in open applications where total loss is likely, including the need for re-lubrication. Total loss would assume 100% release to environment. In reality it is likely there will be residues both on the contact surface treated and as trace residues at the bottle of the bottle for the lubricant as supplied. It is possible that these quantities are very small.
In-use (open applications) Emission factors Indoor Applications	Use ERC emission scenario no.8a for 'widespread use of non-reactive processing aid (no inclusion into or onto article) (indoors)' 45% w.w to air 45% w.w to wastewater and 0% w.w to soil. *Note amendment to ERC. See assumptions.	**Assumption**: see above for open uses **Justification**: see above for open uses
Waste Selection of waste pathways.	It is assumed that 95% of all sealed articles (all uses) enter the waste stream for processing, primarily as WEEE at authorised treatment facilities (ATF), but secondarily through other controlled waste flows (i.e., not landfill). It is assumed that 5% of all sealed articles enter landfill. It is assumed any residues from open applications enter the thermal destruction pathway. All PFAS entering the wastewater pathway comes from the applied ERC emission factors at earlier lifecycle stages (particularly formulation).	**Assumption**: the feedback from the CfE, stakeholder engagement and survey of data suggests that the high majority of PFAS-based lubricants are used in sealed articles, primarily within electrical or electronic equipment, including vehicles (subject to the ELV Directive). Therefore, it is assumed the very high majority of remaining PFAS within sealed articles enters the WEEE / ELV pathway and processing at ATFs. For some applications, the components may be very small (e.g., sensors, small bearings etc.) and it is possible that such items are discarded during maintenance to landfill pathways. **Justification**: Efforts have been made across the EU as part of the management of waste and circular economy to rely on landfill less and less. Although it should also be noted that use of landfill varies Member State by Member State. As indicated in the assumptions, it is likely that the high majority of applications using

		PFAS-based lubricants will be within applications subject to WEEE or ELV Directives and therefore processing at authorised treatment facility (ATF) is likely the primary pathway. The estimate of 5% to landfill is intended to reflect that some materials will go via this pathway. It is possible that 5% may be an underestimate, but in lieu of better data this has been applied.

Note: *) A more precise estimate has been used in the source-flow model, but a wider range is presented here to protect potentially sensitive/confidential market information.

TABLE 26. Summary of assumptions and factors applied to data (construction products)

Component	Value	Assumption and justification
Formulation (Type 1) covering the production of articles containing or made from fluoropolymer and non-polymeric PFAS	Quantities of PFAS (by group) used. PTFE (High MW) = 760 tpa ETFE = 460 tpa PVDF = 103 tpa Other fluoropolymer substances = 28 tpa Non-polymeric PFAS = 678 tpa	**Assumption**: The market data provides usage rates for different PFAS groupings as a range (see Table 1). In each case the upper limit of the range has been used.
		Justification: Assumes a worst-case scenario and utilises the maximum amount of PFAS for each grouping.
Formulation (Type 1) covering the production of articles containing or made from fluoropolymer and non-polymeric PFAS	For fluoropolymer and non-polymeric PFAS emission factors based on Environmental Release Category (ERC) no.3: Air = 1% Wastewater= 0.2% Soil = 0.1%	**Assumption**: Data on emissions during formulation of articles is very scarce. Feedback from stakeholder under the first CfE commented that dust minimisation and capture is used as a standard practice to control emissions and prevent worker exposure. In lieu of better data ERC no.3 has been used covering: 'formulation into a solid matrix'.
		Justification: Estimates for releases is very limited, feedback from industry asserts that emissions are very low and efforts are made to capture and control any dust or vapours generated. The selected ERC default emission factor best represents this set of activities.
Formulation (Type 2) covering the production of commercial construction mixtures containing or made from fluoropolymer and non-polymeric PFAS	Based on total use – PTFE (low MW) = 3 338tpa ETFE = 2 024tpa PVDF = 451tpa Other fluoropolymer substances = 122tpa Side-chain polymers = 30tpa Non-polymeric PFAS = 314 tpa	**Assumption**: Gluge et al (2020) comments that 95% of paints and surface coatings are polymeric, assuming the remaining 5% are non-polymeric. The extrapolated values from Glüge et al (2020) (3 700 tonnes per annum) have been used to apportion between polymeric and non-polymeric. The polymeric substances have then been further disaggregated based on the ratios between PTFE and the other major fluoropolymers in Table 1.
		Justification: Extrapolation of key references and data provided through the CfE has been used to estimate quantities in use, due to a lack of good quality market data.
Formulation (Type 2) covering the production of commercial construction mixtures containing or made from fluoropolymer and non-polymeric PFAS	Use ERC emission scenario no.2 for 'formulation into a mixture' 2.5% w.w to air 2% w.w to wastewater and 0.01% w.w to soil.	**Assumption**: Data on emissions during formulation of mixtures (including blending and elevated temperatures) is very limited. In lieu of presentative data ERC emission factors have been used as standard defaults to help guide the estimates.
		Justification: Formulation of mixtures spans a wider set of applications from paints, adhesives sealants and commercial mixtures used to treat articles. It is likely that emissions will vary on

		a process by process basis, but as a high level approach, the use of ERC default emission factors is justified.
Processing aids (Formulation Type 3)	Assume use quantity: 678 tonnes of non-polymeric PFAS.	**Assumptions**: Very little available data to guide on the use of non-polymeric PFAS in production of articles (Gluge et al (2020) identifies a broadly even split between polymer and non-polymer). In lieu of better data assume that half of all non-polymeric PFAS is used as processing aids in the production of articles. **Justification**: There is limited detail on this topic, however, the high majority of feedback for the use of non-polymeric PFAS in the CfE relates to the use as processing aids in the production of other articles. In some cases, these substances are used with fluoropolymers such as PTFE and in other cases with non-fluorinated polymers such as polypropylene.
Processing aids (Formulation Type 3)	Use ERC emission scenario no.4 for 'use of non-reactive processing aid at industrial site (no inclusion into or onto article' 0.05% w.w to air 0.05% w.w to wastewater and 0.002% w.w to soil.	**Assumption**: As with the other stages there is very limited emission monitoring data. However, feedback from one stakeholder identifies the use of processing aids in the production of construction products where the processing aid is captured within closed systems and re-used. **Justification**: based on the feedback from industry stakeholders the emissions to air in particular look broadly in line with feedback provided. The estimates for wastewater may be an overestimate and should be considered a conservative worst-case.
Application Proportional splits for articles and commercial construction mixtures.	Assume in lieu of better data a 50:50 split between outdoor and indoor applications for both articles and commercial construction mixtures.	**Assumption**: No data available to help guide. Have assumed an even split to remain neutral. **Justification**: see above.
Application assumes emission factors for commercial construction mixtures outdoors.	Use ERC emission scenario no.5 for 'use at industrial site leading to inclusion into/onto article' 24.8% w.w to air 24.8% w.w to water and 0.2% w.w to soil.	**Assumption**: The application of mixtures may cover a very wide range of activities with varying potential for release to air, land, and water. In lieu of more data have assumed the most appropriate ERC default factors. **Justification**: Given the likely wide variation in specific activities these ERC factors represent the best estimate.
Application assumes emission factors for commercial construction mixtures indoors.	Use ERC emission scenario no.5 for 'use at industrial site leading to inclusion into/onto article' 24.8% w.w to air 24.8% w.w to wastewater and 0.2% w.w to soil.	**Assumption**: The application of mixtures may cover a very wide range of activities with varying potential for release to air, and wastewater. In lieu of more data have assumed the most appropriate ERC default factors. **Justification**: Given the likely wide variation in specific activities these ERC factors represent the best estimate.
In-use phase, outdoor applications. Emission factors.	Use ERC emission scenario no.10a for 'widespread use of articles with low release (outdoors)' 0.05% w.w to air	**Assumption**: Both fluoropolymers and non-polymeric PFASs are known to be hard wearing and highly stable to forms of degradation. During the use phase outdoors the primary pathways for emission will be weathering and abrasion from physical /mechanical activities. However, emissions could be expected to be low overall warranting the ERC 10a emission factors.

	1.6% w.w to water and 1.6% to soil	**Justification**: The level of weathering and emissions is likely to vary depending on specific PFAS substance, application, and climate. In lieu of specific data the default values provide a high-level estimate.
In-use phase, indoor applications. Emission factors.	Use ERC emission scenario no.11a for 'widespread use of articles with low release (indoors)' 0.05% w.w to air 0.05% w.w to wastewater and Emissions to soil not applicable.	**Assumption**: As with outdoor applications, the hard-wearing nature of fluoropolymers and non-polymeric PFAS should mean low emissions overall. Primary processes for indoor environments will be contamination of dust through contact with treated surfaces and abrasion through physical /mechanical forces. **Justification**: see same justification for outdoor environments.
Waste	Assume quantities to reach wastewater treatment plants based on preceding steps. Assume all articles made from or containing PFAS not emitted during earlier life-cycle stages enter waste. It is possible that surfaces covered with PFAS based coatings enter the waste cycle (e.g., during repair or demolition), however, the majority of coatings are likely to remain in place with new coats painted on top of old. Therefore, without the necessary data to calculate how much of the coating enters waste it is assumed surface coatings do not enter the waste stage.	**Assumption**: This final stage builds upon the preceding steps to quantify materials entering waste. No further estimates are provided for emissions during the waste cycle. **Justification**. Assumed waste processes based on the logical flow of material.

PFAS and fluorine-free alternatives in lubricants and construction products
The aim of this project was to assess the use of PFAS-based lubricants and construction products along with any fluorine-free alternatives. Additionally, data on emissions, economics and social impacts of a full ban of all PFAS within these sectors have been evaluated.
This report goes beyond the Universal PFAS restriction proposal and the content of the Annex XV restriction dossier as it provides more granular data on substance identification, technical description of uses and emissions (broken down by multiple environmental compartments). This recognises that the Annex XV dossier covers all potential uses of PFASs and thus through necessity works to a higher level of disaggregation.

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