Report summary lubricants

Contents

1. Uses / Applications

Based on Call for Evidence (CfE), stakeholder consultation and literature the uses for lubricants have been presented per sector / industry. The list is not necessarily exhaustive, fluorinated lubricants can be applied in almost any sector.

Table 1. Identified uses of PFAS 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[1]). • As a lubrication additive on the inside coating of metal food and beverages containers - it enables filling without damaging the coating.
Aircraft/aerospace	• Combustion engines • Hydraulic systems incl. control valves (Note: NB! This might or might not be considered a 'lubricant use', but is following advice from the Danish EPA kept here as it is not part of other work packages contributing to the wider PFAS restriction proposal) • Bearings • Actuators of jet engines, and landing gears
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 Note: This might or might not be considered a 'lubricant use', but is following advice from the Danish EPA kept here as it is not part of other work packages contributing to the wider PFAS restriction proposal)
Trains	• Valves in powertrains • Train door lubrication

[1] "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

Sector/industry	Examples
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, greases, and epilames. <u>Note from a stakeholder in the response to the CfE: "Strictly speaking, epilames are not lubricants nor greases</u>. Epilames are antispreading coatings involved in the lubrication process."
Hearing loss applications	• Vacuum pumps and bearings during production. <u>Note that it is not clear whether the PFAS as lubricant also plays a role in the final products</u>, but possibly comparable to epilames 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
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)
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 • Bursting discs and gaskets for heat exchangers, synthesis units and reactors
Diving equipment	• Diving Equipment with O2 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 (Note: <u>This might or might not be considered a 'lubricant use'</u>, but is following advice from the Danish EPA kept here as it is not part of other work packages contributing to the wider PFAS restriction proposal)

Sector/industry	Examples
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. Main PFASs

Information on substances has been identified via the Call for Evidence, via subsequent targeted stakeholder consultation and via literature.

2.1 Tonnage bands

In the following table estimates based on various input from the industry are listed for groups of PFAS. Trade associations have been hesitant in providing data for competitive reasons, so the following is largely based on estimates 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. The numbers presented here are rounded off to protect potentially sensitive and confidential market data. 39 individual substances are identified via these sources, which can be grouped into the following main categories:

Table 2. Total PFAS and main substances or substance groups identified and size of the EU market.

Group/substance	EU market for lubricants (Tpa)	Source
PFAS	1,600[1]	Extrapolation of tonnages PFAS used in lubricants, estimated by Glüge et al (2020) [2] based on the SPIN (Substances in Preparations in Nordic Countries) database
PTFE (Poly(1,1,2,2-tetrafluoroethylene)	<2,000	Based on stakeholder input for total EU market (4,000-5,000 tpa) and stakeholder input on lubricants
PFPE (Perfluoropolyether)	<1,000	Based on references to market surveys, and several stakeholder estimates
Additives (several individual substances which are not specified)	<20	Only very little stakeholder input on the market volumes of these PFAS in these applications has been received, but ranges in the following orders of magnitude are assumed
Solvents (several individual substances which are not specified)	<200	
One other substance that could not be associated with any of the above groups	-	No further information given on this substance in the report

1: Extrapolated tonnages PFAS used in lubricant in the EEA

2: 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.

The use of PFAS anti-erosion/anti-corossion additives in aviation hydraulic fluids is separately noted and judged to be around 1,000 kg/year. This amount is based on a Stockholm convention guidance document which indicates the use of 730 kg PFAS/year in the EU in 2000 for this purpose.

2.2 Import/export

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. 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 has been identified or received.

3. Manufacturing & Market price + market development

3.1 Market price

In terms of the relative market share of fluorinated lubricants to the total lubricants market, stakeholder input suggests that fluorinated lubricants account for less than 1% of the overall lubricants market in terms of tonnage, but likely a much larger share in terms of turnover, reflecting the much higher price of PFAS-based lubricants on average, compared to other lubricants.

No other information is given related to market price.

3.2 Market development

An estimate of usage as far forward as 2050 has been made. In current context the usage projections have been based on market trend data and, 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.

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

- Historically, the use of fluorinated 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.

PTFE micro-powders

The EU is currently in the process of implementing a restriction on the intentional use of microplastics with the combined opinion of the RAC and SEAC presented to the Commission in February 2021. Based on this some applications of PTFE micropowders, that are believed to exist in the 0.25 - 500µm (0.5mm) range, fall well within the scope of the microplastic restriction[2]. The implementation of the restriction for the intentional use of microplastics is conservately estimated to be 2026. ECHA indicates that a vote on the restriction will likely take place in 2022 (given the current timetable). The implementation of a restriction will also likely include a transition period of 3-5 years to allow industry to transition away from current uses.

PTFE micropowder is produced through the irradiation or thermal processing of granular PTFE to produce fine powders. Given the demand for PTFE and its commercial value, it is possible to foresee that production processes could be modified or implemented to contine PTFE powders production, but at a coarser grain (>5mm in all dimensions) to avoid the restriction. This would mean that use can continue after 2026, but that its potential applications are likely to be more limited. No data was identified via the current study on what the post-microplastic restriction usage rates might look like. However, given that current micropowders are believed to exist in the 0.25 - 500µm (0.5mm) range, shifting the size distribution to above 5mm (in all dimensions) is likely to significantly limit the number of viable applications.

[2] RAC and SEAC, 2020, 'Opinion on the Annex XV dossier proposing restrictions on intentionally added microplastics', Revision 5 – 10 December 2020.

Granluar PTFE

For the use of granular PTFE in glide applications, there is very limited data beyond commenting that this may be a more niche application.

PFPEs, PFAS-based solvents and PFAS-based additives

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)[3] upholds this position with use of synthetic oils expected to grow by 5% annually between 2019 and 2025. The industry 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.

3.3 Number of production sites

No information is provided on the number of lubricant production or formulation sites. It is estimated by various stakeholders that fewer than 1,000 workers are involved in the formulation of fluorinated lubricants in the EU.

4. Emissions

In Table 3 the estimated emissions to air, water and land for the baseline year (2020) are given, while in Table 4 the estimated emissions for the period 1990-2050 are given. Note that emissions to the environmental compartments splitted by product manufacturing and product use are not given in the report and are therefore shown combined. In Figure 1, an overview is given of the material flow for all PFAS used in lubricant applications. More information on the data sources and assumptions can be found below.

Table 3. Overview of estimated yearly EEA emissions for 2020 (baseline) by receiving environmental compartment. This table includes product manufacturing and use.

Group	Emissions to air (tonnes)	Emissions to water (tonnes)	Emissions to land (tonnes)	Total Emissions (tonnes)
PTFE (Micropowder)	35	31	31	97
PTFE (granulates)	12	10	10	32
PFPEs	31	27	27	85
PFAS-Solvents	1.9	1.5	1.5	4.9
PFAS-additives	0.4	0.35	0.35	1.1

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

Table 4. Yearly emissions in the EU by vector (tonnes) including projections for BAU (Business As Usual).

Group	Vector	1990	2000	2010	2020 (baseline)	2030 (BAU)	2040 (BAU)	2050 (BAU)
PTFE (micro powder)	Air	0	0	13	35	1.4	1.6	1.7
	Land	0	0	12	31	1.2	1.2	1.5
	Water	0	0	11	31	1.2	1.2	1.5
PTFE (granular)	Air	9	10	11	12	13	14	16
	Land	8	8	9	10	11	13	14
	Water	8	8	9	10	11	13	14
PFOA (as by-product of PTFE (all types)	Air	0.2	0.2	0.5	NEG[1]	NEG	NEG	NEG
	Land	0.2	0.2	0.4	NEG	NEG	NEG	NEG
	Water	0.2	0.2	0.4	NEG	NEG	NEG	NEG
PFPEs	Air	23	25.5	28	31	51	65	71
	Land	20	22	24	27	44	56	62
	Water	20	22	24	27	44	56	62
PFAS-solvents	Air	1.4	1.6	1.7	1.9	3.1	4.0	4.4
	Land	1.1	1.2	1.4	1.5	2.5	3.2	3.5
	Water	1.1	1.2	1.4	1.5	2.5	3.2	3.5
PFAS-additives	Air	0.30	0.33	0.36	0.4	0.7	0.8	0.9
	Land	0.22	0.25	0.27	0.3	0.5	0.6	0.7
	Water	0.22	0.25	0.27	0.3	0.5	0.6	0.7

1: NEG Negligible

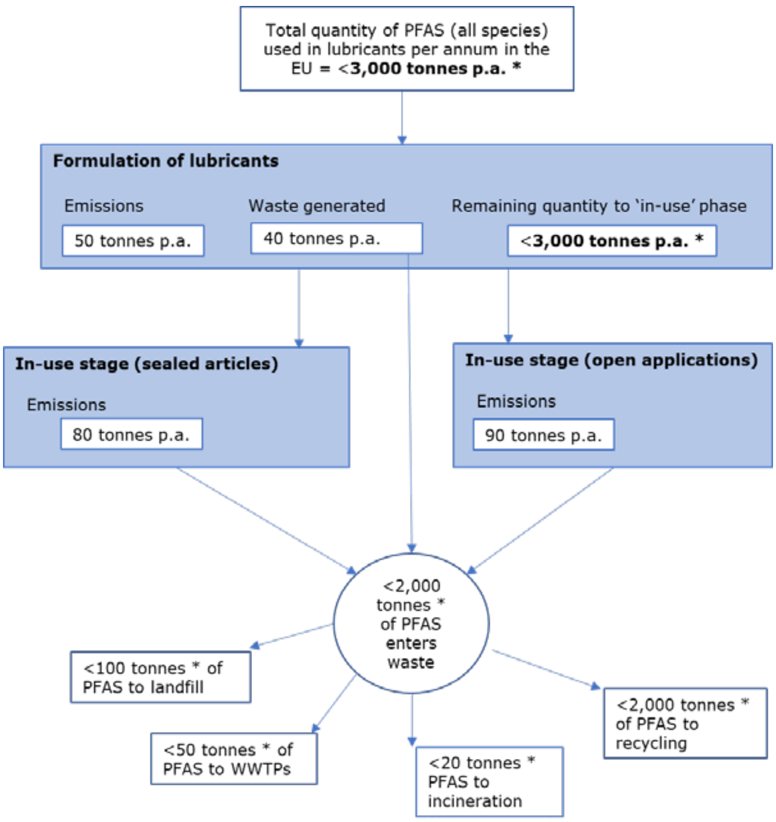

Figure 1. Overview of material flow for all PFAS used in lubricant applications. Note that the figure states EU while the numbers represent the uses in the EEA.

* More 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.

To determine market demand for the different PFAS-species, a number of assumptions have been made to calculate future uses. The assumptions are given below.

General

No considerations of changes in technology, abatement, or unpredicted events (such as Covid-19) are included within the estimates.

PTFE micro-powders

The commercialisation of PTFE micropowder was around 2005[4]. Where there is a lack of data to help support the estimates, it is assumed that there was no manufacture and use of PTFE micropowder before 2005, with an assumed amount of 100 tonnes in 2005, growing steadily to the 900 tonnes per annum estimated for the 2020 baseline.

The projection assumes that demand for PTFE micro-powders continues to grow slightly in 2021 and 2022 (2% increase in 2021 and further 1% increase in 2022). Growth then remains static in 2023, before going into decline leading up to the microplastic restriction in 2026. Based on the assumption that use will continue after the restriction, an assumed rate of usage equivalent to 25% of the existing baseline is applied after 2026, with an annual growth rate of 1% per annum.

Granluar PTFE

For the use of granular PTFE in glide applications, there is very limited data beyond commenting that this may be a more niche application. Therefore, a flat rate of increase of 1% per annum has been applied year on year from 1990 to 2020. Given the niche market the projection also applies a 1% year on year growth from 2020 to 2050.

PFPEs, PFAS-based solvents and PFAS-based additives

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. The projections assume therefore a 5% growth in use of PFAS based lubricants annually between 2020 and 2030, after which it is assumed growth slows due to market saturation, increasing thereafter at 2.5% annually to 2040 and 1% annually from 2040 to 2050. The same trends have been applied to PFAS-based solvents and additives in lieu of better data.

Note: for more information on market development, see the subsection 'market development' above.

[4] Patent lodged by AGC with the US authorities in 2005. US7579409B2.

4.1 Emissions product manufacturing

In Table 5 the assumptions used to calcalute the emissions during product manufacturing are given. Aditionally, the justifications for these assumptions are given. In Table 6 and Figure 1 the emissions during product manufacturing are presented.

Table 5. Key assumptions and justifications for calculation of emissions during manufacturing.

Component	Value	Assumption and Justification
Formulation of lubricants within the EU. Includes the filling of sealed articles for manufacture.	Quantities of PFAs (by group) used. PTFE = <2,000 tpa* (split between micropowders (75%) and granulated PTFE (25%)) PFPEs = <1,000 tpa* PFAS-based additives = <20 tpa*	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 <200 tpa*. However, this includes cleaning products which have a secondary lubricating function, and solvents used in products intended to act primarily as lubricants. Assume a 50/50 share and remove cleaning products as out of scope.	Assumption: There is an overlap in applications, where some cleaning products are used because they provide a secondary lubricating function. 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.
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.

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 6. Overview of estimated emissions for 2020 (baseline) during the formulation (manufacturing) of lubricants and the total emissions.

Group	Formulation All vectors (tonnes)	Total Emissions (formulation + use) All vectors (Tonnes)	Emissions formulation of total emissions (%)
PTFE (Micropowder)	22	97	23
PTFE (granulates)	7	32	22
PFPEs	19	85	22
PFAS-Solvents	1.8	4.9	37
PFAS-additives	0.24	1.1	22

4.2 Emissions product use

In Table 7 the assumptions used to calcalute the emissions during product use are given. Additionally, the justifications for these assumptions are given. In Table 8 and Figure 1 the emissions during product use are presented.

Table 7. Key assumptions and justifications for calculation of emissions during product use.

Component	**Value**	**Assumption and Justification**
In-use (sealed articles) Quantities split between outdoor and indoor applications.	Assume by quantity: 66% used in outdoor applications. 34% used in indoor applications	Assumptions: Based on the major sectors of use, 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.10a for 'widespread use of articles with low release (outdoor)' 0.05% w.w to air 3.2% w.w to water and 3.2% 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.

Component	Value	Assumption and Justification
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: 95% PFPEs: 95% PFAS-solvents: 100% PFAS-based additives: 95%	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.
In-use (sealed articles) Emission factors Indoor applications	Use ERC emission scenario no.11a for 'widespread use of articles with low release (indoor)' 0.05% w.w to air and 0.05% w.w to wastewater 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) Emission factors	Use ERC emission scenario no.10b for 'widespread use of articles with high or intended release (outdoor)' 30% w.w to air 30% w.w to water and 30% 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 10b covers this type of application but assumes that there will be a 100% release (split evenly across the vectors). 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 so an arbitrary value of 10% is assumed, with these materials entering the thermal destruction waste-cycle. 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 and that 10% is an overestimate. But this value has been chosen as a conservative maximum quantity that is not lost to environment.

Component	Value	Assumption and Justification
Waste Selection of waste pathways.	The very high majority of applications using PFAS-based lubricants are electrical or electronic components that would be subject to WEEE Directive processing. It is assumed that 95% of all sealed articles (all uses) enter the WEEE waste stream for processing at authorised treatment facilities (ATF). 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. Equally the use of PTFE for glide applications may also enter landfill. Therefore, a nomina value of 5% is assumed as landfill.

Table 8. Overview of estimated emissions for 2020 (baseline) during in-use (sealed articles and open applications) and the total emissions.

Group	In-use (sealed articles) All vectors (tonnes)	In-use (open applications) All vectors (tonnes)	Total Emissions (manufacturing + use) All vectors (Tonnes)	Emissions sealed articles of total emissions (%)	Emissions open applications of total emissions (%)
PTFE (Micropowder)	35	40	97	36	41
PTFE (granulates)	11	14	32	34	44
PFPEs	31	35	85	37	41
PFAS-Solvents	3.1	0.0	4.9	63	0
PFAS-additives	0.39	0.45	1.1	36	42

5. Exposure

Below information is given on the potential exposure of workers and consumers to PFAS.

5.1 General

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[5], 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% relubrication 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)?

- Consequently 95-97% of the lubricant volume end up in life-time lubrication applications, i.e., they remain in the articles until end of 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[4].
    - Thus, it is assumed that overall, the main quantity of fluorinated lubricants end-up in the metal waste fractions (e.g., as part of a bearing), where the PFAS are assumed to be degraded to fluorides at high temperature during metal recovery or (in some countries) go to landfill. No information was received about whether there will be any losses during dismantling of equipment.

- Between 1% and 10% (probably closer to 1%) of the fluorinated lubricant volume is recycled one way or the other. No information on the techniques used for recycling the fluorinated lubricants has been obtained.

Late in the stakeholder consultation process, 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. Given the timing, 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 the lubricant formulation. In the latter case, the solvents will evaporate when a grease or 'solid lubrication surface' 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.

[5] Note that the emission assessment has conservatively assumed higher values based on Specific Environmental Release Categories (SPERCs).

5.2 Exposure to workers

Lubricant formulation/production

It is estimated by various stakeholders that fewer than 1,000 workers are involved in the formulation of fluorinated lubricants in the EU/EEA. Generally, it is stated by industry stakeholders that worker exposure is very low due to strict controls 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

As appears from the use descriptions there are many different types of parts and equipment incorporating the lubricants and firm estimates are therefore not possible. Estimates of 10,000 – 100,000 workers are made by various stakeholders. 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 fluorinated 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 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 fluorinated 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

Cleaning with PFAS-based solvents may in theory take place during the entire lubricant life cycle. Possible worker exposure during these cleaning activities are thought to be the most critical for the following reasons: The PFAS-based solvents are more toxic than PTFE and PFPE, they are more 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 relubrication ('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).

5.3 Exposure to consumers

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 use of equipment

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

No specific data on indirect exposure of humans via the environment has been identified.

6. Alternatives

Below information is given on the alternatives for PFAS in lubricants.

6.1 General

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. In this context, it shall be noted that no suppliers of possible alternative lubricants responded to the CfE and that several trade associations, also representing suppliers of non-fluorinated lubricants, were consulted in the targeted stakeholder consultation. Identified literature discusses various potential alternatives to PTFE without clearly stating in which applications such alternatives could in practice substitute PTFE.

6.2 Alternatives to PFPE

In general, stakeholders agree that it is very difficult to substitute PFPE as base oil in many applications. In line with this, no literature discussing possible alternatives to PFPE in lubricants has been identified.

6.3 Alternatives to PTFE

Table 9. Overview of the specified alternatives to micropowder and granular PTFE.

Subuse	Non PFAS alternative?	General (unallocated) advantage/disadvantage	Specific advantage / disadvantage	Cost
Lubricating greases and lubricating pastes (solid component)	Graphite	• Friction reduction is less universal, as they are sensitive to humidity, less chemically resistant and less effective in application where rotations and especially 'slideability' is a factor • For base oils containing PFPEs and PTFE, the inorganic alternatives are not an option due to the very poor compatibility with the PFPEs in base oil	n.s.[1]	n.s.
	Molybdenum disulphide		n.s.	n.s.
	Boron nitride		Most promising but: • Performance does not reach those of fluorinated lubricants with PFTE • Boron nitride is considered more toxic by stakeholders as a source of boron acid	Costs are 3 times higher
	Other inorganics (e.g. layer building zinc phosphates, black phosphorous, WS_2 and (modified) graphene)		n.s.	n.s.
Lubricating greases and lubricating pastes (thickener)	Amorphous silica		n.s.	n.s.
Film/lacquer	Water-based phenolic-melamine gold lacquer alternative (Lubrizol)	n.a.[2]	• Still in R&D phase • Not clear whether it possesses other/better environmental persistence characteristics	n.s.
Lubricating greases and lubricating pastes (thickener) (Silicone oil for specific applications[4])	Polyurea	n.a.	• The extent to which this product can be applied as substitute for PTFE thickened silicone oils in general is not clear from the reference	n.s.
High-bearing aromatic thermosetting polyester (ATSP) coating	Graphene nanoplatelets (GNP)	n.a.	• Similar significant decrease in friction • Improved wear resistance at extreme temperatures (300 °C).	n.s.

1: n.s. not specified,

2: n.a. not applicable,

3: Not specified if the alternative is actually intended for lubrication (e.g. as gliding surface)

4: 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[6].

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

Overall, there seems to be much on-going activities related to alternatives which might eventually substitute 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 to the possible health and safety issue associated with such alternatives, some of which are PFAS-based themselves.

6.4 Alternative lubrication systems

Table 610. Overview of alternative lubrication systems.

Subuse	**Non PFAS alternative**	**Specific advantage / disadvantage**	**Cost**
n.s.[1]	Silicone greases/lubricants	• Lower chemical inertness	n.s.
n.s.	*Confidential* material group	• Significantly larger volumes needed due to more frequent lubrication	n.s.
Still in R&D	Ionic lubricants	• Some contain PFAS, some are non-fluorinated • Relevant ionic liquids are very often contain CF (PFAS) • Many are considered toxic according to industry stakeholders	Quite expensive
	Lubricant free technology with tribological restrictions	• If economically and technically feasible, it would have been developed • Unlikely that such systems would not lead to increased resource and energy consumption	n.s.
Research is ongogin	Non-liquid lubrication (polymer self-lubricating coating systems)	n.s.	n.s.
Automotive, aerospace, marine and defence sectors	Materials as graphene, WS_2 and MoS_2 [2]	• The materials can reduce friction as an integrated additive in composite material • Not clear whether and to which extent these systems can substitute PFAS-based lubricants	n.s.

1: n.s. not specified.

2: 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

6.5 Alternatives to PFAS-based solvents and additives

The use of other PFAS than PTFE and PFPEs (i.e. PFAS-based solvents and additives) in relation to lubricants was only tabled late in the consultation process. Consequently, only limited feedback has been received in relation to how critical these uses are. The general message from follow-up interviews in the targeted stakeholder consultation was that they cannot be substituted.

7. Economic impacts in case of a full PFAS ban

Below the economic, environmental, social and other impacts of a full PFAS ban are described, based on the Call for Evidence and targeted stakeholder interviews.

7.1 Economic impacts

- 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.
- There is consensus among the 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 (100-1,000 times more costly), some of which might have to redevelop the technologies used or even discontinue operation in case of a ban. Many downstream sectors would be at risk of significantly reducing efficiency, productivity and competitiveness.
- 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.
    - Substitution costs (costs of using alternatives): 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.
    - Technical costs (development and implementation): According to stakeholder input, reformulation costs could range between some €50,000 and €3 million per lubricant and/or per application. Testing and approval could range €20,000 per new lubricant to several hundred million Euros.
    - Costs for a potential funcitonality loss:
        - Aviation: reduced lifetime of parts and ultimately systems failure
        - Hydraulic and pneumatic systems: reduction of system lifetime by a factor of 10 or more
        - Load roller bearings: shorter relubrication interval, faster replacement of the bearings and higher mainentance costs
        - Greases: PFPE greases provide performance advantages and a lower total cost of ownership compared to alternatives[7]. Operation 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.

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

7.2 Environmental impacts

Alternatives:

- 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). One stakeholder noted that some of the siloxanes currently being regulated in the EU might be alternatives for some applications, but that such regrettable substitution is not preferable.

7.3 Social impacts

- 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.
- It will have a significant impact on the economics and employment in the EU region as production of lubricants containing PFAS will potentially be moved to non-EEA countries. (Note however that in case of a REACH restriction on the placing on the market and/or use of lubricants containing PFAS in the EEA, they could also not be imported back into the EEA).

7.4 Other impacts:

- It was generally claimed by stakeholders that it would take about ten years to develop alternatives (if at all 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.

8. Uncertainties

The uncertainties of the presented information are given here per section.

Substances, uses and applications

- 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.
- On the other hand, there are probably further PFAS substances 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.
- Relatively little specific information on degradation products has been received and a comprehensive literature review on potential degradation of each of the identified substances used has not been performed.

Call for evidence and stakeholder data

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 PFAS 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.
- 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.

SPIN database

There are certain limitations in using data from the SPIN database to estimate tonnages of PFAS 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 notified8 which means that not all lubricants (containing PFAS) will be notified. In addition, confidential information may not be included in the market figures derived from the SPIN database.

[8] 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/).

- 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 per capita is the same across the EEA.

Import and Export

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

Definition of a‘lubricant use’

- An uncertainty is associated with the definition of a 'lubricant use'. PFAS 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.

Emissions

- 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 PFAS 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 above) 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.

Exposure to workers and consumers

- Similar uncertainties as for the market data (see above) apply to the use of information from the CfE on workers associated with PFAS-based lubricants.
- 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.
- There is also some uncertainty about the degree to which certain applications are used by consumers (as opposed to only professional and industrial uses).

Alternatives

- Fluorinated lubricants can be used almost everywhere and the products on the market are rather diverse in order to meet specific requirements. 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.
- 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 PFAS in lubricants and in which applications.

Economic impacts in case of a full PFAS ban

- Information on the main types of costs was patchy covering only some of the many applications of PFAS in lubricants. In addition, some of the input received 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 lubricants, although many of them likely also supply and use products that are not based on PFAS.

9. Annex

PFAS substances used in lubricants

The list below is based on the information provided by the Technical Association of the European Lubricants Industry (ATIEL).

PFAS substances used in lubricants.

PFAS
1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymerized, reduced hydrolyzed
Ethylnonafluorbutylether
Ethylnonafluorisoylether
methyl nonafluorobutyle ether
Propane, 2-(difluoromethoxymethyl)-1,1,1,2,3,3,3-heptafluoro-
Tetradecafluorhexan
1,1,1,3,3-pentafluorobutane
Perfluoroalkylether
Siloxanes and Silicones, Me 3,3,3-trifluoropropyl
Poly(difluoromethylene), α-[2-[(2-carboxyethyl)thio]ethyl]-ω-fluoro-, lithium salt (1:1)
Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl)poly(difluoromethylene) (1:1)
N-(2,3-Dihydro-2-oxo-1H-benzimidazol-5-yl)-3-oxo-2-[[2-(trifluormethyl)phenyl]azo]butyramid
Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd.
1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.
Poly(1,1,2,2-tetrafluoroethylene); PTFE
Tetrafluoroethylene,oxidized,oligomers,reduced,fluorinated
1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd., reduced, hydrolysed reaction products with ammonia
Tetrafluoroethene, oxidized, polymd., reduced, Me esters, reduced, 2,4-dinitrophenyl ethers
Perfluoro compounds, C5-18