UNITED NATIONS

UNEP/POPS/POPRC.19/3

Stockholm Convention on Persistent Organic Pollutants

Distr.: General
9 June 2023

Original: English

Persistent Organic Pollutants Review Committee
Nineteenth meeting
Rome, 9–13 October 2023
Item 5 (a) (ii) of the provisional agenda*

Technical work: consideration of draft risk management evaluations: long-chain perfluorocarboxylic acids, their salts and related compounds

Draft risk management evaluation: long-chain perfluorocarboxylic acids, their salts and related compounds

Note by the Secretariat

I. Introduction

1. At its eighteenth meeting, the Persistent Organic Pollutants Review Committee adopted decision POPRC-18/5 on long-chain perfluorocarboxylic acids, their salts and related compounds. In paragraph 3 of that decision, the Committee decided to establish an intersessional working group to prepare a risk management evaluation that included an analysis of possible control measures for those chemicals in accordance with Annex F to the Convention.

2. In accordance with decision POPRC-18/5 and the workplan for the preparation of risk profiles and risk management evaluations adopted by the Committee (UNEP/POPS/POPRC.18/11, annex III), the intersessional working group has prepared a draft risk management evaluation for long-chain perfluorocarboxylic acids, their salts and related compounds, which is set out in the annex to the present note, without formal editing. Additional information, a draft indicative list of long-chain perfluorocarboxylic acids, their salts and related compounds, and a compilation of comments and responses relating to the draft risk management information are set out in documents UNEP/POPS/POPRC.19/INF/8, UNEP/POPS/POPRC.19/INF/9 and UNEP/POPS/POPRC.19/INF/10, respectively.

II. Proposed action

3. The Committee may wish:

(a) To adopt, with any amendments, the draft risk management evaluation set out in the annex to the present note;

(b) To decide, in accordance with paragraph 9 of Article 8 of the Convention, on the basis of the risk profile adopted at its eighteenth meeting (UNEP/POPS/POPRC.18/11/Add.4) and the risk management evaluation, whether long-chain perfluorocarboxylic acids, their salts and related compounds should be recommended for consideration by the Conference of the Parties for listing in Annexes A, B and/or C to the Convention.

* UNEP/POPS/POPRC.19/1.

Annex*

Long-chain perfluorocarboxylic acids, their salts and related compounds

Draft risk management evaluation

June 2023

* The annex has not been formally edited. The studies and other information referred to in this document do not necessarily reflect the views of the Secretariat, the United Nations Environment Programme (UNEP) or the United Nations. The designations employed and the presentation of the material in such studies and references do not imply the expression of any opinion whatsoever on the part of the Secretariat, UNEP or the United Nations concerning geopolitical situations or the legal status of any country, territory, area or city or its authorities.

Table of contents

Executive summary

1. In 2021, Canada submitted a proposal to list long-chain (C_9–C_{21}) perfluorocarboxylic acids (PFCAs), their salts and related compounds in Annexes A, B and/or C to the *Stockholm Convention on Persistent Organic Pollutants (POPs)*. In September 2022, at its eighteenth meeting, the Persistent Organic Pollutants Review Committee (POPRC) decided that long-chain PFCAs, their salts and related compounds are likely, as a result of their long-range environmental transport, to lead to significant adverse human health and/or environmental effects such that global action is warranted. An intersessional working group was established to prepare a risk management evaluation for these substances that includes an analysis of possible control measures for long-chain PFCAs, their salts and related compounds in accordance with Annex F to the Convention for consideration by the Committee at its nineteenth meeting in October 2023.

2. Long-chain PFCAs, their salts and related compounds are intentionally used, or may have been used, in a range of applications, including: industrial uses; electronic articles, and medical and laboratory devices; photo-imaging; inks; food contact materials; paints, coatings and varnishes (including those applied to building and construction materials); fire-fighting foams; textiles and apparel; personal care products; cleaning and washing agents; ski waxes; and in the automotive industry. In addition, long-chain PFCAs and their related compounds may be unintentionally produced during the manufacture of other per- and polyfluoroalkyl substances (PFASs) and in other industrial processes. Long-chain PFCAs and their related compounds may also be unintentionally produced during thermolysis of fluorinated polymers at temperatures relevant to industrial or consumer high-temperature applications and low-temperature incineration.

3. Long-chain PFCAs can be released to the environment from direct and indirect sources. Direct sources include emissions from the production of PFCAs, as well as emissions from products containing long-chain PFCAs, either as a main ingredient, a residual or a chemical reaction impurity. Indirect sources are those where compounds related to long-chain PFCAs emitted to the environment have transformed to long-chain PFCAs through biotic or abiotic transformation processes. Releases of long-chain PFCAs, their salts and related compounds to the environment may occur at all life cycle stages of articles or products containing them, e.g., during production, use and disposal (including from landfills, wastewater treatment and incineration). The application of contaminated biosolids and compost to agricultural land, and irrigation of these lands with contaminated groundwater, may also lead to secondary release of these substances to the environment. In addition, the clean-up and remediation of contaminated sites, such as those impacted by fire-fighting foams containing PFASs, including long-chain PFCAs, generates PFAS-containing waste streams that are typically disposed of in landfills or sent for destruction (e.g. via high temperature incineration). This could lead to secondary release of long-chain PFCAs into the environment.

4. Prohibiting the intentional production and use of long-chain PFCAs, their salts and related compounds by listing these substances to Annex A, with or without specific exemptions, would positively impact human health and the environment by decreasing emissions and subsequent human and environmental exposure. Available information does not demonstrate that a listing to Annex B would be needed. Further, a listing to Annex A would be consistent with the listings of other PFASs, i.e. perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds and perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds, to the Convention.

5. Although long-chain PFCAs may be unintentionally produced during industrial processes and low temperature incineration of wastes, listing long-chain PFCAs, their salts and related compounds to Annex C is not believed to be a relevant control measure for these substances. However, to reduce releases to the environment resulting from the unintentional production of long-chain PFCAs during industrial processes, manufacturers should aim to minimise the unintentional presence of long-chain PFCAs and their related compounds to the largest possible extent before commercial mixtures and materials are brought into the market. This should be captured in the guidance on best available techniques and best environmental practices (BAT/BEP) for the use of long-chain PFCAs, their salts and related compounds that would be developed following a listing of these substances to the Convention.

6. Further, a listing to the Stockholm Convention would create an obligation for the introduction of waste management measures, in accordance with Article 6 of the Convention. These measures would, among other obligations, contribute to ensuring that wastes containing long-chain PFCAs, their salts and related compounds at concentrations at or above the established low persistent organic pollutant (POP) content value are disposed of in such a way that the POP content is destroyed or irreversibly transformed, or are otherwise disposed of in an environmentally sound manner. In addition, specific technical guidelines on the environmentally sound management of wastes consisting of, containing, or contaminated with these substances would be developed in cooperation with the Basel Convention. These guidelines would identify technologies for the destruction and irreversible transformation of these substances in wastes.

7. Information suggests that alternatives are available for most known applications of long-chain PFCAs, their salts and related compounds. Alternatives include both fluorinated and non-fluorinated substances, as well as alternative (non-chemical) technical solutions. According to information provided by Parties and industry, and gathered through both a literature review and during the development of the regulatory actions proposed in Canada

and in force in the European Union (EU), specific exemptions could be considered for certain applications to allow sufficient time to identify, and transition to, suitable alternatives, and in order to avoid regrettable substitution.

8. Long-chain PFCAs are globally ubiquitous in environmental compartments, including biota, freshwater, saltwater, sediment, soil and rainwater, and humans. Long-chain PFCAs are persistent, bioaccumulative, have adverse effects on human health and/or the environment, and have the potential to undergo long-range environmental transport, in part due to the long-range atmospheric transport of compounds related to long-chain PFCAs. Increasing temporal concentration trends in wildlife, including top predator species, suggest that long-chain PFCAs can approach toxicity thresholds resulting in harm to wildlife populations. In humans, their high persistence can lead to widespread and increasing exposure, potentially resulting in adverse effects. Certain populations, such as Arctic Indigenous Peoples and those who rely on traditional foods for subsistence, are at risk of greater exposure and potential effects. Global action on long-chain PFCAs, their salts and related compounds would provide benefits to humans and biota by reducing releases to the environment and, subsequently, reducing human and wildlife exposure. The restriction of long-chain PFCAs, their salts and related compounds by listing these substances to the Stockholm Convention would also be beneficial to agriculture and human health since, with time, it would reduce the level of contamination of biosolids, compost and groundwater, which are used in agricultural practices to optimise crop growth.

9. Information on the availability and costs of alternatives indicate that the socioeconomic costs of prohibiting or restricting long-chain PFCAs, their salts and related compounds are overall anticipated to be low. However, in countries that have not yet taken regulatory actions on these substances, industry may face greater costs for transitioning to alternatives. In addition, Parties and observers have identified potential social impacts (such as impacts on medical services and the supply of replacement parts for semiconductors, vehicles and electrical and electronic devices) which could result from the restriction of long-chain PFCAs, their salts and related compounds in certain applications. However, high costs are estimated for the management of POP-containing wastes, and remediation of contaminated sites and treatment of water sources contaminated with these substances. Implementation of control measures for long-chain PFCAs, their salts and related compounds would, therefore, contribute to avoiding such future costs. Socioeconomic costs associated with exposure to long-chain PFCAs should also be considered.

10. Overall, the benefits to health, agriculture and biota from taking global action on these substances are expected to outweigh the costs of implementing control measures. Listing long-chain PFCAs, their salts and related compounds to Annex A, with specific exemptions in key sectors could minimise potential socioeconomic costs and impacts by allowing sufficient time for the identification of, and transition to, suitable alternatives, and in order to avoid regrettable substitution. It is also noted that there are analytical challenges in measuring some long-chain PFCAs which present challenges for the management and control of their production, use, import and export.

11. The POPRC recommends that the Conference of the Parties to the Stockholm Convention, in accordance with paragraph 9 of Article 8 of the Convention, consider listing and specifying the related control measures for long-chain PFCAs, their salts and related compounds in Annex A with specific exemptions for production and use, in accordance with Article 4, for the following: 1) cooling applications for the manufacture of high-heat and high-voltage parts for semiconductor manufacturing equipment; 2) inactive/inert fluorine liquid for reliability testing and temperature control for the manufacture of electric components, and electrical and electronic equipment; 3) heat media in a closed system;[1] 4) polytetrafluoroethylene (PTFE) micro powders containing long-chain PFCAs and their salts, in a concentration equal to or below 1 mg/kg (0.0001% by weight), transported or treated for the purpose of reducing the concentration of long-chain PFCAs and their salts below 0.250 mg/kg (0.000025%); and 5) semiconductors designed for replacement parts for applications other than motor vehicles and combustion powered engine vessels. In addition, specific exemptions for the use of long-chain PFCAs, their salts and related compounds for replacement parts for, and repair of, articles where these substances were originally used in the manufacture of those articles and may be available, limited to the following applications, may also be considered: 1) semiconductors designed for replacements parts for combustion powered engine vessels, until end of service life of the articles or 2041, whichever comes earlier; 2) replacement parts for motor vehicles,[2] until end of service life of the articles or 2041, whichever comes earlier; and 3) replacement parts containing heat media in a closed system,[3] until end of service life of the articles, subject to review by the Conference of the Parties no later than or 2043.

12. [In addition, provided additional information becomes available to explain and further describe the need for exemptions, the following exemptions could be considered: 1) lubricants used in the manufacture of fluoropolymers

[1] Including heat media in components of *in vitro* diagnostic medical devices, refractive media in analytical instruments for detecting fluorescence and heat media in thermostatic chambers for reliability and durability testing of electric and electronic equipment.

[2] Covering all land-based vehicles, such as cars, motorcycles, agricultural and construction vehicles and industrial trucks. Applications include semiconductors, coatings, cables, electronics, engines and underhood applications, modules, hydraulic system components and relay assemblies.

[3] Including heat media in components of *in vitro* diagnostic medical devices, refractive media in analytical instruments for detecting fluorescence and heat media in thermostatic chambers for reliability and durability testing of electric and electronic equipment.

in accordance with Article 4; 2) parts and/or materials for electrical and electronic devices, equipment and appliances in accordance with Article 4; 3) inks for marking capacitors and cables; and 4) replacement parts for electrical and electronic devices, equipment and appliances until the end of service life of the articles or 2046, whichever comes earlier].

1. Introduction

13. In June 2021, Canada submitted a proposal to list long-chain perfluorocarboxylic acids (PFCAs), their salts and related compounds in Annexes A, B and/or C to the *Stockholm Convention on Persistent Organic Pollutants (POPs)* (UNEP/POPS/POPRC.17/7). The proposal was considered by the Persistent Organic Pollutants Review Committee (POPRC) at its seventeenth meeting in January 2022, where the Committee concluded that these substances fulfilled the screening criteria specified in Annex D to the Convention (decision POPRC-17/6).

14. At its eighteenth meeting in September 2022, the POPRC adopted the risk profile on long-chain PFCAs, their salts and related compounds (UNEP/POPS/POPRC.18/6/Add.1), and decided that these substances are likely, as a result of their long-range environmental transport, to lead to significant adverse human health and/or environmental effects such that global action is warranted (decision POPRC-18/5). In addition, the Committee established an intersessional working group to prepare a risk management evaluation that includes an analysis of possible control measures for long-chain PFCAs, their salts and related compounds.

15. Parties and observers were invited to submit to the Secretariat the information specified in Annex F to the Stockholm Convention by 5 December 2022.[4] The submitted information, and other relevant information, are considered in this document.

1.1 Chemical Identity

16. Long-chain PFCAs, their salts and related compounds are members of the per- and polyfluoroalkyl substances (PFASs) chemical class. The Organisation for Economic Co-operation and Development (OECD) (2021) defines PFASs 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 ($–CF_3$) or a perfluorinated methylene group ($–CF_2–$) is a PFAS”. The OECD defines long-chain PFCAs as PFCAs with carbon chain lengths C_8 and higher, including perfluorooctanoic acid (PFOA) (OECD 2023). However, throughout this risk management evaluation, the term “long-chain PFCAs” has been used to refer to the PFCAs included in the scope of the proposal. Consistent with the risk profile,[5] the chemical identity of the substances covered by this risk management evaluation includes PFCAs with carbon chain lengths from 9 to 21 inclusive, their salts and related compounds, defined as follows:

(a) PFCAs that have the molecular formula of $C_nF_{2n+1}COOH$ (where $8 \leq n \leq 20$) and their salts;

(b) Any substance that is a precursor and may transform to long-chain PFCAs, where the perfluorinated alkyl moiety has the formula C_nF_{2n+1} (where $8 \leq n \leq 20$) and is directly bonded to any chemical moiety other than a fluorine, chlorine or bromine atom.

17. The chemical identity of long-chain PFCAs, and the available experimental and calculated physical and chemical data for this group, are given in Tables 1 and 2 of UNEP/POPS/POPRC.19/INF/8.

18. An indicative list of Chemical Abstracts Service (CAS) numbers for long-chain PFCAs, their salts and related compounds is provided in UNEP/POPS/POPRC.19/INF/9. Some of the substances on this list have also been identified as compounds related to PFOA in the indicative list of substances covered by the listing of PFOA, its salts and PFOA-related compounds[6] to the Stockholm Convention. Examples of compounds that meet both the definition of PFOA-related compounds and the definition of long-chain PFCAs-related compounds, which have been shown to transform to PFCAs of various lengths (including PFOA, which is C_8 PFCA, and $\geq C_9$ PFCAs), are provided in Table 3 of UNEP/POPS/POPRC.19/INF/8). As these compounds are currently subject to the obligations related to the listing of PFOA, its salts and related compounds, this overlap has been taken into account in this draft risk management evaluation, for example, when identifying exemptions that could be needed for these compounds.

19. C_9 PFCA has been reported to be manufactured through the ozonation of 8:2 fluorotelomer olefin (Ukihashi et al. 1977) or possible carboxylation of perfluorooctyl iodide (Ishikawa and Takahashi 1988). The manufacture of ammonium perfluorononanoate (APFN), the ammonium salt of C_9 PFCA, leads to a different mixture of PFCAs depending on the nature of the starting materials. Armitage et al. (2009) described the homologue profile for commercial APFN to consist primarily of C_9 PFCA (73.6%), C_{11} PFCA (20.0%) and C_{13} PFCA (5.0%).

[4] The deadline for submitting information was later extended to 6 February 2023.

[5] UNEP/POPS/POPRC.18/6/Add.1.

[6] UNEP/POPS/POPRC.17/INF/14/Rev.1

20. Related compounds to long-chain PFCAs include fluorotelomer alcohols (FTOHs) and fluorotelomer derivatives, including side-chain fluorinated polymers and polyfluoroalkyl phosphoric acid mono-/diesters (monoPAPs/diPAPs). Fluorotelomers are a subgroup of per- and polyfluorinated substances that are produced by a process called telomerization, which can produce a range of fluorocarbon chain lengths (Environment Canada 2012; Buck et al. 2011). Substances containing $F(CF_2)_x(CH_2)_2$- groups can also be considered potentially related compounds to long-chain PFCAs, as they will likely result in the release of x:2 FTOHs in the environment (ECHA 2018a,b). Starting materials that may be used for the production of compounds related to long-chain PFCAs consist of FTOH mixtures of fluorinated chain lengths ranging from 4 to 20 carbons (Beatty 2003; Sherman et al. 2001, as described in section 1.1 and Table 4 of UNEP/POPS/POPRC.19/INF/8).

21. Long-chain PFCAs and their related compounds may also be unintentionally produced during the manufacture of other PFASs, including those containing a carbon chain of less than nine carbon atoms and fluoropolymers (Prevedouros et al. 2006; ECHA 2018b; EU Annex F information 2022), and in other industrial processes, such as the production of polytetrafluoroethylene (PTFE) micro powders by ionising radiation or thermal degradation (ECHA 2018b, 2020a) (see section 1.1 of UNEP/POPS/POPRC.19/INF/8 for more details). Long-chain PFCAs and their related compounds may also be unintentionally produced during thermolysis of fluoropolymers at temperatures ranging from 200–600 °C, which are relevant to industrial or consumer high-temperature applications (e.g., ovens, non-stick cooking utensils and combustion engines) and low-temperature incineration (Ellis et al. 2001; Feng et al. 2015; Schlummer et al. 2015).

1.2 Conclusion of the POPs Review Committee regarding Annex E information

22. At its eighteenth meeting in September 2022,[7] after having completed the risk profile for long-chain PFCAs, their salts and related compounds in accordance with paragraph 6 of Article 8 of the Convention, the POPRC:

(a) Adopted the risk profile on long-chain PFCAs, their salts and related compounds;[8]

(b) Decided, in accordance with paragraph 7 (a) of Article 8 of the Convention, that long-chain PFCAs, their salts and related compounds are likely, as a result of their long-range environmental transport, to lead to significant adverse human health and/or environmental effects such that global action is warranted;

(c) Also decided, in accordance with paragraph 7 (a) of Article 8 of the Convention and paragraph 29 of the annex to decision SC-1/7 of the Conference of the Parties, to establish an intersessional working group to prepare a risk management evaluation that includes an analysis of possible control measures for long-chain PFCAs, their salts and related compounds in accordance with Annex F to the Convention; and

(d) Invited, in accordance with paragraph 7 (a) of Article 8 of the Convention, Parties and observers to submit to the Secretariat the information specified in Annex F before 5 December 2022.

1.3 Data sources

23. The draft risk management evaluation is based on the following data sources:

(a) Risk profile for long-chain PFCAs, their salts and related compounds and related additional information document (UNEP/POPS/POPRC.18/Add.1 and UNEP/POPS/POPRC.18/INF/12, respectively);

(b) Information submitted by the following Parties and observers according to Annex F to the Convention and in response to the invitation for comments on the draft risk management evaluation. Annex F information was provided by: Canada, the European Union (EU), Guatemala, Hungary, Japan, the Netherlands, Norway, Oman, Saudi Arabia, Sweden, the United Kingdom of Great Britain and Northern Ireland (UK), the Canadian Vehicle Manufacturers' Association (CVMA), and the Imaging and Printing Association of Europe (I&P Europe). Additional information was provided the Netherlands, Norway, Switzerland, the UK, CVMA and the International Pollutants Elimination Network (IPEN) and Alaska Community Action on Toxics (ACAT);

(c) Regulatory impact analysis statements published for regulatory actions in Canada (Canada 2016, 2022);

(d) Opinions and related background documents from the European Chemicals Agency (ECHA) Committee for Risk Assessment and Committee for Socio-economic Analysis on an Annex XV dossier proposing restrictions on PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTDA, their salts and precursors (ECHA 2018a,b, 2020a,b);

(e) Annexes to the Annex XV Restriction Report for Per- and polyfluoroalkyl substances (PFASs) in fire-fighting foams (ECHA 2022a);

[7] Decision POPRC-18/5.

[8] UNEP/POPS/POPRC.18/6/Add.1.

(f) Assessments of the use of PFASs and their alternatives in various products conducted by the Swedish Chemicals Agency (2015, 2021); the OECD (2020, 2022); the Washington State Department of Ecology (WSDE 2021); and the California Department of Toxic Substances Control (California DTSC 2020; 2022);

(g) Draft guidance on alternatives to PFOA, its salts and PFOA-related compounds (UNEP/POPS/COP.10/INF/25, hereafter referred to the "draft guidance on alternatives to PFOA");

(h) Guidance on alternatives to perfluorooctane sulfonic acid, its salts, perfluorooctane sulfonyl fluoride and their related chemicals (UNEP/POPS/POPRC.9/INF/11/Rev.1, hereafter referred to the "draft guidance on alternatives to PFOS"); and

(i) Peer-reviewed scientific journals, as well as information from reports and other grey literature.

1.4 Status of the chemical group under international agreements or organisations

24. Long-chain PFCAs, their salts and related compounds are members of the PFASs chemical class. In 2009, perfluorinated chemicals and the transition to safer alternatives was recognized as an issue of concern under the Strategic Approach to International Chemicals Management (SAICM) (UNEP 2009). International efforts to address some PFASs (such as the listing of perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF); PFOA, its salts and PFOA-related compounds; and perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds to the Stockholm Convention) and to transition to safer alternatives are being complemented by initiatives in various countries. Efforts have also emerged to raise awareness and initiate actions on other PFASs (UNEP 2019). The Global Chemicals Outlook II (UNEP 2019) identified a number of potential measures to further address PFASs, such as: generating further knowledge and advancing international action on short-chain PFASs and non-fluorinated alternatives; developing approach(es) to assessing and manage PFASs and alternatives, including the chemical grouping approach and the differentiation between essential and non-essential uses, and gathering additional data to conduct assessments; and scaling up development of alternatives to PFASs, including non-fluorinated alternatives, for PFASs in currently essential uses where no alternatives are available.

25. In 2015, the OECD (2015a) provided an overview of risk reduction approaches for PFASs. Responses from participating countries indicated that risk reduction approaches for PFASs are mainly covered under existing national and/or regional regulatory frameworks and cover principally long-chain PFASs (including PFHxS, PFOS, PFOA and C_9 PFCA) and their precursors and salts. The type of risk reduction approaches implemented across countries varies, but there is often a combination of voluntary and regulatory approaches that are used (OECD 2015a).

1.5 National or regional control actions taken

26. As described in section 1.2 of UNEP/POPS/POPRC.19/INF/8, national or regional control actions on long-chain PFCAs, their salts and related compounds were taken or are being considered in Canada, the EU, Switzerland, Norway, the Netherlands, the USA and Australia.

2. Summary of the information relevant to the risk management evaluation

Production, Uses and Releases

27. Estimates and other information on the global production, import and use of long-chain PFCAs, their salts and related compounds have been reported in the literature, and provided in response to the requests for Annex E and Annex F information under the Stockholm Convention. This information is summarized in section 2 of UNEP/POPS/POPRC.19/INF/8. Wang et al. (2014) reported that, since 2002, there has been a geographical shift of industrial sources of PFCAs as a result of the relocation of PFCA, fluoropolymer and other PFAS product production from the USA, Western Europe and Japan to emerging Asian economies, especially China. Data collected for the restriction proposal under REACH to ban the use of PFASs as a class (ECHA 2023a, see section 1.2 of UNEP/POPS/POPRC.19/INF/8) indicate that the production shift to Asian economies was still taking place during the last decade. For example, ECHA (2023) estimated annual tonnages for the manufacture of perfluoroalkyl acids (PFAAs) and their precursors in 2020 to range between 53,902 and 118,051 tonnes/years.

28. Based on the information described in the risk profile, Annex F submissions and additional publications found in the literature, long-chain PFCAs, their salts and related compounds (or products containing them) are intentionally used (see Table 1), or may have been used[9] (see Table 2), in a range of applications. Further details, including references for each identified use, are provided in Table 7 of UNEP/POPS/POPRC.19/INF/8. In addition, available information (including CAS numbers) related to specific long-chain PFCAs, salts and/or related compounds (or products containing them) reported to be used, or to may have been used, in various applications is provided in Table 8 of UNEP/POPS/POPRC.19/INF/8.

[9] For example, based on available patent information and reported detections in articles and products.

29. Based on information provided by I&P Europe and available patent information, long-chain PFCAs, their salts and their related compounds may be present and/or used in photographic materials. I&P Europe has indicated that the use of long-chain PFCAs and related compounds relates to the composition of commercial PFOA-related compounds used by their members in the manufacturing of some remaining photographic coatings applied to film, as these compounds may contain homologues of PFOA and other substances that fulfill the definition of long-chain PFCAs and related substances. These PFOA-related compounds are used in manufacturing operations for traditional and digital imaging products (e.g. for medical, professional, industrial and consumer applications) manufactured predominantly in the USA, Europe, China and Japan. In 2015, the remaining uses were estimated to amount to a total continued use of about 0.3 tonnes/year of PFOA-related compounds in the EU.[10] According to I&P Europe, because uses of PFOA and related compounds will be eliminated from all photographic coatings by July 2025 at the latest, this will automatically result in elimination of any long-chain PFCAs and related compounds present in the few photographic materials concerned (Annex F information 2022). Currently, there is no indication that a longer transition period is required for the photo-imaging industry outside of Europe.

Table 1. Uses of long-chain PFCAs, their salts and related compounds or products containing them

Category	Examples of uses
Industrial uses	Surfactant applications; fluoropolymer polymerisation aids; manufacturing intermediates; analytical reagents; lubricants used in the manufacture of fluoropolymers[11]
Electronic articles, and medical and laboratory devices	Semiconductors; cooling applications for the manufacture of high-heat and high-voltage parts for semiconductor manufacturing equipment; functional fluids in closed systems for computer and electronic product manufacturing; inactive/inert fluorine liquid for reliability testing and temperature control for the manufacture of electric components and electrical and electronic equipment; heat media for in *vitro* medical devices; refractive media in analytical instruments by fluorescence detection
Photo-imaging	Photographic materials
Inks	Printing inks; inks for marking capacitors and cables
Food contact materials	Paper and paperboard food packaging
Paints, coatings and varnishes (including those applied to building and construction materials)	Automotive paints, waxes and polishes; paints, lacquers and varnishes; water-based paints and varnishes; waxes and other floor polishes; glass treatments; products used for masonry/cement surfaces; coatings for wood boards of internal wall cladding; raw materials for surface treatment agents, water/oil repellents and soil repellents
Fire-fighting	Fire-fighting foams; fire extinguishing agents
Textiles and apparel	Carpets; textile water/oil repellents; fabric and carpet protectors; textile impregnants
Personal care products	Cosmetics; sun creams
Cleaning and washing agents	Cleaning products
Automotive industry	Products for motor vehicle repair; vehicle coatings, cables, electronics, engines and underhood applications, modules, hydraulic system components and relay assemblies

Table 2. Other potential uses of long-chain PFCAs, their salts and related compounds or products containing them identified based on patent literature and/or reported detections

Category	Examples of other potential uses
Industrial uses	Mould release agents
Medical devices	UV-hardened dental restorative materials; manufacturing of contact lenses
Food contact materials	Plastic pet food packages; cookware

[10] These quantities are anticipated to have continued to decrease since 2015, as the remaining applications themselves have continued to decrease systematically (I&P Europe Annex F submission 2022).

[11] Clarification on this reported use has been requested from Japan, but no information has been received at this time. In their comments on the third draft risk management evaluation, the UK indicated that industry has stated that long-chain PFCAs are unintentionally present in fluoropolymer micro powder (lubricants) rather than used to manufacture such fluoropolymers. Therefore, the UK has proposed to remove this use from Table 1. No revision has been made at this time, pending receipt of the requested clarification.

Category	Examples of other potential uses
Paints, coatings and varnishes (including those applied to building and construction materials)	Paint sealants; surfactants used in paints and floor waxing; coatings and foil for facades or glass-substituents; window films; stone/tile/wood sealants, thread seal tapes and pastes; surfactants used in caulks, coatings and adhesives
Textiles and apparel	Apparel; medical garments; firefighter turnout gear; home and outdoor textiles; other types of fabric/textiles (i.e., awnings, seat covers for public transportation, maritime applications); fabric, foam and laminated composites of foam/fabric in children's car seats
Personal care products	Dental floss; body lotions
Cleaning and washing agents	Carpet care liquids and foams; dish cleaning or rinsing agents; anti-fog sprays and cloths
Ski waxes	Ski waxes
Automotive industry	Automotive lubricants (i.e., engine oils, hydraulic fluids and greases)

30. Long-chain PFCAs can be released to the environment from direct and indirect sources. Direct sources include emissions from the production of PFCAs, as well as emissions from products containing long-chain PFCAs, either as a main ingredient, a residual or a chemical reaction impurity. Indirect sources are those where compounds related to long-chain PFCAs emitted to the environment have transformed to long-chain PFCAs through biotic or abiotic transformation (OECD 2015b; Wang et al. 2014).

31. Releases of long-chain PFCAs, their salts and related compounds to the environment may occur at all life cycle stages of articles or products containing them, e.g., during production, use and disposal. As described in the risk profile and in additional publications (Jans and Berbee 2020), the release of these substances to the environment from production activities is evidenced by their detection in various environmental matrices collected, for example, in proximity to production facilities, electroplating industrial parks, paper product factories, textile and synthetic fibre producers, detergent and cleaning product manufacturers, and in industrial or urban areas located in India, China, South Korea, Germany, Norway, Japan and the Netherlands. Releases of long-chain PFCAs, their salts and related compounds to the environment from the use of articles and products containing them is documented by their detection in: snow and soil from skiing areas; indoor air and dust samples from private homes, hotels, office buildings, vehicles and daycares; and groundwater and soil collected in sites impacted by fire-fighting foam (UNEP/POPS/POPRC.18/6/Add.1; UNEP/POPS/POPRC.18/INF/12, Table 4). According to I&P Europe (Annex F information 2022), waste management practices and recycling operations have been put in place by the photo-imaging industry in Europe to minimise the environmental releases of long-chain PFCAs and their related compounds from the manufacturing and use of conventional photographic materials (see section 2 of UNEP/POPS/POPRC.19/INF/8 for details).

32. Long-chain PFCAs and their related compounds may also be released to the environment from landfills, incineration facilities and wastewater treatment plants. For example, long-chain PFCAs and their related compounds have been measured in leachate, percolate or soil from landfills, as well as in air around landfills (UNEP/POPS/POPRC.18/6/Add.1; UNEP/POPS/POPRC.18/INF/12, Table 4). Therefore, landfills could be a pathway of these substances to nearby air, vegetation, and surface waters. Composting of paper or paperboard food packaging and other organic waste products containing long-chain PFCAs and their related compounds could also result in the release of these substances into the environment (California DSTC 2020; Munoz et al. 2022a). In the surroundings of Rastatt, Germany, the repeated application of compost mixed with sludge from paper production, contaminated with various precursors, was suspected to be the main cause of the contamination of former arable land with PFAAs and their precursors (Brendel et al. 2018; Würth et al. 2023).

33. Long-chain PFCAs and their related compounds have been measured in sludge, biosolids, influent and effluent from wastewater treatment plants (WWTPs), as well as air surrounding WWTPs (UNEP/POPS/POPRC.18/6/Add.1; UNEP/POPS/POPRC.18/INF/12, Table 4; Munoz et al. 2022a; Jans and Berbee 2020). Additionally, studies, which have analyzed the mass flows of certain long-chain PFCAs in WWTPs, suggest that wastewater treatment transforms related compounds into long-chain PFCAs (Schultz et al. 2006; Sinclair and Kannan 2006), indicating that WWTPs may be a source of these substances to the environment. A recent study on the influence of environmental and ecological factors on the accumulation and distribution of short- and long-chain PFAAs in tree swallows from two sites in southern Ontario, Canada found that WWTPs were a significant environmental point source of long-chain PFCAs to downstream foraging birds (Hopkins et al. 2023). Land application of contaminated biosolids can also be a pathway of long-chain PFCA releases to the terrestrial environment (UNEP/POPS/POPRC.18/6/Add.1; UNEP/POPS/POPRC.18/INF/12, Table 4).

34. Long-chain PFCAs and their related compounds have also been measured in leachate, fly ash and bottom ash from three municipal solid waste incineration facilities located in China (Liu et al. 2021;

UNEP/POPS/POPRC.18/INF/12, Table 4). In the study, the highest levels of measured long-chain PFCAs and related compounds were generally found in the leachate from the incineration facilities, demonstrating the leaching of these substances from wastes. Relatively lower levels were found in the fly ash and bottom ash, indicating that incineration destroyed most of these substances under high temperatures, with some residues still captured by fly ash or remaining in the bottom ash due to incomplete incineration. The authors estimated the sum of C_4–C_{14} PFCAs released annually from the three facilities, which together have an annual solid waste treatment capacity of ~15 000 000 kg/y, to be ~89 kg/y in leachate, and ~4 kg/y in fly ash and bottom ash. These findings show that leachate, fly ash and bottom ash from municipal solid waste incineration facilities are vectors of long-chain PFCAs and their related compounds into the environment.

35. C_9–C_{12} PFCAs, as well as PFOA, were also reported to be unintentionally produced during the thermal decomposition of fluoropolymers (e.g. PTFE) at temperatures and in conditions that are not dissimilar to those that might be found in the open burning of domestic wastes (Ellis et al. 2001). In the study, the percentage produced was, however, found to be minimal (>0.01%). Feng et al. (2015) also observed the production of PFCA analogues of carbon chain lengths ranging from C_1 to C_{18} during the thermolysis of a perfluorosulfonic acid membrane, consisting of a PTFE backbone with perfluoroalkylether pendant chains terminating in sulfonic acid groups. In the study, the thermal degradation of the membrane was investigated by mimicking the typical operating conditions (at temperatures of up to 800 °C) of several chemical applications and the waste disposal process via low-temperature incineration. Although the amount of long-chain PFCAs was found to decrease with the increased chain length, these results suggest that the incineration of PTFE-containing waste, particularly at low-temperatures, is a potential source of long-chain PFCAs to the environment.

36. Lastly, the clean-up and remediation of contaminated sites, such as those impacted by fire-fighting foam containing PFASs, including long-chain PFCAs, generates PFAS-containing waste streams (e.g., fine soils with concentrated PFASs, and used/spent filter media, such as granular activated carbon) that need to be disposed of. Typically, these wastes are disposed of either in landfills (e.g. solid waste and/or hazardous waste landfills) or sent for destruction (e.g. via high temperature incineration). This could lead to secondary release of long-chain PFCAs into the environment (Canada Annex F information 2022).

37. As discussed in section 1.1, long-chain PFCAs, their salts and related compounds may be unintentionally produced during the manufacture of other PFASs, including PFOA (ECHA 2018b). In addition, some related compounds to long-chain PFCAs have also been identified as compounds related to PFOA (see section 1.1). Therefore, the listing of PFOA, its salt and PFOA-related compounds to the Stockholm Convention, as well as the restrictions put in place in many countries, may have impacted (or may, in the future, impact) the environmental releases of some long-chain PFCAs, their salts and related compounds. For example, restrictions on PFOA may have resulted in reductions of the unintentional production and release of some long-chain PFCAs, or in reductions of the use of some compounds related to both substances. In contrast, some industries may have transtioned from PFOA to other long-chain PFCAs (e.g. C_9 PFCA), potentially resulting in an increase in the use of the latter in some applications. Quantitative information related to the interconnections in the management of these two groups of substances has not been identified for inclusion in this risk management evaluation.

2.1 Identification of possible control measures

38. The objective of the Stockholm Convention is to protect human health and the environment from POPs (Article 1). This may be achieved by listing long-chain PFCAs, their salts and related compounds in:

(a) Annex A, with or without specific exemptions, to eliminate releases from intentional production and use; or

(b) Annex B, with specific exemptions and/or acceptable purposes, to reduce releases from intentional production and use; and/or

(c) Annex C to reduce or eliminate releases from unintentional production.

39. Control measures that result from a listing to the Convention include actions that eliminate or restrict intentional production and use of the substance as well as import and export (Article 3). These control measures may allow for time-limited or on-going production or use for certain applications. Measures may also include actions to minimise and, where feasible, eliminate unintentional production (Article 5). Upon listing to the Convention, Parties are required to take appropriate actions to manage stockpiles and wastes in accordance with Article 6 of the Stockholm Convention. Being mindful of the precautionary approach referred to in Article 1 of the Convention, the aim of any risk reduction strategy for long-chain PFCAs, their salts and related compounds should be to reduce and eliminate emissions and releases of these substances to the extent possible. This risk management evaluation considers socioeconomic information submitted by Parties and observers to enable a decision to be made by the Conference of the Parties regarding possible control measures. This document reflects the available information on the differing capabilities and conditions among Parties.

Control measures for releases from intentional production and use

40. As described in section 2, long-chain PFCAs, their salts and related compounds are intentionally produced and used in various applications. Information on alternatives provided in Annex F submissions, and gathered through a literature review and during the development of the regulatory actions proposed in Canada and in force in the EU, demonstrates that alternatives are available for most known applications of these substances (see section 2.3 for details). Specific exemptions may, however, be justified to provide additional time to identify and transition to suitable alternatives in certain applications, and in order to avoid regrettable substitution (see section 2.2.1 for details) and to minimise potential social impacts (see section 2.4 for details).

41. Given that Canada, the EU and Switzerland have regulated the production and use of certain (e.g. C_9–C_{14}) or all long-chain PFCAs, their salts and related compounds covered by this risk management evaluation, and that Parties have identified only a limited number of uses where alternatives have not been identified at this time and/or where there are technical challenges associated with the transition to alternative chemicals or processes, the listing of long-chain PFCAs, their salts and related compounds in Annex A, with specific exemptions, could be the primary control measure to eliminate the production and use of these substances at the global scale. Further, given the similarities between the known applications of long-chain PFCAs, their salts and related compounds and those of other PFASs recently listed to the Convention (i.e. PFOA and PFHxS), and that these were listed to Annex A, it does not seem that a listing to Annex B would be needed for long-chain PFCAs, their salts and related compounds.

42. A listing of long-chain PFCAs, their salts and related compounds to Annex A to the Convention would subject these substances to the provisions of Article 3 of the Convention, requiring Parties to take the legal and administrative measures necessary to eliminate production and use (subject to the provisions of the Annex A listing, such as specific exemptions) and to only import and export these substances in accordance with the Convention. If specific exemptions are included in the listing of long-chain PFCAs, their salts and related compounds to the Convention, then Parties shall take appropriate measures to ensure that any production or use under such exemptions is carried out in a manner that prevents or minimises human exposure and release into the environment. For exempted uses that involve the intentional release of these substances into the environment under conditions of normal use, such release shall be to the minimum extent necessary, taking into account any acceptable standards and guidelines.

Control measures for releases from unintentional production

43. As mentioned in section 1.1, long-chain PFCAs and their related compounds may be unintentionally produced during the manufacture of other PFASs. For example, in the manufacture of PFASs with six perfluorinated carbons, substances with eight perfluorinated carbons are produced as by-products. However, based on available information, it is possible to remove these by-products to a large extent before the end product is brought to the market (Swedish Chemicals Agency 2015). Other control measures, such as using a “purer” starting material when producing perfluorinated acids via electrochemical fluorination or controlling the telomerization process to produce specific chain lengths, could also be considered to minimize the unintentional production of long-chain PFCAs during the manufacture of other PFASs. Long-chain PFCAs may also be unintentionally produced during other industrial processes, such as the manufacture of PTFE micro powders by ionising radiation or thermal degradation. As shown in Table 7 of UNEP/POPS/POPRC.19/INF/8, long-chain PFCAs and their related compounds have been detected in various products and articles. In some cases, they may be present as impurities or as by-products in the commercial mixtures or materials used to manufacture the products and articles. Therefore, manufacturers should aim to minimise the unintentional presence of long-chain PFCAs and their related compounds to the largest possible extent from commercial mixtures and materials. This should be captured in the guidance on best available techniques and best environmental practices (BAT/BEP) for the use of long-chain PFCAs, their salts and related compounds that would be developed following a listing of these substances to the Convention, as it was done for PFOS and PFOA. Section 2.1 of UNEP/POPS/POPRC.19/INF/8 provides information on the availability of technologies for minimising the unintentional production or presence of long-chain PFCAs and their related compounds.

44. As described in section 2, long-chain PFCAs (and PFOA) may also be unintentionally produced during thermolysis of fluoropolymers (e.g. PTFE) at temperatures relevant to low-temperature incineration of waste. As such, listing long-chain PFCAs, their salts and their related compounds to Annex C of the Convention could be considered. However, the formation of PFOA as a by-product in incineration processes was considered in the risk management evaluation on PFOA, its salts and PFOA-related compounds and its addendum.[12] It was noted that the technical measures required to minimise the unintentional produced PFOA from incineration are already required to a certain extent according to existing BAT/BEP for incineration processes, which are applied to control other unintentional POPs (e.g. polychlorinated dibenzo-*p*-dioxins and dibenzofurans). In addition, it was highlighted that the emission of unintentionally produced PFOA from incineration are considered to be negligible compared to the other sources of PFOA emissions. Based on the information assessed, the POPRC did not recommend listing PFOA, its salts and PFOA-related compounds in Annex C to the Convention.

[12] UNEP/POPS/POPRC.13/7/Add.2 and UNEP/POPS/POPRC.14/6/Add.2, respectively.

45. The above considerations, identified by the POPRC for PFOA, are considered relevant for long-chain PFCAs as these PFCAs may be unintentionally produced concurrently. Further, there is no information indicating that long-chain PFCAs are unintentionally produced to a greater extent than PFOA during low-temperature incineration. On this basis, a listing to Annex C is not believed to be a relevant control measure for long-chain PFCAs.

Control measures for release from stockpiles, wastes and contaminated sites

46. Upon entering the waste stream at the end of their life cycle, products and articles containing long-chain PFCAs, their salts and related compounds may continue to be a significant pathway of these substances into the environment. As described in section 2, long-chain PFCAs and their related compounds may be released to the environment from landfills, incineration facilities, wastewater treatment plants and the application of contaminated biosolids and compost.

47. Following a listing to the Stockholm Convention, Parties shall take appropriate waste management measures to ensure that wastes, including products and articles upon becoming wastes, consisting of, containing or contaminated with a listed chemical are managed in a manner protective of human health and the environment, in accordance with Article 6 of the Convention. These measures would contribute to ensuring that wastes containing long-chain PFCAs, their salts and related compounds at concentrations at or above the low POP content value are disposed of in such a way that the POP content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs. Alternatively, waste that contains POPs may be disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low. These measures would also address proper waste handling, collection, transportation and storage to eliminate or reduce emissions and the resulting exposure to long-chain PFCAs, their salts and related compounds.

48. Waste management activities should take into account international rules, standards, and guidelines, including those that have been, or may be developed under, or in cooperation with, the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal*, and relevant global and regional regimes governing the management of hazardous wastes. General technical guidelines on the environmentally sound management of POPs wastes have been developed under the Basel Convention.[13] Following a listing of long-chain PFCAs, their salts and related compounds to the Stockholm Convention, a concentration level for low POP content would be established in cooperation with the Basel Convention. In addition, specific technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with long-chain PFCAs, their salts and related compounds would also be developed by an expert group jointly with the Basel Convention. These Guidelines would identify technologies for the destruction and irreversible transformation of these substances in wastes. Establishing the low POP content value and developing the guidelines under the work of the Basel Convention would help Parties to dispose of waste containing long-chain PFCAs, their salts and related compounds in an environmentally sound manner. In addition, given that there are analytical challenges in measuring some long-chain PFCAs, special instructions may be needed when establishing waste thresholds.

49. Following a listing of long-chain PFCAs, their salts and related compounds to the Stockholm Convention, Parties should also consider emission reduction measures and the development of guidance and use of BAT/BEP in the waste management phase. In addition, Parties shall develop appropriate strategies to identify any existing stockpiles and then ensure their environmentally sound disposal. Parties shall also endeavour to develop appropriate strategies for identifying sites contaminated with long-chain PFCAs, their salts and related compounds. If contaminated sites are identified and remediation is undertaken, it shall be performed in an environmentally sound manner.

2.2. Efficacy and efficiency of possible control measures in meeting risk reduction goals

2.2.1 Technical feasibility

50. The risk management evaluation was developed to provide an analysis of possible control measures for long-chain PFCAs, their salts and related compounds in accordance with Annex F to the Convention, and to provide the basis for a recommendation of the POPRC to the Conference of the Parties. For this purpose, this risk management evaluation aims to identify uses for which there may not be available or accessible chemical and/or non-chemical alternatives. Current or proposed regulatory actions on long-chain PFCAs have provided exemptions based on technical and/or socioeconomic challenges with the transition to alternatives. These exemptions may inform exemptions to be considered for an Annex A listing to the Convention.

51. In Canada, the manufacture, use, sale, offer for sale and import of long-chain PFCAs, their salts and their precursors (and products containing them) has been prohibited since 2016, with a limited number of exemptions. The

[13] The General technical guidelines on the environmentally sound management of POPs wastes are available at: http://www.basel.int/Implementation/TechnicalMatters/DevelopmentofTechnicalGuidelines/TechnicalGuidelines/tabid/8025/.

proposed *Prohibition of Certain Toxic Substances Regulations, 2022* (Canada 2022) propose to further restrict these substances, while allowing time-limited exemptions for the semiconductor industry (with a timeline of up to 2040 for replacements) and for fire-fighting foams (until 2025) (see Table 5 of UNEP/POPS/POPRC.19/INF/8 for details). In its Annex F submission, Canada indicates that similar exemptions may be needed if long-chain PFCAs, their salts and related compounds are listed to the Stockholm Convention to allow time for industry to transition to alternatives.

52. In the EU, the manufacture, use and placing on the market of C_9–C_{14} PFCAs, their salts and related compounds, as well as the import of articles containing these substances, have been restricted under REACH since February 2023, with time-limited derogations for certain applications (see Table 5 of UNEP/POPS/POPRC.19/INF/8 for details). These derogations are mainly intended to align with the derogations for the use of PFOA, its salts and PFOA-related compounds included in the Regulation (EU) 2019/1021 on Persistent Organic Pollutants. Additional derogations were also granted based on information provided by stakeholders (see section 1.2 of UNEP/POPS/POPRC.19/INF/8 for details). In its Annex F submission, the EU indicates that a specific exemption would be needed by the EU to allow the use and placing on the market (including import) of long-chain PFCAs in semiconductors for their use in spare or replacement parts for finished electronic equipment.

53. In its Annex F submission and subsequent communications,[14] Japan indicated that specific exemptions are required for the following applications (as well as for replacement parts, where applicable) since no specific alternative products and/or processes are currently available: 1) lubricants used in fluoropolymer product manufacturing processes; 2) cooling applications for the manufacture of high-heat and high-voltage parts for semiconductor manufacturing equipment; 3) parts and/or materials for electrical and electronic devices, equipment and appliances; 4) inactive/inert fluorine liquid for reliability testing and temperature control for the manufacture of electric components, and electrical and electronic equipment; 5) heat media in a closed system;[15] and 6) inks for marking capacitors and cables. Japan explained that substitutions are challenging because a long period of time is required for the research, development and verification of alternative products or processes with equivalent functions and effects, and changes in raw materials or manufacturing processes of medical devices and materials require approval by national authorities. In addition, for the use of long-chain PFCAs, their salts and related compounds in inactive/inert fluorine liquid for the manufacture electric components, and electrical and electronic equipment, Japan indicated that industry has evaluated various liquids, powders and gases to replace this fluorine-type inert liquid but has not been able to replace them. Japan anticipates that a long period of time is needed for substitution.

54. In its Annex F submission (2022), the UK indicated that available information, including consultations with stakeholders (i.e. downstream users and trade bodies for textiles, flooring, fire protection, and adhesives and sealants sectors), indicates that alternatives to long-chain PFCAs, their salts and related compounds have already been or will be implemented by industry. No technical feasibility issues were identified through these consultations, although many stakeholders did not respond to the UK's call for information (UK Annex F information 2022). The UK conducted an additional stakeholder consultation requesting comments on the second draft risk management evaluation of long-chain PFCAs, their salts and related compounds. From this consultation, industry provided additional information that C_9–C_{21} PFCAs are unintentionally produced at very low levels in the manufacture of PTFE micro powders (as described in section 1.1, and in section 1.1 of UNEP/POPS/POPRC.19/INF/8) and may be present at low concentrations in products containing PTFE micro powders. Therefore, they indicated the need for a specific exemption to allow industry to continue to undertake the process they use to remove long-chain PFCAs (and PFOA) in PTFE micro powders, as this process is split across companies and there is a requirement to transport the material containing long-chain PFCAs (and PFOA) across country borders. Consequently, the UK indicated that a specific exemption for this purpose is required, suggested to be worded as: Concentrations of C_9–C_{21} PFCAs and their salts shall be equal to or below 1 mg/kg (0.0001 % by weight) where they are present in polytetrafluoroethylene (PTFE) micro powders produced by ionising irradiation or by thermal degradation, as well as in mixtures and articles for industrial and professional uses containing PTFE micro powders, until (date). All emissions of C_9–C_{21} PFCAs during the manufacture and use of PTFE micro powders shall be avoided and, if not possible, reduced as far as possible. The limit of 1 mg/kg (0.0001% by weight) shall apply only to manufacture, placing on the market and use of C_9–C_{21} PFCAs and their salts where they are present in PTFE micro powders that are transported or treated for the purpose to reduce the concentration of C_9–C_{21} PFCAs and their salts below the limit of 0.250 mg/kg (0.0000250% by weight).

55. According to I&P Europe (Annex F information 2022), between 2000 and 2015, the photo-imaging industry in Europe has reformulated or discontinued a large number of products, resulting in a reduction of more than 95% in the use of PFOA-related substances (which may contain substances that fulfill the definition of long-chain PFCAs and their related compounds). Further, I&P Europe indicated that uses in photographic coatings will be eliminated by July 2025 at the latest. I&P Europe has indicated that, at this time, the primary barrier to complete elimination of the use of PFOA-related substances remains technical. Thus, the association has indicated that a specific exemption for the use

[14] In response to requests from the drafters for additional information on the requested exemptions.

[15] Including heat media requiring both optical properties and heat-transfer performance in components of *in vitro* diagnostic medical devices, refractive media in analytical instruments for detecting fluorescence and heat media in thermostatic chambers for reliability and durability testing of electric and electronic equipment.

of long-chain PFCAs, their salts and related compounds in photographic coatings applied to films, such as the one currently in place for PFOA, its salts and PFOA-related compounds, would give manufacturers the best chance for technical success.

56. The use of long-chain PFCAs, their salts and related compounds has recently been identified in the automotive industry (see Table 1 and section 2 of UNEP/POPS/POPRC.19/INF/8) in vehicles in production, and in service and replacement parts for vehicles in production and those that have ceased mass production. In response to a request for additional information, the Canadian Vehicle Manufacturers' Association (CVMA) indicated that some of these uses could be the result of indirect use of long-chain PFCAs, their salts and related compounds (e.g. the use of fluoropolymers (e.g. PTFE) that might have been manufactured using these substances as polymerisation aids) rather than direct uses of long-chain PFCAs, their salts and related compounds. However, based on the available information, they are not currently able to differentiate between those uses (see section 2 of UNEP/POPS/POPRC.19/INF/8 for details). In its Annex F submission (2023) and subsequent communications, CVMA indicated that vehicles[16] currently in production, and those that have ceased mass production, will require servicing and maintenance. CVMA also stated that, for service and replacement parts, it is important that parts that are already certified and approved for use continue to be available to consumers to ensure the proper and desired functioning of their vehicle. Based on principles applied to the automotive sector in Canada,[17] vehicle replacement and service parts should be available for 15 years to satisfy consumer demand, legal and/or warranty matters. In Canada, the automotive industry would likely not be producing these replacement parts but would need to import the parts produced or stored in other jurisdictions. Due to the integration of the North American market, replacement parts are stored at distribution centres across Canada and the USA and delivered to dealers based on geographic location, resulting in replacement parts often needing to be imported into Canada from the USA. On this basis, CVMA has expressed the need for an exemption for replacement and service parts for vehicles. In addition, in its comments on the second draft risk management evaluation, the association has indicated that a 5-year lead time is also required to address the use of long-chain PFCAs, their salts and related compounds in vehicles currently in production, consistent with the principles applied to the automotive sector in Canada. The CVMA has also specified that, since February 2021, the use of long-chain PFCAs, their salts and related compounds has been prohibited in new uses (i.e. for parts being approved for new vehicle production after February 2021) per the Global Automotive Declaration Substances List (GADSL). However, parts that were approved before February 2021 could still be in production for up to 5 years. Since long-chain PFCAs, their salts and related compounds could be listed to the Stockholm Convention in 2025 at the earliest (with the listing coming into force in 2026), the use of long-chain PFCAs in new vehicle production is, therefore, anticipated to have ceased prior to the coming into force of a listing of these substances to the Convention.

57. In response to comments expressing the need to further define the list of parts that would be included in a possible specific exemption to a listing under the Convention, the Association indicated that for small batch production of service and replacement parts, it is particularly difficult at this time. Generally, any uses of long-chain PFCAs, their salts and related compounds that could be easily replaced by the industry would be, but for uses that require certification/validation to meet vehicle safety standards, it may not be possible to run the appropriate tests if the vehicle is no longer in serial production. For example, uses have been identified in airbag assemblies, a critical safety component. The entire airbag assembly may not be easily revalidated for vehicles no longer in production, and vehicle manufacturers need to ensure the availability of the same parts as approved for use. In the case of other uses, such as cables, the identified uses may be for cables associated with emission systems or safety equipment, and therefore would not be easily changed. On the other hand, uses in carpets may be more easily eliminated in replacement parts after existing inventories have been used.

58. In response to a request for quantitative estimates in relation to the expressed need for specific exemptions for the automotive sector, the CVMA indicated that the use of long-chain PFCAs, their salts and related compounds has been declining for some time and, as indicated above, that the use of these substances has been prohibited from new uses per the GADSL since February 2021. Many of disclosures in GADSL for the service and replacement parts are for older vehicles that are already well into the typical 15-year timeframe to provide OEM (vehicle manufacturers) replacement parts. The Association indicated that quantitative estimates on the total amount of long-chain PFCAs, their salts and related compounds in inventory cannot be provided, but that a recent analysis performed by seven global OEMs identified approximately 1000 different parts that contained these substances out of millions of total parts. The average weight of long-chain PFCAs, their salts and related compounds was approximately 3 grams per part, but many parts had substantially less than 1 gram per part. CVMA also indicated that none of the identified uses are for parts that regularly require maintenance on a vehicle, such as tires, cabin air filters and various lubricants. Rather the uses identified would be for service and replacement parts that require replacement due to accidents,

[16] As described in UNEP/POPS/POPRC.19/INF/8, long-chain PFCAs, their salts and related compounds have been identified to be used in vehicle coatings, cables, electronics, engines and underhood applications, modules, hydraulic system components and relay assemblies.

[17] More details are available at: https://www.canada.ca/en/environment-climate-change/services/management-toxic-substances/sources/chemical-management-plan-automotive-manufacturing.html#a2.

warranty or other incidents. Therefore, the volume is significantly reduced compared to uses in production vehicles and will decrease exponentially over the course of 15 years.

2.2.2 Cost and benefits of implementing control measures

59. The Regulatory Impact Analysis Statement that was published with the proposed *Prohibition of Certain Toxic Substances Regulations, 2022* noted that the compliance costs associated with the proposed further restriction of long-chain PFCAs, their salts and related compounds exemptions in Canada were overall anticipated to be minimal, given the wide availability of alternatives (Canada 2022). A limited number of exemptions were, however, included in the proposed Regulations based on information gathered during their development due to significant costs and impacts in certain sectors (Canada Annex F information 2022). In the EU, no costs of substitution to alternatives are anticipated since no intentional use of long-chain PFCAs were identified. Further, enforcement costs can be shared with the enforcement costs connected with the implementation of the PFOA restriction under the Stockholm Convention (EU Annex F information 2022). Cost relating to the concentration limits established in the EU for the unintentional presence of C_9–C_{14} PFCAs and to measures applied by industry to minimise and to manage the fraction containing C_9–C_{14} PFCAs in commercial products have, however, been identified (ECHA 2020a,b; see section 2.4.4 for more details). In the UK, the costs of control measures are largely unknown as C_9–C_{21} PFCAs are not intentionally produced. Evidence from engagement with industry identified that, of the downstream users who responded to the UK's call for information, most have already sourced alternatives. Therefore, it is anticipated that the economic costs of substituting to alternatives will be low (UK Annex F information 2022). However, in countries that have not yet taken regulatory actions on long-chain PFCAs, their salts and related compounds, industry is anticipated to face greater costs for transitioning to alternatives, as available information suggests that alternatives to these substances may be more expensive and/or need to be used in greater quantities to obtain the same performance (see section 2.3.2 and 2.4.4 for details). Costs will also include the loss of value of waste that would have previously been sent for recycling and the cost of incineration at conditions required so that the POP content is destroyed or irreversibly transformed (see section 2.4.4 for details). There may also be environmental costs, as incineration of waste which were previously recycled will result in higher carbon emissions and a reduction in the ability to utilize circular economy approaches (UK Annex F information).

60. As described in section 2.4, the implementation of control measures on long-chain PFCAs, their salts and related compounds would have positive impacts on health, agriculture and biota. It would also contribute to reducing, and eventually preventing, the extensive potential costs associated with the management of wastes containing these substances, as well as the remediation of contaminated sites and treatment of contaminated water sources. The overall benefits of taking global action on these substances are, therefore, expected to outweigh the cost of implementing control measures.

2.3 Information on alternatives (products, processes and costs)

61. Alternatives to long-chain PFCAs, their salts and related compounds are anticipated to be the same as those for PFOA, its salts and related compounds. Therefore, the draft guidance on alternatives to PFOA has been used to identify possible alternatives. Generally speaking, there are three types of alternatives to long-chain PFCAs, their salts and related compounds: short-chain fluorinated compounds, fluorine-free compounds and physical (non-chemical) alternatives (Canada Annex F information 2022). Assessments of alternatives to the use of PFASs in various applications, conducted by the Swedish Chemicals Agency (2015, 2021), the OECD (2020, 2022), the WSDE (2021) and the California DTSC (2020, 2022) have also been used to identify possible alternatives. Because these assessments did not speak specifically to long-chain PFCAs, their salts and related compounds, the term "PFASs" is used in these instances to reflect that the information from the cited publication relates to the broad class of PFASs.

2.3.1 Avoiding regrettable substitution

62. When transitioning to alternatives, it is important to avoid regrettable substitution. Therefore, alternatives to long-chain PFCAs, their salts and related compounds should be assessed carefully and safer alternatives should be pursued.

63. Due to the wide range of potential applications and alternatives to long-chain PFCAs, their salts and related compounds, it would be challenging to summarise available information on known (or potential) hazard characteristics of these alternatives. Thus, only general summaries of the available information on, or assessments of, the potential health or environmental hazards of the chemical alternatives are provided in this risk management evaluation. Readers are encouraged to consult the references cited throughout section 2.3.2 for more detailed information. However, because concerns were identified for some of the main groups of potential alternatives to long-chain PFCAs, their salts and related compounds (i.e. other PFASs, siloxanes and silicones), these are further elaborated on below.

64. Due to concerns about their impact on humans and the environment, long-chain PFAAs, including long-chain PFCAs, and their precursors are being substituted by other substances, including fluorinated alternatives which are structurally similar to the substances they replace (Wang et al. 2015). These fluorinated alternatives include short-

chain PFAAs and perfluoropolyethers, in particular per- and polyfluoroether carboxylic acids, which have high environmental stability and mobility. Some of these alternatives have also been reported to cause adverse effects in laboratory animals (Wang et al. 2015). Lohmann et al. (2020) also identified similar concerns between legacy (e.g. C_9 PFCA) and replacement fluoropolymer processing aids (e.g. mono- or poly-fluoroether carboxylic acids or other shorter-chain fluorinated substances) in terms of environmental exposure, bioaccumulation and toxicity. Similarly, the draft guidance on alternatives to PFOA raises concerns related to the use of short-chain PFASs as significant evidence has shown potential health and environmental concerns, including enhanced mobility, uptake in crops, binding to proteins, increasing levels of exposure, and difficulty to capture and to clean-up once released into the environment (Brendel et al. 2018; Ritscher et al. 2018; UNEP/POPS/POPRC.14/6/Add.2). Some short-chain PFASs are also detected in the environment including the Arctic, humans and wildlife (UNEP/POPS/POPRC.13/INF/6) and increasing concentration trends in biota are reported (e.g. Barrett et al. 2021). In addition, one of the primary fluorinated alternatives to long-chain PFCAs, perfluorohexanoic acid (PFHxA) and its related substances was proposed for restriction within the EU in 2020, and is currently under consideration (ECHA 2019). In 2021, the ECHA RAC and SEAC have published an opinion supporting a restriction on these substances, with some derogations (ECHA 2021).

65. In May 2023, Canada has published an Ecological State of the Science Report on short-chain PFCAs, short-chain perfluorosulfonic acids (PFSAs) and long-chain PFSAs (ECCC 2023b), in support of the Draft State of Per- and Polyfluoroalkyl Substances Report (ECCC and Health Canada 2023a). The Ecological State of the Science Report provides a summary of data available from the ecological-related science literature for these groups of substances, including on environmental persistence, bioaccumulation and trophic magnification potential, mobility, Canadian environmental monitoring data, and potential for adverse effects in the environment. Overall, the Report concludes that "*Despite the fact that substance-specific information is lacking for many of these PFAS, what is known about their persistence, mobility, bioaccumulation, and toxicity profiles on the basis of the empirical information presented throughout this report suggests that these SC-PFCAs/PFSAs and LC-PFSAs may share similar ecological concerns with PFAS that have been previously assessed and regulated. Given their extreme persistence properties, it is expected that these substances will remain and accumulate in the environment once released. Consequently, it is expected that the potential for adverse effects resulting from continued exposure to SC-PFCAs, SC-PFSAs, and LC-PFSAs will increase with increasing environmental loads.*" The EU REACH restriction proposal for PFASs (ECHA 2023b) outlines a number of concerns for PFASs, including their very high persistence, bioaccumulation, mobility, potential for long-range environmental transport and (eco)toxicological effects.

66. Based on the above considerations, although fluorinated alternatives to long-chain PFCAs, their salts and related compounds are included in this risk management evaluation, consideration should be given to only transitioning to these alternatives for applications where no suitable fluorine-free alternative has been identified.

67. As described in section 2.3.2, silicones and/or siloxanes products were identified as potential alternatives in certain applications. Certain cyclic siloxanes, such as octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5) and dodecamethylcyclohexasiloxane (D6), were identified as SVHCs and added to the REACH Candidate List, as they were identified as PBT and vPvB (ECHA 2018c). In addition, D4 is suspected of damaging fertility[18] and D5 was identified as a potential carcinogen[19] (Danish EPA 2015). In Canada, a risk assessment concluded that D4 may be entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity (Health Canada and Environment Canada 2008). Consequently, it was listed to Schedule 1–List of Toxic Substances of the *Canadian Environmental Protection Act*, 1999 (CEPA). In addition, Norway has reviewed a group of related linear siloxanes in the Substance Evaluation process under REACH and concluded that octamethyltrisiloxane (L3), octamethyltrisiloxane (L4) and dodecamethylpentasiloxane (L5) meet the criteria for vPvB substances according to Article 57(e) of REACH (Norwegian Environmental Agency 2021a,b,c). ECHA has undertaken an Assessment of Regulatory Needs (ARN) for the group "Hydrocarbyl siloxanes" and identified a need for regulatory risk management action (restriction) in the EU for most of the substances in the group (ECHA 2022b). It has also been noted that there may be a residual quantity of siloxanes in silicones which remain after polymerisation or chemical reaction compounds formed during the process. There is also the possibility that siloxanes are formed during the use of silicone products (e.g. by repeated use of baking moulds at high temperatures) (OECD 2020). Therefore, although siloxanes are identified as alternatives for certain applications, potential concerns are noted for some of these substances.

[18] D4 is classified within the EU as suspected to be toxic to reproduction under Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures.

[19] Danish EPA (2015) refers to a factsheet on Siloxane D5 in Drycleaning Applications Fact Sheet (US EPA 2009) which outlines the results of a two-year chronic and carcinogenicity study on D5 in rats, where female rats exposed to the highest concentration tested exhibited a significant increase in uterine tumors.

2.3.2 Application-specific alternative substances

68. As described in section 2, long-chain PFCAs, their salts and related compounds (or products containing them) are intentionally used, or may have been used, in a range of applications, which can be grouped in the categories outlined below.

Industrial uses

69. Long-chain PFCAs, their salts and/or related compounds have been identified to be used as surfactants, fluoropolymer polymerisation aids, manufacturing intermediates, analytical reagents and lubricants in the manufacture of fluoropolymers.[20]

70. The draft guidance on alternatives to PFOA provides a list of possible non-fluorinated emulsifiers and surfactants, and processes and techniques which may also be suitable alternatives to long-chain PFCAs, their salts and related compounds for manufacturing fluoropolymers. During consultations on the proposed EU restrictions on C_9–C_{14} PFCAs, their salts and related compounds, stakeholders in the EU indicated a general transition trend to move from eight and nine perfluorinated carboxylate polymerisation aids (PFOA or C_9 PFCA) for manufacturing fluoropolymers to certain mono- or polyfluoroether carboxylic acids or other shorter-chain fluorinated substances (ECHA 2018b). Wang et al. (2013, 2015), Lohmann et al. (2020) and the draft guidance on alternatives to PFOA also identify these chemistries in commercialised fluorinated alternatives to long-chain PFCAs and their salts as fluoropolymer processing aids. For fluorotelomer-based products (e.g. fluorotelomer-based surfactants or polymers), which are based on n:2 FTOH (n≥8), the shorter-chain 6:2 FTOH (CAS: 647-42-7) is used as an alternative (ECHA 2018b).

71. ECHA (2018b) indicated that many companies are already using fluorotelomer-based short-chain chemistry to manufacture fluorotelomer-based product and that this is an indication for the technical and economic feasibility of these alternatives. However, $\leq C_6$-based fluorotelomer chemistry was reported to be, in general, more expensive (i.e. higher volumes need to be applied to achieve the same technical performance and costs of these products are higher) (ECHA 2018b). According to some stakeholders the quality/performance of C_6-based products is still not as good as long-chain based products, e.g. with regard to oil repellency (EU Annex F information 2022).

72. Lubricants can be used in polymer processing to lower melt viscosity or to prevent polymers from sticking to metal surfaces (Drobny 2014). Potential alternative lubricants include metal soaps, hydrocarbon waxes, polyethylenes, amide waxes, fatty acids, fatty alcohols, esters, silicones and boron nitride (Drobny 2014; SpecialChem 2023).

73. For other industrial applications, the imide salt of perfluorobutane sulfonic acid (PFBS) is marketed as a surfactant, acid catalyst and as a raw material for ionic liquids (Wang et al. 2013).

Electronic articles, and medical and laboratory devices

74. Long-chain PFCAs, their salts and/or related compounds have been identified to be used in semiconductors, cooling applications for the manufacture of high-heat and high-voltage parts for semiconductor manufacturing equipment, functional fluids in closed systems for computer and electronic product manufacturing, and heat media in closed systems.[21]

75. Long-chain PFASs can be used in anti-reflective coatings used in the manufacturing of semiconductors, which make up electronic devices. More specifically, C_{10} PFCA has been reported by the semiconductor industry to be used in specialized semiconductors (i.e. micro-electromechanical system (MEMS)-based semiconductors) imported within products into Canada (ECCC 2023a). The industry, however, has indicated that long-chain PFCAs, their salts and related compounds are not used in photolithography or etch processes. The draft guidance on alternatives to PFOA provides a list of possible non-fluorinated alternatives to the use of PFOA in the manufacturing of semiconductors, which may also be suitable alternatives to long-chain PFCAs (e.g. nitrobenzenesulfonate (NBS); acceptor-substituted thiosulfonate anions such as benzo[*b*]thiophene-2-sulfonic acid, 4(or 7)-nitro-, ion(1-) (TBNO) or 2-thiophenesulfonic acid, 5-chloro-4- nitro-, ion(1-) (TN); aromatic anions, such as pentacyanocyclopentiadienide (CN5) or methoxycarbonyl-tetracyanocyclopentadienide (CN4-C1); triphenylsulfonium (TPS)). The EU REACH restriction proposal for PFASs (ECHA 2023b) identifies a number of non-fluorinated alternatives to PFASs in the semiconductor industry, which may also be suitable alternatives to long-chain PFCAs, for example: aromatic PAG and heteroaromatic PAGs (PAG triphenylsulfonium benzo[*b*]thiophene-2-sulfonic acid, 4(or 7)-nitro-, ion(1-) (TPS

[20] As indicated in Section 2, clarification on this reported use has been requested from Japan, but no information has been received at this time. It has been reported by the UK that long-chain PFCAs are unintentionally present in fluoropolymer micro powder (lubricants) rather than used to manufacture such fluoropolymers. No revisions have been made to the risk management evaluation at this time, pending receipt of the requested clarification.

[21] Including inactive/inert fluorine liquid for reliability testing and temperature control for the manufacture of electric components and electrical and electronic equipment, heat media for *in vitro* medical devices and refractive media in analytical instruments by fluorescence detection.

TBNO); polyetheretherketone (PEEK); hydrocarbon-based greases, molybdenum disulfide and graphite; and mineral oils, synthetic oils, natural oils and hydrocarbon fluids.

76. Short-chain PFAS alternatives to long-chain PFASs used in anti-reflective coatings are also available on the market (e.g. fluoropolymer with a short fluoroalkyl side chain that is less than C_4, PFBS or functionalized fluoroethanesulfonates) (OECD 2022; UNEP/POPS/COP.10/INF/25).

77. As described in the draft guidance on alternatives to PFOA, the potential health and environmental concern of fluorine-free photoresist is not clear for all alternatives. Where information was available, it suggests these may be "safer" alternatives than PFASs. However, some technical limitations were identified for fluorine-free alternatives which are currently prohibitive to high-volume manufacturing. A technical paper prepared by the Semiconductor PFAS Consortium Photolithography Working Group (2023) indicates that the semiconductor industry has moved away from long-chain PFASs, and now relies on short-chain PFASs-containing materials. The technical paper indicates that despite significant research by chemical suppliers, almost all cases of fluorine-free alternatives are unlikely to provide the essential properties present in PFAS systems.

78. Limited information is available regarding the use of long-chain PFCAs, their salts and related compounds in other electronic articles, and in medical and laboratory devices, making the identification of potential alternatives for this sector challenging. Silicones fluids are advertised to be suitable for high-temperature applications in electronics (e.g. heating medium for solar systems) and could potentially be considered as alternatives (Shin-Etsu Silicone 2021). The EU REACH restriction proposal for PFASs (ECHA 2023b) identifies a number of non-fluorinated alternatives to PFASs in the semiconductor industry, which may also be suitable alternatives to long-chain PFCAs, for example: ethylene propylene diene monomer (EPDM) and silicone rubbers as alternatives for fluoroelastomers in sealing; silicone materials, PEEK, mica, EPDM, polyvinyl chloride, polyethylene, ceramic based and one confidential polymer as alternatives for wire insulation; mineral oils, synthetic oils, natural oils and hydrocarbon fluids as alternatives in heat transfer fluids for immersion cooling (no current but possible future use); and cyano group instead of CF_3 for liquid crystal displays (LCD). For heat transfer fluids, hydrocarbon-, ester- and polydimethylsiloxanes-based products and other non-fluorinated alternative products were identified from an internet search and ChemSec (2023b) report on PFAS alternatives in electronics (IPEN/ACAT comments on the third draft risk management evaluation). Based on the available information, ECHA (2023b) concluded that there is sufficiently strong evidence that technically feasible alternatives exist for heat transfer fluids for immersion cooling.

79. In its Annex F submission, Japan indicated that an alternative to the use of compounds related to long-chain PFCAs, with both the optical properties and heat-transfer performance required for heat media for medical device applications, has not been identified. In addition, for refractive index solutions for analytical instruments by fluorescence detection, Japan has not identified an alternative that can keep the laser injection efficiency to the analytical column comparable. Japan also indicated that an alternative with a high boiling point has not been identified for inactive/inert fluorine liquids for quality evaluation testing of electric components and electrical and electronic equipment.

Photo-imaging

80. Long-chain PFCAs, their salts and/or related compounds, or products containing them, have been identified to be used in photographic materials.

81. In its comments on the first draft risk management evaluation, IPEN indicated that transitioning to digital solutions is the most common alternative to the use of chemicals, including long-chain PFCAs, their salts and related compounds, in photo-imaging. The Swedish Chemicals Agency (2015) identifies surface-active hydrocarbons and silicone chemicals as fluorine-free chemical alternatives to the use of PFASs in the photographic industry. Possible alternatives identified in the draft guidance on alternatives to PFOA in the photographic industry (i.e. shorter-chain fluorotelomer-based products; C_3 and C_4 perfluorinated compounds and silicone products) may also be potential alternatives to long-chain PFCAs, their salts and related compounds.

82. According to I&P Europe (Annex F information 2022), even though imaging products from different companies may perform in a similar manner and the basic manufacturing processes are similar across the industry, the formulae for imaging coatings are proprietary and differ across companies and products. Thus, replacement substances must be assessed by each manufacturer for their own specific formulations. According to the association, successful alternatives to PFOA-related substances[22] include non-perfluorinated chemicals, chemicals with short (C_3–C_4) perfluorinated chains, telomers, and in a few cases reformulations that are inherently less sensitive to the build up of static electricity. According to I&P Europe (Annex F information 2022), the cost of research and development of alternatives represents a significant financial burden for the photo-imaging industry, and the cost associated with the substitution of PFOA-related substances in the remaining uses has, in most cases, become prohibitive as a result of these uses being niche products in declining markets.

[22] Which may contain substances that fulfill the definition of long-chain PFCAs and their related substances.

Inks

83. Long-chain PFCAs, their salts and/or related compounds have been identified to be used in printing inks and inks for marking capacitors and cables.

84. In its comments on the second draft risk management evaluation, the EU indicated that alternative technologies to inkjet marking, such as ultraviolet (UV) laser wire and capacitor marking, appear to be readily available. A subsequent internet search found examples of UV laser markers (Spectrum Technologies 2023; LightMachinery 2023; Tri-Star Technologies 2023) and CO_2 lasers (e.g. LightMachinery 2023) advertised to be suitable for marking wire insulation materials and/or a variety of non-metals, plastics or ceramic materials.

85. Siloxane and silicone polymers were identified as fluorine-free chemical alternatives to the use of PFOS (UNEP/POPS/POPRC.9/INF/11/Rev.1) and other PFASs (Swedish Chemicals Agency 2015) as wetting agents in the ink industry. The draft guidance on alternatives to PFOA and PFOS also identify sulfosuccinates, propylated naphthalenes and propylated biphenyls, and fatty alcohol polyglycol ether sulphate (sometimes together with a sulfosuccinate) as fluorine-free alternatives in printing inks, and may also be potential alternatives to long-chain PFCAs, their salts and related compounds. The draft guidance on alternatives to PFOS describes some of the commercial products containing these substances for use in the ink industry, their function, as well as potential health and environmental effects. Overall, other than information related to siloxanes (see section 2.3.1), the reported data on toxicological and/or environmental properties is limited. However, some potential health (e.g., skin sensitization or dermatitis, or chronic effects) or environmental effects (e.g., potential for bioaccumulation or toxicity to aquatic organisms) have been reported for some of these alternatives (see UNEP/POPS/POPRC.9/INF/11/Rev.1 for details).

Food contact materials

86. Long-chain PFCAs, their salts and/or related compounds have been identified to be used in paper and paperboard food packaging.

87. Alternatives to long-chain PFCAs and/or their related compounds used as coatings for paper or paperboard food (or pet food) packaging can consist of physical barriers, where the paper structure itself serves as an obstacle to penetration, or chemical barriers. Polystyrene, plastic or polylactic acid (sometimes referred to as "corn plastic") can also be used as substitutes for paper and paperboard food packaging for many applications, and some plastics may be treated with other PFASs (OECD 2020; WSDE 2021). However, there has been a trend in OECD countries to seek to reduce or eliminate the use of polystyrene, plastic or polylactic acid for food-on-the-go for reasons of non-sustainability. The result has been a return to the use of paper and paperboard-based food packaging, particularly for cups, food containers, carryout bags and straws (OECD 2020).

88. The OECD (2020) identifies a number of alternatives for creating physical barrier properties in paper and paperboard. Vegetable parchment, made by using sulphuric acid, offers a very high barrier to water and fat and is suitable for use as food wrappers and liners (OECD 2020). Cellulose-based physical alternatives can also be used. These can be divided into natural greaseproof paper (NGP), microfibrillar cellulose (MFC), cellulose nanofibrils (CNFs) and cellulose nanocrystals (CNCs). NGP is made as a result of intensive refining of wood pulp and has both water and grease barrier properties. To improve these properties and reduce air permeability, greaseproof papers are typically coated with starch, carboxymethyl cellulose (CMC) or polyvinylalcohol (OECD 2020). NGP is mainly used as grease and water-resistant paper in food processing and packaging that is intended for contact with fatty foodstuffs (OECD 2020). MFC, CNFs and CNCs are produced by refining cellulose using mechanical processes such as high pressure homogenization, grinding and refining, and are used as a coating on paper or plastic. OECD (2020) reports that the use of these materials is still in development but should be watched as possible future alternatives. A physical barrier can also be made by laminating an extra layer of plastic or aluminum onto the material that will be used in food packaging. The disadvantage, however, is that the facilities must have laminating machines, which adds extra costs and results in food packaging material that is difficult to recycle (OECD 2020).

89. Alternatively, a chemical barrier can be used to confer repellence/barrier performance against grease, stains and water, which can be achieved either by the addition of chemicals to the pulp during paper production or as a surface treatment to the paper (OECD 2020). The OECD (2020) and WSDE (2021) identify silicone, water-based synthetic biopolymer or vegetable-oil based bio-wax barrier products as chemical alternatives to the use of PFASs in paper and paperboard food packaging. Other non-fluorinated coatings used to improve the grease resistance of paper and paperboard, reviewed in OECD (2020), WSDE (2021), Trier et al. (2017), include: aqueous dispersions of copolymers (styrene and butadiene); aqueous dispersions of waxes; starch; clay; stone (calcium carbonate mixed with a resin); chitosan; and water soluble hydroxyethylcellulose. Additional coating agents include: siloxane-based polymers; non-fluorinated alkyl ketene dimer and alkyl succinic anhydride; styrene–acrylic copolymers; talc-filled water-based polyacrylate; pigment-filled hydrophobic monomer dispersions; polyvinyl alcohols and montmorillonite/polyethylene-coatings; and modified wheat protein. Some of these alternatives may contain plastic (e.g., styrene-acrylic copolymers, hydrophobic monomer dispersions, polyvinyl alcohols and polyethylene coatings).

90. Lastly, short-chain PFASs are currently used in food packaging (OECD 2020; WSDE 2021) and could be considered as alternatives to the use of long-chain PFCAs, their salts and related compounds. Wang et al. (2013)

identifies a number of 6:2 fluorotelomer-based products developed by manufacturers to replace products based on long-chain fluorotelomer derivatives. However, as noted above, those may constitute regrettable substitutions.

91. The OECD (2020) conducted an assessment of the grease and water repellency performance of short-chain PFAS packaging and some non-PFAS alternatives. Across the range of alternatives, both short-chain PFASs and some non-PFAS alternatives can meet the grease barrier performance that is required across the range of food packaging applications considered in the study. PFAS-based food packaging was assessed to be significantly cheaper than non-fluorinated alternatives to achieve a grease and water repellence performance that is acceptable for food packaging use (i.e. alternatives were estimated to cost between 11% and 32% more than PFAS-treated paper) (OECD 2020). Similarly, the WSDE (2021) conducted an assessment of alternatives to PFASs in food packaging, including of their potential hazard properties, performance, cost and availability. Overall, the assessment identifies what were considered to be "safer alternatives" (i.e. alternatives that met all the established hazard, exposure, performance, and cost and availability criteria) for certain food packaging applications.[23] For other applications, the assessed alternatives either did not meet all the criteria or, in most cases, there was insufficient data available to complete the assessment. For the hazard assessment, among the assessed alternatives, only siloxane-coated materials were concluded to be "not favorable" alternatives, although there was insufficient data for a number of alternatives. For their part, Trier et al. (2017) concluded, based on well-established business cases, that safer (from a food safety point of view) and more sustainable non-fluorinated alternatives to PFASs in paper and paperboard food packaging products are available for all intended functional uses and food types. They also found that, except for NGP, which can be more expensive, alternatives are cost-neutral for retailers.

Paints, coating and varnishes (including those applied to building and construction materials)

92. Long-chain PFCAs, their salts and/or related compounds have been identified to be used in varnishes. In this risk management evaluation, and as defined in OECD (2022), the term "varnishes" is meant to encompass floor finishes, floor polishes, coatings for countertops, waxes (other than ski waxes) and protective coatings. The Swedish Chemicals Agency (2015) identifies siloxane and silicone polymers as fluorine-free alternatives to PFASs in polish and car wax. For floor polishes, a non-fluorinated alternative is to use soft waxes, which are a mixture of cleaning agents and polishes. Sulfosuccinates have also been identified as alternatives to the use of PFASs in varnishes. As with paints for household applications (described below), short-chain PFASs alternatives (e.g. perfluorobutane sulphonic acid, PFHxA, methyl nonafluorobutyl ether and methyl nonafluoroisobutyl ether), sometimes manufactured in combination with silica-based substances or other non-PFAS components, were identified as being used as surfactants in varnishes (OECD 2022).

93. Long-chain PFCAs, their salts and/or related compounds have also been identified to be used in various other building and construction materials, such as glass treatments, coating for wood boards and products used for masonry and cement surfaces. A derivative of PFHxA is marketed as a surface treatment for glasses, natural stones, metals, wood, cellulose and ceramics (Wang et al. 2013).

94. Long-chain PFCAs, their salts and/or related compounds are reported to be used in paints and/or to have been detected in surfactants used in paints; however, except for automotive paints, the specific function of the paint (e.g. architectural and chemical industry, household applications) cannot be determined based on the available information.

95. Long-chain PFCAs, their salts and/or related compounds may be used in automotive paints and paint sealants to prevent environmental damage. The OECD (2022) has identified polysilazanes, silicon dioxide-based formulations as non-fluoro alternatives to the use of PFASs in automotive paints, including products suitable for use on various metals (e.g. steel and aluminium), plastics and surfaces that are already painted. Another type of alternative is a powder made up of aluminium oxide, coated with titanium dioxide, tin oxide and auxiliaries, which is used for its high colour intensity, sparkle effect and depth (OECD 2022). Aliphatic diisocyanate-based polyurethane coatings have also been described for use in automotive coatings and are marketed as providing weather resistance, including to yellowing or degradation due to sunlight. They also provide gloss retention, resistance to water, oil and chemicals (e.g. salt) which adds to vehicle corrosion and scratch resistance (OECD 2022). Protection from the environment can also be conferred in the E-coats of automotive coatings, such as epoxy-based coatings (OECD 2022).

96. PFASs, including short-chain PFASs, are used as binders or resins in paints for the architectural (e.g. "cool roof paint", paints for buildings and construction, bridges) and chemical (e.g. storage or reaction tanks, oil and gas, chemical plants) industries for their corrosion and weather resistance properties. Non-fluorinated alternatives to the use of PFASs as binders in paints for these industries include: acrylic; polyester-based formulations; polyurethane; alkyds; phenolic or silicone alkyds; and phenolic, vinyl and epoxy coatings (OECD 2022).

97. Short-chain PFASs alternatives (e.g. perfluorobutane sulphonic acid, PFHxA**,** methyl nonafluorobutyl ether and methyl nonafluoroisobutyl ether) were identified as being used as surfactants in paints for household applications to lower the surface tension thereby improving wetting, levelling, anti-blocking and oil repellence properties (OECD 2022). Non-fluorinated alternatives to PFASs in paints for household applications include silica-based coatings (e.g.

[23] Wraps and liners, plates, food boats and pizza boxes.

silicone polymers made of silanes and siloxanes) and sulfosuccinates, which can act as levelling and/or wetting agents (OECD 2022). In addition, the Swedish Chemicals Agency (2015) identifies fatty alcohol polyglycol ether sulfonates, siloxane and silicone polymers, and polypropylene glycol ethers amines and sulfates as fluorine-free levelling and wetting agents.

98. The OECD (2022) conducted an assessment of the performance and costs of selected non-fluorinated alternatives to PFASs in household and architectural paints. Overall, PFAS-based products were found to perform better (e.g. at lowering the surface tension of the paints, or providing weatherability and durability to the paints) than the selected non-fluorinated alternatives. A case study for architectural paints for use on a bridge indicated that PFAS-based products have a markedly higher initial cost (by 26%) than non-fluorinated alternatives, although after 30 years the latter was found to be more expensive (by 16%) due to the higher frequency and cost associated with recoating.

Fire-fighting foam

99. Long-chain PFCAs, their salts and/or related compounds have been identified to be used in fire-fighting foams and fire extinguishing agents. The main function of PFASs, including long-chain PFCAs and their related compounds, in fire-fighting foams is to act as a surfactant, that is, to form a film over the surface of a burning liquid in order to prevent flammable gases from release and reignition. PFAS-containing fire-fighting foams are used for fires in many different applications involving flammable liquids and are used in equipment ranging from small fire extinguishers up to large tank fire suppression systems. They can be applied with both mobile and stationary equipment and are also used in training and testing of equipment (ECHA 2022a).

100. Short-chain PFAS-based fire-fighting foams are widely available (UNEP/POPS/COP.10/INF/25). However, due to the regulatory pressure and consumer preferences for fluorine-free replacements, many producers of PFAS-containing foams have introduced fluorine-free alternatives (ECHA 2022a). Most of these fluorine-free foams are advertised for use on class B hydrocarbon fuel fires (such as oil, diesel and aviation fuels), as well as class A fires (such as wood, paper, textiles). ECHA (2022a) identifies replacement substances or substance groups used in fluorine-free foam concentrates, which were grouped in four classes: hydrocarbons; detergents; siloxanes; and proteins. ECHA (2022a) also provides an analysis, e.g. in terms of technical feasibility by sectors, availability and risks, of a short list of fluorine-free alternative products to PFAS-containing fire-fighting foams. This analysis concludes that fluorine-free alternatives are generally considered to be technically feasible in most applications.

101. The human health and environmental risks of fluorine-free foams are considered lower than PFAS-containing foams, even if required quantities are greater (ECHA 2022a). However, concerns related to the PBT and/or vPvB properties of some siloxanes have been identified as previously discussed in section 2.3.1.

Textiles and apparel

102. Long-chain PFCAs, their salts and/or related compounds have been identified to be used, or have been detected, in various textiles and treatments for textiles, including apparel, medical garments, firefighter turnout gear, and home and outdoor textiles.

103. The California DTSC (2022) and the Danish Environmental Protection Agency (EPA) (2015) identify a number of potential non-fluorinated alternatives to PFASs in treatments for textiles and leather and during the manufacture of textile and leather products, as summarized in Table 9 of UNEP/POPS/POPRC.19/INF/8. Additionally, Shabanian et al. (2020) describe design parameters for fabricating oil-repellent textile finishes using perfluoro compound-free surface chemistries. More specifically, they demonstrate that robust oil repellency can be achieved by adding a secondary, smaller length-scale texture to each fibre of a given weave, when the size, spacing and surface chemistry of both the fabric and the additional texture are properly controlled.

104. Wang et al. (2013) and the draft guidance on alternatives to PFOA identify fluorinated surface treatment alternatives (e.g. products containing C_4 side-chain fluorinated polymers, copolymers derived from 6:2 fluorotelomers and organosiloxane) to the use of long-chain PFCAs and long-chain PFSAs for the treatment of textiles.

105. The Danish EPA (2015) assessment of alternatives to the use of PFASs in textiles, which considered paraffin- and silicone-based treatment agents only, concluded that no alternatives matching the PFAS-based repellents on all technical parameters are available. For some applications, where repellency against oil, alcohol and oil-based dirt is not required, these alternatives were considered to provide acceptable properties at similar costs to using PFAS-based agents. In the EU REACH restriction report for C_9–C_{14} PFCAs, their salts and precursors, the dossier submitter at the time estimated the production costs for fluorine-free textiles to be 2.3–3.5 % higher than if C_6 PFCA was used as a substitution (ECHA 2018a). Research conducted as part of the POPFREE project (RISE 2020), an initiative aimed to stimulate production and use of non-fluorinated alternatives to PFASs in several applications, suggest that non-fluorinated alternatives or techniques may not be currently available to replace the use of PFASs in work wear (e.g. medical garments), where textiles must meet certain oil/dirt repellency requirements. In these specific cases, the use of short-chain PFCAs alternatives to long-chain PFCAs and their related compounds may need to be considered.

106. The Danish EPA (2015) provides a detailed assessment of the potential human health and environmental hazard properties of the main ingredients of the identified non-fluorinated alternative products. As over 20 individual

products were assessed, only an overview of the findings for the main types of alternatives is provided here. Overall, based on the available information, paraffin repellent chemistries appear to be of low toxicity to aquatic and terrestrial organisms, but some products using paraffin repellent chemistries were reported to contain additional ingredients which may be harmful to human health. In regard to silicone repellent chemistries, the Danish EPA (2015) identifies potential hazard to human health or the environment for ingredients present in some products, such as certain siloxanes (see section 2.3.1). For products using polyurethane repellent chemistries and dendrimer-based repellent chemistries, there was insufficient health and environmental information to assess the alternatives products. Similarly, the California DTSC (2022) provides information on the potential hazard characteristics of alternatives to PFASs in the treatment of textiles. For some alternatives, the reported potential hazard characteristics relate to the alternative itself (e.g. siloxanes, silicone or titanium dioxide nanoparticles), whereas, in other cases, they are dependent on the components of their building blocks or emulsions. This further highlights the importance of carefully assessing and selecting alternatives in order to avoid regrettable substitution.

Personal care products

107. Long-chain PFCAs, their salts and/or related compounds have been identified to be used, or have been detected, in various personal care products, such as cosmetics, sun creams, dental floss and body lotions.

108. The Research Institutes of Sweden (RISE 2020) identifies potential non-fluorinated alternatives to the use of PFASs in cosmetics, i.e. synthetic waxes (e.g. magnesium stearate or sodium myristate) for pressed powders and silicones and fats for lip pencils. In the case of powders, the fluorinated-free alternatives had to be used in higher amounts than the PFASs. RISE (2020) also notes that PFAS-free powders and lip pencils are already on the market, demonstrating that a transition to non-fluorinated alternatives is possible. Based on a comparison of their recent study with previous monitoring studies (i.e. Fujii et al. 2013 and Schultes et al. 2018), the Swedish Chemicals Agency (2021) reported a potential trend in substituting the use of long-chain PFASs, including long-chain PFCAs, in cosmetic products with short-chain PFASs.

109. Available information, including from stakeholder consultations, suggests that PFASs in cosmetics can be replaced by other ingredients and do not have unique functions (Swedish Chemicals Agency 2021). Making existing products, which contain PFASs, non-fluorinated might, however, require a completely new formulation of the products, as direct substitution of PFASs by one or several compounds might only work in specific cases. Consultations with stakeholders indicate that some companies/brands have found new formulations without PFASs that work for the functionality of their products (Swedish Chemicals Agency 2021).

Cleaning- and washing agents

110. Long-chain PFCAs, their salts and/or related compounds have been identified to be used, or have been detected, in various cleaning and washing agents, including cleaning products, carpet care products, dish cleaning or rinsing agents, and anti-fog sprays and cloths.

111. The Swedish Chemicals Agency (2015) identifies siloxane and silicone polymers as fluorine-free alternatives to the use of PFASs in cleaning agents.

Ski waxes

112. Long-chain PFCAs and their related compounds have been measured in ski waxes/gliders or their raw materials (UNEP/POPS/POPRC.18/Add.1). Although some publications have indicated that long-chain PFCAs are thought to be unintentionally present in ski waxes (e.g. Fang et al. 2020), high concentrations have been measured in some ski waxes (e.g. Kotthoff at al. 2015, with different long-chain PFCAs found in concentrations in the milligram per kilogram range) that could be assumed to be functional quantities.

113. A report by Wood (2021), for the Norwegian Environmental Agency, indicates that there is a concerted move in the ski treatment sector towards phasing out the use of PFASs and moving to safer alternatives, and that a number of companies have developed alternative fluorine-free ski wax products. Fluorine-free ski waxes have been estimated to account for 70% of the total market, the remaining 30% being fluorinated products (Wood 2021). There is also an ongoing strategy to phase out the use of fluorinated ski waxes in the global ski community, and national associations (e.g. Nordiq Canada, U.S. Ski and Snowboard, New England Nordic Ski Association) and international entities (e.g. International Ski Federation and International Biathlon Union) are planning to, or have begun, taken action to restrict the use of fluorinated ski waxes (Nordiq Canada 2023; FIS 2022; US EPA 2022; Carlson and Tupper 2020). In most fluorine-free products, a mixture of substances is used to attain the necessary function of the wax. The alternatives consist mainly of hydrocarbons and paraffins, most often as paraffin waxes, but also of siloxanes. New nanoparticles are also being developed as alternatives. In addition, alterations to the ski itself can be used to improve performance and, therefore, replace some of the functionality of the wax (Wood 2021). RISE (2020) identifies fluorine-free ski waxes developed by industry partners (i.e. RedCreek, Brav, Swix) during the course of the POPFREE project.

114. Wood (2021) conducted an assessment of alternatives to PFASs in ski waxes, and concluded that alternatives are broadly capable of providing the required functionality of PFAS-based waxes, although there can be a loss of functionality (e.g. effect on performance), and that alternative ski waxes tend to be less expensive than PFAS-based

waxes. Overall, the risk posed by hydrocarbons and paraffin waxes was concluded to be less than that of PFASs, however, there may be some risks from environmental releases and occupational exposure due to the fact that human health and environmental concerns have rarely been investigated (Wood 2021).

Automotive industry

115. Long-chain PFCAs, their salts and/or related compounds have been identified to be used in the automotive industry, including in vehicle coatings, cables, electronics, engines and underhood applications, modules, hydraulic system components and relay assemblies. Possible use in automotive textiles has also been identified, but needs to be confirmed. Information on the specific function of long-chain PFCAs, their salts and/or related compounds for these applications in the automotive industry is not available, which presents challenges for the identification of potential alternatives for this sector.

116. Possible alternatives to the use of long-chain PFCAs, their salts and related compounds in automotive paints and paint sealants have been described above (see section on *Paints, coating and varnishes*). The OECD (2022) identifies various chemical alternatives to the use of PFASs in cable and wiring: epoxy-based coatings, polyurethane, polyester, polyolefin, polyvinylchloride, silicone, chlorosulfonated polyethylene, polyethylene, cross-linked polyethylene, chlorinated polyethylene, thermoplastic elastomer, neoprene, ethylene-propylene rubber and nylon. For many of these alternatives, flame retardants need to be added to the coating. The OECD (2022) conducted an assessment of the performance and costs of selected non-fluorinated alternatives to PFASs in cable and wiring. Fluoropolymers were concluded to be the choice of material if a high performance is required over a wide range of parameters (including fire safety), and alternative materials to be sufficient for other applications. Due to the higher cost of fluoropolymers, compared to non-fluorinated alternatives, the former are chosen only where performance requirements necessitate their use. According to stakeholder consultations conducted in 2020-2021, fluoropolymers have a small percentage of the overall market share (i.e. <10%), with alternatives having more than 90% of the market share (OECD 2022).

117. For the other applications found in the automotive industry, no information on alternatives to the use of long-chain PFCAs, their salts and related compounds has been identified for inclusion in this risk management evaluation. Alternatives are, however, anticipated to be the same as those for PFOA, its salts and related compounds.[24]

2.4 Summary of information on impacts on society of implementing possible control measures

2.4.1 Health, including public, environmental and occupational health

118. Human health concerns associated with long-chain PFCAs, their salts and related compounds are documented in the risk profile, and summarized here. Long-chain PFCAs have been detected globally, on all continents, as well as in all environmental compartments. In humans, C_9–C_{18} PFCAs have been detected globally in various tissues and fluids, and increasing temporal trends for long-chain PFCAs have been reported in some populations. Exposure of the general population to long-chain PFCAs and their related compounds may take place through exposure to indoor dust, food, drinking water, indoor/outdoor air and consumer products. While the relative importance of each of these pathways for the general population remains unclear, evidence suggests that consumption of wildlife species, and particularly top predator species, may be the main pathway for Indigenous Peoples, including circumpolar Indigenous populations (Inuit and First Nations), who rely on traditional food for subsistence. Additionally, maternal transfer through cord blood and human milk are sources of long-chain PFCAs for the fetus and for nursing infants/children. Occupational exposure to certain workers (e.g. firefighters, ski wax technicians) can also lead to higher serum levels of long-chain PFCAs as compared to the general population. Further, toxicological and epidemiological evidence indicates that long-chain PFCAs are associated with adverse effects in humans, including hepatotoxicity, developmental/reproductive toxicity, immunotoxicity, thyroid toxicity and altered cardiometabolic functions. Therefore, listing long-chain PFCAs, their salts and related compounds to the Convention would provide benefits to human health by reducing releases to the environment and, subsequently, human exposure.

119. Japan (Annex F information 2022) indicated that there is a concern about the reduction of medical services, such as diagnosis, treatment, and therapy, which could result from the unavailability of substances related to long-chain PFCAs for the production of medical equipment and materials (i.e., in heat media in medical and laboratory devices). Listing long-chain PFCAs, their salts and related compounds to Annex A with specific exemptions in key sectors could minimise potential impacts to health by allowing additional time to transition to alternatives.

120. According to I&P Europe (Annex F information 2022), the non-availability of PFOA-related substances[25] for the manufacture of the remaining imaging products could impact the healthcare sector. For example, it could be financially challenging for health care establishments to invest in new technologies necessitated by the discontinuation of conventional photographic products. According to the association, developing countries, as well as

[24] Refer to UNEP/POPS/POPRC.13/7/Add.2.

[25] Which may contain substances that fulfill the definition of long-chain PFCAs and their related substances.

EU countries with a relatively higher amount of such photographic products in the medical sector, could be further impacted. It is noted, however, that I&P Europe indicated that use in photographic coatings will be eliminated by July 2025 at the latest and that, in the EU, the derogations for PFOA and long-chain PFCAs in photographic coatings under REACH will expire in July 2025. Currently, there is no information indicating that a longer transition period is required for the photo-imaging industry outside of Europe. In addition, the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) noted that "digital image management is currently the preferred method for medical imaging" and that the rapid adoption of digital technology in healthcare results from "efficiencies inherent in digital capture, storage and display and the competitive cost structures of such systems when compared to alternatives involving film". IAEA and WHO (2015) identified several advantages to digital imaging in healthcare. IPEN/ACAT (comments on the first draft risk management evaluation, 2023) also provided examples of developing countries and remote communities transitioning to, and benefiting from, digital imaging in health care systems (e.g. Mayes and White 2017; Tahir et al. 2022).

2.4.2 Agriculture, including aquaculture and forestry

121. The application of biosolids to agricultural land is an important way of managing this wastewater treatment product to recycle essential plant nutrients and organic matter in agriculture. However, C_9–C_{14} PFCAs have been detected in water (surface, well and ground) and soil from agricultural sites with a history of land application of biosolids (UNEP/POPS/POPRC.18/6/Add.1; UNEP/POPS/POPRC.18/INF/12, Table 4; Washington et al. 2010; Yoo et al. 2010). Studies comparing the concentrations of long-chain PFCAs or their related compounds in soils with a history of land application of biosolids to background sites (Pepper et al. 2021; Washington et al. 2010; Yoo et al. 2010) report higher concentrations in the former, although the magnitude of the measured level differed among studies (see Table 10 of UNEP/POPS/POPRC.19/INF/8 for details). Some long-chain PFCAs and related compounds were also measured in compost (Munoz et al. 2022a, see Table 11 of UNEP/POPS/POPRC.19/INF/8 for details). Thus, the application of contaminated biosolids and compost, and irrigation with contaminated groundwater, can be pathways of long-chain PFCAs, their salts and related compounds to agricultural land. Further, certain long-chain PFCAs and related compounds have been shown to be translocated into crops (Bizkarguenaga et al. 2016; Krippner et al. 2015), which could be a route to human exposure to these substances. Therefore, the restriction of long-chain PFCAs, their salts and related compounds by listing these substances to the Stockholm Convention would be beneficial to agriculture, as well as human health, since, with time, it would reduce the level of contamination of biosolids, compost and groundwater.

2.4.3 Biota (biodiversity)

122. As described in the risk profile, long-chain PFCAs are persistent in the environment, which increases their probability, magnitude and duration of exposure to wildlife. Long-chain PFCAs are also subject to long-range environmental transport, with the potential for transfer to a receiving environment in locations distant from the sources of their release. As such, releases of long-chain PFCAs can lead to elevated concentrations in organisms over wide areas. Long-chain PFCAs may also biomagnify through the food chain, resulting in increased concentrations for top predator species. Several different long-chain PFCAs may be present simultaneously in the tissues of organisms, increasing the likelihood and potential severity of harm compared to looking at a single long-chain PFCA. Current environmental monitoring data measure concentrations that are below the available tested toxicity thresholds. However, increasing temporal concentration trends in wildlife, including top predator species, as well as the very high persistence of PFCAs suggest that long-chain PFCAs can approach toxicity thresholds resulting in harm for wildlife populations in the future. Therefore, the restriction of long-chain PFCAs, their salts and related compounds by listing these substances to the Stockholm Convention would be beneficial to biota and biodiversity by decreasing emissions of these substances and, with time, wildlife exposure.

2.4.4 Economic aspects and social costs

123. When considering the economic aspects of listing long-chain PFCAs, their salts and related compounds to the Stockholm Convention, consideration should also be given to costs associated with health impacts, management of wastes, and remediation of contaminated sites and water sources. The treatment of PFAS-contaminated landfill leachate, and associated costs, was studied in experiments using a broad spectrum of techniques. Overall, the costs were found to be high. In the study, these were compared with societal costs caused by emissions of PFASs and with costs for reducing PFAS emissions by phasing out PFASs in various products. The results clearly show that reducing emissions by phasing out PFASs is at least two magnitudes cheaper than purifying PFASs from leachate (Sweden Annex F information 2022; Malovanyy et al. 2021). Another study, aimed to elaborate a benchmark approach for assessing the proportionality of risk reduction measures, conducted a comparison of the estimated costs related to three types of control measures (i.e., substitution, emission control and clean-up/remediation) for some PBT and vPvB substances, including PFOS and PFOA (Oosterhuis and Brouwer 2015; Oosterhuis et al. 2017). Overall, although many factors were found to influence the costs of control measures, the lowest estimates were generally found for substitution measures. A recent report by ChemSec (2023a) estimated the costs of PFASs to society globally at €16 trillion per year. Their analysis used European data on healthcare costs from exposure to PFASs (as estimated by the

Nordic Council of Ministers), as well as estimated costs of remediation of contaminated soil and water, and extrapolated to a global scale.

124. A recent report on knowledge and guidance for water/wastewater treatment of PFASs shows that there are currently no techniques that achieve a far-reaching PFAS removal from municipal wastewater without significant resource consumption and related costs. For a continued use of biosolids as a fertilizer, upstream mitigation is needed, with, for example, disconnection or treatment of PFAS-contaminated leachate. Several ongoing projects indicate, however, that a certain portion of PFASs in wastewater can be removed as a side-effect of advanced treatment for pharmaceutical removal (Sweden Annex F information 2022; Baresel et al. 2022).

125. The destruction of fire-fighting foam containing long-chain PFCAs, their salts and related compounds is another economic consideration to take into account. For example, to prevent the emergence of contaminated areas, the Swedish Civil Contingencies Agency (MSB) has received 8 million Swedish krona (SEK) (approximately $766,000 United States Dollars (USD)) for the procurement of collection, transport and destruction of PFAS-foam liquids from the fire rescue service. MSB estimates that the grant will be sufficient for the destruction of about half of the ≥360,000 L of PFAS-contaminated foam fluid for which the emergency services have sought destruction (Sweden Annex F information 2022).

126. The clean-up and remediation of contaminated sites, such as those impacted with fire-fighting foam containing PFASs, including long-chain PFCAs, their salts and related compounds, generates PFASs-containing waste streams that need to be disposed of. Typically, these wastes are disposed of either in landfills or sent for destruction. The management of PFAS-containing wastes from contaminated sites is very costly relative to the clean-up of contaminated sites impacted with other contaminants (Canada Annex F information 2022).

127. Costs for waste disposal may be affected by the ability of industry and technology to separate out waste containing long-chain PFCAs, their salts and related compounds above the low POP content from waste that can be recycled. Separation and storage of POP wastes until environmentally sound disposal will result in increased costs, faced by waste handlers. If sorting technology does not exist, waste streams that are likely to contain long-chain PFCAs, their salts and related compounds at or above the low POP content may need to be incinerated or otherwise disposed of in an environmentally sound manner, which will come at a higher cost. Costs will also include the loss of value of waste that would have previously been sent for recycling and the cost of incineration at conditions required so that the POP content is destroyed or irreversibly transformed. There may also be environmental costs, as incineration of waste which were previously recycled will result in higher carbon emissions and a reduction in the ability to utilize circular economy approaches (UK Annex F information).

128. There are few remedial methods that are both cost-effective and remove PFASs entirely from the environment (Repas 2021). Many remedial methods rely on immobilizing PFASs *in situ* via adsorption of activated charcoal or co-precipitation with metal ions. While these solutions limit the mobility of PFASs in the environment, the PFASs are not removed or destroyed, meaning that sites will require ongoing risk management and eventual remediation once suitable technologies are developed (Repas 2021). Other water treatment technologies are being developed which utilize exotic materials and high energies, limiting their practicality in field deployment (Repas 2021). Repas (2021) reports on ongoing work pertaining to the bioremediation of PFASs, which the author indicates could result in a more complete removal of PFASs from the environment at a lower cost than other emerging methods. In addition, recent work from Trang et al. (2022) found that PFCAs could be mineralized through a sodium hydroxide-mediated defluorination pathway. According to the authors, these findings could inform the development of engineered PFAS degradation processes. Nonetheless, considering the high cost of the methods currently used for the remediation of contaminated sites, it can be argued that it would be cost effective to regulate the use of long-chain PFCAs, their salts and related compounds beforehand rather than cleaning up and remediating contaminated sites.

129. The guideline “Remediation management for local and wide-spread PFAS contamination” (Held and Reinhard 2020), developed for the German Federal Ministry for the Environment, provides information related to the selection, evaluation and determination of remedial solutions and management concepts for the remediation of sites contaminated with PFASs, including long-chain PFCAs. This guideline includes detailed descriptions of the available technologies for the remediation of contaminated water and soil, as well as some case studies. As an example, for a site contaminated with PFAS-containing fire-fighting foams in Germany in the late 2000s, the total cost[26] of “standard technology pump-and-treat” remediation (as of 2018) was estimated to approximately 3.10 € per 1 m^3 of treated groundwater or approximately 92,000 € per 1 kg of PFASs removed. In the guideline, one particular challenge identified for the remediation of contaminated soil is the limited possibilities for decontaminating the soil and the small number of existing disposal sites (not limited to Germany) that accept PFAS-containing soils.

130. Due to the large replacement costs for a contaminated water source, it can be argued that it would be more cost effective to regulate the use of long-chain PFCAs, their salts and related compounds beforehand rather than abating or replacing a contaminated water source (ECHA 2018b). For example, in June 2019, Uppsala vatten, a

[26] The total cost consisted of the investment costs for a groundwater treatment plant using PFAS sorption on activated carbon, and operating and maintenance costs.

company responsible for the treatment of wastewater and delivery of drinking water to the Municipality of Uppsala, Sweden, filed a lawsuit against the Swedish Armed Forces for 252 million SEK (approximately $24,000,000 USD) for incurred and future costs related to the treatment of drinking water contaminated with PFASs (Sweden Annex F information 2022). As another example, the waterworks in the municipality of Tullinge, Sweden have been shut down since 2012 due to PFAS contamination from a past military airfield. Since then, water has been purchased from another waterworks for its 16,000 inhabitants (Sweden Annex F information 2022).

131. Social costs associated with exposure to PFASs, including long-chain PFCAs, their salts and related compounds, should also be considered. For example, elevated blood levels of PFASs, resulting from high levels of the substances in the municipal drinking water, have resulted in a court case towards a company with requests for financial compensation (Sweden Annex F information 2022). Other examples include lawsuits filed in response to PFASs water contamination in Paulsboro, New Jersey, USA (Graber et al. 2019), Merrimack, New Hampshire, USA (Panikkar et al. 2019) and in the Western Scheldt river, Zealand, Netherlands (Reuters 2023).

132. Based on consultations with stakeholders on the upcoming C_9–C_{14} PCFAs restriction in the EU, industry based in Europe has already shifted from the use of long-chain per- and polyfluorinated substances to either short-chain homologues (such as C_6-based chemistries) or fluorine-free alternatives (ECHA 2018b). Thus, no major effects for stakeholders in Europe were foreseen as a result of the recent restriction in the EU. However, it was acknowledged that importers of articles may be affected by the restriction, because they will need to make sure that the imported articles comply with the concentration limits established for C_9–C_{14} PFCAs, and their salts and related substances (ECHA 2018b). In addition, industry outside of the EU may experience cost increases as a result of the transitioning away from the use of long-chain PFCAs for the production of fluoropolymers (ECHA 2018b). Socioeconomic impacts relating to the concentration limits established in the EU for the unintentional presence of C_9–C_{14} PFCAs, and to measures applied by industry to minimise the fraction containing C_9–C_{14} PFCAs in commercial products and/or to manage it have also been identified (ECHA 2020a,b). For example, the costs relating to the profit losses relating to forgone sales of C_9–C_{14} PFCAs and cost of incineration were concluded by ECHA (2020a) to be potentially significant, given the share of the long-chain side fraction in the product (20%) and the estimated volume to be handled as waste instead of exported (estimated to range between 40 and 400 tonnes/year). ECHA (2020a) noted however that, based on the available information, it appears these impacts can be greatly alleviated in a short period of time by implementing and refining existing alternative technologies. Further, it is noted that the long-chain fraction also includes a C_8 fraction,[27] already subject to restrictions including the listing of PFOA to the Stockholm Convention, which may therefore limit the potential uses of, and possibilities to sell, the long-chain side fraction.

133. According to I&P Europe (Annex F information 2022), restrictions on the remaining uses of PFOA-related substances[28] would have an impact on the photo-imaging industry's ability to manufacture a number of imaging products, including diagnostic medical products, and would impose a financial burden by requiring investment in research and development during a time when the imaging industry is focused on the invention of innovative new digital imaging technologies. According to the association, photo-imaging in all areas of society, including medical, industrial, professional and entertainment, plays an important role in improving the quality of life for people around the world, including the developing nations. It is noted, however, that I&P Europe indicated that use in photographic coatings will be eliminated by July 2025 at the latest. In addition, in the EU, the derogations for PFOA and long-chain PFCAs in photographic coatings under REACH will expire in July 2025. Currently, there is no information indicating that a longer transition period is required for the photo-imaging industry outside of Europe. Therefore, considering that a listing of long-chain PFCAs, their salts and related compounds to the Convention would come into force in 2026 at the earliest, it would seem that there are no socioeconomic costs to this sector associated with listing these substances to the Convention.

134. According to Japan (Annex F information 2022), there is a concern that a disruption in the supply of parts for semiconductors and electrical and electronic devices containing substances related to long-chain PFCAs could impact the entire industry, as the supply of many electrical and electronic devices using these parts would be disrupted.

135. Overall, the benefits to health, agriculture and biota of global action on these substances are expected to outweigh the costs of implementing control measures. Listing long-chain PFCAs, their salts and related compounds to Annex A with specific exemptions in key sectors could minimise these impacts to health and social costs by allowing additional time to transition to alternatives.

2.4.5 Movement towards sustainable development

136. Prohibiting long-chain PFCAs, their salts and related compounds by listing these substances under Annex A to the Convention would support movement towards the United Nations Sustainable Development Goals (SDGs) established in 2015. Specifically, SDG Targets 3.9 (relating to the reduction of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination), 12.4 (relating to the environmentally sound

[27] Expected to be >60% of the 20% share of the long-chain side fraction.

[28] Which may contain substances that meet the definition of long-chain PFCAs and their related substances.

management of chemicals and all wastes), and 15.5 (relating to action to halt biodiversity loss) would be supported by a global action on these substances. Furthermore, PFASs and the transition to safer alternatives are recognized under SAICM as an issue of concern.

137. In the EU, the European Commission's Chemicals Strategy for Sustainability Towards a Toxic-Free Environment emphasizes that all uses of PFASs should be phased-out unless the use is essential (European Commission 2020). As described in section 1.2 of UNEP/POPS/POPRC.19/INF/8, in the Netherlands, there are ongoing activities to restrict PFASs, or limit PFAS releases, e.g., through activities with fire-brigades and the paper and paperboard industry (the Netherlands Annex F information 2023). In addition, a restriction proposal under REACH to ban all uses of PFASs as a class, with a number of specific time-limited derogations, has been developed and submitted by Germany, the Netherlands, Sweden, Denmark and Norway and is currently under consideration within the EU. The restriction dossier was submitted to ECHA in January 2023 (ECHA 2023).

138. In May 2023, the Government of Canada published the draft State of Per- and Polyfluoroalkyl Substances Report (ECCC and Health Canada 2023a) and the Risk Management Scope for per- and polyfluoroalkyl substances (PFAS) (ECCC and Health Canada 2023b) for a 60-day public comment period. The draft State of PFASs Report provides a qualitative assessment of the fate, sources, occurrence and potential impacts of PFASs on the environment and human health; this draft report proposes to conclude that PFASs as a class are toxic to human health and the environment under the *Canadian Environmental Protection Act, 1999* (CEPA). The Risk Management Scope outlines the risk management options under consideration for the class of PFASs. The Government of Canada is considering regulatory and/or non-regulatory controls to minimize environmental and human exposure to the class of PFASs from firefighting foams; gathering information necessary to identify and prioritize options for reducing environmental and human exposure from the class of PFASs from other sources and products; and aligning with actions in other jurisdictions, where appropriate. If the proposed conclusion is confirmed in the final State of PFASs Report, a Risk Management Approach document would be published with additional opportunities for public and stakeholder engagement.

139. On 20 December 2022, 3M, a major PFAS manufacturer, announced[29] that it will exit PFAS manufacturing (including fluoropolymers) and work to discontinue the use of PFASs across its product portfolio by the end of 2025. The company explained that the decision is based on careful consideration and a thorough evaluation of the evolving external landscape, including multiple factors such as accelerating regulatory trends focused on reducing or eliminating the presence of PFASs in the environment and changing stakeholder expectations.

2.5 Other considerations

2.5.1 Access to information and public education

140. Parties and observers have submitted information on access to information and public education (see section 2.4.1 of UNEP/POPS/POPRC.19/INF/8).

2.5.2 Status of control and monitoring capacity

141. Many commercial laboratories today have analytical packages with quantitative analyses of about 30 individual PFASs, including C_9–C_{14} PFCAs (as described in Swedish Chemicals Agency 2021), although there is a lack of standardized analysis protocols (ECHA 2018a). As described in the risk profile, there are analytical challenges in measuring PFCAs at the upper end of the range (i.e. for C_{15}–C_{21} PFCAs) which may need to be considered in monitoring plans for long-chain PFCAs.

142. In Canada, certain long-chain PFCAs (C_9–C_{12}, C_{14}) have been and/or continue to be monitored under Canada's Chemicals Management Plan (CMP) in humans through biomonitoring conducted under the ongoing Canadian Health Measures Survey (CHMS) (Health Canada 2013, 2019, 2021a,b) and the Maternal-Infant Research on Environmental Chemicals (MIREC) cohort (e.g. Rawn et al. 2022), as well as in studies conducted in Canada's Arctic, including Old Crow, Yukon, in multiple First Nations communities in the Northwest Territories, and in adult Inuit including multiple time points for pregnant Inuit women, in Nunavik (Quebec) (AMAP 2021; Aker et al. 2021; Aker et al. 2023a,b). In addition, certain long-chain PFCAs (e.g. C_9–C_{18} PFCAs) are also monitored in various environmental matrices (e.g. air, sediment, precipitation, surface water) and biota (e.g. apex avian predators, mid-trophic avian species, fish, mussels, ringed seals, polar bears, belugas) through a number of projects under the CMP, the Northern Contaminants Program and the Global Atmospheric Passive Sampling (GAPS) Network (e.g. Muir et al. 2019; Munoz et al. 2022b; Gewurtz et al. 2013; Rauert et al. 2018; Saini et al. 2023).

143. Over the last 10 years, Hungary has been monitoring POPs and other organic pollutants, including perfluorocarbons, in surface water and drinking water (Hungary Annex F information 2022).

[29] https://news.3m.com/2022-12-20-3M-to-Exit-PFAS-Manufacturing-by-the-End-of-2025.

144. In Norway, several PFASs, including long-chain PFCAs and their related compounds, are monitored through a number of monitoring programs[30] (Norway Annex F information 2022).

145. In Sweden, enforcement projects (Enforcement 7/21: PFAS in chemical products and goods)[31] related to the presence of PFASs in chemical products and articles were conducted to, among other objectives, investigate the presence of restricted PFASs in chemical products and articles available on the market and ensure that companies take action if the EU POPs Regulation (EU No 2019/1021) requirements for regulated PFASs are not met (Sweden Annex F information 2022). A similar joint enforcement project was also conducted by the Nordic Enforcement Group (Talasniemi et al. 2022). In addition, the presence of PFASs that are not yet restricted in any chemical legislation and extractable organic fluorine were analyzed to improve the knowledge of the authorities on the use of PFASs in various products and articles (Sweden Annex F information 2022). Additionally, long-chain PFCAs are included in the Swedish National Food Agency's market basket studies. In the 2015 survey (Swedish National Food Agency 2017), C_6 and C_8 PFCAs exhibited a more general contamination of several food groups, whereas C_9–C_{13} PFCAs, PFOS and their related compounds were mostly found in the fish baskets (Sweden Annex F information 2022). The next survey will be conducted during 2022 through 2024.

146. In the UK, individual substances from PFAS groups, including long-chain PFCAs and their related compounds, are currently monitored. The UK Environment Agency holds monitoring data for a range of PFCAs in groundwater, surface water and freshwater fish.

3. Synthesis of information

3.1 Summary of risk profile information

147. Due to the ongoing production and use of long-chain PFCAs, their salts and related compounds, long-chain PFCAs are directly or indirectly emitted into the environment from human activities. Long-chain PFCAs are globally ubiquitous in environmental compartments, including biota, freshwater, saltwater, sediment, soil and rainwater, and humans. Long-chain PFCAs are persistent, bioaccumulative, have adverse effects on human health and/or the environment, and have the potential to undergo long-range environmental transport, in part due to the long-range atmospheric transport of compounds related to long-chain PFCAs. Increasing temporal concentration trends in wildlife, including top predator species, suggest that long-chain PFCAs can approach toxicity thresholds resulting in harm to wildlife populations. In humans, the high persistence of long-chain PFCAs can lead to widespread and increasing exposure, potentially resulting in adverse effects. Certain populations, such as Arctic Indigenous Peoples and those who rely on traditional foods for subsistence, are at risk of greater exposure and potential effects.

148. On this basis, at its eighteenth meeting in September 2022, the POPRC concluded that long-chain PFCAs, their salts and related compounds are likely, as a result of their long-range environmental transport, to lead to significant adverse human health and/or environmental effects such that global action is warranted.

3.2 Summary of risk management evaluation information

149. Long-chain PFCAs, their salts and related compounds are intentionally used, or may have been used, in a range of applications, including in: industrial uses; electronic articles, and medical and laboratory devices; photo-imaging; inks; food contact materials; paints, coatings and varnishes (including those applied to building and construction materials); fire-fighting foams; textiles and apparel; personal care products; cleaning and washing agents; ski waxes; and in the automotive industry. In addition, long-chain PFCAs and their related compounds may be unintentionally produced during the manufacture of other PFASs and in other industrial processes, and during thermolysis of fluoropolymers at temperatures relevant to industrial or consumer high-temperature applications and low-temperature incineration.

150. Long-chain PFCAs can be released to the environment from direct and indirect sources. Direct sources include emissions from the production of PFCAs, as well as emissions from the life cycle of products containing long-chain PFCAs, either as a main ingredient, or as residuals or chemical reaction impurities in products. Indirect sources are those where compounds related to long-chain PFCAs emitted to the environment have transformed to long-chain PFCAs through biotic or abiotic transformation. Releases of long-chain PFCAs, their salts and related compounds to the environment may occur at all life cycle stages of articles or products containing them, e.g., during production, use and disposal (including from landfills, wastewater treatment and incineration). The application of contaminated biosolids and compost to agricultural land, and irrigation of these lands with contaminated groundwater, may also lead to secondary releases of long-chain PFCAs, their salts and related compounds to the environment. In addition, the clean-up and remediation of contaminated sites, such as those impacted with fire-fighting foam containing PFASs,

[30] The monitoring data is available at: Vannmiljø (miljodirektoratet.no) or in reports from the monitoring programs at: Basisovervåking - Miljødirektoratet (miljodirektoratet.no).

[31] Enforcement 7/21: PFAS in chemical products and goods - Kemikalieinspektionen (in Swedish).

including long-chain PFCAs, generates PFAS-containing waste streams that are typically disposed of either in landfills or sent for destruction. This could lead to secondary releases of long-chain PFCAs into the environment.

151. Prohibiting the intentional production and use of long-chain PFCAs, their salts and related compounds by listing these substances to Annex A with or without specific exemptions would positively impact human health and the environment by decreasing emissions and, subsequently, human and environmental exposures. Available information does not demonstrate that a listing to Annex B would be needed for these substances. Further, a listing to Annex A would be consistent with the listings of other PFASs recently added to the Convention (i.e. PFOA, in 2019, and PFHxS, in 2022).

152. Although long-chain PFCAs may be unintentionally produced during industrial processes and low temperature incineration of wastes, listing long-chain PFCAs, their salts and related compounds to Annex C is not believed to be a relevant control measure for these substances.

153. To reduce releases to the environment resulting from the unintentional production of long-chain PFCAs during industrial processes, manufacturers should aim to minimise the unintentional presence of long-chain PFCAs and their related compounds to the largest possible extent before commercial mixtures and materials are brought into the market. This should be captured in the guidance on BAT/BEP for the use of long-chain PFCAs, their salts and related compounds that would be developed following a listing of these substances to the Convention.

154. Further, an Annex A listing would create an obligation for the introduction of waste management measures, in accordance with Article 6 of the Convention. These measures would, among other obligations, contribute to ensuring that wastes containing long-chain PFCAs, their salts and related compounds at concentrations at or above the low POP content (established in cooperation with the Basel Convention) are disposed of in such a way that the POP content is destroyed or irreversibly transformed, or are disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low. In addition, specific technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with these substances would also be developed. These guidelines would identify technologies for the destruction and irreversible transformation of these substances in wastes.

155. Available information suggests that alternatives are available for most known applications of long-chain PFCAs, their salts and related compounds. Alternatives include both fluorinated and non-fluorinated substances, as well as alternative (non-chemical) technical solutions. However, information on potential alternatives for some uses, and information on the potential health or environmental hazards, and costs and technical feasibility of some of the potential alternatives, is limited. According to information provided by Parties and industry, and gathered through a literature review and during the development of the proposed regulatory actions in Canada and the recently adopted regulation in the EU, specific exemptions could be considered for certain applications (see section 3.3) to allow sufficient time to identify, and transition to, suitable alternatives, and in order to avoid regrettable substitution.

156. Global action on long-chain PFCAs, their salts and related compounds would provide benefits to human health and biota by reducing releases to the environment and, subsequently, human and wildlife exposure. The restriction of long-chain PFCAs, their salts and related compounds by listing these substances to the Stockholm Convention would also be beneficial to agriculture and human health since, with time, it would reduce the level of contamination of biosolids, compost and groundwater, which are used in agricultural practices to optimise crop growth.

157. Information on the availability and costs of alternatives from a literature review, as well as information gathered during the development of the regulatory actions proposed in Canada and in force in the EU, indicate that the socioeconomic costs of prohibiting or restricting long-chain PFCAs, their salts and related compounds are overall anticipated to be low. However, in countries that have not yet taken regulatory actions on these substances, industry may face greater costs for transitioning to alternatives. In addition, Parties and observers have identified potential social impacts (such as impacts on medical services and the supply of replacement parts for semiconductors, vehicles and electrical and electronic devices) which could result from the restriction of long-chain PFCAs, their salts and related compounds in certain applications. However, high costs are estimated for the management of POP-containing wastes, and remediation of contaminated sites and treatment of water sources contaminated with these substances. Implementation of control measures for long-chain PFCAs, their salts and related compounds would, therefore, contribute to avoiding such future costs. Socioeconomic costs associated with exposure to long-chain PFCAs should also be considered.

158. Overall, the benefits to health, agriculture and biota of taking global action on these substances are expected to outweigh the costs of implementing control measures. Listing long-chain PFCAs, their salts and related compounds to Annex A with a limited number of specific exemptions in key sectors could minimise potential socioeconomic costs and impacts by allowing sufficient time to identify, and transition to, suitable alternatives, and in order to avoid regrettable substitution. It is also noted that there are analytical challenges in measuring some long-chain PFCAs which present challenges for the management and control of their production, use, import and export.

3.3 Suggested risk management measures

159. The most efficient control measure for reducing the releases of long-chain PFCAs, their salts and related compounds to the environment would be to list these substances in Annex A without exemptions. Listing long-chain PFCAs, their salts and related compounds in Annex A would also entail that the provisions of Article 3 on export and import and of Article 6 on identification and sound disposal of stockpiles and waste would apply. Given that there are analytical challenges in measuring some long-chain PFCAs, special instructions may be needed when establishing waste thresholds.

160. Based on the information submitted by Parties and observers in the Annex F submissions during the risk management evaluation and the collective experience reported, the phase-out of long-chain PFCAs, their salts and related compounds may involve challenges for some sectors. In order to enable an efficient substitution of these substances in the various applications, the prohibition should enter into force in a reasonable timeframe, which allows sufficient time for efficient and non-regrettable substitutions. A longer timeframe may be considered for replacement parts for some long-lived articles to minimise potential impacts on the supply of these parts, such as the reduction of the service life of these articles or a large number of these articles becoming waste before the end of their expected service life.

161. The following specific exemptions could be considered:

<table>
<tr><th>Production and/or use of long-chain PFCAs, their salts and related compounds</th><th>Specific exemptions</th></tr>
<tr><td>1) Cooling applications for the manufacture of high-heat and high-voltage parts for semiconductor manufacturing equipment</td><td rowspan="5">In accordance with Article 4</td></tr>
<tr><td>2) Inactive/inert fluorine liquid for reliability testing and temperature control for the manufacture of electric components, and electrical and electronic equipment</td></tr>
<tr><td>3) Heat media in a closed system, including heat media in components of in vitro diagnostic medical devices, refractive media in analytical instruments for detecting fluorescence, and heat media in thermostatic chambers for reliability and durability testing of electric and electronic equipment</td></tr>
<tr><td>4) Polytetrafluoroethylene (PTFE) micro powders containing long-chain PFCAs and their salts, in a concentration equal to or below 1 mg/kg (0.0001% by weight), transported or treated for the purpose of reducing the concentration of long-chain PFCAs and their salts below 0.250 mg/kg (0.000025% by weight</td></tr>
<tr><td>5) Semiconductors designed for replacement parts not covered under 6) or 7)</td></tr>
<tr><td>6) Semiconductors designed for replacement parts for combustion powered engine vessels</td><td rowspan="2">Until end of service life of the articles or 2041,[32] whichever comes earlier</td></tr>
<tr><td>7) Replacement parts for motor vehicles[33]</td></tr>
<tr><td>8) Replacement parts containing heat media in a closed system, including heat media in components of in vitro diagnostic medical devices, refractive media in analytical instruments for detecting fluorescence, and heat media in thermostatic chambers for reliability and durability testing of electric and electronic equipment.</td><td>Until end of service life of the articles, subject to review by the Conference of the Parties no later than 2043[34]</td></tr>
</table>

162. Any specific exemptions should be well defined, narrowly tailored and time-limited to match the needs expressed by Parties or others for any uses, with the aim of limiting the negative impacts of continued production and

[32] This proposed timeline is based on principles applied for the automotive sector in Canada, where vehicle replacements parts should be available for a minimum of 15 years after model build up (see Section 2.2.1 for details).

[33] Covering all land-based vehicles, such as cars, motorcycles, agricultural and construction vehicles and industrial trucks. Applications include semiconductors, coatings, cables, electronics, engines and underhood applications, modules, hydraulic system components and relay assemblies.

[34] This proposed timeline is based on the timelines agreed to at the eleventh meeting of the Conference of the Parties (COP) for replacement parts for medical and analysis devices in the listings of Dechlorane plus and UV-328, i.e. subject to review by the COP 17 years after the coming into force of the listings.

use of long-chain PFCAs, their salts and related compounds to human health and the environment. As such, additional information and justification of the need for specific exemptions, especially for uses where alternatives appear to be available, would be beneficial to further consider and define the specific exemptions that have been requested, in particular those identified in the table below:

Production and use of long-chain PFCAs, their salts and related compounds	Specific exemptions
1) Lubricants used in the manufacture of fluoropolymers	In accordance with Article 4
2) Parts and/or materials for electrical and electronic devices, equipment and appliances	
3) Inks for marking capacitors and cables	
4) Replacement parts for electrical and electronic devices, equipment and appliances	Until end of service life of the articles or 2046,[35] whichever comes earlier

4. Concluding statement

163. Having decided that long-chain PFCAs, their salts and related compounds are likely, as a result of their long-range environmental transport, to lead to significant adverse human health and/or environmental effects such that global action is warranted;

164. Having prepared a risk management evaluation and considered the management options, and noting that available information suggests that alternatives are available for most known applications. There may, however, be concerns with some alternatives, such as short-chain fluorinated alternatives. Therefore, alternatives to long-chain PFCAs, their salts and related compounds should be selected very carefully to avoid regrettable substitution;

165. The POPs Review Committee recommends, in accordance with paragraph 9 of Article 8 of the Convention, that the Conference of the Parties to the Stockholm Convention consider listing and specifying the related control measures for long-chain PFCAs, their salts and related compounds in Annex A with specific exemptions for production and use, in accordance with Article 4, of the following: 1) cooling applications for the manufacture of high-heat and high-voltage parts for semiconductor manufacturing equipment; 2) inactive/inert fluorine liquid for reliability testing and temperature control for the manufacture of electric components, and electrical and electronic equipment; 3) heat media in a closed system;[36] 4) polytetrafluoroethylene (PTFE) micro powders containing long-chain PFCAs and their salts, in a concentration equal to or below 1 mg/kg (0.0001% by weight), transported or treated for the purpose of reducing the concentration of long-chain PFCAs and their salts below 0.250 mg/kg (0.000025% by weight); and 5) semiconductors designed for replacement parts for applications other than motor vehicles and combustion powered engine vessels. In addition, specific exemptions for the use of long-chain PFCAs, their salts and related compounds for replacement parts for, and repair of, articles where these substances were originally used in the manufacture of those articles and may be available, limited to the following applications, may also be considered: 1) semiconductors designed for replacement parts for combustion powered engine vessels, until end of service life of the articles or 2041, whichever comes earlier; 2) replacement parts for motor vehicles,[37] until end of service life of the articles or 2041, whichever comes earlier; and 3) replacement parts containing heat media in a closed system,[38] until end of service life of the articles, subject to review by the Conference of the Parties no later than or 2043.

166. [In addition, provided additional information becomes available to further explain and describe the need for exemptions, the following exemptions could be considered: 1) lubricants used in the manufacture of fluoropolymers in accordance with Article 4; 2) parts and/or materials for electrical and electronic devices, equipment and appliances in accordance with Article 4; 3) inks for marking capacitors and cables; and 4) replacement parts for electrical and electronic devices, equipment and appliances until end of service life of the articles or 2046, whichever comes earlier].

[35] This proposed timeline is based on the timelines included for the recommended exemptions for replacement parts in the risk management evaluations on Dechlorane plus (UNEP/POPS/POPRC.18/11/Add.1) and UV-328 (UNEP/POPS/POPRC.18/11/Add.2), i.e. 20 years after the coming into force of the listing.

[36] Including heat media in components of *in vitro* diagnostic medical devices, refractive media in analytical instruments for detecting fluorescence and heat media in thermostatic chambers for reliability and durability testing of electric and electronic equipment.

[37] Covering all land-based vehicles, such as cars, motorcycles, agricultural and construction vehicles and industrial trucks. Applications include semiconductors, coatings, cables, electronics, engines and underhood applications, modules, hydraulic system components and relay assemblies.

[38] Including heat media in components of in vitro diagnostic medical devices, refractive media in analytical instruments for detecting fluorescence, and heat media in thermostatic chambers for reliability and durability testing of electric and electronic equipment.

5. References

Aker A, Lemire M, Ayotte P. 2021. Environmental Contaminants: Persistent Organic Pollutants and Contaminants of Emerging Arctic Concern. Nunavik Inuit Health Survey 2017 Qanuilirpitaa? How are we now? Quebec: Nunavik Regional Board of Health and Social Services (NRBHSS) & Institut national de santé publique de Québec (INSPQ). Available from: https://nrbhss.ca/sites/default/files/health_surveys/Environmental_Contaminants_POPs_fullreport_en.pdf (Accessed: 12 May 2023).

Aker A, Ayotte P, Caron-Beaudoin É, De Silva A, Ricard S, Lemire M. 2023a. Associations between dietary profiles and perfluoroalkyl acids in Inuit youth and adults. Science of the Total Environment 857, 159557. https://doi.org/10.1016/j.scitotenv.2022.159557.

Aker A, Ayotte P, Caron-Beaudoin É, De Silva A, Ricard S, Gaudreau É, Lemire M. 2023b. Plasma concentrations of perfluoroalkyl acids and their determinants in youth and adults from Nunavik, Canada. Chemophere 310, 136797. https://doi.org/10.1016/j.chemosphere.2022.136797.

AMAP (Arctic Monitoring and Assessment Programme). 2021. AMAP Assessment 2021: Human Health in the Arctic. Tromsø, Norway. Available at: https://www.amap.no/documents/doc/amap-assessment-2021-human-health-in-the-arctic/3593 (Accessed: 11 January 2023).

Armitage JM, MacLeod M, Cousins IT. 2009. Comparative Assessment of the Global Fate and Transport Pathways of Long-chain Perfluorocarboxylic Acids (PFCAs) and Perfluorocarboxylates (PFCs) Emitted from Direct Sources. Supporting Information. Environ Sci Technol. 43(15):5830–5836. https://doi.org/10.1021/es900753y.

Baresel C, Karlsson L, Malovanyy A, Thorsén G, Goicoechea Feldtmann M, Holmquist H, Dalahmeh S, Ahrens L, Winkens Pütz K. 2022. Report PFAS – how can Swedish wastewater treatment plants meet the challenge? Compilation of knowledge and guidance for water/wastewater actors regarding PFAS. (PFAS – hur kan svenska avlopps-reningsverk möta utmaningen? Kunskapssammanställning och vägledning för VA-aktörer kring PFAS). Uppsala university, Lutz Ahrens, SLU. Report 2022-7. In Swedish (with English summary) Available from: https://www.mynewsdesk.com/se/svenskt-vatten/news/ny-svu-rapport-pfas-hur-kan-svenska-avloppsreningsverk-moeta-utmaningen-avlopp-och-miljoe-456229 (Accessed: 19 December 2022).

Barrett H, Du X, Houde M, Lair S, Verreault J, Peng H. 2021. Suspect and Nontarget Screening Revealed Class-Specific Temporal Trends (2000−2017) of Poly- and Perfluoroalkyl Substances in St. Lawrence Beluga Whales. Environ. Sci. Technol. 55:1659−1671. https://doi.org/10.1021/acs.est.0c05957.

Beatty RP, Inventor. E. I. du Pont de Nemours and Company, assignee. 2003 Apr 1. Fluorinated lubricant additives. United States Patent US 6541430. Available from: https://patents.justia.com/patent/6541430 (Accessed: 24 October 2022).

Bizkarguenaga E, Zabaleta I, Prieto A, Fernández LA, Zuloaga O. 2016. Uptake of 8:2 perfluoroalkyl phosphate diester and its degradation products by carrot and lettuce from compost-amended soil. Chemosphere. 152: 309‒317. https://doi.org/10.1016/j.chemosphere.2016.02.130.

Brendel S, Fetter É, Staude C, Vierke L, Biegel-Engler A. 2018. Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. Environmental Sciences Europe. 30(9):1–11. https://doi.org/10.1186/s12302-018-0134-4.

Buck RC, Franklin J, Berger U, Conder JM, Cousins IT, de Voogt P, Jensen AA, Kannan K, Mabury SA, van Leeuwenkk SPJ. 2011. Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins. Integr. Environ. Assess. Manag. 7(4):513–541. https://doi.org/10.1002/ieam.258.

California DTSC (Department of Toxic Substances Control. State of California). 2020. Product – Chemical Profile for Food Packaging Containing Perfluoroalkyl or Polyfluoroalkyl Substances. Available from: https://dtsc.ca.gov/wp-content/uploads/sites/31/2020/07/Draft-Profile_PFASs-in-Food-Packaging_FINAL_ADA.pdf (Accessed: 16 June 2023).

California DTSC (Department of Toxic Substances Control. State of California). 2022. Potential Alternatives to PFASs in Treatments for Converted Textiles or Leathers. Available from: https://dtsc.ca.gov/wp-content/uploads/sites/31/2022/05/Public-PFAS-Treatments-Alternatives-Summary_accessible.pdf (Accessed: 24 November 2022).

Canada. 2016. Regulations Amending the *Prohibition of Certain Toxic Substances Regulations, 2012*. Canada Gazette Part II, Vol. 150, No. 20. Available from: https://gazette.gc.ca/rp-pr/p2/2016/2016-10-05/html/sor-dors252-eng.html (Accessed: 12 May 2023).

Canada. 2022. Proposed *Prohibition of Certain Toxic Substances Regulations, 2022*. Canada Gazette Part I, Vol. 156, No. 20. Available from: https://www.canadagazette.gc.ca/rp-pr/p1/2022/2022-05-14/pdf/g1-15620.pdf#page=93 (Accessed: 18 October 2022).

Carlson GL, Tupper S. 2020. Ski wax use contributes to environmental contamination by per-and polyfluoroalkyl substances. Chemosphere. 261:128078. https://doi.org/10.1016/j.chemosphere.2020.128078.

ChemSec. 2023a. The top 12 PFAS producers in the world and the staggering societal costs of PFAS pollution. Available from: https://chemsec.org/reports/the-top-12-pfas-producers-in-the-world-and-the-staggering-societal-costs-of-pfas-pollution/ (Accessed: 13 June 2023).

ChemSec. 2023b. Check Your Tech. A guide to PFAS in electronics. Available from: https://chemsec.org/app/uploads/2023/04/Check-your-Tech_230420.pdf (Accessed: 12 June 2023).

Danish EPA (Danish Environmental Protection Agency). 2015. Alternatives to perfluoroalkyl and polyfluoro-alkyl substances (PFAS) in textiles. Available from: https://www2.mst.dk/Udgiv/publications/2015/05/978-87-93352-16-2.pdf (Accessed: 2 December 2022).

Drobny JG. 2014. Handbook of Thermoplastic Elastomers (Second) Edition). Chapter 3- Additives. Pages 17–32. https://doi.org/10.1016/B978-0-323-22136-8.00003-X.

ECCC (Environment and Climate Change Canada). 2023a. Personal communication.

ECCC (Environment and Climate Change Canada). 2023b. Supporting Document: Ecological State of the Science Report on Short-chain PFCAs, Short-chain PFSAs, and Long-chain PFSAs. Gatineau (QC): Government of Canada. Available from: https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/supporting-document-ecological-state-science-report-sc-pfcas-sc-pfsas-lc-pfsas.html (Accessed: 25 May 2023).

ECCC and Health Canada (Environment and Climate Change Canada and Health Canada). 2023a. DRAFT State of Per- and Polyfluoroalkyl Substances (PFAS) Report. Gatineau (QC): Government of Canada. Available from: https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/draft-state-per-polyfluoroalkyl-substances-report.html (Accessed: 25 May 2023).

ECCC and Health Canada (Environment and Climate Change Canada and Health Canada). 2023b. Risk management scope for per- and polyfluoroalkyl substances (PFAS). Available from: https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/risk-management-scope-per-polyfluoroalkyl-substances.html (Accessed: 12 June 2023).

ECHA (European Chemicals Agency). 2018a. Committee for Risk Assessment (RAC). Committee for Socio-economic Analysis (SEAC). Background document to the Opinion on an Annex XV dossier proposing restrictions on C9-C14 PFCAs including their salts and precursors. 29 November 2018. Available from: https://echa.europa.eu/documents/10162/02d5672d-9123-8a8c-5898-ac68f81e5a72 (Accessed: 23 October 2020).

ECHA (European Chemicals Agency). 2018b. Committee for Risk Assessment (RAC). Committee for Socio-economic Analysis (SEAC). Opinion on an Annex XV dossier proposing restrictions on PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTDA; their salts and precursors. Compiled version prepared by the ECHA Secretariat of RAC's opinion (adopted 14 September 2018) and SEAC's opinion (adopted 29 November 2018). Available from: https://echa.europa.eu/documents/10162/5aabe3cc-a317-4b2f-5446-5fc22c522c31 (Accessed: 23 October 2020).

ECHA (European Chemicals Agency). 2018c. Inclusion of substances of very high concern in the Candidate List for eventual inclusion in Annex XIV. Available from: https://echa.europa.eu/documents/10162/2be7bcbf-f797-c28c-2c67-939664155c7c (Accessed: 16 January 2023).

ECHA (European Chemicals Agency). 2019. Annex XV Restriction Report Proposal for a Restriction. Undecafluorohexanoic acid (PFHxA), its salts and related substances. Available from: Annex XV reporting format 040615 (europa.eu) (Accessed: 27 February 2023).

ECHA (European Chemicals Agency). 2020a. Committee for Risk Assessment (RAC). Committee for Socio-economic Analysis (SEAC). Opinion related to the request by the Executive Director of ECHA under Art. 77(3)9(c) of REACH to prepare a supplementary opinion on: Proposed derogations from the restrictions on C9–C14 perfluorocarboxylic acids (C9–C14 PFCA), their salts and related substances and on perfluorooctanoic acid (PFOA), its salts and PFOA-related substances. Compiled version prepared by the ECHA Secretariat of RAC's opinion (adopted 30 November 2020) and SEAC's opinion (adopted 10 December 2020). Available from: https://echa.europa.eu/documents/10162/13579/art77_3c_pfoa_pfca_derogations_compiled_rac_seac_opinions_en.pdf/6582d9a1-56b2-3e88-a70f-cdf3ab33d421 (Accessed: 29 November 2022).

ECHA (European Chemicals Agency). 2020b. 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. Available from:

https://echa.europa.eu/documents/10162/17086/report_pfcas_additional_derogation_en.pdf/527979b6-87ea-c9b7-a504-4ae2a4da73bf (Accessed: 24 February 2023).

ECHA (European Chemicals Agency). 2021. Committee for Risk Assessment (RAC). Committee for Socio-economic Analysis (SEAC). Opinion on an Annex XV dossier proposing restrictions on undecafluorohexanoic acid (PFHxA), its salts and related substances. Available from: https://echa.europa.eu/documents/10162/97eb5263-90be-ede5-0dd9-7d8c50865c7e (Accessed: 27 February 2023).

ECHA (European Chemicals Agency). 2022a. Annexes to Annex XV Restriction Report. Per- and polyfluoroalkyl substances (PFASs) in firefighting foams. Available from: https://echa.europa.eu/documents/10162/faf3207a-4910-292e-e994-2ab1281a0512 (Accessed: 28 October 2022).

ECHA (European Chemicals Agency). 2022b. Assessment of regulatory needs for the group "Hydrocarbyl siloxanes" Available from: https://echa.europa.eu/assessment-regulatory-needs/-/dislist/details/0b0236e1873ced74 (Accessed: 1 March 2023).

ECHA (European Chemicals Agency). 2023a. Annex XV Restriction Report Proposal for a Restriction. Per- and polyfluoroalkyl substances (PFASs). Available from: https://echa.europa.eu/documents/10162/4e564987-9902-9d7e-3fab-2d7f73753053 (Accessed: 27 February 2023).

ECHA (European Chemicals Agency). 2023b. Annex to the Annex XV Restriction Report Proposal for a Restriction. Per- and polyfluoroalkyl substances (PFASs). Annex E. Available from: https://echa.europa.eu/documents/10162/57812f19-8c98-ee67-b70f-6e8a51fe77e5 (Accessed: 13 June 2022).

European Commission. 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Chemicals Strategy for Sustainability Towards a Toxic-Free Environment. Available from: https://environment.ec.europa.eu/strategy/chemicals-strategy_en (Accessed: 27 February 2023).

Ellis DA, Mabury SA, Martin JW, Muir DCG. 2001. Thermolysis of Fluoropolymers as a potential source of halogenated organic acids in the environment. Nature. 412:321–324. https://doi.org/10.1038/35085548.

Environment Canada. 2012. Ecological Screening Assessment Report Long-Chain (C9–C20) Perfluorocarboxylic Acids, their Salts and their Precursors. Available from: http://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=CA29B043-1 (Accessed: 18 October 2022).

Feng M, Qu R, Wei Z, Wang L, Sun P, Wang Z. 2015. Characterization of the thermolysis products of Nafion membrane: A potential source of perfluorinated compounds in the environment. Sci Rep. 5:9859. https://doi.org/10.1038/srep09859.

Fang S, Plassmann MM, Cousins IT. 2020. Levels of per- and polyfluoroalkyl substances (PFAS) in ski wax products on the market in 2019 indicate no changes in formulation. Environ. Sci.: Processes Impacts. 22:2142. https://doi.org/10.1039/D0EM00357C.

FIS (International Ski Federation). 2022. FIS postpones full implementation of fluor wax ban. Available from: https://www.fis-ski.com/en/international-ski-federation/news-multimedia/news-2022/fis-postpones-full-implementation-of-fluor-wax-ban (Accessed: 9 June 2023).

Fujii Y, Harada KH, Koizumi A. 2013. Occurrence of perfluorinated carboxylic acids (PFCAs) in personal care products and compounding agents. Chemosphere. 93:538–544. https://doi.org/10.1016/j.chemosphere.2013.06.049

Gewurtz SB, de Silva AO, Ahrens L, Armellin A, Backus SN, Barclay K, Evans M, Gledhill M, Guerra P, Harner T, Hung H, King M, Lee SC, Letcher RJ, Martin PA, Marvin C, McGoldrick DJ, Pelletier M, Pomeroy J, Rondeau M, Sauve M-C, Sekela M, Shoeib M, Smith DW, Smyth SA, Spry D, Struger J, Syrgiannis J, Waltho J. 2013. Perfluoroalkyl contaminants in the Canadian environment: Multi-media assessment of current status and trends. Environment International. 59:183–200. https://doi.org/10.1016/j.envint.2013.05.008.

Graber JM, Alexander C, Laumbach RJ, Black K, Ohman Strickland P, Georgopoulos PG, Marshall EG, Shendell DG, Alderson D, Mi Z, Mascari M, Weisel CP. 2019. Per- and polyfluoroalkyl substances (PFAS) blood levels after contamination of a community water supply and comparison with 2013-14 NHANES. J Expo Sci Environ Epidemiol. 2019 March; 29(2): 172–182. https://doi.org/10.1038/s41370-018-0096-z.

Health Canada. 2013. Second Report on Human Biomonitoring of Environmental Chemicals in Canada: Results of the Canadian Health Measures Survey Cycle 2 (2009–2011). Ottawa, ON, Canada. Available from: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/environmental-contaminants/second-report-human-biomonitoring-environmental-chemicals-canada-health-canada-2013.html (Accessed: 12 May 2023).

Health Canada. 2019. Fifth Report on Human Biomonitoring of Environmental Chemicals in Canada: Results of the Canadian Health Measures Survey Cycle 5 (2016–2017). Ottawa, ON, Canada. Available from: h https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/environmental-contaminants/fifth-report-human-biomonitoring.html (Accessed: 12 May 2023).

Health Canada. 2021a. Sixth Report on Human Biomonitoring of Environmental Chemicals in Canada: Results of the Canadian Health Measures Survey Cycle 6 (2018–2019). Ottawa, ON, Canada. Available from: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/environmental-contaminants/sixth-report-human-biomonitoring.html (Accessed: 12 May 2023).

Health Canada. 2021b. Per- and polyfluoroalkyl substances (PFAS) in Canadians. Ottawa, ON. Available from: https://www.canada.ca/content/dam/hc-sc/documents/services/environmental-workplace-health/reports-publications/environmental-contaminants/human-biomonitoring-resources/per-polyfluoroalkyl-substances-canadians/pfas-v2-eng.pdf (Accessed: 15 December 2022).

Health Canada and Environment Canada. 2008. Screening Assessment for the Challenge. Octamethylcyclotetrasiloxane (D4). Chemical Abstracts Service Registry Number 556-67-2. Available from: https://www.ec.gc.ca/ese-ees/2481B508-1760-4878-9B8A-270EEE8B7DA4/batch2_556-67-2_en.pdf (Accessed: 16 January 2023).

Hopkins KE, McKinney MA, Letcher RJ, Fernie KJ. 2023. The influence of environmental and ecological factors on the accumulation and distribution of short- and long-chain perfluoroalkyl acids in a mid-trophic avian insectivore. Environ. Pollut. https://doi.org/10.1016/j.envpol.2023.121133.

IAEA and WHO (International Atomic Energy Agency. World Health Organization). Worldwide implementation of digital imaging in radiology, IAEA Human health series No. 28. Available from: http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1647web.pdf (Accessed: 2 March 2023).

Ishikawa N, Takahashi M. 1988. Patent: Process for preparing a perfluorinated or polyfluorinated aliphatic carboxylic acid. US 457822. (As cited in Wang et al. 2014).

Jans ACH, Berbee RPM. 2020. Sources of PFAS for Dutch surface waters. (Provided as part of the Netherlands Annex F information).

Kotthoff M, Müller J, Jürling H, Schlummer M, Fiedler D. 2015. Perfluoroalkyl and polyfluoroalkyl substances in consumer products. Environ Sci Pollut Res. 22:14546–14559. https://doi.org/10.1007/s11356-015-4202-7.

Krippner J, Falk S, Brunn H, Georgii S, Schubert S, Stahl T. 2015. Accumulation Potentials of Perfluoroalkyl Carboxylic Acids (PFCAs) and Perfluoroalkyl Sulfonic Acids (PFSAs) in Maize (*Zea mays*). J. Agric. Food Chem. 63:3646−3653. https://doi.org/10.1021/acs.jafc.5b00012

LightMachinery. 2023. Web page on Marking. Available from: https://lightmachinery.com/lasers/laser-applications/marking/ (Accessed: 12 May 2023).

Liu S, Zhao S, Liang Z, Wang F, Sun F, Chen D. 2021. Perfluoroalkyl substances (PFASs) in leachate, fly ash, and bottom ash from waste incineration plants: Implications for the environmental release of PFAS. Science of the Total Environment 795:148468. https://doi.org/10.1016/j.scitotenv.2021.148468.

Lohmann R, Cousins IT, DeWitt JC, Glüge J, Goldenman G, Herzke D, Lindstrom AB, Miller MF, Ng CA, Patton S, Scheringer M, Trier X, Wang Z. 2020. Are Fluoropolymers Really of Low Concern for Human and Environmental Health and Separate from Other PFAS? Environ. Sci. Technol. 54:12820−12828. https://doi.org/10.1021/acs.est.0c03244.

Malovanyy A, Hedman F, Goicoechea Feldtmann M, Harding M, Yang J. 2021. Cleaning of PFAS-contaminated water from waste treatment plants. (Rening av PFAS-förorenat vatten från avfallsanläggningar.) IVL March 2021 Report B 2412. In Swedish (with English summary). Available from: https://www.ivl.se/download/18.5bcd43b91781d2f501c5ca/1623157611518/B2412.pdf (Accessed: 19 December 2022).

Mayes J, White A. 2017. How smartphone technology is changing healthcare in developing countries. Journal of Global Health. Spring 2017. Vol. II. Issue II. Available from: https://journals.library.columbia.edu/index.php/jgh/article/view/4993/3110 (Accessed: 12 May 2023).

Muir D, Bossi R, Carlsson P, Evans M, De Silva A, Halsall C, Rauert C, Herzke D, Hung H, Letcher R, Rigét F, Roos A. 2019. Levels and trends of poly- and perfluoroalkyl substances in the Arctic environment–An update. Emerging Contaminants. 5:240-271. https://doi.org/10.1016/j.emcon.2019.06.002.

Munoz G, Michaud AM, Liu M, Vo Duy S, Montenach D, Resseguier C, Watteau F, Sappin-Didier V, Feder F, Morvan T, Houot S, Desrosiers M, Liu J, Sauvé S. 2022a. Target and Nontarget Screening of PFAS in Biosolids, Composts, and Other Organic Waste Products for Land Application in France. Environ. Sci. Technol. 56(10):6056–6068. https://doi.org/10.1021/acs.est.1c03697.

Munoz G, Mercier L, Duy SV, Liu J, Sauvé E, Houde M. 2022b. Bioaccumulation and trophic magnification of emerging and legacy per-and polyfluoroalkyl substances (PFAS) in a St. Lawrence River food web. Environmental Pollution. 309:119739. https://doi.org/10.1016/j.envpol.2022.119739.

Nordiq Canada. 2023. Wax Tech Resources. Available from: https://nordiqcanada.ca/coaches-and-wax-techs/wax-techs/wax-tech-resources/ (Accessed: 9 June 2023).

Norwegian Environmental Agency. 2021a. Substance Evaluation Conclusion document for octamethyltrisiloxane (L3), EC No 203-497-4, CAS RN 107-51-7. Available from: https://echa.europa.eu/documents/10162/8419cc85-de6a-66e2-94a4-fd99e27e3d2c (Accessed: 23 February 2022).

Norwegian Environmental Agency. 2021b. Substance Evaluation Conclusion document for decamethyltetrasiloxane (L4), EC No 205-491-7, CAS RN 141-62-8. Available from: https://echa.europa.eu/documents/10162/cf630a5c-3104-b72a-ed4c-9fb730992209 (Accessed: 23 February 2022).

Norwegian Environmental Agency. 2021c. Substance Evaluation Conclusion document for dodecamethylpentasiloxane (L5), EC No 205-492-2, CAS RN 141-63-9. Available from: https://echa.europa.eu/documents/10162/c3d2870b-5aa0-69ab-cf5c-320d5c0db5c9 (Accessed: 23 February 2022).

OECD (Organisation for Economic Co-operation and Development). 2015a. Risk reduction approaches for PFASs a cross-country analysis. https://www.oecd.org/chemicalsafety/risk-management/Risk_Reduction_Approaches%20for%20PFASS.pdf (Accessed: 18 October 2022).

OECD (Organisation for Economic Co-operation and Development). 2015b. Working towards a global emission inventory of PFASs: focus on PFCAs - status quo and the way forward. OECD Environment, Health and Safety Publications Series on Risk Management. No. 30. Available from: https://www.oecd.org/chemicalsafety/Working%20Towards%20a%20Global%20Emission%20Inventory%20of%20PFASS.pdf (Accessed: 27 October 2022).

OECD (Organisation for Economic Co-operation and Development). 2020. PFASs and Alternatives in Food Packaging (Paper and Paperboard). Report on the Commercial Availability and Current Uses. OECD Series on Risk Management, No. 58, Environment, Health and Safety, Environment Directorate, OECD. Available from: https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/PFASs-and-alternatives-in-food-packaging-paper-and-paperboard.pdf (Accessed: 21 November 2022).

OECD (Organisation for Economic Co-operation and Development). 2021. Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance. Series on Risk Management No. 61. Available from: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO(2021)25&docLanguage=en (Accessed: 26 January 2023).

OECD (Organisation for Economic Co-operation and Development). 2022. Per- and Polyfluoroalkyl Substances and Alternatives in Coatings, Paints and Varnishes (CPVs). Report on the Commercial Availability and Current Uses. OECD Series on Risk Management, No. 70, Environment, Health and Safety, Environment Directorate, OECD. Available from: https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/per-and-polyfluoroalkyl-substances-alternatives-in-coatings-paints-varnishes.pdf (Accessed: 29 November 2022).

OECD (Organisation for Economic Co-operation and Development). 2023. Portal on Per and Poly Fluorinated Chemicals. Available from: https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/aboutpfass/.

Oosterhuis F, Brouwer R. 2015. Benchmark development for the proportionality assessment of PBT and vPvB substances. IVM Institute for Environmental Studies. Available from: https://echa.europa.eu/documents/10162/17241/R15_11_pbt_benchmark_report_en.pdf/a695a7fd-e2bd-4dc5-b69a-bc02f9f98fef?t=1449837319194 (Accessed: 27 February 2023).

Oosterhuis F, Brouwer R, Janssen M, Verhoeven J, Luttikhuizenk C. 2017. Towards a Proportionality Assessment of Risk Reduction Measures Aimed at Restricting the Use of Persistent and Bioaccumulative Substances. Integr Environ Assess Manag 2017:1100–1112. https://doi.org/10.1002/ieam.1949.

Panikkar B, Lemmond B, Allen L, DiPirro C, Kasper S. 2019. Making the invisible visible: results of a community-led health survey following PFAS contamination of drinking water in Merrimack, New Hampshire. Environ Health. 18:79. https://doi.org/10.1186/s12940-019-0513-3.

Pepper IL, Brusseau ML, Prevatt FJ, Escobar BA. 2021. Incidence of PFAS in soil following long-term application of class B biosolids. Science of the Total Environment. 793:148449. https://doi.org/10.1016/j.scitotenv.2021.148449.

Prevedouros K, Cousins IT, Buck RC, Korzeniowski SH. 2006. Sources, fate, and transport of perfluorocarboxylates. Environ Sci Technol. 40:32–44. https://doi.org/10.1021/es0512475.

Rauert C, Shoieb M, Schuster JK, Eng A, Harner T. 2018. Atmospheric concentrations and trends of poly- and perfluoroalkyl substances (PFAS) and volatile methyl siloxanes (VMS) over 7 years of sampling in the Global Atmospheric Passive Sampling (GAPS) network. Environmental Pollution. 238:94–102. https://doi.org/10.1016/j.envpol.2018.03.017.

Rawn DFK, Dufresne G, Clément G, Fraser WD, Arbuckle TE 2022. Perfluorinated alkyl substances in Canadian human milk as part of the Maternal-Infant Research on Environmental Chemicals (MIREC). Science of the Total Environment. 831:154888. https://doi.org/10.1016/j.scitotenv.2022.154888.

Repas T. 2021. Biodegradation of perfluoroalkyl substances. Available from: https://fixed.earth/wp-content/uploads/2021/01/January2021-Fixed-Earth-Innovations-PFAS.pdf (Accessed: 6 December 2022).

Reuters. 2023. Dutch government to hold 3M liable for ‘forever chemicals’ damage. Available from: https://www.reuters.com/business/environment/dutch-government-hold-3m-liable-forever-chemicals-damage-2023-05-23/ (Accessed: 9 June 2023).

RISE (Research Institutes of Sweden). 2020. POPFREE Promotion of PFAS-free alternatives. Final report. Available from: https://www.ri.se/sites/default/files/2020-12/POPFREE%20Final%20report%20public.pdf (Accessed: 7 December 2020)

Ritscher A, Wang Z, Scheringer M, Boucher JM, Ahrens L, Berger U, Bintein S, Bopp SK, Borg D, Buser AM, Cousins I, Dewitt J, Fletcher T, Green C, Herzke D, Higgins C, Huang J, Hung H, Knepper T, Vierke L. 2018. Zürich Statement on Future Actions on Per- and Polyfluoroalkyl Substances (PFASs). Environmental Health Perspectives. 126(8):1–5. https://doi.org/10.1289/EHP4158.

Saini A, Chinnadurai S, Schuster JK, Eng A, Harner T. 2023. Per- and polyfluoroalkyl substances and volatile methyl siloxanes in global air: Spatial and temporal trends. Environmental Pollution. 323:121291. https://doi.org/10.1016/j.envpol.2023.121291.

Schlummer M, Sölch C, Meisel T, Still M, Gruber L, Wolz G. 2015. Emission of perfluoroalkyl carboxylic acids (PFCA) from heated surfaces made of polytetrafluoroethylene (PTFE) applied in food contact materials and consumer products. Chemosphere. 129:46–53. https://doi.org/10.1016/j.chemosphere.2014.11.036.

Schultes L, Vestergren R, Volkova K, Westberg E, Jacobson T, Benskin JP. 2018. Per- and polyfluoroalkyl substances and fluorine mass balance in cosmetic products from the Swedish market: implications for environmental emissions and human exposure. Environmental Science: Processes & Impacts. 20(12):1680–1690. https://doi.org/10.1039/C8EM00368H.

Schultz MM, Higgins P, Huset CA, Luthy RG, Barofsky DF, Field JA. 2006. Fluorochemical Mass Flows in a Municipal Wastewater Treatment Facility. Environ. Sci. Technol. 40:7350–7357. https://doi.org/10.1021/es061025m.

Semiconductor PFAS Consortium Photolithography Working Group. 2023. PFOS and PFOA Conversion to Short-Chain PFAS-Containing Materials Used in Semiconductor Manufacturing. Available from: https://www.semiconductors.org/wp-content/uploads/2023/06/FINAL-PFOS-PFOA-Case-Study-Paper.pdf (Accessed: 20 June 2023).

Shabanian S, Khatir B, Nisar A, Golovin K. 2020. Rational design of perfluorocarbon-free oleophobic textiles. Nature Sustainability 3(12):1059–1066. https://doi.org/10.1038/s41893-020-0591-9

Sherman MA, Kirchner JR, Del Pesco TW, Huang H, inventors. E. I. du Pont de Nemours and Company, assignee. 2001. Fluorochemical oil and water repellents. World Intellectual Property Organization Patent WO 01/10922 A1. Available from: https://patents.google.com/patent/WO2001010922A1/en?oq=WO2001010922A1 (Accessed: 24 October 2022).

Shin-Etsu Silicone. 2021. Silicone Fluid (For North & South America). Available from: https://www.shinetsusilicone-global.com/catalog/pdf/fluid_us.pdf (Accessed: 2 March 2023).

Sinclair E., Kannan K. 2006. Mass Loading and Fate of Perfluoroalkyl Surfactants in Wastewater Treatment Plants. Environ Sci Technol. 40(5): 1408–1414. https://doi.org/10.1021/es051798v.

SpecialChem. 2023. Lubricants for Polymers. https://polymer-additives.specialchem.com/selection-guide/lubricants (Accessed: 2 March 2023).

Spectrum Technologies. 2023. Web page on Laser Wire Markers. Available from: https://www.spectrumtech.com/product/laser-wire-markers/ (Accessed: 12 May 2023).

Swedish Chemicals Agency. 2015. Occurrence and use of highly fluorinated substances and alternatives. Available from: https://www.enviro.wiki/images/d/df/KEMI2015.pdf (Accessed: 7 December 2022).

Swedish Chemicals Agency. 2021. PFAS in chemical products and articles. An enforcement project with focus on restrictions in the POPs Regulation on PFOA and PFOS. Report 3/22. Available from:

https://www.kemi.se/download/18.5e6048c31817afbc50ef72/1656335359490/Enforcement-3-22-PFAS-in-chemical-products-and-articles.pdf (Accessed: 1 March 2023).

Swedish National Food Agency. 2017. Swedish Market Basket Survey 2015 – per capita-based analysis of nutrients and toxic compounds in market baskets and assessment of benefit or risk. Available from: https://www.livsmedelsverket.se/globalassets/publikationsdatabas/rapporter/2017/swedish-market-basket-survey-2015-livsmedelsverkets-rapportserie-nr-26-20172.pdf (Accessed: 19 December 2022).

Tahir MY, Mars M, Scott RE. 2022. A review of teleradiology in Africa – Towards mobile teleradiology in Nigeria. SA J Radiol. 26(1):2257. https://doi.org/10.4102/sajr.v26i1.2257.

Talasniemi P, Björkqvist S, Ashja M, Rosen A, Iversen C, Bæringsdóttir BB. 2022. Nordic Working Paper. Nordic enforcement project on PFOS and PFOA in chemical products and articles. Available from: https://www.norden.org/en/publication/nordic-enforcement-project-pfos-and-pfoa-chemical-products-and-articles (Accessed: 19 December 2022).

Trang B, Li Y, Xue X, Ateia M, Houk KN, Dichtel WR. 2022. Low-temperature mineralization of perfluorocarboxylic acids. Science. 377:839–845. https://doi.org/10.1126/science.abm8868.

Trier X, Taxvig C, Rosenmai AK, Perdersen GA. 2017. PFAS in paper and board for food contact - options for risk management of poly- and perfluorinated substances. Available from: https://www.norden.org/en/publication/pfas-paper-and-board-food-contact (Accessed: 6 December 2022).

Tri-Star Technologies. 2023. Web page on Wire Marking Systems. Available from: https://tri-star-technologies.com/product-category/wire-marking-systems/?gclid=EAIaIQobChMIsZnZ3c7v_gIV7vHjBx3PcAAXEAAYASAAEgIZ3PD_BwE (Accessed: 12 May 2023).

Ukihashi H, Hayashi T, Takasaki Y. 1977. Patent: Process for producting perfluoorocarboxylic acid. US 4138417. (As cited in Wang et al. 2014).

UNEP (United Nations Environment Programme). 2009. Report of the International Conference on Chemicals Management on the work of its second session. SAICM/ICCM.2/15. Available from: http://www.saicm.org/Portals/12/documents/meetings/ICCM2/doc/ICCM2%2015%20FINAL%20REPORT%20E.pdf (Accessed: 15 January 2023).

UNEP (United Nations Environment Programme). 2019. Global Chemicals Outlook II – From Legacies to Innovative Solutions: Implementing the 2030 Agenda for Sustainable Development. Available from: https://www.unep.org/resources/report/global-chemicals-outlook-ii-legacies-innovative-solutions (Accessed: 18 October 2022).

UNEP/POPS/COP.10/INF/25. Draft guidance on alternatives to perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds. February 2022.

UNEP/POPS/POPRC.13/INF/6. Supporting information related to the draft risk management evaluation on pentadecafluorooctanoic acid (CAS No: 335- 67-1, PFOA, perfluorooctanoic acid), its salts and PFOA-related compounds.

UNEP/POPS/POPRC.14/6/Add.2. Addendum to the risk management evaluation on perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds.

UNEP/POPS/POPRC.18/6/Add.1. Risk profile: long-chain perfluorocarboxylic acids, their salts and related compounds.

US EPA (United States Environmental Protection Agency). 2009. Siloxane D_5 in Drycleaning Applications. Fact sheet. Office of Pollution Prevention and Toxics. Publication number: 744F03004. Available from: https://nepis.epa.gov/epa/html/pubs/pubtitleoppts.html (Accessed: 4 May 2023).

US EPA (United States Environmental Protection Agency). 2022. Enforcement Alert. Available from: https://www.epa.gov/system/files/documents/2022-01/pfasskiwax.pdf (Accessed: 9 June 2023).

Wang Z, Cousins IT, Scheringer M, Buck RC, Hungerbühler K. 2013. Fluorinated alternatives to long-chain perfluoroalkyl carboxylic acids (PFCAs), perfluoroalkane sulfonic acids (PFSAs) and their potential precursors. Environment International. 60:242–248. https://doi.org/10.1016/j.envint.2013.08.021.

Wang Z, Cousins IT, Scheringer M, Buck RC, Hungerbühler K. 2014. Global emission inventories for C_4–C_{14} perfluoroalkyl carboxylic acid (PFCA) homologues from 1951 to 2030, Part I: production and emissions from quantifiable sources. Supplementary Information. Environment International. 70:62–75. https://doi.org/10.1016/j.envint.2014.04.013.

Wang Z, Cousins IT, Scheringer M, Buck RC, Hungerbühler K. 2015. Hazard assessment of fluorinated alternatives to long-chain perfluoroalkyl acids (PFAAs) and their precursors: Status quo, ongoing challenges and possible solutions. Environment International. 75:172–179. https://doi.org/10.1016/j.envint.2014.11.013.

Washington JW, Yoo H, Ellington J, Jenkins TM, Libelo EL. 2010. Concentrations, Distribution, and Persistence of Perfluoroalkylates in Sludge-Applied Soils near Decatur, Alabama, USA. Environ. Sci. Technol. 44:8390–8396. https://doi.org/10.1021/es1003846.

Würth A, Mechler M, Menberg K, Ikipinar MA, Martus P, Söhlmann R, Boeddinghaus RS, Blum P. 2023. Phytoscreening for Per- and Polyfluoroalkyl Substances at a Contaminated Site in Germany. Environ. Sci. Technol. 2023, 57, 4122−4132. https://doi.org/10.1021/acs.est.2c04519.

Wood (Wood Environment & Infrastructure Solutions UK Limited). 2021. PFAS in the treatment of skis −Use, Emissions and Alternatives. Available from: https://www.miljodirektoratet.no/publikasjoner/2021/april-2021/pfas-in-the-treatment-of-skis/ (Accessed: 28 February 2023).

WSDE (Washington State Department of Ecology). 2021. Per- and Polyfluoroalkyl Substances in Food Packaging Alternatives Assessment. Available from: https://apps.ecology.wa.gov/publications/documents/2104004.pdf (Accessed: 25 November 2022).

Yoo H, Washington JW, Ellington JJ, Jenkins TM, Neill MP. 2010. Concentrations, Distribution, and Persistence of Fluorotelomer Alcohols in Sludge-Applied Soils near Decatur, Alabama, USA. Environ. Sci. Technol. 2010, 44, 22, 8397–8402. https://doi.org/10.1021/es100390r.