

ANNEX XV RESTRICTION REPORT

PROPOSAL FOR A RESTRICTION

SUBSTANCE NAME(S): Per- and polyfluoroalkyl substances (PFAS) in firefighting foams

CONTACT DETAILS OF THE DOSSIER SUBMITTER:

European Chemicals Agency (ECHA)

Telakkakatu 6, PO BOX 400, FI-00121, Helsinki, Finland

VERSION NUMBER: 1.0

DATE: 14 January 2022

CONTENTS

Summary	1
1. Problem identification.....	10
1.1. Hazard, exposure/emissions and risk.....	10
1.1.1. Identity of the substance(s), and physical and chemical properties.....	10
1.1.1.1. Substance identity restriction scope	10
1.1.1.2. Overview of PFASs used in firefighting foams	14
1.1.2. Justification for grouping	15
1.1.3. Classification and labelling.....	16
1.1.4. Hazard assessment.....	16
1.1.4.1. Overview	16
1.1.4.2. Persistence	18
1.1.4.3. Long range transport potential (LRTP).....	19
1.1.4.4. Mobility	20
1.1.4.5. Accumulation in plants	21
1.1.4.6. Bioaccumulation	21
1.1.4.7. Endocrine Activity / Endocrine Disruption.....	23
1.1.4.8. Ecotoxicity	23
1.1.4.9. Effects on human health.....	24
1.1.4.10. Concerns triggered by combinations of properties	27
1.1.5. Exposure assessment	33
1.1.6. Risk characterisation.....	36
Case by case assessment according to para 0.10 of Annex I to REACH	36
1.2. Justification for an EU wide restriction measure.....	37
1.3. Baseline.....	38
1.3.1. Overview.....	38
1.3.2. Definition of the baseline scenario for the assessment of economic impacts	39
2. Impact assessment.....	40
2.1. Introduction	40
2.2. Analysis of risk management options (RMOs).....	41
2.2.1. Overview of current regulatory measures	42
2.2.1.1. Stockholm Convention.....	42
2.2.1.2. EU Regulation	43

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

2.2.1.3. Controls in Member States and other jurisdictions.....	45
2.2.2. Industry measures	46
2.2.2.1. Substitution and phase-out.....	46
2.2.2.2. Containment and control	47
2.2.3. Main restriction options assessed	48
2.2.4. Other risk management options not assessed in detail	49
2.2.5. Proposed restriction option	50
2.3. Overview of impacts	54
2.4. Economic impacts	59
2.5. Human health and environmental impacts.....	63
2.6. Other impacts	68
2.7. Practicality and monitorability.....	68
2.8. Proportionality to the risk (including comparison of options).....	70
2.8.1. Comparison of different users	72
2.8.2. Transition periods.....	73
2.8.3. Concentration thresholds.....	78
2.8.4. Cost-effectiveness estimates.....	79
2.8.5. Additional risk management measures	81
3. Assumptions, uncertainties and sensitivities	82
4. Conclusion	91
References	94
Additional references	97

TABLES

TABLE 1. SUMMARY OF MAIN RESTRICTION OPTION (RO) ASSESSED, THEIR EMISSION REDUCTION POTENTIAL, COST AND COST EFFECTIVENESS	4
TABLE 2. TOTAL EMISSIONS OF PFASs TO THE ENVIRONMENT UNDER THE BASELINE PER SECTOR OR USE* ..	35
TABLE 3. PROPOSED TRANSITIONAL PERIODS FOR THE RESTRICTION PER SECTOR/TYPE OF USE.....	59
TABLE 4. ESTIMATED ECONOMIC IMPACTS FOR EACH RO AND COST CATEGORY	60
TABLE 5. ESTIMATED ECONOMIC IMPACTS FOR EACH RO AND INDUSTRIAL SECTOR	61
TABLE 6. TOTAL AVOIDED PFAS EMISSIONS OVER 30 YEARS, COMPARED TO THE BASELINE, USING THE BEST ESTIMATE SCENARIOS (LOW AND HIGH SCENARIO IN BRACKETS), WITH AND WITHOUT (T PFASs, FIGURES ROUNDED)	65
TABLE 7. ESTIMATED AVOIDED EMISSIONS OF PFASs (BEST ESTIMATE) FOR EACH RO AND SECTOR OR TYPE OF USE, COMPARED TO THE BASELINE.....	66

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

TABLE 8. SUBSTITUTION POTENTIAL, SOCIO-ECONOMIC IMPACTS AND PFAS-RELATED RISK REDUCTION POTENTIAL ACROSS THE MAIN IDENTIFIED USER SECTOR AND PROPOSED TRANSITIONAL PERIODS.....	76
TABLE 9. ESTIMATED C-E RATIOS FOR EACH RO AND SECTOR OR TYPE OF USE	79
TABLE 10. INCREMENTAL COST-EFFECTIVENESS (C/E) OF RO1, RO2 AND RO3.....	80
TABLE 11. COST-EFFECTIVENESS OF RECENT REACH RESTRICTIONS	80
TABLE 12. INPUT PARAMETERS FOR THE CALCULATION OF THE EMISSIONS IN THE FIVE SCENARIOS RO1 – RO5 (“LOW”, “BEST” AND “HIGH” ESTIMATES).....	84
TABLE 13. INPUT PARAMETERS FOR THE CALCULATION OF THE TRANSITION COSTS, SOURCES AND USE (LOW, BEST AND HIGH SCENARIOS)	87

FIGURES

FIGURE 1. MAIN PFAS SUBGROUPS, INCLUDING THE SUBGROUP OF STABLE SUBSTANCES (PFAAs) OR ‘ARROWHEADS’ AND THE PRECURSORS TO THE PFAAs. FIGURE ADAPTED FROM OECD (2021b) – SEE FIGURE 9 THEREIN FOR MORE DETAILS ON THE GROUPING AND NOMENCLATURE. THE TERMS ‘ARROWHEAD’ AND ‘PRECURSOR’ ARE DESCRIBED IN SECTION 1.1.2.	12
FIGURE 2. PFAS PROPERTIES AND PROPERTY-RELATED CONCERNS RESULTING FROM COMBINATIONS OF THE PROPERTIES.	18
FIGURE 3. MODELLING OF DEVELOPMENT OF NOMINAL BIOTA CONCENTRATIONS FOR PFBS OVER TIME.	29
FIGURE 4. SPLIT OF PFAS-CONTAINING FIREFIGHTING FOAMS BY SECTOR. SOURCE: (WOOD ET AL., 2020) BASED ON DATA PROVIDED TO THE AUTHORS BY EUROFEU.	33
FIGURE 5. MATERIAL FLOW DIAGRAM SHOWING THE CONNECTION BETWEEN THE DIFFERENT LIFE CYCLE STAGES OF FORMULATION, IN-USE, STOCK AND WASTE TREATMENT FOR PFASs IN FIREFIGHTING FOAMS UNDER THE BASELINE SCENARIO.	35
FIGURE 6. SCHEMATIC SUMMARISING POTENTIAL EFFECTS OF A RESTRICTION ON THE PLACING ON THE MARKET OF PFAS-CONTAINING FIREFIGHTING FOAMS (RO 1)	57
FIGURE 7. SCHEMATIC SUMMARISING POTENTIAL EFFECTS OF A RESTRICTION ON THE USE /PLACING ON THE MARKET OF PFAS-CONTAINING FIREFIGHTING FOAMS (RO 2, 3, 4 AND 5)	58
FIGURE 8. MATERIAL FLOW DIAGRAM FOR THE LIFE CYCLE STAGES TRAINING AND INCIDENTS, INCLUDING RMMs AS FORESEEN IN ALL THE ROS.	65

List of abbreviations

Acronym	Explanation
3F	Fluorine-free foam
8:2 FTSA	8:2 fluorotelomer sulfonic acid
6:2 FTOH	6:2 fluorotelomer alcohol
6:2 FTSA	6:2 fluorotelomer sulfonic acid
8:2 Cl-PFESA	8:2 Cl-polyfluorinated ether sulfonate
ADONA	Ammonium 4,8-dioxa-3H-perfluorononanoate, 3H-perfluoro-3-[(3-methoxy-propoxy)propanoic acid]
AFFF	Aqueous Film-Forming Foam
ALT	Serum alanine transferase
AR-AFFF	Alcohol Resistant-Aqueous Film Forming Foam
AR-FFFP	Alcohol-Resistant Film-Forming Fluoro-Protein
BAU	Business as usual
BCF	Bioconcentration Factor
C	Carcinogenicity
CAF	Compressed air foam
M	Mutagenicity
R	Reproductive toxicity
STOT RE	Specific target organ toxicity on repeated exposure
CMR	Carcinogenic, mutagenic or toxic for reproduction
COP	Conference of the Parties
CTD	Characteristic Travel Distance
EA	Endocrine Activity
ECHA	European Chemicals Agency
ED	Endocrine Disruption
EFSA	European Food Safety Authority
Eurofeu	European Committee of the Manufacturers of Fire Protection Equipment and Fire Fighting Vehicles
F-53B	6:2 Cl-polyfluorinated ether sulfonate (6:2 Cl-PFESA)
FFFC	Fire Fighting Foam Coalition
FFFP	Fluoroprotein foam concentrates and film forming fluoro-protein
FOSA	Perfluorooctane sulfonamide
FP	Fluoro Protein
FPA Australia	Fire Protection Association Australia
FPAR	Fluoro-Protein Alcohol-Resistant
HFCs	Hydrofluorocarbons
HFES	Hydrofluoroethers
HFOs	Hydrofluoroolefins
HFPO-DA	Hexafluoropropylene oxide dimer acid, 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid, FRD-903, GenX
IPCC	Intergovernmental Panel on Climate Change
K _d	sediment/water distribution coefficients
kg	Kilogram
LAST	Large atmospheric storage tank
LOQ	Limit Of Quantification

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

L RTP	Long-Range Transport Potential
MoD	Ministry of Defence
mg	Milligram
MWV	Mineralölwirtschaftsverband (German associations for Mineral oil Industry)
ng	Nanogram
PBT	Persistent, bioaccumulative and toxic
PCTFE	Polychlorotrifluoroethylene
PFAAs	Polyfluoroalkyl acids
PFAS	Per- and Polyfluoroalkyl Substance
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane Sulfonic acid
PFCA s	Perfluoroalkyl Carboxylic acid
PFDA	Perfluorodecanoic acid
PFECAs	Perfluoroalkylether carboxylic acids
PFHpA	perfluoroheptanoic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic acid
PF OA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFSA s	Perfluoroalkane sulfonic acids
PFUnDA	Perfluoroundecanoic acid
POP	Persistent Organic Pollutants
POPRC	POP Review Committee
PTFE	Polytetrafluoroethylene
RMM	Risk management measure
RMO	Risk management option
SDS	Safety data sheet
SVHC	Substances of Very High Concern
TFA	Trifluoroacetic acid
TWI	Tolerable Weekly Intake
US EPA	U.S. Environmental Protection Agency
UTV	Unabhängige Tanklagerverband e.V. (German Independent tank farm association)
vPvB	Very persistent and very bioaccumulative
WFVD	Der Verband Bundesverband Betrieblicher Brandschutz (German Industrial Fire-Fighters Association)
WWTP	Wastewater Treatment Plant

Summary

This report details a human health and environmental risk assessment of the use of per- and polyfluoroalkyl substances (PFASs) in firefighting foams and describes an assessment of the effectiveness, practicality, monitorability and socioeconomic impacts of different risk management options (RMOs), including different restriction options (ROs) under REACH, to address the identified risk. The work was conducted by ECHA at the request of the European Commission¹.

The assessment concluded that the risks to human health and the environment from the use of PFASs in firefighting foams in the EU are not adequately controlled and that a restriction under REACH is the most appropriate means to address the identified risks; a preferred restriction option is identified.

The preferred restriction option would ban the placing on the market, use and export of PFASs in firefighting foams after use/sector-specific transitional periods. The restriction is estimated to reduce emissions of PFASs in the European Union by around 13 200 tonnes over the 30-year period following its implementation (the assessment period). The societal cost of implementing the restriction over the same period is estimated to be €6.8 billion² with an average cost of €515 per kilogram of emission avoided. Several elements determining the costs are uncertain and therefore the costs could be as low as €3 billion or as high as €17 billion.

PFASs are a family of thousands of synthetic (i.e. man-made) chemicals that are used widely in the EU, including in firefighting foams. All PFASs contain at least one perfluorinated carbon atom (see section 1.1.1.1). A carbon-fluorine bond is one of the strongest chemical bonds in organic chemistry. All PFASs are very persistent in the environment. This is the key hazardous property common to all PFASs. Many PFASs are likely to persist in the environment longer than any other synthetic organic substance. Consequently, if releases of PFASs are not minimised, humans and other organisms will be exposed to progressively increasing amounts of PFASs until such levels are reached where effects are likely. In such an event these exposures are practically irreversible. Even if further releases of PFASs were immediately prevented, existing environmental stocks would continue to be a source of exposure for generations.

PFASs are known to have additional hazardous properties. However, due to the heterogeneity of chemical structures in the PFAS class, these additional hazardous properties vary dependent on the molecular structure of specific PFASs. Nevertheless, most PFASs are mobile in water; humans and other biota cannot avoid exposure to such PFASs. For example, contamination of groundwater, surface water (freshwater, estuarine and marine) and biota with PFASs is already widespread and -specific to firefighting foams- at many locations with intensive use of firefighting foams. Drinking water contamination is already widely reported and will become ubiquitous if releases of PFASs are not minimised. Drinking water is very difficult and costly to treat to remove PFASs, contrary to other common contaminants. Plants also accumulate PFASs. Consumption of plant material, e.g.

¹ https://echa.europa.eu/documents/10162/17233/request_echa_pfas_fff_en.pdf/aa089887-bc27-e642-747e-b935809075cc?t=1601895611682

² Using 4% discount rate to the cost to the EU is estimated at €390 million per year during the assessment period. The corresponding emission reduction would be of 440 tonnes per year.

grains and vegetables either as roots or above ground plant parts, function as a source of PFASs to humans and animals.

Some PFASs are distributed to remote areas by long-range transport processes. Some PFASs are gases (fluorinated gases or F-gases³). These PFASs are distributed around the globe once released where they contribute substantially to climate change⁴.

The most thoroughly researched PFASs (so-called 'long-chain' PFASs) are suspected carcinogens, cause harm to the developing child and trigger effects at low concentrations in organs such as the liver or in the immune system. However, for most PFASs there are insufficient data to adequately assess their effects on human health and the environment (i.e. to demonstrate that they can be used safely). As research efforts progressed beyond long-chain PFASs (e.g., to shorter chain PFASs such as 6:2 FTOH) similar adverse effects to long chain PFASs were reported. There are also data indicating that some PFASs are potential endocrine disruptors. The environmental effects of some PFASs are sufficient to warrant classification (e.g., 6:2 FTOH). Adverse effects resulting from 'combined exposure' to complex mixtures of PFASs are likely for both humans and wildlife. However, these effects cannot be currently assessed quantitatively with sufficient certainty for regulatory purposes.

Due to the above-mentioned hazardous properties, a quantitative risk assessment is not appropriate, but releases of PFASs should be minimised in accordance with paragraph 0.10 of Annex I to REACH.

Whilst some PFASs are already restricted in firefighting foams either in the EU or internationally (e.g., PFOS, PFOA, PFHxS, PFHxA and related substances) or are proposed for future risk management in the EU (e.g., PFHxS and PFHxA), the risks posed by the PFASs class in firefighting foams (also termed the PFASs universe) are not adequately controlled, requiring additional risk management.

The precise identities of the PFASs currently used in firefighting foams are largely unknown due to manufacturer confidentiality. Industry report that they mostly belong to the C6 chain length category (i.e., PFHxA related substances). However, substances with shorter chain length structures have also been used in firefighting foams⁵ and novel unregulated PFASs could theoretically be developed for use in firefighting foams in the future. Consequently, a restriction covering the **whole PFASs class**, rather than specific PFASs or groups of related PFASs with a common final (terminal) degradation product⁶, is appropriate to address the risks from PFASs in firefighting foams, including those arising from so called 'regrettable substitution' in the future.

³ F-gases are subject to a phase-down administered by Regulation (EU) 517/2014 due to their high global warming potential and contribution to climate change. Hydrofluorocarbons (HFCs) are also subject to a global phase-down under the Montreal Protocol Kigali Amendment.

⁴ See for example the IPCC 4th Assessment Report: <https://unfccc.int/process-and-meetings/transparency-and-reporting/greenhouse-gas-data/frequently-asked-questions/global-warming-potentials-ipcc-fourth-assessment-report>

⁵ As per uses reported in REACH registration dossiers.

⁶ Sometimes termed as an 'arrowhead' e.g., PFOA is the arrowhead structure for all PFOA-related substances.

Around 30 000 tonnes of firefighting foams are manufactured in the EU per year by around 25 manufacturers. Despite previous restrictions on specific PFASs in firefighting foams, 18 000 tonnes (60 %) of the current manufactured tonnage are PFAS-containing foams. It is estimated that €90 million of revenues are generated from the sales of firefighting foams, with 25 % of revenues assumed to be resulting from exports to non-EEA countries. Precise data on imports are not available but they are presumed to be in the same order of magnitude as the exports.

Firefighting foams are used for extinguishing fires that involve flammable liquids ("class B fires") by a variety of sectors (e.g., oil/(petro-)chemical sector, municipal fire brigades, marine, airport, defence and ready-for-use products). By far, the largest sector of use is the oil/(petro-)chemical industry (consuming 59 % of the annual tonnage). Firefighting foams are used both for training and in a variety of 'live' fire incidents, ranging from small fires to large tank fires.

Alternative (fluorine-free) firefighting foams are available and have been successfully used in the sectors identified above. However, use of alternatives in certain specific scenarios (i.e., for fires in large flammable liquid storage tanks and at installations using multiple different flammable liquids) is not yet widespread pending the successful conclusion of performance tests for alternative foams and application methods for these scenarios⁷.

To minimise the adverse socio-economic impacts associated with the phase out of PFAS-containing foams, including any potential to compromise fire safety, specific transitional arrangements (i.e., transitional periods) should be applied for each type of use and user sector. During these transitional periods PFAS-containing foams may still be used. Such a differentiation is justified because the likelihood of emissions⁸ to the environment from the uses, as well as progress with substitution of PFAS-containing foams, is different for each use and user sector.

Uses for training and testing, use by municipal fire services and use in civilian marine applications can be relatively quickly substituted without adverse impacts. Whereas a longer transition period of up to 10 years appears to be justified for certain applications (notably for large atmospheric storage tank fires and industries dealing with numerous different flammable liquids at the same site) where further testing is required to determine the technical feasibility of alternatives, and where potential fire-safety risks from using inappropriate alternatives may be higher.

Several stakeholders requested longer transition periods (of up to 12 years) or an exemption for defence applications. The defence sector is a relatively small user of PFAS-containing firefighting foams in the EU (around 6 % of volumes sold). Despite some notable exceptions, defence applications are able to transition to fluorine-free alternatives in a similar time frame as required for civilian aviation (where rapid extinguishing times are

⁷ Alternatives to PFAS-containing foams have mostly been tested in small-scale tests as specified in technical standards against a limited number of flammable liquids. Fluorine-free foams behave differently to PFAS-containing foams and show more variability in their performance. However, large-scale tests have also demonstrated satisfactory technical performance under certain conditions. Additional testing with other flammable liquids in a more complete range of fire scenarios is needed to ensure the effectiveness of fluorine-free firefighting foams. Since large fire incidents are rare and large fire testing is costly, limited practical experience has been gained until now in such challenging fire scenarios. Importantly, it is not only the foam itself which needs to be considered, but the performance of the foam in combination with (i) the flammable liquid to be tackled and (ii) the foam application method (application system and application parameters).

⁸ In this report the terms "emissions" and "releases" are used interchangeably.

also required). In a limited number of cases (such as currently 'in service' military ships), exemptions or longer transitional periods could be justified. However, these scenarios would appear to be relevant to only very few Member States. Therefore, a generally longer transition period or exemption is not considered justified.

Longer transition periods are justified only for the most sensitive applications within the oil(petro-)chemical sector, i.e. those installations subject to the Seveso Directive on major accident hazards⁹.

For all other sectors, shorter transition periods are expected to be sufficient to ensure a transition to PFAS-free alternatives, while having limited socio-economic consequences.

Regarding an appropriate concentration limit for PFASs in foams and equipment that previously used PFAS-containing firefighting foams, stakeholder input suggests that a PFAS concentration of 1 ppm can be achieved using a relatively simple cleaning process and would avoid the majority of emissions. Lower concentration limits are achievable with more complex and costly cleaning processes. However, setting a lower concentration limit would lead to a relatively small additional reduction in PFASs emissions, compared to the overall reduction achieved by the restriction and is therefore less desirable from a cost-effectiveness perspective.

Finally, the restriction proposal includes an obligation for users to prepare 'PFAS-foam management plans' and apply best-practice risk management measures to continue to use PFAS-containing foams during any applicable transitional period. This obligation would cover, among other items, foam purchase, containment, treatment, proper disposal of foams and fire water run-off, as well as use of personal protective equipment. These measures provide a relatively effective reduction in PFASs emissions and exposure of workers and professionals at a relatively low cost during the transition periods over which PFAS-containing foams could continue to be used.

The EU is not alone in phasing out PFASs in firefighting foams. Several US states, including California, New York, Washington have also done so. Various other initiatives exist also including some in Australia (see section 2.2.2.2). This global trend of substituting PFASs in firefighting foams facilitates the implementation of any EU-wide restriction.

Table 1 summarises the main restriction options (RO) assessed, their emission reduction potential, cost and cost effectiveness. Recognising the uncertainties in the results, they are considered to provide robust order of magnitude estimates, and to describe the differences between different ROs. The different RO are described and analysed in Section 2.2, including some which have been considered but not assessed in detail.

Table 1. Summary of main restriction option (RO) assessed, their emission reduction potential, cost and cost effectiveness

Restriction option		Emission reduction (tonnes over 30 years)	Cost to society (€billion over 30 years)	Cost-effectiveness (€/kg avoided emission)
1	Restriction on the placing on the market but use continued to be allowed until expiry date of the stocks	11 800	5.9	500

⁹ Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Restriction option		Emission reduction (tonnes over 30 years)	Cost to society (€billion over 30 years)	Cost-effectiveness (€/kg avoided emission)
2	Restriction on the placing on the market and use after use/sector-specific transitional periods	13 000	6.8	520
3 ^[1]	Restriction on the export, placing on the market and use after use/sector-specific transitional periods	13 200	6.8	520
4	Restriction on the placing on the market and use after use/sector-specific transitional periods, with a derogation mechanism via a permit system to which only Seveso establishments and defence sites would be eligible	12 600	5.2	415
5	Restriction on the placing on the market and use for all uses after sector or use-specific transitional periods, unless adequate risk management measures are in place to capture all the emissions to the environment	12 500	15.0	1 200

Notes: 1 - Option #3 is the Dossier Submitter's preferred restriction option

The Dossier Submitter proposes restriction option 3 as most appropriate EU-wide measure to address the identified risks from the use of PFASs in firefighting foams. The restriction option is specified in detail below "Proposed restriction". Restriction options 4 and 5 are not considered to be practical as explained in Section 2.7.

Proposed restriction

Restriction on the export, placing on the market and use of PFASs in firefighting foams.

Column 1	Column 2
Per- and polyfluoroalkyl substances (PFASs) defined as: any substance that contains at least one fully fluorinated methyl (CF₃) or methylene (CF₂) carbon atom (without any H/Cl/Br/I attached to it). [The ancillary requirement in paragraph 7 of column 2 of this entry applies to all firefighting foams, whether or not they contain a substance falling within this column of this entry.]	1. Shall not be placed on the market or exported as substances on their own, as a constituent in other substances or in mixtures for use in firefighting foam concentrates where the concentration of total PFASs is greater than 1 ppm¹⁰ 10 years after entry into force. 2. Shall not be used on their own, as a constituent in other substances or in mixtures in firefighting foam concentrates where the concentration of total PFASs is greater than 1 ppm. 3. Paragraph 2 shall apply from: a. 18 months after entry into force for training and testing (except testing of the firefighting systems for their function); b. 18 months after entry into force for municipal fire services (except if also in charge of

¹⁰ Corresponding to 1 000 ppb, or 0.0001% (w/v).

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Column 1	Column 2
	industrial fires for establishments covered by Directive 2012/18/EU (Seveso III) and for use in these establishments only); c. three years after entry into force for civilian ships; d. five years after entry into force for portable fire extinguishers as defined by EN3-7; e. 10 years after entry into force for establishments covered by the Directive 2012/18/EU (Seveso III)¹¹ (upper and lower tiers); f. five years after entry into force for all other uses not covered by paragraphs 3(a), 3(b) 3(c), 3(d) and 3(e). 4. Without prejudice to paragraph 3, six months after entry into force users of firefighting foam concentrates where the concentration of total PFASs is greater than 1 ppm shall: a. ensure that firefighting foam concentrates are only used for fires involving flammable liquids (class B fires); b. minimise emissions to the environment and direct and indirect exposures to humans of firefighting foams to the extent that is technically and economically feasible. c. establish a site-specific 'PFAS-containing firefighting foams management plan' which shall include: i. a justification for the use of each firefighting foam concentrate where the concentration of total PFASs is greater than 1 ppm (including an assessment of the technical and economic feasibility of alternatives). ii. details of the conditions of use and disposal of each PFASs containing foam used on site specifying how paragraph 4(b) is achieved (including plans for the containment, treatment and appropriate disposal of liquid and solid wastes arising in the event of foam use,

¹¹ Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Column 1	Column 2
	routine cleaning and maintenance of equipment or in the event of accidental leakage/spillage of foam). iii. The management plan shall be reviewed at least annually and be kept available for inspection by enforcement authorities on request. d. Ensure that the collected PFAS-containing waste with a concentration of PFASs above the one mentioned in paragraph 2 shall be handled for adequate treatment. The treatment shall minimise releases of PFASs to environmental compartments as far as technically and practically possible and shall exclude municipal wastewater treatment, irrespective of any pre-treatment. For each event of foam use or accidental spillage or leakage, proof of appropriate management and disposal of the foam concentrates, water-added foams and fire run-off waters shall be documented and kept available for enforcement authorities. 5. From six month after entry into force, firefighting foam concentrates containing PFASs above the threshold indicated in paragraph 1 which are held in stock and need to be disposed of shall be handled for adequate treatment. The treatment shall minimise releases of PFASs to environmental compartments as far as technically and practically possible and excluding any wastewater treatment, irrespective of any pre-treatment. Proof of appropriate disposal shall be documented and kept available for enforcement authorities. 6. From six months after entry into force, packaging of firefighting foam concentrates placed on the market or used, containers of firewater runoffs or other PFAS-waste in relation with the use of firefighting foams or the cleaning of firefighting foam equipment in concentrations above the one mentioned in paragraph 1 shall be labelled indicating the presence of PFASs above this threshold with the following wording: "WARNING: Contains per- and polyfluoroalkyl substances (PFASs)". This information shall be displayed in a clear and visible manner in the official language(s) of the Member State(s) where the firefighting foam concentrate is placed on the market, unless the Member State(s) concerned provide(s) otherwise.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Column 1	Column 2
	7. [From six months after entry into force, packaging of firefighting foam concentrates placed on the market containing organofluorine substances above 1 ppm, but where the concentration of total PFASs is not greater than 1 ppm, shall be labelled: "Contains non-PFAS organofluorine substances with a total organofluorine concentration of (<i>insert concentration</i>) ppm". This information shall be displayed in a clear and visible manner in the official language(s) of the Member State(s) where the firefighting foam concentrate is placed on the market, unless the Member State(s) concerned provide(s) otherwise.]

Explanatory notes:

- (1) "Testing of the firefighting systems for their function" means testing the fire protection system in the same way as it would operate in case of emergency. Other types of testing include but are not limited to: testing of foam agents during their development phase, testing of foam agents by users to evaluate products' suitability on specific combustibles, testing of correct proportioning of firefighting foam concentrates.
- (2) Municipal fire services (i.e. local authority fire and rescue services) are covered under the restriction entry 3 (b.), except if they are also in charge of industrial fires for establishments covered by the Seveso-III Directive and for use in these establishments only. In this case, the transitional period of paragraph 3(e) applies.
- (3) Other uses of firefighting foams include – but are not limited to -: civilian aviation, defence, aerospace, offshore oil/gas/chemical facilities, onshore oil/gas/chemical manufacturing or processing facilities which are not covered by paragraph a. (Seveso establishments), power plants, glass manufacturers, waste treatment facilities, food processing industry, metal processing, etc.
- (4) The use of PFASs-containing foam agents in portable fire extinguishers are covered by paragraph 3(d), with a proposed transitional period of five years, irrespective of the sector of use, i.e. their use would be continued to be allowed during this period even if the sector where they are used is subject to a shorter transitional periods (e.g. ships).
- (5) "Civilian ships" refers to marine and non-marine civilian ships.
- (6) Foam concentrates are the foam formulations purchased by the users and which are further mixed with water at the moment of the use. Water-added foams are the foam concentrates mixed with water at the moment of the use. Fire run-off waters (or "firewater runoff") are the run-off waters containing the firefighting foam concentrate mixed with water and all other elements mixed with them during the use of the firefighting foam during a fire incident, training or other use (e.g. flammable liquids, dirt, etc).
- (7) The labelling of the containers containing PFASs above the threshold indicated in paragraph 1 aims at facilitating the identification and handling of the PFAS-containing foam concentrates, firewater runoff and waste.
- (8) Placing on the market after 10 years is banned as the use is not allowed in any of the sectors or uses anymore at that time.
- (9) The ancillary requirement detailed in paragraph 7 is intended to facilitate the enforcement of the proposed restriction by means of 'total fluorine' analytical methods,

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

rather than targeted analysis of specific PFAS. The utility of this requirement shall be reviewed after the consultation on the Annex XV report.

pre-publication – do not cite

1. Problem identification

PFASs are a family of thousands of synthetic chemicals that are used widely in the EU, including in firefighting foams. All PFASs are very persistent in the environment. Consequently, if releases of PFASs are not minimised, humans and other organisms will be exposed to progressively increasing amounts of PFASs until such levels are reached where effects are likely. In such an event these exposures are practically irreversible.

Most PFASs are mobile in water; humans and other biota cannot avoid exposure to such PFASs. For example, contamination of groundwater, surface water (freshwater, estuarine and marine) and biota with PFASs is already widespread and -specific to firefighting foams- at many locations with intensive use of firefighting foams. Drinking water contamination is already widely reported and it is very difficult and costly to treat to remove PFASs. Plants also accumulate PFASs. Consumption of plant material, e.g. grains and vegetables either as roots or above ground plant parts, function as a source of PFASs to humans and animals.

Some PFASs are distributed to remote areas by long-range transport processes. Some PFASs are gases (fluorinated gases or F-gases). These PFASs are distributed around the globe once released where they contribute substantially to climate change.

The most thoroughly researched PFASs (so-called 'long-chain' PFASs) are suspected carcinogens, cause harm to the developing child and trigger effects at low concentrations in organs such as the liver or in the immune system. However, for most PFASs there are insufficient data to adequately assess their effects on human health and the environment. As research efforts progressed beyond long-chain PFASs similar adverse effects to long chain PFASs were reported. There are also data indicating that some PFASs are potential endocrine disruptors. The environmental effects of some PFASs are sufficient to warrant classification (e.g., 6:2 FTOH). Adverse effects resulting from 'combined exposure' to complex mixtures of PFASs are likely for both humans and wildlife. However, these effects cannot be currently assessed quantitatively with sufficient certainty for regulatory purposes.

This chapter defines per- and polyfluoroalkyl substances (PFASs) and presents a human health and environmental hazard and risk assessment of the use of per- and polyfluoroalkyl substances (PFASs) in firefighting foams.

1.1. Hazard, exposure/emissions and risk

1.1.1. Identity of the substance(s), and physical and chemical properties

1.1.1.1. Substance identity restriction scope

For the purpose of this restriction proposal, PFASs are defined as substances that contain at least one fully fluorinated methyl (CF_3 -) or methylene ($-\text{CF}_2$ -) carbon atom, without any H/Cl/Br/I attached to it. This definition is equal to the OECD definition, derived in 2021, which reads as: "PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few exceptions, any chemical with at least a perfluorinated methyl group ($-\text{CF}_3$) or a perfluorinated methylene group ($-\text{CF}_2$ -) is a PFAS." (OECD, 2021b).

For the purpose of the Annex XVII restriction entry, we propose to use the following phrasing:

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Per- and polyfluoroalkyl substances (PFASs) defined as:

Any substance that contains at least one fully fluorinated methyl (CF₃) or methylene (CF₂) carbon atom (without any H/Cl/Br/I attached to it).

This restriction proposal covers all substances containing PFASs as defined above as a constituent (including as impurity or additive)¹² as well as in mixtures.

The substance scope includes PFASs (as defined above) irrespective of their market status. Hence substances on the EU market and other than those currently on the EU market are included to avoid regrettable substitution to substances that would have the same identified risks. Some of the substances in the scope, which are neither registered under REACH or CLP-notified, may be or may have been on the market outside of the EU. The substance scope also includes theoretical substances that are likely never to have been on the market.

Figure 1 shows the main PFASs subgroups as defined by (OECD, 2021b)

¹² As defined in the ECHA Guidance for identification and naming of substances under REACH and CLP (May, 2017, Version 2.1).

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS



Figure 1. Main PFASs subgroups, including the subgroup of stable substances (PFAAs) or 'arrowheads' and the precursors to the PFAAs. Figure adapted from OECD (2021b) – see figure 9 therein for more details on the grouping and nomenclature. The terms 'arrowhead' and 'precursor' are described in Section 1.1.2.

PFASs are a large group of organic chemicals that have been used since the 1950s, i.e., as ingredients for or intermediates of surfactants and surface protectors for assorted industrial and consumer applications. PFASs used in firefighting foams are discussed in section 1.1.1.2.

In perfluoroalkyl substances all C-H bonds have been replaced by C-F, while in polyfluoroalkyl substances one or more C-H bond(s) have been replaced by C-F but some C-H bonds still remain in the molecular structure. Polyfluoroalkyl substances containing at least one perfluorinated moiety are included in the scope of the proposal.

PFASs can be divided into subgroups in several ways. Figure 1 provides one way to differentiate, where the subgrouping is based on main chemical moieties present. Further ways to differentiate are for example carbon chain length and non-polymeric vs polymeric structures. The non-polymeric PFASs comprise a range of diverse molecules and include, inter alia, perfluoroalkyl carboxylic acids (PFCAs e.g., PFOA), perfluoroalkane sulfonic acids (PFSAAs e.g., PFOS)¹³, fluorotelomer-based compounds (e.g., 6:2 FTOH), per- and polyfluoroalkanes (e.g., perfluorooctane), perfluorotrialkylamines and per- and polyfluoroalkyl ether compounds, such as perfluoroalkyl ether carboxylic acids (PFECAs, e.g., HFPO-DA). Within the polymeric PFAS group, fluoropolymers (polymers consisting of a polymeric fluorinated carbon backbone) and side-chain fluorinated polymers (polymers consisting of non-fluorinated polymer backbones with per- or polyfluoroalkyl side-chains attached) are differentiated from one another. Please, see section B.1.1 for examples of these groups.

A distinct PFASs subgroup are the trifluoroacetic acid (TFA) precursors. They are a special subclass of PFASs often containing only a single –CF₃ group. Most of these occur – in addition to TFA itself- in gaseous form. Such fluorinated gases or “F-gases” are treated as a distinct group in this report due to their distinct properties.

A recent study by the OECD/UNEP Global PFC Group identified 4 730 CAS-numbers associated with individual PFASs or PFASs mixtures (OECD/UNEP, 2018). A comparison of REACH registered and/or CLP notified PFASs in 2019 with the OECD/UNEP list revealed that there may be more than 9 000 different individual PFASs. Of these, 6 257 were notified only to the ECHA classification and labelling database and there were 508 substances with active registrations, 257 of these were full and the remainder intermediate. In addition, The US EPA have assembled a consolidated ‘master list’ of 6 330 PFASs by combining information from several existing lists (U.S. EPA, 2020).

The scope of the proposed restriction is harmonised with the OECD definition (OECD, 2021b) for practical reasons. The OECD definition of PFASs is based solely on chemical structure and does not take into account hazardous properties or risks. Irrespective of this, as described in Section 0, the substance scope is considered to be a concern -based scope (with the exception of the excluded substances. For these no rationale was presented by OECD for their exclusion and these have not been elaborated in this report either).

¹³ A frequently used division is based on alkyl chain length where perfluoroalkyl carboxylic acids (PFCAs) with seven or more perfluorinated carbons and PFSAAs with six or more perfluorinated carbons are considered as “long-chain” PFCAs and PFSAAs, respectively, and those with shorter perfluoroalkyl chains “short-chain” PFCAs and PFSAAs (OECD, 2021). It is noted that this definition has not been extended to other PFAAs nor to other PFASs. In this document, alkyl chain length of PFCAs and PFSAAs is indicated as C[number of carbons].

1.1.1.2. Overview of PFASs used in firefighting foams

Long-chain PFASs were used as surfactants specifically because of their potent water and oil repellence at low concentrations. However, short-chain PFASs are nowadays used due to the phase out of long-chain PFASs.

Firefighting foam concentrates usually contain general classes of compounds, such as surfactants, solvents, stabilisers and thickeners. However, each foam formulation is unique and even foams with the same name differ over time in the combination of specific ingredients.

The main function of PFASs in firefighting 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 being released from it as well as from reigniting.

Different types of PFAS-containing foams are available on the market, mainly:

- "Aqueous Film Forming Foam" (AFFF) which form an aqueous film on the surface of the flammable liquid by the foam solution as it drains from the foam blanket;
- "Alcohol Resistant-Aqueous Film Forming Foam" (AR-AFFF) which are resistant to polar solvent and alcohol liquids;
- "Fluoro Protein" foams (FP) and
- "Film Forming Fluoro-Protein" foams (FFFP)¹⁴.

However, other types of PFAS-containing foams also exist, such as "Alcohol-Resistant Film-Forming Fluoro-Protein" foams (AR-FFFP) and "Fluoro-Protein Alcohol-Resistant" foams (FPAR)¹⁵.

Thanks to their properties, PFAS-containing foams are therefore used in fires involving flammable liquids (Class B fires¹⁶) across a range of sectors. The quantities of foam used by different sectors are discussed in section 1.1.5 and annex A.2.2. PFAS-containing firefighting 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 fires. They can be applied with both mobile and stationary equipment and are also used in training and testing of equipment.

Firefighting foams are made up of water, air and a foam concentrate mixed together during use.

ECHA's substance database was searched for structures covered by the substance scope of this proposal. A large number of highly diverse PFASs substances were identified as potentially being used in firefighting foams with carbon chain length from C2 to ≥C8. No PFAS-substance with only a single -CF₃ moiety has been identified for this use. Briefly, PFASs classes found to be used in firefighting are:

¹⁴ <https://www.chemguard.com/about-us/documents-library/foam-info/general.htm>

¹⁵ https://pfas-1.itrcweb.org/3-firefighting-foams/#3_1

¹⁶ The European Standard Classification of Fires distinguishes between the following fires:

Class A – fires involving combustible solid materials (e.g. wood, paper or textiles);

Class B - fires involving flammable liquids (e.g. petrol, diesel or oils);

Class C - fires involving gases;

Class D - fires involving metals;

Class K - fires involving live electrical apparatus;

Class F - fires involving cooking oils.

- Unsubstituted long-chain PFASs
- Unsubstituted short-chain PFASs
- Substituted short- and long-chain PFASs
- Fluorotelomers
- Others

See Annex B.1.1 for details on the PFASs used in firefighting foams.

According to the European Committee of the Manufacturers of Fire Protection Equipment and Fire Fighting Vehicles (Eurofeu) as well as the US association Fire Fighting Foam Coalition (FCCC), PFASs used in firefighting foam technology in the EU are presently exclusively of PFHxS, PFHxA and related substances. FFCC further indicates that PFASs based on <C6-chemistry have never been used as an active ingredient for firefighting foams as the chemistry is not suitable. These would be unintended by-products of the synthesis process (telomerisation process).

Eurofeu further commented that PFOS, PFOA and related substances-based foams are solely legacy foams and that there has been no use of C8 beyond impurities in the C6-surfactant production since 2010. Eurofeu has not received any information about fluoro-compounds with chain lengths of less than C6 being used in firefighting foam technology today. According to the information received by their members, sales for fluorine-containing foams for aviation and municipal fire brigades applications are declining rapidly (Eurofeu, 2021).

1.1.2. Justification for grouping

PFASs are considered as a group because all members of the group share a common hazard and risk (described in Sections 1.1.4 and 1.1.6). This is, in essence, the result of the very persistent property of the perfluorinated part(s) of PFASs molecules.

Specific PFASs have previously been assessed (and in some cases have been subject to risk management) on the basis of the PFASs moieties that they contain (see section B.1.4). For example, PFOA is a very persistent (vP) substance that is the common final (terminal) product of the environmental (bio)degradation of various different PFASs which all contain the perfluorooctanoate moiety. PFASs have been allocated to subgroups based on their respective terminal degradation product (respective common perfluorinated moiety) (see Figure 1). The terminal degradation products are often referred to as **arrowhead substances**, while the parent substances degrading to the arrowheads are referred to as **precursors** (e.g., 6:2 FTOH is a precursor of PFHxA). Term **related substance(s)** is used interchangeably with the term precursor. Over sufficient time horizons all precursor substances will contribute to environmental stocks of their corresponding arrowhead substances (see Section 1.1.4 for further details). This grouping approach is acknowledged as a basis for risk assessment also by several scientists (see, e.g., Cousins et al., 2020a).

Based on the experience with European regulatory activities on PFASs since 2014, it is expected that PFASs restricted individually or per arrowhead group (e.g., PFOA and related substances) might simply be replaced with slightly different non-restricted PFASs (e.g., ADONA or HFPO-DA) with the same risks. This observation provides the main motivation to include all PFASs having equivalent hazard and risk in a single restriction, to avoid regrettable substitution by other PFASs.

Some PFASs included in the scope of the proposed restriction may have a negligible or indeed no current use. However, such PFASs would need to be included in the scope, either because their use may increase as a result of becoming an alternative for another, restricted PFASs, or due to new uses/applications.

To summarise, the grouping is based on structural similarity (common perfluorinated moieties) that triggers equivalent hazards and risks among the substances covered, primarily related to the very persistent property of the substances. However, the grouping is also justified by the desire to avoid regrettable substitution and prevention of future exposures of those PFASs which are not currently in use.

It is noted that there are various other fluorinated substances on the market which appear related to PFASs and which may have similar hazards. These are further discussed in section B.1.1.

1.1.3. Classification and labelling

Over 6 000 PFASs have a classification (mostly a self-classification) for at least one environmental, human health and/or physicochemical endpoint in the ECHA classification and labelling notifications database.

The following human health endpoints are considered of most concern following long-term exposure of humans: carcinogenicity (C), mutagenicity (M), reproductive toxicity (R) including lactation effects (L), and specific target organ toxicity (STOT RE). 388 PFASs have a classification for at least one of these five endpoints, of which 44 are harmonised classifications. See Annex B.3 for more information. Note that it was not assessed whether the effects leading to the classification are due to the PFAS-moieties or due to some other structures in the substance.

With regard to the environmental hazards, 1 129 PFASs have a self-classification. For more detail see Annex B.3.

1.1.4. Hazard assessment

1.1.4.1. Overview

PFASs is a broad term used to cover approximately 4 700 specific chemical species¹⁷ which have a wide range of uses. These uses are principally based around the carbon-fluorine bond which is particularly strong and offers physical properties that include high water and oil repellence¹⁸. The same properties mean that many PFASs substances are also highly mobile (within the natural environment) and highly persistent (see below the sections on hazard assessment, and Appendix 3 of the underlying study¹⁹). This can create issues where PFASs substances emitted to the environment reach and contaminate important

¹⁷ OECD, 2018, PFAS database, toward a new comprehensive global database of per and polyfluoroalkyl substances.

¹⁸ Buck et al, 2011, 'Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification and origins', Integrated environmental assessment and management vol 7 issue 4.

¹⁹ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

resources such as groundwater, on which abundant literature is available, including from the use of firefighting foams²⁰.

The Nordic Council of Ministers²¹ indicates that the contamination may be poorly reversible or even irreversible, and may reach levels that could render natural resources such as soil and water unusable far into the future, resulting in continuous exposure and unavoidable harmful health effects, particularly for vulnerable populations, such as children. The example of PFOS in firefighting foams applied during the explosion in 2005 of the Buncefield oil storage facility is cited, which contaminated an aquifer that is an important public drinking water source for the Greater London area, so that it is no longer available as a water supply.

There is evidence to suggest that exposure to PFASs can lead to adverse health effects in humans (by eating or drinking food or water contaminated by PFASs). In particular the US EPA²² highlight studies that indicate the long-chain (chain length of 8 or more) species PFOS and PFOA can cause reproductive and developmental, liver and kidney, and immunological effects on laboratory animals. Furthermore, both chemicals have caused tumours in animal studies. Their use is already restricted in the EU and elsewhere. Some short-chain PFASs (PFHxS, PFBS, HFPO-DA) have also been listed as SVHCs, based on there being an equivalent level of concern to the named groups of chemicals under the authorisation provisions under REACH (carcinogens, mutagens and reprotoxicants (CMRs) and persistent, bioaccumulative and toxic/very persistent and very bioaccumulative (PBTs/vPvBs) chemicals).

The Nordic Council of Ministers²³ commented that the annual health-impacts within an EEA exposure study (from all uses of PFASs, not only firefighting foams) was estimated at €52-84 billion. This gives an indication of the scale of the issue and magnitude of the potential impacts from the environmental build-up of PFASs. The same study describes remediation costs associated with contamination from PFASs at European sites ranging from several hundred thousand up to €40 million with one high-cost example for the Dusseldorf Airport, Germany estimating a total remediation cost of up to €100 million.

Based on the physical properties of PFASs (particularly mobility and persistence) along with identified health effects for some PFASs, PFASs represent a challenging environmental and human health hazard issue.

²⁰ See e.g.

- Dauchy et al., 2017, Per- and polyfluoroalkyl substances in firefighting foam concentrates and water samples collected near sites impacted by the use of these foams, *Chemosphere*, Vol. 183, 2017, Pages 53-61, <https://doi.org/10.1016/j.chemosphere.2017.05.056>.
- EFSA, 2012. Perfluoroalkylated substances in food: occurrence and dietary exposure. *EFSA J.* 10, 2743. Available at: <https://www.efsa.europa.eu/efsajournal/pub/2743>;
- Hu et al. 2016 Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Defence Fire Training Areas, and Wastewater Treatment Plants, *Environ. Sci. Technol. Lett.* 2016, 3, 10, 344-350;
- Hurley et al, 2016 Preliminary Associations between the Detection of Perfluoroalkyl Acids (PFAAs) in Drinking Water and Serum Concentrations in a Sample of California Women, *Environ. Sci. Technol. Lett.* 2016, 3, 7, 264-269;
- Ingelido et al, 2018, *Environment International*, Volume 110, January 2018, Pages 149-159

²¹ Nordic Council of Ministers, 2019, 'The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS', <http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

²² US EPA, 2019, 'Basic information on PFAS', <https://www.epa.gov/pfas/basic-information-pfas>

²³ Nordic Council of Ministers, 2019, 'The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS', <http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

All PFASs are considered to be very persistent, either on the basis of their own very persistent properties or the very persistent properties of their terminal degradation product (arrowhead). Additional hazardous properties depend on the specific structure of a PFAS. Properties of concern identified in investigated PFASs as well as concerns resulting from specific combinations of properties are listed in Figure 2 and further described below.

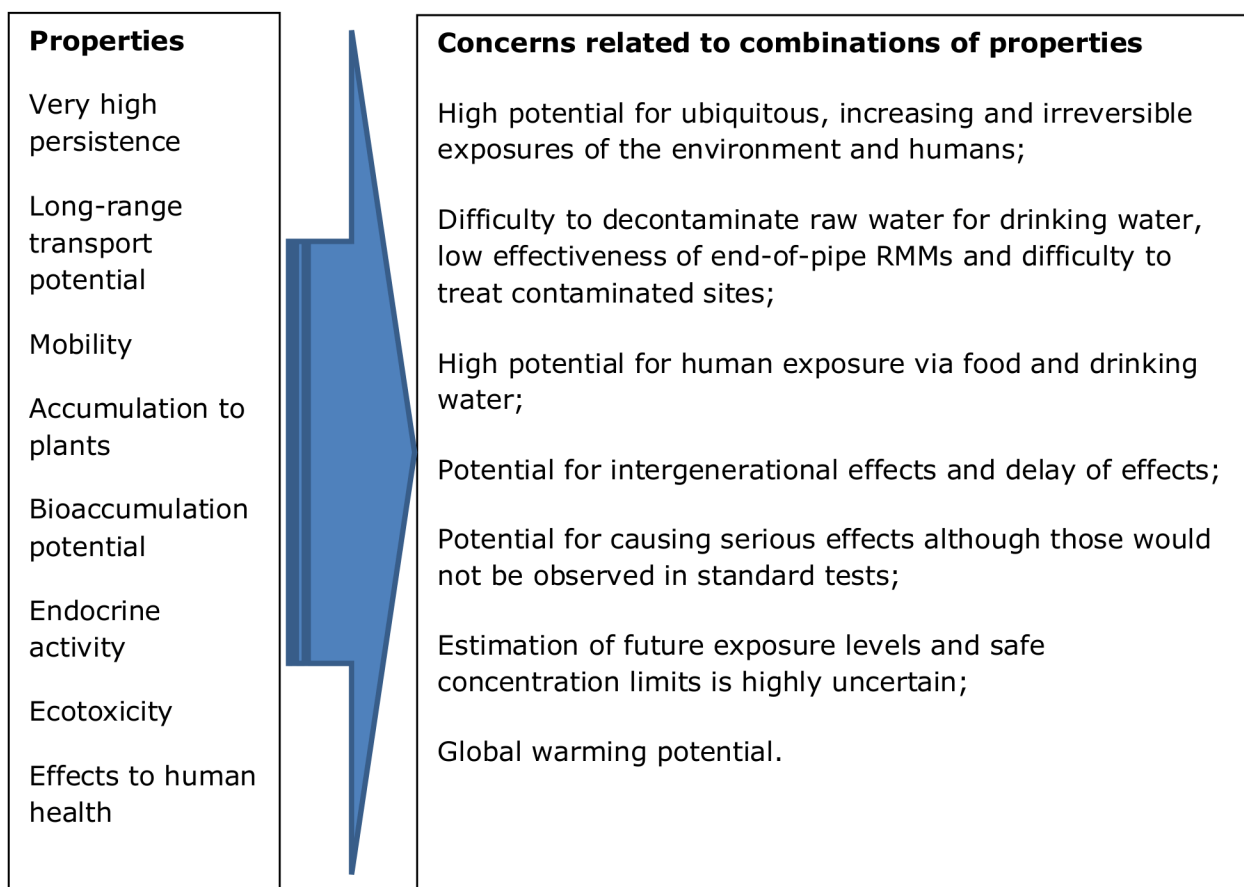


Figure 2. PFAS properties and property-related concerns resulting from combinations of the properties.

1.1.4.2. Persistence

As detailed in Annex B.4.1., PFASs are among the most stable organic compounds. Common for all the PFASs is that they have perfluoroalkyl moieties present. These moieties resist environmental and metabolic degradation due to the very stable C-F bonds. As presented in

Figure 1 and introduced in section **Error! Reference source not found.**, PFASs can be divided with regard to the hazard assessment into “precursors” and “arrowheads”. The precursors are known or expected based on modelling to degrade on a timescale from hours to years to the arrowheads, such as PFCAs, PFECAs and PFSAAs. There is a common understanding about grouping PFASs according to their stable degradation end-products (e.g., Cousins et al., 2020b).

After gradual degradation of the non-fluorinated part, the degradation stops when only perfluorinated carbons, and in some cases other moieties at their highest oxidation state and with high persistence, are left in the substance (see more in Annex B.4.1).

Environmental degradation of the non-fluorinated moieties in PFAS precursors often leads to the formation of PFAS intermediate and ultimate degradation products with increased mobility in water and/or air via oxidative chemical and biochemical degradation processes in the environment. See description of the precursor degradation in Annex B.4.1.3.

Lifetimes of the arrowhead PFASs in the environment exceed the criteria for very persistent substances in Annex XIII to REACH by far. For example, PFAAs are key arrowheads in the environment, and if PFAAs degrade, they do it so slowly that it is not observable in standard tests.

The high persistence of PFASs is their main concern, for the following reasons:

The continuous use and release of these very persistent substances leads to sustained exposure and increasing stocks in the environment. The high persistence in the environment will lead, inevitably, after release to distribution of PFASs from one environmental compartment to another e.g., from soil to freshwater to marine environment). Even if releases of PFASs are minimised now, PFASs will remain in the environment for very long time (see further details in section B.4.1). Furthermore, the combined historic releases of precursor PFASs form arrowhead PFASs over time. Therefore, the precursor stocks in the environment represent a long-term source of arrowhead substances, even if the releases of precursors are stopped. The longer the stock is allowed to increase, the less effective the emission reduction will become.

The increasing stock pollution will result in increasing likelihood that known and unknown effects occur, be it by a single chemical and/or in a mixture with other substances (e.g. Bil 2021).

The persistence as the core concern of PFASs has also been pointed out by scientists for instance in the Helsingør Statement on PFASs (Scheringer et al., 2014) as well as the follow up Madrid statement (Blum et al., 2015). (Cousins et al., 2019) suggested to regulate PFASs on the basis of their very high persistence only and has named this the “P-sufficient approach” to regulatory action. Persistence alone was the justification for the regulation of PFASs as a class in California (Balan et al., 2021).

Further papers have discussed the role of persistence in decision making as the most important criterion or only property to justify regulation (Stephenson, 1977; Klöpffer, 1994; Mackay, D. 2014 Persson et al., 2013). See also section B.4.1.3.

1.1.4.3. Long range transport potential (LRTP)

The LRTP is assessed and discussed in section B.4.2.5. PFASs may concentrate in the respective compartment into which PFASs partition according to their specific properties (e.g., water-soluble substances concentrate in water, while volatile substances partition to air). PFASs can be transported by air, water and matrices to which they are adsorbed or absorbed, such as dust, sediments, migratory animals, or through matrices in which it is included as additive, e.g. polymers. Because of non-degradability, the movement of their carriers leads to global drift of PFASs over long distances from the point of release. Calculated characteristic travel distances (CTD) of FTOHs and PFCAs reach thousands of kilometres in air and water. For volatile PFASs, such as FTOH, the long-range transport route is expected to change from LRTP via air to water when the substances degrade to their corresponding arrowhead PFCAs. Transport pathways are also for other precursor-PFASs complex due to the change of the fate properties along the degradation.

As provided by monitoring data (see Annex B.4.2.4/Appendix 10) PFAS contamination is not geographically limited but PFASs are found ubiquitously in the environment. This is due to their wide dispersive uses and distribution in a global market but also due to their global distribution in long-range environmental transport from source regions to the entire global environment including remote areas.

1.1.4.4. Mobility

Generally substances with a moderate to high solubility in water combined with a low adsorption potential can be considered to have a high mobility in the aqueous environment. Such substances tend to stay in the water phase, rather than bind to organic material and sediments.

Water solubility of PFASs varies from very soluble to almost insoluble (see examples in Annex B.1.3). For example, the water solubility of PFCAs and PFSA is high with carbon chain length below 8 but with increasing carbon chain length the solubility tends to decrease.

The adsorption potential of PFASs is also subject to variation depending on the PFAS (see details in Annex B.4.2.1). Data for PFCAs, PFSA and perfluoroalkylphosphonic acids indicate that there is a trend of increasing K_{oc} values with increasing chain length (e.g., PFCAs $\log K_{oc}$ 0.437-3.3, PFSA 0.352-3.675). Perfluorinated olefins which lack a functional group have higher K_{oc} values than the PFAAs with the same chain length. It is expected that PFASs lacking a functional group will be more adsorptive than a PFAS with a functional group of the same chain length.

It should however be noted that up to a chain length of 4 carbons perfluoroalkanes have boiling points below 0 °C. It is more likely that these short-chain perfluoroalkanes evaporate into the air when released to the environment. The same applies to the short-chain perfluoroalkylethers without further functional groups (see Annex B.1.3).

Ding et al. (2018) measured the partitioning behaviour of PFASs between the dissolved phase, surface sediment and suspended particulate matter in the Dalian Bay, China. PFOA, PFBA, and PFBS were the predominant PFASs in the water dissolved phase, while PFBS, PFOS and PFOA were the most prevalent compounds in suspended particulate matter. A $\log K_d$ for PFBS of 3.4 was reported, and it was concluded that PFSA (including PFBS) and the long-chain PFCAs were more inclined to prefer the suspended particulate matter phase.

Generally, short-chain PFAAs and many long-chain PFAAs can be considered mobile in water (see section B.2.1 for details). Degradation of precursor -PFASs in the environment to PFAAs also render the precursors mobile in water at some point of time. For example, fluorinated olefins, which are not necessarily all mobile themselves, degrade into PFCAs (see Annex B.4.1.3) hence becoming mobile. Same occurs, e.g., to side-chain fluorinated polymers.

Measured data illustrating the distribution of PFASs in the environment is provided in section B.4.2.4/Appendix 10. These support the findings based on property data on the mobility of PFASs.

Mobility of PFASs in water contributes to their long-range transport potential, drinking water contamination potential, uptake in plants and in combination with high persistency

to increase of internal exposures in biota. See further discussion on mobility as a concern in section B.4.2.1 and the subsection “Combination of...” below.

For those PFASs, which are volatile (see Annex B.4.2.2), distribution in the environment occurs mainly via air.

1.1.4.5. Accumulation in plants

Studies on accumulation of PFASs in plants are lacking for the majority of PFASs. However, several studies provide evidence that plants accumulate many PFASs to levels which exceed the expected levels based on equilibrium partitioning (see further details in Annex B.4.4). According to the review by Li et al. (2022), the reported average log BAF values range between 0 and 1 (or even exceed 1 for PFBA), indicating potential of PFASs to transfer from contaminated soil to plants. High accumulation of some PFASs is also indicated for instance by the study Blaine et al. (2013), where the accumulation of PFCAs (C5-C10) and PFSAs (C4, C6, C7, C8, C10) was investigated in lettuce and tomato grown on biosolid-amended soils. The reported BAFs for lettuce in this study ranged between 0.19 – 28.4 (municipal soil), and between 0.52 – 56.8 (industrially impacted soil) (C10 PFDS < LOQ). The greatest accumulation was seen for C4 PFCA. Another study with plants from biosolid-amended fields (Yoo et al., 2011) reports the highest accumulation factor among all measured PFASs (PFCAs, PFSAs, FTOHs) for PFHxA, with a grass/soil accumulation factor of 3.8. Accumulation potential (BAF) decreased logarithmically with increasing chain length. It is noted that all the studied PFASs are arrowhead PFASs, hence also very persistent.

A recent review article on exposure routes, bioaccumulation and toxic effects of PFASs on plants shows that bioaccumulation processes of PFASs in plants highly vary because of the complexity of PFAS chemistry (Li et al., 2022).

Whereas short-chain PFASs typically accumulate in above-ground plant parts, long-chain PFASs accumulate in roots and show lower translocation factors to the above-ground plant parts. This is influenced by the higher water solubility, lower molecular size and lower hydrophobicity of the short-chain PFASs. Studies also indicate that the short-chain PFCA are more effectively taken up by plants compared to the long-chain PFCA (Felizeter et al., 2014, Yoo et al., 2011).

Consumption of plant material, e.g. grains and vegetables either as roots or above ground plant parts, function as a source of PFASs to humans and animals. Accumulation of many arrowhead PFASs in plants increases the relevance of this route of exposure. Accumulation in plants is of additional relevance when agricultural soil is contaminated with PFASs, leading to the contamination of agricultural plants (see Annex B.4.2.4/Appendix 10 and B.4.5 for an example case).

1.1.4.6. Bioaccumulation

The assessment of bioaccumulation is provided in Annex B.4.3 and B.5.1. Annex B.4.2.4/Appendix 10 on monitoring data also provide information on bioaccumulation in the field. By now, C11-C14 PFCAs and C6-PFSA have been shown to fulfil the vB-criterion and C8-C10-PFCA the B criterion (vB not assessed) under REACH.

Studies with mammalian species show that PFASs are readily absorbed and distributed across various tissues and that some PFASs (particularly the long-chain PFASs) have a long half-life in organisms. Data for PFCAs and PFSAs and some PFECAs indicate that PFASs

partition into proteins. Binding to albumin and transporter proteins, which are classes of proteins ubiquitously expressed, efficiently distributes PFASs into different tissues, and enhance passage across brain, placental barriers, and transfer via milk. Accordingly, PFASs do not follow typical accumulation patterns, i.e. partitioning into adipose tissue, but rather bind and accumulate in protein-rich organs like liver.

Generally, BCF measurements have been focused on PFHxS, PFOS, PFOA, PFNA, and PFDA. Accordingly, in general, carbonyl and sulfonyl PFAS classes are relatively data rich, whereas phosphate, fluorotelomer, and ether PFAS classes are data -limited for fish and lack data for most other taxonomic classes. Among the 43 PFASs compounds for which mean BCF and BAF studies are available in different aquatic species 62 % (27 compounds) have a BCF and/or BAF values above the REACH threshold for B. For example, additional PFASs such as F-53B and p-perfluorooxobenzenesulfonate (OBS) were recently shown to significantly accumulate in common carp (Shi et al. 2015; 2020). The existing studies suggest that PFPiAs and PFPAs follow similar pattern with PFCAs where the total number of perfluoroalkyl carbons correlate with the BCF. In a BCF study of Chen et al. (2016) the long-chain PFPiAs (total carbon ranged C12 to C18) would appear to exceed BCF of 5 000 in fish (whole-body log BCFs ranged between 4.6 and 9.2), while the log BCF values of the PFPAs (C6-C10) ranged between 1.2 and 2.3 (see further details in Annex B.4.3).

Furthermore, PFASs, particularly the PFAAs as arrowheads, accumulate more in air-breathing organisms as compared to gill breathing organisms, because unlike the latter, air-breathers cannot readily eliminate PFASs by passive diffusion. Elimination to water via gills is facilitated by the appropriate solubility of most PFASs, while air-breathing organisms are not able to excrete PFASs by ventilation via the lungs to air. Thus, established assessment methods of bioaccumulation based on bioconcentration testing in aquatic organisms do not function as methodology for estimating the bioaccumulation behaviour of PFASs (see Annex B.4.5) in general. Unfortunately, in comparison with freshwater species, laboratory bioaccumulation data are very limited for air-breathers. Further discussion on toxicokinetic behaviour from experimental studies in laboratory mammals, is provided in Annex B.5.1 and B.4.3 (under subsection “Toxicokinetics in animals”).

Short-chain PFASs are generally more hydrophilic and mobile in aqueous systems than long-chain PFASs. Short-chain PFASs are also more readily excreted by urinary excretion in air-breathing organisms and tend to be less bioaccumulative, while the strength of bioaccumulation potential usually increases with perfluoroalkyl chain length. In general, BCFs and BAFs of PFASs with 8 or more carbons increase uniformly with increasing number of carbons in the alkyl chain, with highest bioaccumulation potential of compounds with 12 to 14 carbon-chain length. Available laboratory bioconcentration studies in freshwater fish indicate that PFASs with a shorter alkyl chain, i.e. HFPO-DA, EEA-NTH, ADONA, are generally less bioaccumulative in fish. However, the relationship between chemical structure, affinity to proteins and accumulation pattern is complex though and still a matter of research. For example, a comparison of laboratory BCFs with field BAFs revealed that 60% (26 of 43 comparisons) of the BAFs are greater than their corresponding BCFs (Burkhard 2021), possibly due to multiple exposure routes taking place in field conditions (e.g. exposure via food in addition to exposure from the water phase only).

Due to the aforementioned properties, many PFASs accumulate in air-breathers, and long-chain PFASs biomagnify in marine and fresh-water food webs, reaching high levels in top predators including humans and vulnerable species (see monitoring Annex B 4.2.4). It is noted that as a consequence this may negatively affect the recommendations related to

consumption of meat and/or entrails of certain animals (e.g., deer, fish for PFOS and PFOA in EFSA, 2018).

Field studies on long- and short-chain PFASs that can be analytically distinguished demonstrate that PFASs (primarily PFBA, PFBS, PFHpA, PFHxA, PFHxS, PFOS, FOSA, 6:2 FTOH, F-53B, 6:2 Cl-PFESA, TFA, and C9-C11 PFCAs) are found in all environmental compartments in mammals, birds, fish or other vertebrates throughout Europe and globally. Notable is that not just arrowheads but also precursors (e.g., 6:2 FTOH, F-53B, 6:2 Cl-PFESA) are found in biota, even though only very few studies focus on their detection. Given the fact that for the majority of PFASs no or insufficient data are available on bioaccumulation behaviour, substantial and large uncertainties remain. In conclusion and considering the increasing lines of evidence from modelling, laboratory and monitoring studies, there is a justified concern for a subset of PFASs of being bioaccumulative while large uncertainties remain for the majority of compounds due to lack of data.

It is noted that routine target analysis of food items and wildlife usually includes only the most commonly used and/or identified C4–C15 PFCAs and C4–C10 PFASs, missing a large fraction of other PFASs. Hence the actual combined exposures of all PFASs, also considering the expected specific bioaccumulation behaviour as described above, may be even higher than the one observed in the monitoring programs.

Overall, the data on the bioaccumulation potential of PFASs, which are currently available, are not sufficient to substantiate bioaccumulation in the environment for all PFASs.

1.1.4.7. Endocrine Activity / Endocrine Disruption

Collected evidence of EA/ED of several PFASs indicates that adverse effects through interaction of PFASs with the hormone system as well as cross generational exposure cannot be excluded (see details in Annex B.7.4). In summary, the *in silico*, *in vitro* and *in vivo* data listed in Annex B.7.4 provide indications of interactions of various PFASs with the endocrine system of environmental species.

1.1.4.8. Ecotoxicity

There is evidence for a subset of PFASs that adverse effects occur (see Annex B.7). The large amount of different substances in the group of PFASs with heterogeneous properties (e.g. due to different functional groups) makes the assessment of their ecotoxicity very complex. It is noted, that most recently, 6:2 FTOH was evaluated by RAC to warrant a classification of Aquatic Chronic 1 (ECHA, 2021).

Considering the effective uptake and even accumulation of many PFASs by plants, consideration of plant toxicity is also relevant. However, environmentally relevant concentrations of PFASs rarely lead to obvious phenotypic/physiological damages in plants, but markedly perturb some biological activities at biochemical and molecular scales. PFASs exposure induces the over-generated reactive oxygen species and further damages plant cell structure and organelle functions.

Overall, the data on the ecotoxicity of PFASs, which are currently available, are not sufficient to substantiate adverse effects in the environment for all PFASs.

1.1.4.9. Effects on human health

Available scientific literature on PFASs that have been investigated in animal and epidemiological studies clearly show human health hazards and concerns for many PFASs (for details, see Annex B.5).

There is a vast amount of literature published on the health effects of PFASs, mostly on the PFAA arrowheads PFCAs and PFSAs, especially on PFOA and PFOS. Other PFASs have been less well-studied, but attention of the research and available hazard information is increasing. Some precursors to PFAAs may be of less concern with regard to human health effects, but will ultimately add to exposure of PFAAs due to degradation (see Annex B.4.1 for details) and hence, also add to the concern. Below the human health effects as reported for PFASs are summarized, per main PFAS category.

PFAAs (arrowheads/precursors)

In humans, many PFAAs are readily absorbed after oral exposure, while less is known regarding absorption after inhalation and dermal exposure (details in Annex B.5.1.). Many PFAAs bind to proteins and are thus distributed to protein-rich tissues including liver, kidneys, and blood. PFAA precursors are metabolised in humans to arrowhead PFAAs, which are not further metabolised. Estimated human elimination half-lives for PFAAs range from a few days (such as PFBA) and a month (PFHxA, PFBS) to a couple of years (such as PFOA, PFNA, PFDA, PFHxS or PFOS) or >10 years (e.g. PFUnDA). Half-lives are much shorter in rodents than in humans and a difference in half-lives between sexes is often observed. Consequently, the observed toxicity in rodents underestimates the toxicity to humans. PFAAs are mainly excreted via urine and faeces and are released to the environment. PFAAs have a strong potential for bioaccumulation in humans as shown by the long half-lives (details in Annex B.5.1) due to the protein-binding properties (details in Annex B.4.3).

EFSA extensively reviewed the epidemiological evidence for association between PFAS exposure and adverse effects in humans (EFSA, 2018; EFSA, 2020). Most data were on PFOS and PFOA, but information was available also for some other PFCAs and PFSAs. EFSA inferred that there is sufficient evidence to conclude that there is association between increased serum levels of various PFCAs and PFSAs and reduction in vaccine antibodies, increased propensity of infections, increased serum cholesterol, increased serum alanine transferase (ALT) and reduced birth weight. EFSA also identified some evidence of increased propensity of infections (Annex B.5.3). The association with immune effects was considered the most sensitive endpoint in humans (supported by data from experimental animals) and based on this EFSA has established a Tolerable Weekly Intake (TWI) of 4.4 ng/kg bw/week for the sum of PFOA, PFOS, PFNA and PFHxS (EFSA, 2020). Epidemiological studies published after the EFSA opinion generally support or strengthen conclusions on the above-mentioned associations and some more data on other PFAAs than PFOS and PFOA have become available. Furthermore, additional data for the PFOS alternative 6:2 Cl-PFESA (F-53B), which were not evaluated by EFSA, indicate similar associations with these health outcomes.

Experimental animal studies across different groups of PFASs demonstrate that liver, kidney, thyroid, immune system, and reproduction are main targets of PFAAs' toxicity, as outlined in Annex B.5. In rodent studies, the most consistent effects included enlarged liver, hepatocellular hypertrophy, increased serum ALT, increased kidney weight, toxicity to reproduction, effects on lymphoid organs, and decreased serum thyroid hormone levels. In particular liver effects have been observed for most PFAAs for which animal studies are available (Annex B.5.2). For PFOS, PFOA, PFNA, and PFDA and their salts this has resulted

in harmonized classifications for carcinogenicity (Carc. 2), reproductive toxicity (Repr. 1B), lactation effects (Lact.) and specific target organ toxicity - repeated exposure (STOT RE 1, except for PFDA), see Annex B.3. Harmonized classifications for PFHpA (Repr. 1 and STOT RE 1) and 6:2 FTOH (STOT RE 2) have been agreed by RAC but are not yet officially included in Annex VI of CLP.

Data available for less well-studied PFAA arrowheads and some PFAA precursors indicate that these PFASs can have similar effects as the well-studied ones mentioned above (see Annex B.5). For example, PFBA exposure of experimental animals resulted in similar effects on liver (enlarged liver, hepatocellular hypertrophy and partially necrosis) as well as thyroid hypertrophy and full litter resorption, although effects occur at higher concentrations compared to PFOS/PFOA. Another example is HFPO-DA (GenX), which was initially introduced as a safer alternative to PFOA but showed comparable concerns as PFOA (Blake et al., 2020) and for which US EPA recently proposed an even lower reference dose than for PFOA and PFOS (EPA US, 2021).

As supporting evidence for similar toxicity concerns, a number of other PFAAs and PFAA precursors have self-classifications for Carc., Repr., Lact. and/or STOT RE. These self-classifications cover, for example, the following PFAS categories: the side chain aromatics (part of which are TFA precursors), the fluoro-telomers (e.g. fluorotelomer alcohols, epoxides, (meth)acrylates, sulfonic acids, etc.), and other PFAA-precursors (e.g., perfluoroalkyl iodides, sulfonamides, carbonyl amides etc.; details in Annex B.3). Exemplarily of note, HFPO-DA, PFOS, 6:2 FTSA and 8:2 FTSA have self-classifications for STOT RE, and PFOS as well for reproductive toxicity. Even though there is still a large number of PFASs that have no (self-)classification for the properties of concern, the absence of classification does not mean that these PFASs do not have these properties. It is more likely that for the vast majority of these substances, no study data are available to serve as a basis for classification. In the absence of evidence to the contrary, it can therefore be assumed that some of the less well studied PFAAs and PFAA precursors also exhibit one or more of the properties of concern.

Many PFASs contain only a single $-CF_3$ group and are considered TFA precursors as a special subclass of PFAAs. This group is heterogeneous with various types of effects and mechanisms of actions. The effects of these substances measurable in standard tests can often be attributed to the non-fluorinated parts of the substances. However, as these substances will ultimately degrade in the environment to TFA (see Annex B.4.1.3), they will contribute to the overall exposure to and risks of PFAAs. Concerns for human health by TFA itself are limited to effects at high doses in experimental animals: liver effects (increased liver weight, hepatocellular hypertrophy, increased ALT), increased kidney weight, decreased white blood cells, reduced weight of reproductive organs, litter loss, reduced body weight of offspring, and malformations.

Polymeric PFASs

Polymeric PFASs cover fluoropolymers (incl. fluoroelastomers), side-chain fluorinated polymers as well as per- and polyfluoropolyethers. For fluoropolymers, it is often assumed that they are non-toxic due to their alleged size- and chemically inertness-related non-bioavailability (Henry et al., 2018). The non-bioavailability has been questioned by Lohmann et al. (2020), summarising variability of airborne fluoropolymer particle size as well as membrane crossing capabilities of macromolecules, such as polymers and corresponding nanoparticles (details in Annex B.5.1). Furthermore, polymer molecules, e.g. from plastics or resins, are not all of the same large size and that especially the low molecular weight fraction is small enough to be diffusible. Additionally, the polymer-specific chemical diversity (e.g. size, reactive groups, polymerization aids, additives, unintentional

PFAS by-products, impurities, etc.) determine their potential toxicity (more details in Annex B.5.2). Blood and liver concentrations of polychlorotrifluoroethylene (PCTFE) trimer and tetramer oligomers as well as PCTFE 3.1 oils of different compositions were reported after oral exposure in monkeys (Jones et al., 1991), which indicates systemic distribution of polymers with low molecular weight.

Excessive inhalation of aerosolized fluoropolymer-containing products and pyrolysis products of fluoropolymers in humans and experimental animals is reported to cause respiratory illness, such as acute chemical pneumonitis, and reactive airway dysfunction syndrome, occasionally accompanied by nonspecific systemic symptoms, such as fever, chills, malaise, arthralgias, and nausea (REFs: Strøm and Alexandersen 1990; Hays and Spiller 2014; Johnson et al. 2018). These effects are of unclear etiology but demonstrate a potential toxicological relevance of fluoropolymers and their degradation products in acute inhalation exposure scenarios. However, toxicological relevance was also shown in continuous inhalation rodent exposure studies.

Repeated oral animal studies (mainly with rodents) with polytetrafluoroethylene (PTFE) and polychlorotrifluoroethylene (PCTFE) trimer and tetramer oligomers, reported adverse health effects, such as loss of body weight and/or liver effects, which would generally fit the typical effects observed for PFASs (details in B.5.2). However, insufficiently reported study details weaken the power of the available effect data for PTFE and PCTFE. Clarity on effects after repeated oral exposure of the highly diverse group of fluoropolymers cannot be given on the basis of available data. However, at any point in their lifecycle fluoropolymers may generate PFAAs, e.g. during incomplete incineration at end-of-life (Lohmann et al., 2020), and as such contribute to the overall exposure to and risks of PFAAs.

The structures of side-chain-fluorinated polymers and polyfluoropolyethers are different from that of fluoropolymers. Little to no data is available on the toxicity of these two groups of polymeric PFASs. However, for side-chain fluorinated polymers it is expected that they release PFAAs at any point in their lifecycle, and will thus contribute to the overall exposure to and risks of PFAAs (Wood, 2020, OECD, 2021a).

F-gases

For various HFCs, HFOs, and HFEs, some effects are similar to those observed for PFCAs and other PFAA arrowheads, in particular effects on liver and lymphoid organs (see Annex B.5). Data available indicate that most of the F-gases have lower potencies compared to the arrowheads. Moreover exemplarily, some F-gases (e.g. some HFOs) ultimately degrade to PFAAs, e.g. TFA or PFBA (Annex B.4.1.3). Hence, also F-gases will contribute to the overall exposure to and risks of PFAAs.

Cumulative effects of co-occurring PFASs

Many different PFASs co-occur in the environment, drinking water, food, and in human blood (see section B.4.2.4). Many PFASs exhibit similar effects, such as effects on the liver, kidney, thyroid, serum lipids, and immune system. Accordingly, an assessment of hazards and risks taking into account such combined exposure would reflect exposure conditions more realistically than single compound assessments.

The similarity of the effects of most PFAS groups raises concerns about cumulative effects of PFASs. The lack of toxicity data for most PFASs precludes precise modelling of combined effects of all PFASs but concentration addition has been suggested as a precautionous first tier, irrespective of the modes/mechanisms of action of the mixture

components (Backhaus and Faust, 2012). This might give a realistic worst-case estimation of combined toxicities for risk assessment procedures even if similarity of components is unknown (Backhaus et al., 2000, Martin et al., 2021). Dose addition has also been adopted as the default assessment approach in EFSA's "Guidance on harmonised methodologies for human health, animal health and ecological risk assessment of combined exposure to multiple chemicals" (EFSA, 2019).

However, due to the immense number of PFASs and the lack of toxicological data for the vast majority of them, a combined assessment for all PFASs is unattainable within the scope of this restriction. In conclusion, it is emphasized at this point that combined exposure to different PFASs affecting the same target organs may result in combined additive effects rendering exceedance of effect thresholds or limit values more likely than assessment of individual substances.

Cumulative effects are considered in further detail in Annex B.5.4.

1.1.4.10. Concerns triggered by combinations of properties

Most of the PFASs manufactured, used and released to the environment can be expected (and are in case of investigated PFASs known) to have several of the above listed properties, depending on the specific identity of the PFAS. A combination of at least two or more properties is expected in particular for the arrowhead PFASs (see more details in Annex B.1.3, B.4., B.5 and B.7). As explained above, all arrowhead PFASs are very persistent, and their precursors will contribute to the environmental concentrations of the arrowheads as well through degradation in the environment. The presence of some of the additional properties is expected to correlate with each other: these are mobility in water with enrichment in plants and LRTP, volatility with global warming, volatility with LRTP.

In the following sections the concerns triggered by certain combinations of PFAS properties are discussed.

High potential for ubiquitous, increasing and irreversible exposure of the environment and humans

Although exceptions may occur, the overall expectation is, using the general knowledge on degradation pathways and, more specifically, the observations from monitoring data, model data, degradation testing (see Annex B.4.1. for details) and information on mobility (Annex B.4.2.1 and volatility (see Annex B.4.2.2) that the more time that passes after the release of PFASs into the environment, the more the environment is exposed to those PFASs which are the most mobile in water and/or the most volatile (F-gases) and most persistent among the PFASs.

Very persistent properties in combination with mobility in the aquatic environment results in a scenario where none of the environmental compartments act as a potential removal pathway (i.e. a sink). In this scenario, mobility increases the already high potential of very persistent substances to result in exposures of biota and humans. Marine surface water is an important compartment for very persistent and mobile PFASs and facilitates their distribution by advection (Cai et al., 2012b). Occurrence of elevated concentrations of PFASs in waters near the points of releases are problematic, because mobile substances are also bioavailable for efficient uptake in the food chain. Cai et al. (2012b) discusses this for coastal waters as an intermittent storage before PFASs are further diluted in the marine environment.

The very persistent PFASs have time to be distributed in and between environmental compartments, such as aquatic and atmospheric media. Combined with mobility, the distribution and transport via aqueous media is efficient and faster than for non-mobile substances. PFASs therefore reach effectively all media, including groundwater aquifers which function as drinking water reservoirs. This is illustrated by monitoring data showing that measured PFASs are already ubiquitously present in the environment (see section B.4.2.4).

Furthermore, PFASs are subject to long-range transport. Long-range transport in combination with very high persistence means that even the most remote sites of the globe and most vulnerable environments cannot be protected from PFAS exposures.

For the very persistent PFASs environmental concentrations increase as a result of releases until reaching a steady state at a far point of time. In consequence also PFASs having less or no bioaccumulative properties can show elevated levels in biota as illustrated by monitoring data (B 2.4.2). Recent models demonstrate that mobile and persistent PFASs will ultimately reach over time -unless the exposure is removed- such high levels in organisms that will affect both ecosystems and human health widely (Crookes and Fisk 2018). The report by Crookes and Fisk (2018) indicates that also substances which have bioconcentration factors below 2000 L/kg could potentially reach similar levels in biota compared to substances that are known to bioaccumulate, provided that they are sufficiently persistent and mobile in the environment. For example, calculations in the study show that a substance with a half-life of 365 days and a BCF of 800 l/kg may reach comparable concentrations in a system as a substance with a half-life of 60 days and a BCF of 5000 l/kg, if time allows for steady-state to be reached. See Annex B.4.3. "Persistence compensating for low bioaccumulation potential" for further details.

As a case study applying the model of Crookes and Fisk (2018), the nominal biota concentration calculations were repeated for PFBS and compared with some relevant model substances (ECHA 2019a). A degradation half-life in water of 10 years for PFBS was assumed, representing a best-guess estimate in the absence of any measured degradation half-life, and the calculations were performed with the following bioaccumulation values: BCF Fish: 23.5 (Chen et al., 2016); BAF crab 110 (Naile et al., 2013) and BAF fish 1736 (Campo et al., 2015). The outcome of the modelling of development of biota concentrations for PFBS over time is shown in Figure 3. The model substances (A, B, C and D) have combinations of half-life and BCF as shown in Figure 3. An assumption in the model is that the substance is mobile and not removed from the aqueous phase so that the concentration, and therefore the exposure, is maintained unchanged over time.

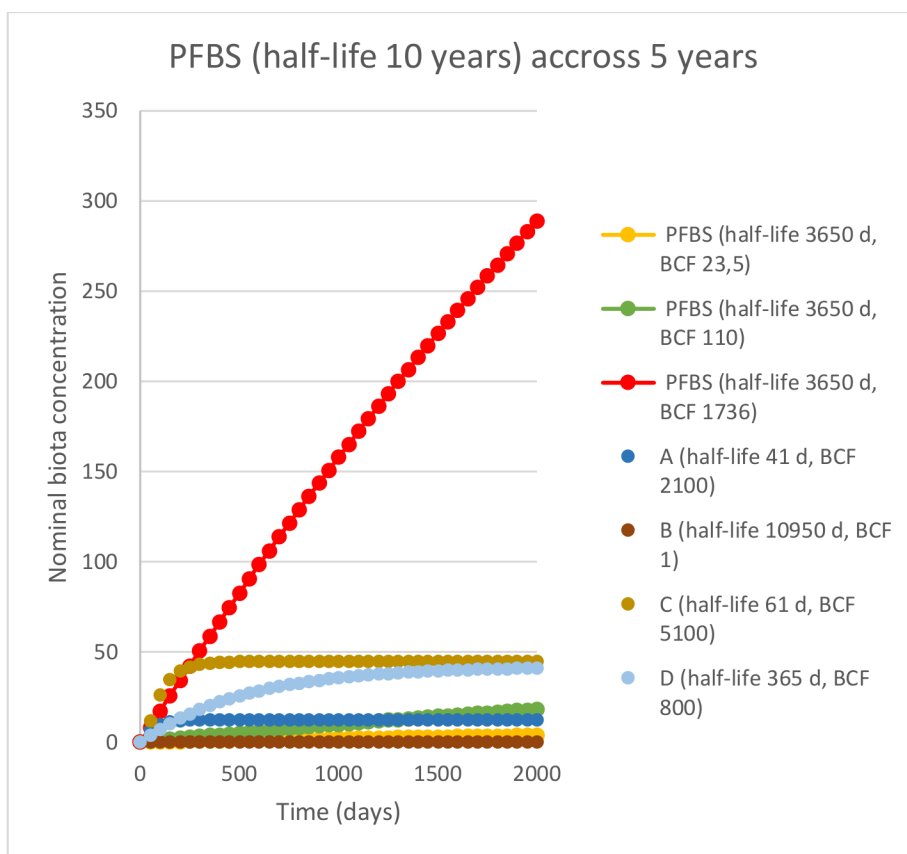


Figure 3. Modelling of development of nominal biota concentrations for PFBS over time.

Figure 3 demonstrates in a simplified way that when considering an appropriate long time scale, e.g., few decades (note figure X shows only 5.5 years), a long degradation half-life for a substance may lead to high steady-state concentrations in biota, even when the BCF is only moderate. The red line represents a BCF of 1736 for PFBS reported in fish (Campo et al., 2015) and demonstrates the effect of a long half-life in combination with a relatively high BCF. However, as is outlined in (ECHA 2019a), this BCF is an outlier and may be an overestimate, and the red line is disregarded in this evaluation. The green line represents a BAF of 110 measured in crab (Naile et al., 2013). The graph shows that this moderate BAF in combination with a half-life of 10 years, may lead to very high concentrations in biota over time. The green line even crosses the dark blue line, representing a substance with half-life in water of 41 days and a BCF of 2100, i.e. a substance just exceeding the P and B criteria in REACH Annex XIII. For the substance B combination of BCF of 1 and half-life of 30 years the high steady state would be reached very slowly far beyond the time-scale of the simulation. When the model from the Crookes and Fisk (2018) report is used for PFAS, concentrations of very persistent and mobile subgroups in biota may be expected to exceed the biota concentrations for a persistent and bioaccumulative substance over time. The steady state in biota would only be reached for PFASs in the model in far future.

Bioaccumulation and mobility can be seen as properties facilitating exposure and enhancing the likelihood of adverse effects in particular when combined with the very persistent property. With regard to bioaccumulation this is due to the slowly reversible internal exposure caused by a slow elimination kinetics in organisms and therefore elevated internal levels. Exposure to very persistent and mobile PFASs occurs continuously via drinking water and food crops. Finally, some PFASs (e.g., PFOA) can be both, mobile and

bioaccumulative and distinguishing between the impact of each of the properties to the observed levels is not always possible.

To conclude, mobility in combination with very high persistence cause a high potential for increasing contamination of surface waters and aquifers. This contamination is very difficult to reverse. Even if releases are ceased, the exposure levels of the arrowhead PFASs continue to increase until the precursor PFASs have gradually all vanished from the environment. The environmental stock of the arrowhead PFASs formed is expected to prevail in the environment for decades if not centuries and is readily available for uptake by biota and humans.

Difficulty to decontaminate raw water and to reduce emissions with site-specific risk management

The combination of the very high persistence of PFASs and mobility and for many PFASs also of surface activity trigger specific challenges to wastewater treatment and decontamination of, e.g., raw water used for drinking water and contaminated sites (e.g., groundwater contamination around airports, see Annex B.4.5).

Municipal sewage treatment plants are not able to remove very persistent and mobile PFASs as they remain in the water phase and cannot be degraded within the retention time by the available micro-organisms. The available chemical removal methods are expected to reach removal of only a small fraction from the aqueous phase. The suspended PFASs, however, cannot be not degraded in sludge, or are in an ideal case merely degraded from precursor forms towards arrowhead forms. The monitoring data in influents and effluents of municipal sewage treatment plants supports this pattern (see Annex B.4.2.4).

Conventional and advanced raw water treatment methods applied to produce process water for industry and drinking water are neither able to remove PFASs effectively due to their persistence and inertness to chemical and thermal reaction. Thermolysis and sonolysis might achieve complete mineralization but come with a high process cost. Other treatment processes cannot remove PFCAs and PFSAs. The same applies to PFECAs. Conventional adsorption, ion-exchange, and membrane filtration can remove long-chain PFASs, but are less effective for the more hydrophilic short-chain PFASs. See Annex B 4.5 for details.

Raw water used for drinking water is obtained either from groundwater, bank filtration or surface waters. Monitoring data already reveal a contamination of either drinking water itself or raw water, ground water and river bank filtrates used for the preparation of drinking water (see Annex B.4.2.4). A recent review paper from (Li et al., 2020) on drinking water treatment concludes that short-chain PFAS are more widely detected, also persistent and even more mobile in aquatic systems, and thus may pose broader risks on the human and ecosystem health as compared to their long-chain counterparts. Routine target analysis, however, usually only addresses very few PFASs missing a large fraction. Furthermore, due to an analytical gap in the past the problem of persistent and mobile organic compounds and their impact on drinking water quality has been underestimated (Reemtsma et al., 2016), making older monitoring data possibly giving too optimistic views of the presence of PFASs in the environment.

The challenges are further elaborated in Annex B.4.5. To conclude, there are significant limitations to remove the PFASs from raw water and wastewater or sludge. In general, it seems that releases to water cannot be mitigated with on-site removal techniques, although some specific exceptions may apply. Exposure of humans via drinking water

cannot be prevented effectively. Removal or remediation might only be feasible for contamination hotspots in few specific cases, but not for the majority of the environment, such as large aquifers, surface waters and the world's oceans.

High potential for human exposure via food and drinking water

Accumulation of many PFASs in edible plants, the bioaccumulation potential observed in some PFASs in a.o. fishery products and the very high persistence and mobility as discussed above mean that human exposure via food can be expected to be transmitted broadly by many routes of nutrition. Furthermore, drinking water is also a source of PFAS exposures due to the difficulty to decontaminate raw water prepared for drinking water. The exposure via drinking water and via food is expected to increase in future due to expected increasing concentrations of the arrowhead PFASs in the environment unless releases of PFASs are ceased. Even then it will take a very long time until the environmental concentrations are considerably reduced due to the high persistence of the substances. To conclude, the abovementioned combined properties of PFASs induce a high potential for exposure of the human population at large. Current exposure of the general population can be observed for several PFASs from the available biomonitoring data (see section B.4.2.4).

Potential for intergenerational effects and delay of effects

Several PFASs are transferred to the offspring (see Annex B.4.2.4 and B.5). The high potential for human exposures and the expected increasing and irreversible exposures, as discussed above, in combination with the intergenerational transfer of PFASs indicate that none of the stages of human life and wildlife can be effectively protected from exposure to PFASs. The very long-term exposures, continuing over decades or even centuries increase the likelihood for intergenerational effects. Furthermore, although effects would not be yet observed, the expected increase of exposures to the arrowhead PFASs even after releases have been ceased together with the above discussed results from tests on human health toxicity and endocrine disruptive effects raise the likelihood of effects to be observed at a later stage. At such point of time the effects would be very difficult to reverse.

Considering the increasing lines of evidence for effects of well-studied PFASs occurring at lower levels than previously anticipated (EFSA, 2020), combined with increasing findings of hazardous properties of less studied PFASs (e.g., ECHA, 2020; ECHA, 2021) and the increasing stock pollution and the expected irreversible ubiquitous environmental contamination as outlined above indicates a threat of irreversible damage for future generations. The findings from studies investigating endocrine effects add to the concern. If yet unidentified adverse effects do occur these cannot be reversed.

Potential for causing serious effects although those would not be observed in standard tests

Already only the arrowhead PFASs constitute a diverse mixture of exposure whereas all the released PFASs in combination with the arrowhead PFASs form a very complex cocktail in the environment. As concluded in Annex B.5.4, combined effects should not be excluded but rather expected in this situation. There are no standard tests available which could simulate the exposure of PFASs taking place in the real environment. Additionally, potential effects arising from low-dose long-term exposure, as well as multigenerational exposures cannot be appropriately addressed by standard tests.

Additionally, the fact that exposures may take place at a different location than where releases occurred, and at a different moment in time due to the persistence, impedes the understanding of potential effects taking place.

Estimation of future exposure levels and safe concentration limits is highly uncertain

Currently no appropriate tools exist to estimate exposures reliably far in future. The prediction is further complicated for PFASs by the degradation of the precursors to the arrowhead PFAS. Number of PFASs in total yet higher than the number of PFASs manufactured and used can be expected to be simultaneously present in the environment. Environment is also exposed to intermittent degradation products. In example, side-chain fluorinated polymers (SFPs) which degrade in the environment at a very slow rate are a long-lasting constant source especially if long timeframes are investigated for emissions and exposures over centuries. This applies particularly to the end of service-life where surface soils and landfills constitute a major global reservoir for PFASs (Washington et al., 2019).

Currently it is also not possible to reliably assess (eco)toxicity of all PFASs. This is on the one hand reflected by the increasing lines of evidence for effects of well-studied PFASs occurring at lower levels than previously anticipated (EFSA, 2020) and findings for less studied PFASs (ECHA, 2020; ECHA, 2021). On the other hand, the prediction of safe levels is more challenging, if not impossible, due to the complex mixture of used PFASs actually prevailing in the environment over long-term. The simultaneous exposure to the transient degradation products of the precursors impedes such a prediction before they finally form their respective arrowhead substances. As pointed out in sections B.5 and B.7 on effects to human health and ecotoxicity, both similar effects and different types of effects have been observed in available data across the PFASs. Combined effects can be expected over the long-term increasing exposure periods, as described in section B.5.11. This furthermore complicates the derivation of safe levels.

Global warming potential

Some of the PFASs are persistent and volatile and will partition to the atmosphere where they will stay for a very long time. These PFASs may have a considerable global warming potential which could contribute to the greenhouse effect and global warming. In fact, some of the strongest greenhouse gases known are PFASs. For details, see Annex B.7.2.

One of the most relevant subclasses of PFASs that contribute to global warming are the F-gases, e.g. hydrofluorocarbons (HFCs), hydrofluoroolefins (HFOs) and hydrofluoroethers (HFEs). Emitted F-gases reside in the atmosphere. The Environmental Coalition on Standards (ECOS) notes in a recent report that even though F-gases 'only' account for approximately 2% of the greenhouse gas (GHG) emissions in the European Union by weight, their contribution to the radiative forcing is about 20%, thus being a major contributor to global warming (ECOS, 2021). F-gases in the atmosphere will degrade over a shorter or longer timeframe and the contribution to global warming will be removed, e.g., via formation of TFA that precipitates with rain or other species like HF and CO₂.

1.1.5. Exposure assessment

Based on an extrapolation of data provided by Eurofeu (see Annex A for more details) it is estimated that **about 18 000 tonnes of PFAS-containing firefighting foam concentrates are sold in the EU per year**, fluctuating between 14 000 to 20 000 tonnes²⁴. Of the total (central estimate), about 10 800 tonnes are estimated to be employed in fixed systems and about 7 200 in mobile systems²⁵. The split by sector is detailed in Figure 4 below. This shows that chemical/petrochemical is by far the largest user sector of foams (59 %), but municipal fire brigades, marine applications, airports and defence applications also account for significant volumes. Ready for use products only account for a very small share of PFAS-containing foams, the vast majority of this category are fire extinguishers.

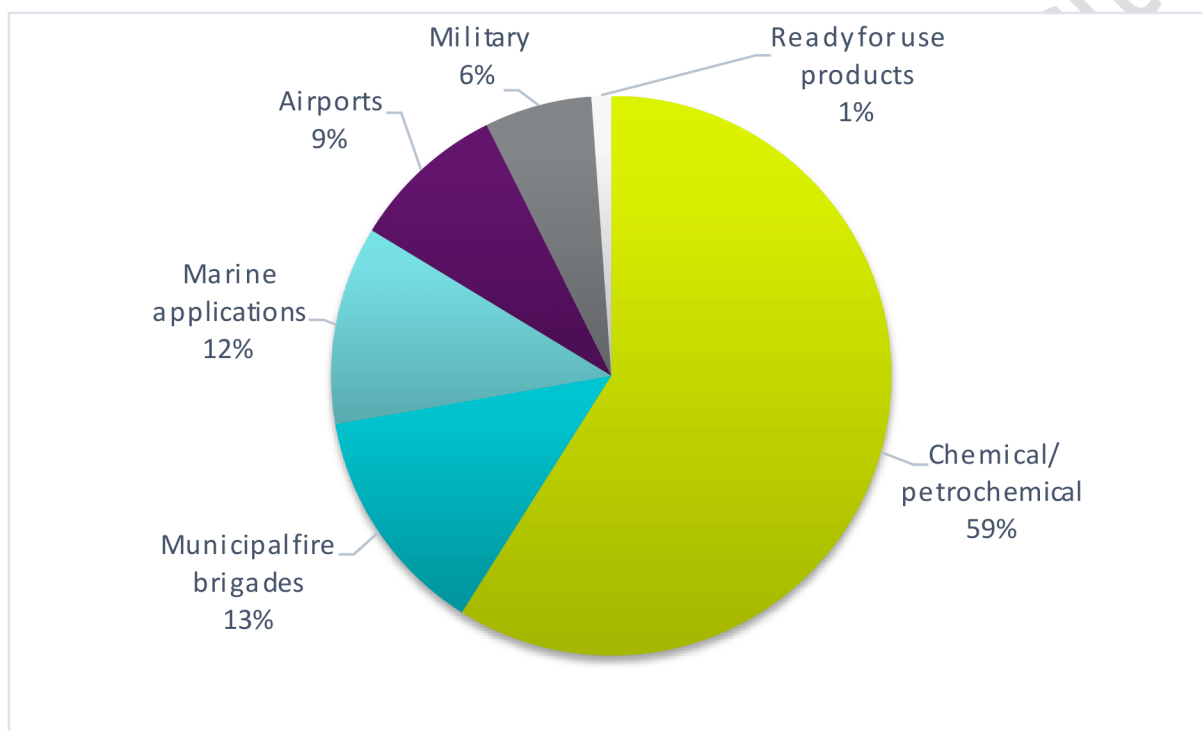


Figure 4. Split of PFAS-containing firefighting foams by sector. Source: (Wood et al., 2020) based on data provided to the authors by Eurofeu.

The use of these PFAS-containing firefighting foams accounts for an annual consumption of around 480-560 tonnes of fluorosurfactants per year in the EU, based on data provided by Eurofeu.

According to the model calculations under the baseline scenario²⁶, a total annual emission of around 470 tons of PFASs across the environmental compartments would occur²⁷. This

²⁴ All these figures have been extrapolated from the original values provided by Eurofeu, which covered approximately 70 % of the market. The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split.

²⁵ All these figures have been extrapolated from the original values provided by Eurofeu, which covered approximately 70 % of the market. The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split.

²⁶ Using the central scenario (i.e. best estimates input parameters)

²⁷ With the same sectoral breakdown as the sales data.

represents a total of around **14 100 tonnes of cumulative emissions of PFASs over 30 years**.

The emission estimates are based on data and assumptions from Wood et al. (2020) and further refined based on additional stakeholder input, ECHA Guidance R.16 (ECHA 2016b) and, where no data are available, based on expert judgement (see list of input parameters in Section 3 “Assumptions, uncertainties and sensitivities”).

Eight sectors/use categories were considered²⁸:

- Oil/(petro-)chemical industry
- Other industries²⁹
- Civilian aviation
- Defence
- Municipal fire services
- Ready-to-use applications
- Marine applications
- Training and testing (for all the above categories except Ready-to-use applications)³⁰.

Using a source-flow model and the assumptions outlined in Section 3 “Assumptions, uncertainties and sensitivities” and Annex B.9., F.5.2 and Appendix 8 the material flow and emissions to the environment occurring at different life cycle steps were calculated for the baseline (and each assessed restriction option). The sources of emissions under the baseline scenario are illustrated in Figure 5.

Regarding the emissions of PFAS-containing foams by life cycle stage, a central estimate of 10 % annual use for incident management and 2 % for training and testing is assumed, across all sectors (percentages compared to foam stock)³¹. During training exercises, aside from marine applications, it is assumed that the efficacy of bunding³² and/or other control measures is relatively good³³. This means that for training and testing, much of the firefighting concentrate within runoff is contained and, under the baseline scenario, sent primarily to either an on-site or off-site wastewater treatment plant (WWTPs). For incidents, the collection of firewater runoffs³⁴ is considered to be less effective and variable among sectors and, under the baseline scenario, the collected fire waters are mainly sent to WWTPs³⁵. It is noted that municipal WWTPs are not effective in removing/eliminating PFASs (see section B.4.5 and B.4.2.4).

²⁸ See Annex E.2.5 on technical feasibility of alternatives for details on the sectors/use categories.

²⁹ Assumed to represent 2% of the PFAS-containing foams sales to the oil/(petro-)chemical industry indicated by Eurofeu, the remaining 98% assumed to be used by Seveso establishments. See section A.2.3.1 in Annex for more details.

³⁰ “Training and testing” has been segregated as a separate type of use, across all sectors of use, to better assess the impact of a shorter transitional period compared to longer transitional periods for uses for real fire incidents.

³¹ See Annex B.9 for details

³² The use of retaining walls to contain fire water run-off.

³³ Assumed to be 97% (see assumptions and input parameters in section 3. “Assumptions, uncertainties and sensitivities”).

³⁴ Fire runoff waters (or “fire water runoff”) are the run-off waters containing the firefighting foam concentrate mixed with water and all other elements mixed with them during the use of the firefighting foam during a fire incident, training or other use (e.g. flammable liquids, dirt, etc).

³⁵ In absence of more specific and representative data, the Dossier Submitter assumes for a conservative assessment that the typical treatment method of collected fire waters containing PFASs is wastewater treatment plant (see Annex B.9 for more details).

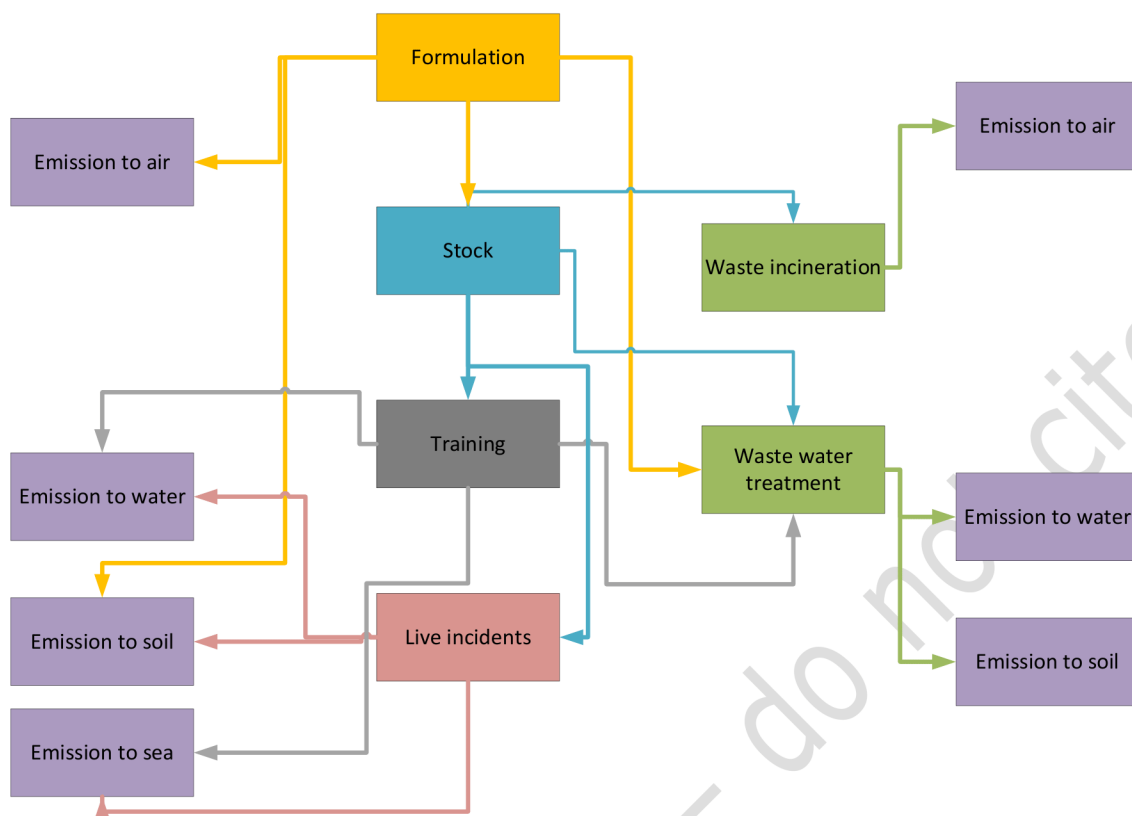


Figure 5. Material flow diagram showing the connection between the different life cycles stages of formulation, in-use, stock and waste treatment for PFASs in firefighting foams under the baseline scenario.

Table 2 describes the calculated total emissions of PFASs in the environment under the baseline per sector or use.

Table 2. total emissions of PFASs to the environment under the baseline per sector or use*

Sector/type of use	Annual emissions (t/y)
oil/(petro-)chemical industry (Seveso establishments)	200
Other industries	<10
Civilian aviation	40
Defence	20
Municipal fire services	50
Ready-to-use applications	<10
Marine applications	50
Training and testing	80
All sectors	~470

*Note: Rounded figures. These are approximate values

Regarding the emissions to the environment, it should be noted that while the non-fluorinated firefighting foams make up approximately one third of the market, the volumes of alternative surfactants can be greater than their PFAS counterparts due to greater

concentrations within the product itself, potentially leading to higher emissions of the non-fluorinated alternatives. However, it is important to recognise that emission alone is not an indicator of impact, and the degradation rates, potential for bioaccumulation, and harmful effects also need to be considered (as discussed in section 0 and in more detail in Annex B.5).

For the non-fluorinated alternatives, the effectiveness of wastewater treatment is considered to be relatively good³⁶, minimising the emission which is split between surface water and soil. In contrast, wastewater treatment is expected to be ineffective at treating PFASs, meaning direct release to surface water or soil depending on the partition coefficient.

1.1.6. Risk characterisation

All PFASs exceed the vP criteria, either themselves (arrowheads) or by degrading to arrowhead PFASs. The half-lives of the most stable PFASs (e.g., PFAAs) are known to be in the order of years, by far exceeding the vP criteria. Due to the high diversity of the PFASs the bioaccumulation potential and ecotoxicity are expected to largely vary among the substances. Therefore, no conclusion on B/vB and T criteria was derived for each substance/subgroup. The very high persistence is not sufficient to identify the PFASs as PBT or vPvB substances. However, the additional properties described above combined with the very high persistence add substantially to the overall concern which are very similar to those of the PBT/vPvB substances. Therefore the case-by-case approach has been investigated below.

Case by case assessment according to para 0.10 of Annex I to REACH

As summarised in section 1.1.4 on the properties, PFASs have a high potential for ubiquitous, increasing and irreversible exposures of the environment. This in combination with a difficulty to decontaminate raw water for drinking water and low effectiveness of end-of-pipe wastewater treatment trigger a high potential for human exposure via food and drinking water. These together, in addition with the intergenerational transfer mechanisms, lead to a potential for intergenerational effects and delay of effects. Due to the complex co-occurrence of PFASs in the environment and the very long-term exposures, standard tests do not provide sufficient understanding of possible effects. Furthermore, due to the exposure to mixture of PFASs in the environment, complex degradation patterns of precursor PFASs to arrowheads and due to the very high persistence and hence exposure times reaching decades if not centuries, quantification of future exposure levels and safe concentration levels is highly uncertain for PFASs. Combined effects may be expected for PFASs. The significant global warming potential of many volatile PFASs adds yet another category of effects to the picture.

Because of the persistence of PFASs, its mobility and long range transport potential, concerns have been expressed about whether their releases into the environment might ultimately reach concentration levels that could breach so-called 'planetary boundaries' – a point at which the earth is no longer able to assimilate or degrade a human-released chemical which is discovered only too late to have a disruptive effect on a vital earth system, and the effects of the pollutant cannot be readily reversed (Persson et al., 2013; Diamond et al., 2015). At the time when notable effects from PFASs exposure occur in

³⁶ Calculation of emissions of non-fluorinated alternatives has not been undertaken under this report. However, Wood et al. (2020) made a basic assessment for several alternative substances.

the environment it will be difficult, if not impossible, to remove the contamination. Due to the ubiquitous occurrence of PFAS this may ultimately lead to an impairment or total loss of important natural resources, as well as increased overall pressure on human health and the ecosystems (Goldenman 2017). Examples could be a loss in biodiversity or impaired ecosystem services (e.g. regulating or provisioning services).

Continued emissions of PFASs will result in increasing exposures and therefore a high likelihood that effect thresholds of PFASs known to cause effects are exceeded and those of PFASs with yet unknown effects to occur. These would be caused by single PFASs and/or in a mixture with other PFASs. It should be noted also that for human sensitive endpoints of PFASs, such as effects on the immune system, and in highly exposed populations, effect thresholds of the most studied long-chain PFASs PFOA and PFOS are already exceeded today (EFSA, 2020).

It is obvious that PFASs should be treated as non-threshold substances for the purpose of risk assessment in a similar manner to PBT/vPvB substances. Their releases should be accordingly used as a proxy for risk. To minimise the likelihood of adverse effects in the future all releases should be minimised. According to REACH Annex I, paragraph 0.10, a case-by-case approach applies for PFASs as underpinned by the available information on their high persistence in the environment in combination with the additional properties summarised above.

Section 1.1.5 summarises the information on the current releases of PFASs from firefighting foams to the environment. Manufacture, placing on the market and use of some PFASs have already been restricted in the EU (e.g. PFOA, PFOS and, as of February 2023, C9-C14 PFCAs and their salts and related substances) or are in the process of being restricted (e.g. PFHxS and PFHxA and their salts and related substances), however most of the PFASs need to be still addressed by regulatory risk management. Monitoring data for some PFASs show that PFASs are ubiquitously distributed in the environment. It should be noted that so far only a limited subset of PFASs are addressed in monitoring programs and therefore current monitoring results are expected to provide only a partial picture of the overall exposures to PFASs.

In conclusion, the observations of the ongoing releases and exposures together with the non-threshold nature of the hazard warrant a need for minimisation of the releases by the proposed restriction.

It is noted that RAC supported the proposal to restrict microplastics based on a closely similar case-by-case hazard and risk assessment approach (ECHA, 2020). Analogously, a specific case for excluding a PFAS from the scope of the proposed restriction could be made if sufficient evidence is provided that the specific PFAS is not very persistent itself and does not degrade into a very persistent PFAS.

1.2. Justification for an EU wide restriction measure

Section 0 has illustrated the hazards and combined concerns associated with PFASs. In section 1.1.5 an overview of the current releases and exposures due to the use of PFASs in firefighting foams was provided. Section 1.1.6 summarises that due to the non-threshold nature of the hazards, the risks cannot be quantified and that current releases of PFASs should be minimised. Any release should be considered a proxy for risk. Due to the ongoing releases, the risks are currently not adequately controlled.

While in some user sectors PFAS-based foams have been increasingly replaced by fluorine-free alternatives and industry best practice guidance recommends not using PFAS-containing foams in training and testing, around 18 000 tonnes of PFAS-containing firefighting foams are still used annually in the EU in applications involving flammable liquid fires (Class B fires), including for testing and training. This use leads to releases to the environment, with surface water and soil being the key receiving environmental compartments. Some PFASs were shown to be ubiquitous contaminants, for instance in arctic wildlife (Muir et al., 2019).

The use of certain long-chain PFAS substances has been regulated in the past. This has led to the replacement of these regulated PFASs with fluorine-free alternatives in some cases, but also with other PFASs substances (e.g. short-chain PFASs), as illustrated by the fact that a high share of firefighting foams used still contain PFASs.

Some national regulations exist that require the containment of firewater run-off, but the consultation suggested that containment is rarely 100 % effective, that the collected fire water is usually sent to WWTP (unless prescribed differently by local/national legislation) and the effectiveness of WWTP in the degradation of PFASs is known to be poor. Industry best practice measures aim to minimise the use and release of PFAS-containing foams (e.g. ceasing its use in training and testing, as has happened in many locations already) but the stakeholders consultation suggested that these are not being fully implemented (e.g. the use of PFAS-containing foams in training and testing has been reported). Stakeholder input did not allow to conclude on their relative effectiveness.

In conclusion, it has been demonstrated that the use of PFASs in firefighting foams is associated with risk to the environment - and human health via the environment - that is not adequately addressed by the current measures in place (current measures are discussed in more detail in Section 1.3). Even if additional measures were introduced at Member State level, there is potential for discrepancies in the definitions and scope of any national restrictions (e.g. definition of substances covered, uses covered, concentration thresholds, transition periods). This has implications not only for the degree to which the environment is protected, but also in terms of ensuring the functioning of the internal market. Firefighting foams being traded over the borders, different restrictions in different Member States could make it very challenging to market firefighting foam products available for sale in all Member States. It would therefore not be meaningful or possible to restrict them nationally due to internal market considerations. Moreover, due to their mobility and persistence PFASs emissions lead to cross-border pollution. Therefore, potential further regulatory management on EU-level is likely required.

1.3. Baseline

1.3.1. Overview

The baseline presented here comprises an overview of the current use of PFAS-containing firefighting foams based on the market analysis (used in particular as baseline economic activity for the assessment of economic impacts) and an overview of the current regulatory and voluntary industry measures to control the risk of this use. Resulting baseline exposure has already been presented in Section 1.1.5 and are not repeated here.

1.3.2. Definition of the baseline scenario for the assessment of economic impacts

The baseline scenario describes the situation in the absence of any further risk management. It was used to compare restriction scenarios (defined in the next sub-section), to ensure that the socio-economic assessment (SEA) evaluates the impacts of the RMOs being assessed.

More details are provided in the market analysis (see Annex A), but the key points are below.

- It is estimated that currently some 14 000 – 20 000 tonnes (likely closer to the upper end of the range; 18 000 tonnes have been taken as best estimate in the calculations) of PFAS-containing firefighting foams are sold per year in the EU and used in various sectors including chemicals/petrochemicals, municipal firefighting, marine, airports, defence, railways and fire extinguishers. Their use is particularly important and widespread where there is a risk of Class B fires, i.e. where flammable liquids are present. They are used for firefighting, but in some cases also for training and testing of equipment.
- Around 9 000 tonnes per year of fluorine-free foams are already used in most of the same applications, although the split by sector varies from that of PFAS-containing foams. Several stakeholders, including manufacturers of firefighting foams, have indicated that the use of fluorine-free foams has been increasing, particularly in applications where PFAS-containing foams can be very easily replaced (e.g. training). This trend is expected to continue in the future to some extent (even in the absence of any restriction on PFAS-containing foams). Some stakeholders also noted containment of fire water run-off, particularly from training. However, these run-offs seem to be mostly sent to WWTP which are considered not effective in preventing releases of PFASs to the environment, therefore the impact of this measure in terms of reduced emissions of PFASs is considered to be close to zero.
- In addition, there are significant existing stocks of PFAS-containing foams which have been already purchased. These may need to be disposed of and replaced. The total quantity of these stocks is uncertain, but are estimated as follows:
 - Annual sales of PFAS-containing foams are estimated at between 14 000 – 20 000 tonnes per year.
 - Current annual sales of fluorine-free foams are estimated at 7 000 – 9 000 tonnes per year. Historically, this demand would have been served by PFASs containing foams, hence the total annual sales of PFAS-containing foams could have been some 21 000 - 29 000 tonnes.
 - The shelf life of PFAS-containing foams is reported to be typically between 10 and 20 years (and up to a maximum of 30 years)³⁷. Given that foams may be used before the end of their shelf life, the actual lifetime of foams could be shorter. Bipro (2011) suggests that the average lifespan of firefighting foams is 15 years, which appears consistent with the information above and the stakeholder's consultations.

³⁷ Proposal for a restriction: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances
<https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19>

- No reliable information is available regarding the stock of PFAS-foam at EU level. In this report, the total stock has been calculated as a function of the annual sales and the annual usage rates. Under the best estimate scenario, the value of 148 500 tonnes has been calculated³⁸.

2. Impact assessment

2.1. Introduction

The Annex XV restriction dossier on the use of per- and polyfluoroalkyl substances (PFASs) in firefighting foams was prepared at the request of the European Commission. As identified in section 1.1.6, uses of PFASs in firefighting foams are considered to pose a risk to the environment and humans via the environment that is not adequately controlled.

This impact assessment is prepared to assess whether restriction is the most appropriate Risk Management Option (RMO) to control the risks; and to justify which of several Restriction Options (RO) is identified as the preferred option.

The impact assessment estimates the costs and benefits of different ROs. The environmental benefits are described in a qualitative manner including quantified elements on emissions and cost-effectiveness (cost of reducing 1 kg of emission). For sensitivity analysis low, best and high estimates on emissions, costs and cost-effectiveness are reported complemented with one parameter sensitivity analysis. These low and high estimates are also used to present the estimated costs per sector and cost category as ranges, to avoid false impression of accuracy in the results.

The assessment horizon is set to 30 years to allow full substitution of existing stocks after the longest sectoral transition period and shelf lives of the firefighting foams. During a shorter time horizon (such as 20 years), some PFAS-containing foams in use would still not be affected by the restriction. It is assumed that there is no trend in the quantities used or other input parameters. The geographical boundary of the assessment is the EEA, and potential impacts occurring outside the EEA are described qualitatively only.

The proposed restriction comprises the following elements:

- Ban on placing on the market of PFAS-containing firefighting foams
- Ban on use of PFAS-containing firefighting foams
- Ban on export of PFAS-containing firefighting foams
- Transition periods for different sectors and uses
- Concentration limit for PFASs content (including contamination) in foams
- Requirement to implement a PFAS-containing firefighting foams management plan and best practice risk management measures

The first three points (ban on placing on the market, use and export) are covered by the main quantitative impact assessment in this section. The justification for the proposed transition periods is provided qualitatively in Section 2.8.2 and the justification for the proposed concentration threshold is provided in Section 2.8.3. Additional risk management

³⁸ (Wood et al., 2020) estimated a stock between 210 000 and 435 000 tonnes. Comments from stakeholders on the PFHxA restriction proposal indicate that the figure of 62 500 tonnes would be a more realistic figure (e.g. (FFFC, 2020)). However, the Dossier Submitted decided to derive the estimated stock based on the sales figures of PFAS-containing FAS foams (which are more accurately known) and the average annual usage rates indicated by industry stakeholders. See details on the calculations in Appendix 8.

measures (implementation of management plan and best practice RMMs) are described in Section 2.2.5 and justified in Section 2.8.5.

2.2. Analysis of risk management options (RMOs)

In response to the identification of this risk, the Dossier Submitter has conducted an analysis of diverse risk management options (RMOs) to identify the most appropriate option for addressing the identified risks, including various permutations of a REACH restriction.

The Dossier Submitter notes that the Commission's choice to address the risks of PFASs, including in firefighting foams, by means of a restriction under the REACH regulation was part of the recently published 'The EU's chemical strategy for sustainability towards a toxic-free environment'³⁹ (generally referred to as Chemical Strategy for Sustainability or CSS), that included a draft of both legislative and non-legislative initiatives to protect citizens and the environment from harmful chemicals while boosting innovation for safe and sustainable chemicals in Europe. It is part of the EU's zero pollution ambition, which is a key commitment of the European Green Deal.

As a REACH restriction is envisaged to deliver the objectives of the CSS⁴⁰, the assessment of alternative **novel** Union-wide legislative risk management options (RMOs) was not specifically considered by the Dossier Submitter. Instead, it was presumed that during the development of the CSS due consideration was given to the most appropriate means to effectively achieve the strategy's objectives; resulting in the conclusion that a REACH restriction was most appropriate.

The CSS also commits the European Commission to address PFASs via a group approach to prevent regrettable substitution, improve reporting of PFASs releases into the environment (via the Industrial Emission Directive and the European Pollutant Release and Transfer Register), address PFASs via international fora such as the Stockholm Convention and establish financial support for research and innovation of PFASs alternatives as well as remediation practices.

In addition, the Dossier Submitter compared the relative merits of the proposed restriction with risk management via **existing** Union-wide legislation, such as the POPs Regulation (and by extension the Stockholm Convention), the Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD), and the Urban Wastewater Treatment Directive (UWWTD).

The possibility to address the risks posed by PFASs in firefighting foams with other REACH regulatory measures and existing Union-wide legislation and other possible Union-wide RMOs was examined (see section 2.2.1). Measures already taken by Member States and in other jurisdictions are also briefly described below for completeness, as are industry initiatives on PFAS in firefighting foams (see section 2.2.2). Whilst it was recognised - and taken into account when developing the scope of the proposed restriction - that some existing EU legislation or other measures could have an impact on the risk management of

³⁹ https://ec.europa.eu/environment/strategy/chemicals-strategy_en

⁴⁰ The Annex to the CSS indicates the following measure: "Proposal to restrict PFAS under REACH for all non-essential uses including in consumer products" via REACH (Comitology) with a timeline of 2022-24.

certain sectors, approaches other than a REACH restriction were deemed inappropriate to address the uses identified to be contributing to risk that is not adequately controlled.

Annex E.1.3 describes the risk management options other than restriction considered, as well as the reasons for their rejection.

Therefore, the option to use a restriction under REACH to address the identified risks was investigated further (see section 2.2.3).

2.2.1. Overview of current regulatory measures

2.2.1.1. Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants (POPs) restricts at international level the production and use of a number of specific PFASs, namely perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds and perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF). The Convention includes a specific exemption for the use of firefighting foams containing PFOA, its salts and PFOA related compounds and perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride.

PFOS, its salts and PFOSF are listed under Annex B of the Stockholm Convention, which restricts production and use to specified acceptable purposes and specific exemptions. Upon its initial listing in 2009, an acceptable purpose was included under the Convention allowing the use PFOS in firefighting foams⁴¹. At the POP Review Committee (POPRC) meeting in 2018, the committee recommended, based on the findings of an assessment of alternatives to PFOS⁴², that the acceptable purposes for the production and use of PFOS, its salts and PFOSF for firefighting foam be amended to a specific exemption for the use of firefighting foam for liquid fuel vapour suppression and liquid fuel fires (Class B fires) already in installed systems, including both mobile and fixed systems, and with the same conditions put in place for PFOA (see below). This exemption was agreed accordingly at the Ninth Meeting of the Conference of the Parties (COP) to the Stockholm Convention in 2019⁴³.

At their 14th meeting in September 2018, POPRC recommended listing PFOA, its salts and PFOA-related compounds in Annex A to the Convention⁴⁴, including a specific exemption for the use of firefighting foams containing PFOA already installed in systems including both mobile and fixed systems subject to specific conditions. Parties to the Convention can register for this exemption if they: i) ensure that FFFs that contain or may contain PFOA shall not be exported or imported except for the purpose of environmentally sound disposal; ii) do not use firefighting foams that contain or may contain PFOA for training or testing purposes (unless all releases are contained); iii) by the end of 2022 if possible, but no later than 2025, restrict uses of firefighting foams that contain or may contain PFOA, to sites where all releases can be contained; iv) ensure all fire water, waste water, run-off, foam and other wastes are managed. This exemption was also agreed accordingly at the

⁴¹ SC-4/17 :

⁴² UNEP/POPS/POPRC.14/INF/8:

<http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC14/Overview/tabid/7398/Default.aspx>

⁴³ SC-9/4:

<http://www.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP9/tabid/7521/Default.aspx>

⁴⁴ POPRC-14/2:

9th COP meeting in 2019⁴⁵ when listing the PFOA, its salts and related substances in the Annex A to the Convention.

At its fifteenth meeting, the POPRC adopted the risk management evaluation on perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds and recommended to the Conference of the Parties that it consider listing the chemicals in Annex A to the Convention without specific exemptions⁴⁶. The COP will decide on the listing of the substance at its 10th meeting in June 2022. The eventual listing under the Convention would enter into force one year after the date of the communication of its adoption by the depositary for the Convention.

2.2.1.2. EU Regulation

The provisions of the Stockholm Convention and the Aarhus Protocol are implemented in the European Union by the POPs Regulation (EC 2019/1021)⁴⁷. Once the COP adopts a decision to amend the Annex(es) to the Stockholm Convention to list a new substance, the decision needs to be transposed in Union law by amending Annex I, II and/or III of the POPs Regulation. These amendments are done by delegated acts

PFOS, its salts and PFOS related substances were originally restricted in the EU under REACH Annex XVII (entry 53). However, following the addition of PFOS, its salts and PFOSF to the Stockholm Convention in 2009, the entry 53 in Annex XVII to REACH was removed⁴⁸ and the substances were included under the Annex I to the POPs Regulation in 2010⁴⁹. PFOS, its salts and its derivatives are currently listed under Annex I of the POPs Regulation.

The production, placing on the market and use of PFOS, its salts and PFOS-derivatives⁵⁰ on their own, in mixtures or in articles is severely restricted under the POPs Regulation, with no exemptions allowing for the use of the substance in firefighting foams⁵¹.

PFOA and its ammonium salt have been identified under REACH as a SVHCs and included in the Candidate List in 2013 (ED/69/2013). PFOA, its salts and related substances were initially restricted under entry 68 of Annex XVII to REACH. However, following the addition of PFOA to the Stockholm Convention in 2019, the entry 68 in Annex XVII to REACH was removed⁵² and the substances were included under the Annex I to the POPs Regulation⁵³. The production, placing on the market and use of PFOA, its salts and derivatives⁵⁴ on their

⁴⁵ SC-9/12

<http://www.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP9/tabid/7521/Default.aspx>

⁴⁶ POPRC-15/1 :

<http://www.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC15/Overview/tabid/8052/Default.aspx>

⁴⁷ <http://data.europa.eu/eli/reg/2019/1021/2021-03-15>

⁴⁸ <http://data.europa.eu/eli/reg/2011/207/oj>

⁴⁹ <http://data.europa.eu/eli/reg/2010/757/oj>

⁵⁰ Covering substances with the formula: C₈F₁₇SO₂X (X = OH, Metal salt (O-M+), halide, amide, and other derivatives including polymers)

⁵¹ Substances and mixtures containing PFOS, its salts and related substances as unintentional trace contaminant equal to or below 10 mg/kg are allowed to be used and placed on the market.

⁵² <http://data.europa.eu/eli/reg/2020/2096/oj>

⁵³ http://data.europa.eu/eli/reg_del/2020/784/oj

⁵⁴ 'Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds' means the following:

(i) perfluorooctanoic acid, including any of its branched isomers;

(ii) its salts;

(iii) PFOA-related compounds which, for the purposes of the Convention, are any substances that degrade to PFOA, including

own, in mixtures or in articles is severely restricted, but a number of exemptions are included in the POPs Regulation, including a derogation allowing the use of PFOA, its salts and PFOA-related compounds in firefighting foam for liquid fuel vapour suppression and liquid fuel fire (Class B fires) already installed in systems by 4 July 2020, including both mobile and fixed systems, until 4 July 2025, subject to the following conditions:

- (a) firefighting foam that contains or may contain PFOA, its salts and/or PFOA-related compounds shall not be used for training;
- (b) firefighting foam that contains or may contain PFOA, its salts and/or PFOA-related compounds shall not be used for testing unless all releases are contained;
- (c) as from 1 January 2023, uses of firefighting foam that contains or may contain PFOA, its salts and/or PFOA-related compounds shall only be allowed in sites where all releases can be contained;
- (d) firefighting foam stockpiles that contain or may contain PFOA, its salts and/or PFOA-related compounds shall be managed in accordance with Article 5 to the POPs Regulation.

Perfluorohexane-1-sulphonic acid (PFHxS) and its salts, have been identified as SVHCs and included in the Candidate List in June 2017 (ED/30/2017). There is an ongoing restriction proposal for PFHxS, its salts and PFHxS-related substances⁵⁵. The final RAC and SEAC opinion on the restriction proposal was published on 11 June 2020, which includes an exemption allowing the use of concentrated firefighting foam mixtures that are placed on the market 18 months after the entry into force of the restriction. It is expected that PFHxS, its salts and PFHxS-related substances will ultimately also be regulated at EU-level under the POPs Regulation, when its listing to the Stockholm Convention is finalised (see above).

In December 2019, a proposal for a restriction under REACH on PFHxA was published⁵⁶. The proposal includes certain transition periods and derogations for uses in firefighting foams. The proposal indicated that concentrated firefighting foam mixtures placed on the market until 18 months after the entry into force of the restriction could still be used in the production of other firefighting foam mixtures until five years after the entry into force, except for use of firefighting foam for training and testing (if not 100% contained). An exception was proposed for concentrated firefighting foam mixtures for certain defence applications until a successful transition to alternatives can be achieved, and for concentrated firefighting foam mixtures for cases of class B fires in storage tanks with a surface area above 500 m² until 12 years after the entry into force. The opinion of ECHA's Risk Assessment Committee and Committee for Socio-economic Analysis on this restriction proposal was adopted in December 2021.

any substances (including salts and polymers) having a linear or branched perfluoroheptyl group with the moiety (C7F15)C as one of the structural elements.

The following compounds are not included as PFOA-related compounds:

- (i) C8F17-X, where X = F, Cl, Br;
- (ii) fluoropolymers that are covered by CF₃[CF₂]_n-R', where R'=any group, n> 16;
- (iii) perfluoroalkyl carboxylic acids (including their salts, esters, halides and anhydrides) with ≥ 8 perfluorinated carbons;
- (iv) perfluoroalkane sulfonic acids and perfluoro phosphonic acids (including their salts, esters, halides and anhydrides) with ≥ 9 perfluorinated carbons;
- (v) perfluorooctane sulfonic acid and its derivatives (PFOS), as listed in Annex I to POPs

⁵⁵ <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e1827f87da>

⁵⁶ <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d>

See also Annex E.1.3 for additional information on EU legislation in relation with PFASs.

2.2.1.3. Controls in Member States and other jurisdictions

In 2016, The Swedish Chemicals Agency (KEMI) published its strategy for reducing the use of PFASs (KEMI, 2016) beyond solely the implementation of EU legislation. This included specific measures to tackle PFASs in firefighting foams, including a proposal for national regulations covering, for example:

- legal requirement for the collection and destruction of fluorine-based firefighting foam
- imposing reporting requirements
- review of exemptions - with the aim of reducing the number of exemptions as much as possible

In some non-EU countries, there are also regulations in place, specifically targeting PFASs in firefighting foams. For example, in Norway⁵⁷, there are regulations in place that focus on the following:

- The monitoring and screening of PFASs in the environment in general
- The monitoring and clean-up of PFAS polluted soil caused by airport fire drills
- A requirement for airports to monitor levels of PFASs at their fire drill sites and propose measures to reduce pollution
- A requirement for airports to screen and report levels of PFASs in their soil, and must propose measures to reduce pollution

In the USA, at federal level, the US EPA has developed and launched a PFASs Action Plan (US-EPA, 2019) to evaluate whether and how to regulate PFASs compounds under various federal environmental programmes (including TSCA). The primary focus of this plan is to reduce environmental and public health concerns when PFASs are released into the environment (e.g., through setting safe drinking water limits and remediation criteria). While the plan specifically references the use of firefighting foams as a key source of PFAS contamination and exposure, it does not set limits or actions specifically at national level for use of PFASs in foams.

Additionally, the Fiscal Year 2020 National Defence Authorization Act (NDAA) enacted the phase out of the US Department of Defence's use of PFAS-containing firefighting foam by October 2024 (with an exception for shipboard use). However, the Secretary of Defence may waive the prohibition for one year (renewable once for another year until 2026) if duly justified, such as the protection of life and safety or because no agent or equipment solutions are available that meet the military specifications. The NDAA also immediately prohibits the uncontrolled release of aqueous film-forming foam (AFFF) in testing and training, but allows emergency use or non-emergency use if completely contained (US-NDAA, 2020).

It should be noted that several individual US States also implement their own legislation, and there is a wide variety of approaches, measures, and timescales adopted. The Fire Fighting Foam Coalition summarised in July 2021 the main provisions of several states (FFFC, 2021b). As an example of some of the States with the strictest approaches⁵⁸:

⁵⁷ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/norway.htm>

⁵⁸ See also e.g. <https://www.saferstates.com/>

- Washington bans the sale and the use for training purposes of PFAS-containing firefighting foams from 1 July 2020, except for terminals, oil refineries and chemical plants which can use them until 1st January 2024 with a possibility to apply for waivers that could extend until 1st January 2028. Uses required by federal law such as Federal Aviation Administration airports and military uses remain allowed. (US-WA, 2018), (US-WA, 2020).
- In California, a law was adopted in September 2020 restricting the manufacture, sale or use of PFAS-containing firefighting foams from 1 January 2022 except when required by federal law. Additional transition periods apply for certain uses, including for terminal and oil refineries under certain conditions (1st January 2028, with the possibility to apply for waivers that could extend the use until 1st January 2032) (US-CA, 2020).

In Australia, the biggest source of concentrated emissions of PFASs is from historical use of PFAS-containing firefighting foams, particularly at firefighting training grounds. The Industrial Chemicals (Notification and Assessment) Act (ICNA Act), requires industry to provide toxicity data for new substances (including PFASs) or products containing new PFASs being introduced into Australia. Based on the level of toxicity and environmental persistence, the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) recommends restrictions on how these substances can and cannot be used⁵⁹.

The Australian Department of Defence commenced phasing out its use of PFOS and PFOA-containing firefighting foams. Furthermore, PFASs use is also limited by Air Services Australia, a government-owned corporation that provides air traffic control management, which has transitioned away from fluorinated firefighting foam to non-fluorinated firefighting foam including the destruction of remaining stockpiles⁶⁰.

2.2.2. Industry measures

2.2.2.1. Substitution and phase-out

As noted in several documents under the Stockholm Convention, for over a decade, a number of alternatives to the use of C8-based fluoro-surfactants (containing PFASs) in firefighting foams have been developed and are now widely available. These include short-chain (C6) fluoro-surfactants, as well as fluorine-free firefighting foams; and other developing firefighting foam technologies that avoid the use of fluorine.

The use of C8-based AFFF has been largely phased out in favour of these alternatives. For example, it is reported that the volume of AFFF-containing PFOS used in the USA declined from around 21 million litres in 2004 to less than 9 million litres in 2011 (Darwin, 2011).

The POPRC officially recognises that a transition to the use of short-chain per- and polyfluoroalkyl substances (PFASs) for dispersive applications such as firefighting foam is not a suitable option from an environmental and human health point of view and that some time may be needed for a transition to alternatives without PFASs (POPRC-14/3).

In the USA, in 2006, the US EPA launched the PFOA Stewardship Program following concerns raised about the impact of PFOA and long-chain PFASs on human health and the

⁵⁹ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/australia.htm>

⁶⁰ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/australia.htm>

environment, including concerns about their persistence and presence in the environment⁶¹. The programme involved eight major companies⁶² committing to reducing PFOA from facility emissions and product content by 95 percent no later than 2010, and to work toward eliminating PFOA from emissions and product content no later than 2015. All participating companies state in the most recent progress reports, that they met the PFOA Stewardship Program goals⁶³.

2.2.2.2. Containment and control

In Germany⁶⁴, the regulatory authorities and firefighting associations have compiled a leaflet on PFASs in firefighting, which has reportedly resulted in an increased awareness of the risks associated with certain PFASs by industry, NGOs and the public.

In Norway⁶⁵ fluorine-containing firefighting foam has been substituted with fluorine-free alternatives in most civilian airports and fluorine-containing foam is no longer in use at firefighting training sites with the Norwegian defence forces. Furthermore, it is reported that PFASs are being gradually substituted with fluorine free-alternatives in the offshore sector, and the volumes of fluorine-containing foam used in this sector are decreasing.

One respondent to the consultation questionnaire conducted by Wood (Wood et al., 2020) reported that the Swedish Petroleum and Biofuels Institute has previously (2011) provided guidance on how to plan and implement the prevention of spillage and secondary containment embankments, methods for emergency response, and for the assessment and preventing product tanks to lift off inside water filled bunds/embankments. It was estimated that ~80 % of the member companies were in compliance with this guidance.

The trade association, the Fire Fighting Foam Coalition (FFFC) has published a best practice guidance document for the safe use of firefighting foams for Class B fires⁶⁶, with the aim to “foster use of foam in an environmentally responsible manner so as to minimize risk from its use” (FFFC, 2016).

The guidance covers the following aspects of Class B firefighting foam use:

- **Foam Selection** – specifying situations where the use of Class B foams is, and is not, recommended, e.g. limiting the use of Class B foams to situations that present ‘a significant flammable liquid hazard’.
- **Eliminating Foam Discharge** – noting that this is not always possible in emergency situations, but emphasising the possibility to achieve this in training and the testing of foam systems and equipment.

⁶¹ <https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program>

⁶² Arkema, Asahi, BASF, Clariant, Daikin, 3M/Dyneon, DuPont, Solvay Solexis

⁶³ <https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/20102015-pfoa-stewardship-program-2014-annual-progress>

⁶⁴ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/germany.htm>

⁶⁵ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/norway.htm>

⁶⁶ Covering aqueous film-forming foam (AFFF), alcohol resistant aqueous film-forming foam (AR-AFFF), film-forming fluoroprotein foam (FFFP), alcohol resistant film-forming fluoroprotein foam (AR-FFFP), and fluoroprotein foam (FP, FPAR). Document available here: https://b744dc51-ddb0-4c4a-897d-1466c1ae1265.filesusr.com/ugd/331cad_188bf72c523c46adac082278ac019a7b.pdf

- **Training** – providing guidance on the formulation of training foams, the design, construction and operation of training facilities.
- **Foam System Testing** – including guidance on acceptance tests, conducted pursuant to installation of the system; and maintenance tests (i.e. of firefighting vehicles).
- **Containing Foam Discharge** – guidance to prevent discharge to the environment, both for manual and fixed systems.
- **Firewater and foam concentrate disposal** – with an emphasis on incineration but also covering coagulation, flocculation, electro-flocculation, reverse osmosis, and adsorption on granular activated carbon (GAC).

Similarly, the Fire Protection Association Australia (FPA Australia) has published a guidance document on the selection and use of firefighting foams (FPA-AUS, 2020). This covers, for example,

- **Factors impacting on selection and use** – including firefighting performance, environmental impact, system and equipment compatibility
- **Environmental and firefighting performance indicators**
- **Fluorinated and fluorine-free firefighting foams**
- **Environmental best practice** - including training and system testing and commissioning, fire water effluent, remediation of contaminated soil and water, cleaning/change out of existing foams

The consultation did not yield information on the extent to which these best practice measures outlined by the likes of the FFFC and FPA Australia are being implemented, or their effectiveness.

2.2.3. Main restriction options assessed

The following five main REACH restriction options (ROs) have been assessed and are summarised below:

RO 1: Restriction (ban) on the placing on the market of PFAS-containing firefighting foams with different transitional periods per type of use. The use of legacy foams, i.e. foams already in stock at producers' or users' sites, is still permitted.

RO 2: Restriction (ban) on the placing on the market and the use of PFAS-containing firefighting foams with different transitional periods per type of use.

RO 3: Restriction on the export, placing on the market and use of PFAS-containing firefighting foams with different transitional periods per type of use. This restriction option is similar to RO 2 with the additional ban of exports of PFAS-containing firefighting foams at the end of the longest transitional period applicable for the placing on the market in the EU.

RO 4: Restriction on the placing on the market and use of PFAS-containing firefighting foams with different transitional periods per type of use and the provision for a derogation mechanism via the local environmental permit system to which Seveso establishments and defence sites would be eligible. This restriction option is similar to RO 2, however, Seveso establishments and defence sites would not be granted a specific transitional period but the use on these sites would be subject to the temporary approval by the relevant local/national competent authorities in charge of delivering the operating permit to the operator, based on an assessment of the risks to human

health, the environment and other risks such as fire risks and the efforts made to transition to safer alternatives.

RO 5: Restriction of all the uses of PFAS-containing firefighting foams after a transitional period per type of use, unless measures to ensure full recovery and safe disposal of all fire run-off waters and are implemented.

Additional details on the ROs are provided in Annex E.1.1.

In addition, for all the restriction options described above, additional risk management measures during the transitional periods have been considered, which are described in section 2.2.5.

2.2.4. Other risk management options not assessed in detail

Additional regulatory risk management options have also been considered but not assessed in detail for the reasons described below:

- a. Restriction of a few uses only, others derogated until suitable alternatives are found (based on reporting and restriction review) and full containment of releases*

The restriction would entail:

- A ban on the use of PFAS-containing firefighting foams in training, testing and municipal fire services only, after a short transitional period;
- the other uses would be allowed (derogated) until suitable alternatives are found
- an annual reporting requirement would apply to the derogated firefighting foam users (reporting to ECHA) about their use of PFAS-containing firefighting foams and availability of alternatives
- a periodic review of the restriction by the Commission would be implemented for the update of the derogations
- the mandatory collection of all PFAS-containing waste and their adequate treatment, minimising releases of PFASs to environmental compartments.

This RO is a derivative from RO 5 described above and has not been taken forward for the same reasons. Even though the uses where suitable alternative already exist would be banned, the derogated uses are likely to continue for an extensive period of time due to a much weaker incentive for substitution than a clearly indicated ban date.

The requirement for the complete collection of firewater (i.e. also for incidents management) is unlikely to be technically or economically implementable in practice for most sectors in case of small or large fire incidents due to the type of terrain and infrastructures. Large sites such as airports (covering all air strips, taxi runways, plane waiting zones, fuel storage sites, etc.), defence training sites (being mostly unpaved, irregular terrains with vegetation and obstacles) or smaller sites such as intervention sites of municipal brigades, offshore oil platform and marine ships are all types of use of firefighting foams where a full capture of fire waters in case of a fire incident are highly unlikely.

Regarding the annual reporting requirement of users to ECHA, this would entail the need for significant additional resource for ECHA in terms of IT development and staff time to process and analyse the data (these resource needs have not been quantified). The Commission would also have additional resource needs to make

use of the collected information and regularly assess the need for ending the derogations. The required additional resources have not been quantified.

- b. Restriction of a few uses only, other uses would be subject to authorisation under REACH Title VII*

This risk management option would entail:

- A ban on the use of PFAS-containing foams in training, testing and municipal fire services only, after a short transitional period;
- The other uses would also be banned unless they are applied for an authorisation under REACH Title VII Chapter 2 and the authorisation granted.

This risk management option has not been taken forward in the assessment for the following reasons: it would require the identification of all PFASs as Substances of Very High Concern (many as substances of equivalent concern), inclusion in the Candidate List and Authorisation List which would be a cumbersome, uncertain and unlikely and would encompass all uses of PFASs (covered by the Authorisation title), i.e. not only the use in firefighting foams. In addition, the fire safety aspects for major accidents are already dealt with under the Seveso Directive.

2.2.5. Proposed restriction option

The proposed restriction option is RO 3:

Restriction on the export, placing on the market and use of PFAS-containing firefighting foams with different transitional periods per type of use. The ban on export would apply at the end of the longest transitional period applicable for the placing on the market in the EU (i.e. ten years after entry into force of the restriction). During the transitional periods corresponding to each type of use, additional risk management measures described in section 2.8.5. would apply to minimise the emissions of PFASs in the environment as long as technically and economically feasible.

This RO is considered to be the most effective in reducing the emissions of PFASs in the environment while providing clearly defined deadlines for transitioning to alternatives without compromising fire safety. The transitional periods are adapted to each type or sector of use based on the availability of suitable alternatives and provide a clear signal to manufacturers to invest in the development of alternatives for all types of uses and a clear signal to users in starting to implement the transition by testing the alternatives and – where needed- making the technical and organisational adaptations.

The ban on exports after the longest transitional period would allow a further reduction of emissions from the foam formulation and storage taking place in the EU. In addition, this approach is in line with the EU Chemicals Strategy for Sustainability which states that “*The EU will [...] lead by example, and, in line with international commitments, ensure that hazardous chemicals banned in the European Union are not produced for export, including*

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

by amending relevant legislation if and as needed”⁶⁷. This approach is particularly relevant for PFAS considering their persistence and their potential for long range transport.

The detailed restriction conditions are the following:

Restriction on the export, placing on the market and use of PFASs in firefighting foams.

Column 1	Column 2
Per- and polyfluoroalkyl substances (PFASs) defined as: any substance that contains at least one fully fluorinated methyl (CF₃) or methylene (CF₂) carbon atom (without any H/Cl/Br/I attached to it). [The ancillary requirement in paragraph 7 of column 2 of this entry applies to all firefighting foams, whether or not they contain a substance falling within this column of this entry.]	1. Shall not be placed on the market or exported as substances on their own, as a constituent in other substances or in mixtures for use in firefighting foam concentrates where the concentration of total PFASs is greater than 1 ppm⁶⁸ 10 years after entry into force. 2. Shall not be used on their own, as a constituent in other substances or in mixtures in firefighting foam concentrates where the concentration of total PFASs is greater than 1 ppm. 3. Paragraph 2 shall apply from: a. 18 months after entry into force for training and testing (except testing of the firefighting systems for their function); b. 18 months after entry into force for municipal fire services (except if also in charge of industrial fires for establishments covered by Directive 2012/18/EU (Seveso III) and for use in these establishments only); c. three years after entry into force for civilian ships; d. five years after entry into force for portable fire extinguishers as defined by EN3-7; e. 10 years after entry into force for establishments covered by the Directive 2012/18/EU (Seveso III)⁶⁹ (upper and lower tiers); f. five years after entry into force for all other uses not covered by paragraphs 3(a), 3(b) 3(c), 3(d) and 3(e). 4. Without prejudice to paragraph 3, six months after entry into force users of firefighting foam

⁶⁷ 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 - COM(2020) 667 final, 2020, available at https://eur-lex.europa.eu/resource.html?uri=cellar:f815479a-0f01-11eb-bc07-01aa75ed71a1.0003.02/DOC_1&format=PDF

⁶⁸ Corresponding to 1 000 ppb, or 0.0001% (w/v).

⁶⁹ Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Column 1	Column 2
	concentrates where the concentration of total PFASs is greater than 1 ppm shall: a. ensure that firefighting foam concentrates are only used for fires involving flammable liquids (class B fires); b. minimise emissions to the environment and direct and indirect exposures to humans of firefighting foams to the extent that is technically and economically feasible. c. establish a site-specific 'PFAS-containing firefighting foams management plan' which shall include: i. a justification for the use of each firefighting foam concentrate where the concentration of total PFASs is greater than 1 ppm (including an assessment of the technical and economic feasibility of alternatives). ii. details of the conditions of use and disposal of each PFAS-containing foam used on site specifying how paragraph 4(b) is achieved (including plans for the containment, treatment and appropriate disposal of liquid and solid wastes arising in the event of foam use, routine cleaning and maintenance of equipment or in the event of accidental leakage/spillage of foam). iii. The management plan shall be reviewed at least annually and be kept available for inspection by enforcement authorities on request. d. Ensure that the collected PFAS-containing waste with a concentration of PFASs above the one mentioned in paragraph 2 shall be handled for adequate treatment. The treatment shall minimise releases of PFASs to environmental compartments as far as technically and practically possible and shall exclude municipal wastewater treatment, irrespective of any pre-treatment. For each event of foam use or accidental spillage or leakage, proof of appropriate management and disposal of the foam concentrates, water-added foams and fire run-off waters shall be

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Column 1	Column 2
	documented and kept available for enforcement authorities. 5. From six month after entry into force, firefighting foam concentrates containing PFASs above the threshold indicated in paragraph 1 which are held in stock and need to be disposed of shall be handled for adequate treatment. The treatment shall minimise releases of PFASs to environmental compartments as far as technically and practically possible and excluding any wastewater treatment, irrespective of any pre-treatment. Proof of appropriate disposal shall be documented and kept available for enforcement authorities. 6. From six months after entry into force, packaging of firefighting foam concentrates placed on the market or used, containers of firewater runoffs or other PFAS-waste in relation with the use of firefighting foams or the cleaning of firefighting foam equipment in concentrations above the one mentioned in paragraph 1 shall be labelled indicating the presence of PFASs above this threshold with the following wording: "WARNING: Contains per and polyfluoroalkyl substances (PFASs)". This information shall be displayed in a clear and visible manner in the official language(s) of the Member State(s) where the firefighting foam concentrate is placed on the market, unless the Member State(s) concerned provide(s) otherwise. 7. [From six months after entry into force, packaging of firefighting foam concentrates placed on the market containing organofluorine substances above 1 ppm, but where the concentration of total PFASs is not greater than 1 ppm, shall be labelled: "Contains non-PFAS organofluorine substances with a total organofluorine concentration of (<i>insert concentration</i>) ppm". This information shall be displayed in a clear and visible manner in the official language(s) of the Member State(s) where the firefighting foam concentrate is placed on the market, unless the Member State(s) concerned provide(s) otherwise.]

The restriction entry does not prescribe any specific disposal method. Based on the collected information, the disposal of PFAS-containing waste in hazardous waste incinerator and cement kilns are currently considered as best available techniques. However, the Dossier Submitter underlines the fact that few field studies on the fate and emissions of PFASs resulting from these disposal techniques are available and calls for more research

in the field to confirm the effectiveness of the destruction of PFASs. Other, new disposal techniques are also being developed but their effectiveness and applicability at industrial scale needs to be demonstrated.

Explanatory notes:

- (1) "Testing of the firefighting systems for their function" means testing the fire protection system in the same way as it would operate in case of emergency. Other types of testing include but are not limited to: testing of foam agents during their development phase, testing of foam agents by users to evaluate products' suitability on specific combustibles, testing of correct proportioning of firefighting foam concentrates.
- (2) Municipal fire services (i.e. local authority fire and rescue services) are covered under the restriction entry 3 (b.), except if they are also in charge of industrial fires for establishments covered by the Seveso-III Directive and for use in these establishments only. In this case, the transitional period of paragraph 3(e) applies.
- (3) Other uses of firefighting foams include – but are not limited to -: civilian aviation, defence, aerospace, offshore oil/gas/chemical facilities, onshore oil/gas/chemical manufacturing or processing facilities which are not covered by paragraph a. (Seveso establishments), power plants, glass manufacturers, waste treatment facilities, food processing industry, metal processing, etc.
- (4) The use of PFAS-containing foam agents in portable fire extinguishers are covered by paragraph 3(d), with a proposed transitional period of five years, irrespective of the sector of use, i.e. their use would be continued to be allowed during this period even if the sector where they are used is subject to a shorter transitional periods (e.g. ships).
- (5) "Civilian ships" refers to marine and non-marine civilian ships.
- (6) Foam concentrates are the foam formulations purchased by the users and which are further mixed with water at the moment of the use. Water-added foams are the foam concentrates mixed with water at the moment of the use. Fire run-off waters (or "firewater runoff") are the run-off waters containing the firefighting foam concentrate mixed with water and all other elements mixed with them during the use of the firefighting foam during a fire incident, training or other use (e.g. flammable liquids, dirt, etc).
- (7) The labelling of the containers containing PFASs above the threshold indicated in paragraph 1 aims at facilitating the identification and handling of the PFAS-containing foam concentrates, firewater runoff and waste.
- (8) Placing on the market after 10 years is banned as the use is not allowed in any of the sectors or uses anymore at that time.
- (9) The ancillary requirement detailed in paragraph 7 is intended to facilitate the enforcement of the proposed restriction by means of 'total fluorine' analytical methods, rather than targeted analysis of specific PFAS. The utility of this requirement shall be reviewed after the consultation on the Annex XV report.

2.3. Overview of impacts

Under RO 1, manufacturers and importers will be allowed to place PFAS-containing foam concentrates on the market for specific types of uses and sectors until the end of the specific transitional periods. The manufacture for export would still be allowed without time limit. Users of PFAS-containing foams will be allowed to use the PFAS-containing foams concentrates as long as they have them in stock but will not be able to make additional purchases after the end of the transitional period corresponding to the use concerned. A progressive reduction in the use of PFAS-containing foams is expected with a concomitant progressive increase of the use of the fluorine-free alternatives. Since continued use is allowed, the restriction would not lead to early disposal of PFAS-containing foam

concentrates (i.e. the PFAS-containing foams would be used until the end of their shelf life). Users would benefit from extended periods to transition to alternatives. Six months after the entry into force of the restriction, additional risk management measures would apply that aim to reduce the amounts of PFAS-containing foams used and at collecting the firewater runoff and other PFAS waste to the extent that is technically and economically feasible.

Under RO 2, manufacturers and importers will be allowed to place PFAS-containing foam concentrates on the market during ten years and users will be allowed to use these foams until the end of the transitional periods corresponding to their sector/type of use, after which the safe disposal of the remaining PFAS-foam stocks will be required. The manufacture for export would still be allowed without time limit. During the transitional periods, the required further testing of alternatives and adaptation of firefighting foam equipment will take place progressively to ensure transition by the end of the transitional period. Similarly to RO 1, six months after the entry into force of the restriction, additional risk management measures would apply that aim to reduce the amounts of PFAS-containing foams used and at collecting the firewater runoff and other PFASs waste to the extent that is technically and economically feasible.

RO 3 is similar to RO 2 but with an additional ban of the manufacture for export after ten years (longest transitional period of the use/sector-specific transitional periods). Emissions of PFASs from the formulation stage in the EU would stop after the ban manufacturers would incur surplus losses.

RO 4 bans the use in a similar way as RO 2 with the exception that use of PFAS-containing foams at Seveso establishments and defence sites would not be assigned a transitional period. Instead, to be able to continue using PFAS-containing foams after the entry into force of the restriction, these establishments and sites would be required to apply for it via the local/national competent authorities that deliver operating permits. The Dossier Submitters considers that the incentive for substitution for these sectors is much weaker under this RO and assumes that most of these users would apply for a continued use and be granted an authorisation for a total period of ten years (expected time for a transition to alternatives for the Seveso establishments), and that the progressive transition would actually only take place after this period of ten years. In other words, a relative steady-state use of PFAS-containing foams in these sectors would be observed during ten years, followed by a linear decline until a full transition 20 years after the entry into force of the restriction. Users other than at Seveso establishments and defence sites would follow the same transition pattern as envisaged under RO 2. The same requirement for risk management measures as in RO 2 would apply for all types of uses and exports would similarly be allowed without time limit.

RO 5 bans the use in a similar way as RO 2 with use/sector-specific transitional periods, however, users able to demonstrate a minimisation of the emissions of PFASs would be allowed to continue using PFAS-containing foams without time limit. In practice, the Dossier Submitter assumes that only Seveso establishments would possibly be able to meet this requirement and that most of them would take advantage of this allowed continued use for at least the assessment period considered in this restriction proposal (30 years after entry into force). This would result in lower but continued emissions of PFASs since risk management measures in the context of firefighting are unlikely to be 100% effective. The users not being able to meet the requirement for a minimisation of the emissions of PFASs would need to transition to fluorine-free alternatives in the same pattern as RMO 2 and with the same requirement during the transitional period to apply

the risk management measures to the extent technically and economically feasible. Exports would be allowed without time limit.

The two figures below summarise the main effects (i.e. anticipated responses from the supply chains along with associated impacts) resulting from the different risk management options.

The impacts of these ROs are analysed in detail in Annex E, Sections E.4, E.5 and E.6.

pre-publication – do not cite

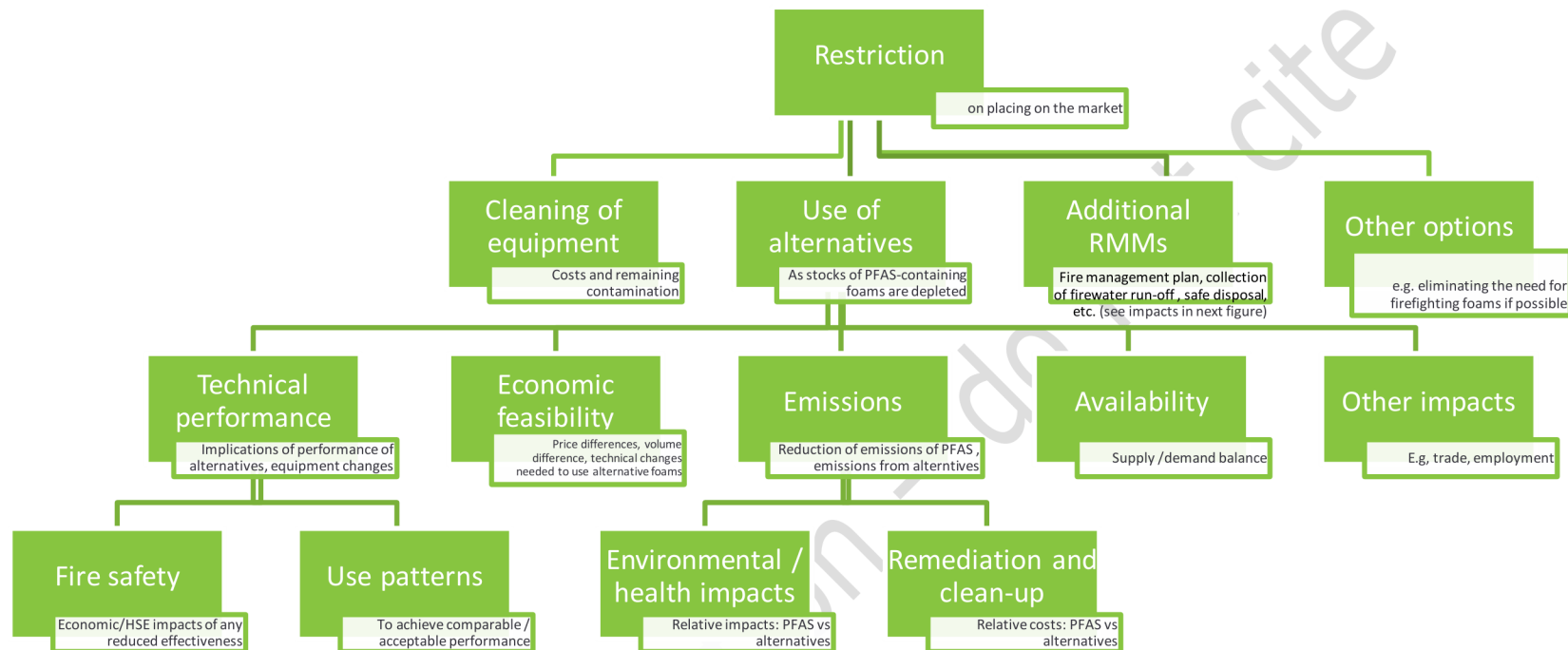


Figure 6. Schematic summarising potential effects of a restriction on the placing on the market of PFAS-containing firefighting foams (RO 1)

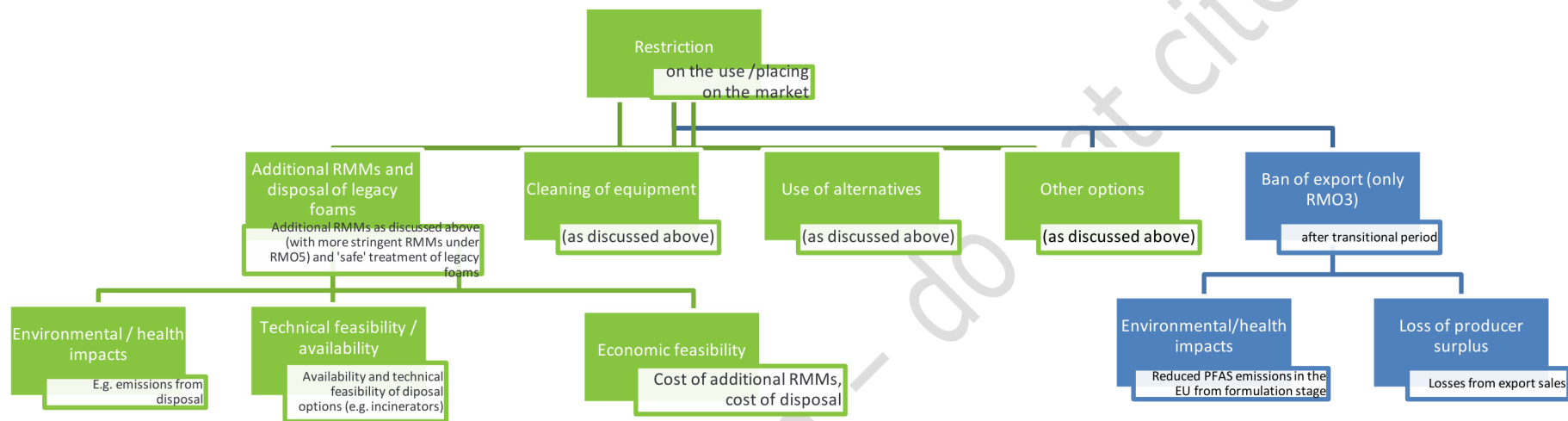


Figure 7. Schematic summarising potential effects of a restriction on the use /placing on the market of PFAS-containing firefighting foams (RO 2, 3, 4 and 5)

2.4. Economic impacts

The proposed transitional periods are set to allow the development of fluorine-free firefighting foams and the adaptation of existing firefighting systems while providing a similar level of fire protection as under the use of PFAS-containing foams. For this reason, specific transition periods by application and use sector are proposed (see Table 3 and justifications in section 2.8.2) and these are reflected in the estimated costs for each use/sector.

Table 3. Proposed transitional periods for the restriction per sector/type of use

Sector/type of use or placing on the market	Transitional period from the entry into force
Seveso establishments	10 years
Other industries	5 years
Civilian aviation	5 years
Defence	5 years
Municipal fire services	18 months
Ready-to-use applications	5 years
Marine applications	3 years
Training and testing	18 months
Export	10 years

The following cost categories were monetised in the assessment of economic impacts:

- **Cost of using alternative foams:**
This cost element considers the difference in prices between PFAS-containing and fluorine-free foams, and additional volumes of fluorine-free foams needed to achieve the same level of fire protection.
- **Depreciation of existing stocks:**
For ROs restricting the use of firefighting foams already in stock, the lost value of the foams is estimated.
- **Cost of technical changes needed to adapt equipment for the use of alternative foams:**
Technical changes are needed to use fluorine-free foams, e.g. changes in firefighting nozzles, heavy duty applicators, specialist equipment and mobile foam units.
- **Incineration/disposal costs of PFAS-containing foams:**
This category could potentially represent both costs and savings. If use of existing foams is banned, these foams would have to be disposed of safely introducing costs to the industry. On the contrary, alternative foams do not require incineration if they expire. As the assumptions made in the analysis imply that existing foam would be used before it expires (in 15 years), only the cost of incinerating existing foam stocks (for ROs with use ban) is considered.
- **Savings resulting from avoided clean-up:**
Savings for some users may occur in the case of avoided clean-up of contaminated land after a fire incident. Clean-up is considered to result from recent activity which is often still ongoing at the site. This is different from remediation which is carried out

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

due to historical activities (see Annex E.4.3 for further information on clean-up and remediation).

- **Cost of cleaning equipment to comply with the proposed concentration threshold:**
To comply with the proposed concentration limits, firefighting equipment needs to be cleaned to avoid residual amounts of PFASs in the fluorine-free foams.
- **Cost of additional RMMs for training/testing and incidents:**
The ROs contain a requirement to safely use PFAS-containing foams during the transitional periods. This could include collection and disposal of fire water run-off.
- **Producer surplus loss due to export ban (only for RO3):**
Producers of PFAS-containing foams lose profits if not being allowed to sell their products to non-EEA countries. No producer surplus changes are calculated for the sales within the EEA. This is because quantities of alternative foams produced and sold in the EEA are considered to increase due to the need to maintain the same level of fire protection. Furthermore, possible changes in production costs are already covered by the price element in the calculation of cost of using alternative foams.
- **Cost of full containment of the foams (only for RO5):**
RO 5 allows continued use of PFAS-containing foams if the releases are minimised. This would require technical adaptations to achieve full containment.

A more detailed description of the cost categories and how they have been estimated is provided in Annex E.4. Sector-specific unit costs are used for monetising technical changes needed to use alternative foams and the cleaning of existing equipment.

There are also significant savings in terms of reduced remediation of contaminated sites. However, these have been considered as part of the benefits of the proposed restriction as described in the benefit and proportionality assessment in section 2.8.

Furthermore, large savings resulting from avoided contamination of drinking water resources can also be expected to benefit drinking water suppliers. Based on section 1.1.4, release reduction would avoid extensive drinking water contamination and thereby considerable costs of development and implementation of efficient drinking water purification techniques. These (unquantified) savings are also considered as part of the benefits assessment (section 2.8).

Table 4 summarises the estimated economic impacts for each RO and each cost category.

Table 4. Estimated economic impacts for each RO and cost category

Cost category	RO1 (NPV € over 30 years)	RO2 (NPV € over 30 years)	RO3 (NPV € over 30 years)	RO4 (NPV € over 30 years)	RO5 (NPV € over 30 years)
Cleaning of equipment	2.0 billion (1 to 4 billion)	2.5 billion (1 to 5 billion)	2.5 billion (1 to 5 billion)	2.1 billion (1 to 4 billion)	1.2 billion (0.6 to 2.4 billion)
Technical changes needed	3.5 billion (2 to 11 billion)	3.5 billion (2 to 11 billion)	3.5 billion (2 to 11 billion)	2.6 billion (1 to 8 billion)	300 million (150 to 900 million)
Disposal / incineration of foams	0	110 million (100 to 140 million)	110 million (100 to 150 million)	61 million (55 to 80 million)	67 million (60 to 80 million)

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Depreciation of stocks disposed	0	170 million (150 to 200 million)	170 million (150 to 200 million)	92 million (80 to 120 million)	100 million (90 to 130 million)
Cost of alternative foams	260 million (-60 to 700 million)	480 million (-0.1 to 1 billion)	480 million (-0.1 to 1 billion)	330 million (-80 to 900 million)	300 million (-70 to 800 million)
Savings due to avoided clean-up	73 million (100 to 40 million)	120 million (240 to 60 million)	120 million (240 to 60 million)	91 million (50 to 180 million)	78 million (40 to 150 million)
Cost of export ban (producer surplus)	not applicable	not applicable	8 million (4 to 24 million)	not applicable	not applicable
Cost of additional RMMs for training/testing and incidents	96 million (60 to 200 million)	60 million (30 to 120 million)	60 million (30 to 120 million)	105 million (50 to 200 million)	59 million (30 to 120 million)
Cost of full containment	not applicable	not applicable	not applicable	not applicable	13 billion (6 to 40 billion)
SUM	5.9 billion (3 to 16 billion)	6.8 billion (3 to 17 billion)	6.8 billion (3 to 17 billion)	5.2 billion (2 to 13 billion)	15 billion (7 to 40 billion)

The proposed restriction includes a requirement to use PFAS-containing foams safely during the transition periods by applying sector-specific best practices to the extent that these are technically and economically feasible. In the absence of information on the actual measures that are feasible in different sectors and for different users, the Dossier Submitter estimated these costs based on the disposal costs of PFAS-containing foams used for training and incidents. The additional cost of this requirement is presented in Table 4 under the cost category 'Cost of additional RMMs for training/testing and incidents'. This requirement is estimated to cost €30 to €200 million (NPV over 30 years).

The results suggest that the most significant cost categories are related to technical changes needed to use alternative foams followed by the costs of cleaning equipment. These are also the cost elements that are based on sector-specific assumptions about unit costs (see section 3 on assumptions and Annex E.4).

Table 5 presents the impacts per affected industrial sector.

Table 5. Estimated economic impacts for each RO and industrial sector

Sector/type of use	RO1 (NPV € over 30 years)	RO2 (NPV € over 30 years)	RO3 (NPV € over 30 years)	RO4 (NPV € over 30 years)	RO5 (NPV € over 30 years)
Seveso establishments	4.5 billion 2 to 12 billion	4.9 billion (2 to 13 billion)	4.9 billion (2 to 13 billion)	3.3 billion (2 to 9 billion)	13 billion (7 to 40 billion)
Other industries	20 million 6 to 50 million	27 million (9 to 60 million)	27 million (9 to 60 million)	27 million (9 to 60 million)	27 million (9 to 60 million)

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Civilian aviation	38 million 0* to 100 million	70 million (6 to 160 million)	70 million (6 to 160 million)	70 million (6 to 160 million)	70 million (6 to 160 million)
Defence	25 million 0* to 65 million	45 million (3 to 100 million)	45 million (3 to 100 million)	15 million (0.4 to 40 million)	45 million (3 to 100 million)
Municipal fire services	980 million 0.5 to 2 billion	1.2 billion (0.6 to 3 billion)	1.2 billion (0.6 to 3 billion)	1.2 billion (0.6 to 3 billion)	1.2 billion (0.6 to 3 billion)
Ready-to-use applications	2.5 million 0* to 8 million	7 million (0* to 15 million)	7 million (0* to 15 million)	7 million (0* to 15 million)	7 million (0* to 15 million)
Marine applications	300 million 100 to 700 million	390 million (150 to 900 million)	390 million (150 to 900 million)	390 million (150 to 900 million)	390 million (150 to 900 million)
Training and testing	35 million 0* to 100 million	130 million (0* to 310 million)	130 million (0* to 310 million)	130 million (0* to 310 million)	130 million (0* to 310 million)
SUM	5.9 billion (3 to 16 billion)	6.8 billion (3 to 17 billion)	6.8 billion (3 to 17 billion)	5.2 billion (2 to 13 billion)	15 billion (7 to 40 billion)

* For some sectors the analysis suggests negative costs based on lower bound estimates. This is because of the assumption made for the prices of PFAS-containing and PFAS-free foams and the potential savings from avoided clean-up. This does not seem to be a plausible outcome and for these sectors the lower bound costs are reported as zero in the table.

The costs presented in Table 5 show that the highest economic impacts are expected for Seveso establishments. This is due to high quantities of firefighting foams used in this sector as well as more expensive technical changes needed to maintain the same level of fire safety when using alternative foams.

The cost analysis results in the following key results. RO1 describes a ban on placing on the market of PFAS-containing foams with an estimated cost of €5.9 billion (ranging between €3 and €16 billion) (NPV over 30 years). RO2 additionally bans the use of foams already placed on the market but not yet used. In comparison to RO1, the additional cost to cover this use is estimated to be €0.9 billion (ranging between €0.4 and €1.7 billion) (NPV over 30 years). RO3 further bans the export of PFAS-containing foams after a transition period of 10 years. The additional cost to cover exports as compared to RO2 is estimated to be €8 million (ranging between €4 and to €24 million) (NPV over 30 years). As expected, the total costs for RO4 are lower than for RO3 because some industry sectors (Seveso establishments and defence) would benefit from a permit system and could continue using PFAS-containing foams for a longer time. The significantly higher estimated costs for RO5 reflect the technical challenges necessary to achieve full containment.

2.5. Human health and environmental impacts

All PFASs are very persistent in the environment. Many PFASs are likely to persist in the environment longer than any other man-made organic substance. As a consequence, if releases are not minimised, humans and other organisms will be exposed to progressively increasing amounts of PFASs until such levels are reached where effects are likely. In such an event the exposures are practically irreversible. Even if further releases of PFASs were immediately prevented, existing environmental stocks would continue to be a source of exposure for generations. There are several additional concerns arising from the use of PFASs, e.g., that a ubiquitous contamination of drinking water resources is unavoidable unless releases are minimised. Human exposures occur efficiently via all environmental exposure routes and cannot be avoided or mitigated. Some PFASs can accumulate in plants, others have bioaccumulation potential in biota and humans. Exposures are also transmitted effectively to unborn and breastfeeding children. Humans and biota are exposed to a complex mixture of PFASs and combined effects are likely. For further details, see section 1.1.4 and section 1.1.6.

Use of PFASs in firefighting foams is substantially contributing to long-term general human and environmental exposures of PFASs besides other uses. The proposed restriction is providing a partial solution to the need to prevent the increase of general PFAS-exposures. However, specific to the use of PFASs in firefighting foams, the potential to contaminate local environments, where firefighting, equipment maintenance and training take place, is high (see Annex C.4.3). The proposed restriction directly prevents such contaminated sites to be formed in future.

The environmental persistence of the assessed non-fluorinated alternatives is considerably lower than that of PFAS compounds.

It is not possible to quantify the human health and environmental impacts of avoided releases. Following the SEAC approach for evaluating PBT and vPvB cases, the avoided released quantities of PFASs are used as a proxy of the environmental and human health risks, and thus of human health and environmental impacts of the proposed restriction.

The evolution of emissions of PFASs to the environment over a 30-year assessment period was estimated in Excel for each of the five RO scenarios, maintaining the following main assumptions:

- RO1: ban on placing on the market after a transitional period per type of use or sector but use allowed until depletion of stocks;
- RO2: ban on placing on the market after ten years and use banned after transitional periods per type of use or sector;
- RO3: same as RMO2 but in addition, taking into account the emissions from formulation for export which are banned after a transitional period of ten years;
- RO4: ban on use after sector/use-specific transitional periods, considering a progressive decline of oil/chemical (Seveso establishments) and defence uses after ten years to simulate the effect of a gradual substitution in these sectors due to the pressure induced by the permit system;
- RO5: ban on use after sector/use-specific transitional periods, considering that only the Seveso establishments would be able to meet the requirement for full containment after the transitional periods, i.e. considering that all uses would stop after their respective transitional period, except Seveso establishment which would continue

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

using PFAS-containing foams at the same level during the entire assessment period of 30 years.

The risk management measures described in the proposed restriction entry have been considered in the emission modelling for all ROs.

As for the baseline, using a source-flow model and several assumptions that are outlined in section 3, in Annex E.5.2 and in Appendix 8 the material flow and emissions per environmental compartments occurring at the different life cycle steps have been calculated for each RO.

In addition, as sensitivity analysis, “Best”, “Low” and “High” estimates scenarios were calculated for each ROs using different values for several input parameters (see section 3).

Compared to the baseline, additional risk management measures are proposed in the five ROs to reduce the emissions of PFASs from the continued use during the transitional periods. Among them, all ROs foresee the collection of all PFAS releases, especially those originating from the use of the firefighting foam in training, testing and live incidents. The safe disposal of remaining stock of firefighting foam concentrates after the end of the transitional periods is also foreseen under certain ROs. Figure 8 schematically describes the emissions expected from the in-use phase under the five ROs. The emission modelling takes these emission sources into account.

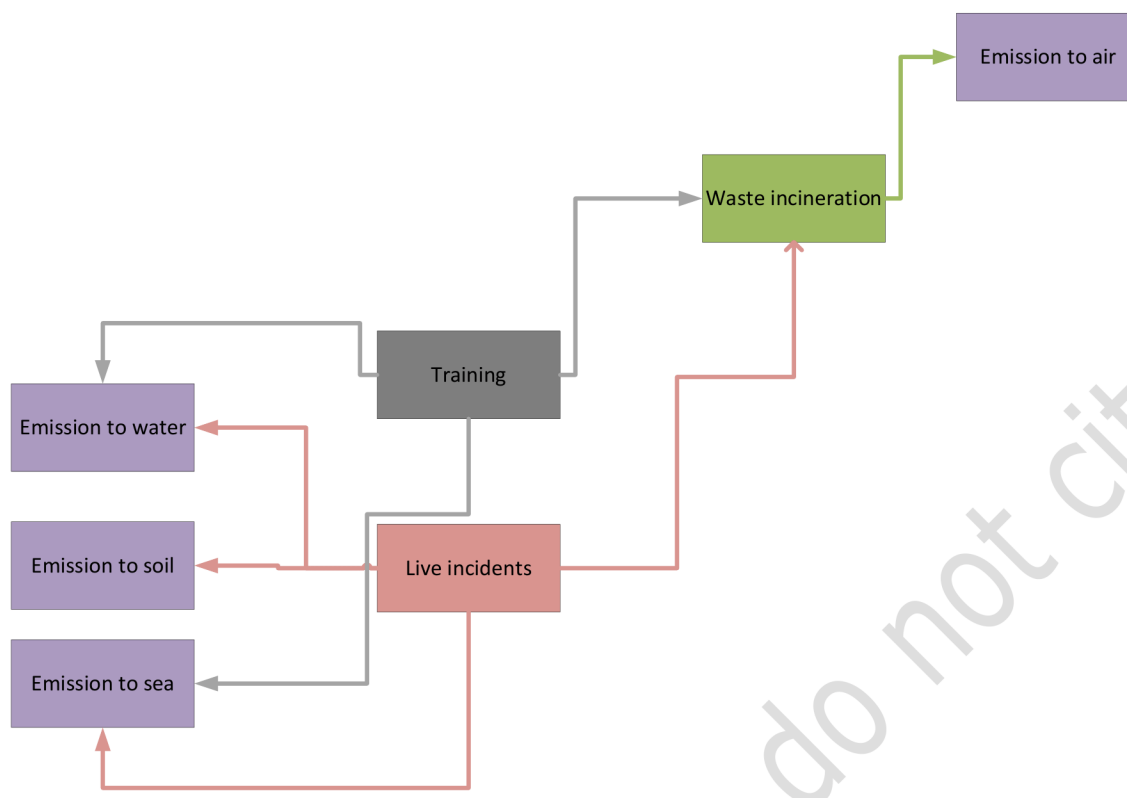


Figure 8. Material flow diagram for the life cycle stages training and incidents, including RMMs as foreseen in all the ROs.

Avoided emissions under the different ROs

For each RO, total avoided emissions of PFASs in the environment over 30 years, compared to the baseline have been calculated. To illustrate the impact of the additional risk management measures proposed under each RO (reduction of emissions as technically and economically feasible, i.e. maximisation of collection and safe disposal for training/testing and incidents), in addition to the progressive phase out, simulations have also been done with and without these risk management measures. These are summarised in Table 6 below and documented in Annex section B.9.

Table 6. Total avoided PFAS emissions over 30 years, compared to the baseline, using the best estimate scenarios (low and high scenario in brackets), with and without (t PFASs, figures rounded)

RO	Total avoided PFAS emissions over 30 years, with risk management measures (t PFASs)	Total avoided PFAS emissions over 30 years, without risk management measures (t PFASs)
RO1	11 800 (7 600 – 15 000)	7 900 (5 300 – 10 500)
RO2	13 000 (8 000 – 16 600)	11 200 (6 900 – 14 900)
RO3	13 200 (8 000 – 16 800)	11 300 (7 000 – 15 000)
RO4	12 600	8 800

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

	(7 900 – 14 500)	(5 500 – 12 500)
RO5	12 500 (7 900 – 14 400)	6 700 (4 500 – 8 900)

Note: Baseline emissions of PFASs over 30 years are estimated at 14 100 tonnes in the EU.

RO3 is the RO which is calculated to lead to the greatest PFAS emissions reduction, up to 13 200 tonnes over 30 years. In contrast, RO1 is the RO which leads to the smallest emissions reduction with around 11 800 tonnes. The calculations also show the large impact of the proposed additional risk management measures on the emission reductions.

The evolution of the emissions over the assessment period for each RO with and without RMMs, for each sector/type of use has been modelled and the results presented in Annex E.5.2 and in Appendix 8.

Table 7 summarises the best estimates of the avoided emissions for each RO per sector/type of use. These are used to estimate the cost-effectiveness ratios in the proportionality section. Estimations of the low and high emissions scenarios and the evolution of annual and cumulative emissions (over the assessment period) of PFASs in the environment under the main ROs and with different transitional periods per type of use are presented in annex section F.5.2 and in Appendix 8. Estimates of cumulative emissions to the environment should not be interpreted strictly as equivalent to environmental stocks. This is due to the large uncertainties in predicting future exposures for PFASs, as concluded in section 0.

Table 7. Estimated avoided emissions of PFASs (best estimate) for each RO and sector or type of use, compared to the baseline

Sector/type of use	RO1 (tonnes over 30 years)	RO2 (tonnes over 30 years)	RO3 (tonnes over 30 years)	RO4 (tonnes over 30 years)	RO5 (tonnes over 30 years)
Seveso establishments	6087	6232	6281	5966	5653
Other industries	128	131	132	131	131
Civilian aviation	810	940	950	940	940
Defence	540	627	633	440	627
Municipal fire services	1095	1473	1489	1473	1473
Ready-to-use applications	84	117	118	117	117
Marine applications	939	1266	1280	1266	1266
Training and testing	2129	2244	2269	2244	2244
All sectors (rounded numbers)	11 800	13 000	13 200	12 600	12 500

Notes:

- (1) Baseline emissions of PFASs over 30 years are estimated at 14 100 tonnes in the EU.
- (2) Except where indicated, the results are not rounded to show the difference in the risk reduction capacity of different restriction options (i.e. avoided emissions). This should not be interpreted as suggesting accuracy in the results.

The modelling used suggests that RO1 results in reduced emissions of around 11 800 tonnes over 30 years. By restricting the use of the foams already placed on the market (RO 2) additional releases of around 1 200 tonnes could be avoided. RO3 would also restrict the

export of foams and provide additional release reduction of around 120 tonnes (based on more exact figures that reported above in the table). As could be expected, the avoided releases estimated for RO4 and RO5 are lower than for the proposed RO3 as industry would continue using the PFAS-containing foams for longer. The highest release reduction is achieved in the sector with highest use volumes, i.e. in the SEVESO establishments. As all the quantities used for training/testing and fire incidents are assumed in the emission calculations to be ultimately released in the environment, the only difference in release profile between the industrial sectors or type of use is related to the efficiency of the RMMs when using PFAS-containing foams during the transition periods.

The proposed transitional periods are set to allow the development of fluorine-free firefighting foams, their testing by the users and the adaptation of the existing firefighting systems to provide similar level of fire protection as PFAS-containing foams. This is to exclude the possibility for fire safety risks that could have human health or environmental impacts. This is an important starting point as the Dossier Submitter has not estimated the human health and environmental costs of increased fire damage.

During the transition periods, additional risk management measures are proposed to minimise the emissions of PFASs in the environment. These RMMs are estimated to reduce releases by around 2 000 to 6 000 tonnes over 30 years depending on the RO. The higher end estimate is for the RO allowing the use of PFAS-containing foams for longer, i.e. RO5.

One of the measures to achieve minimised emissions is the safe disposal of PFAS-containing waste. The exposure assessment assumes incineration as disposal method to estimate the emissions to the environment from disposal. However, it is noted that the nature and quantities of emissions of PFASs or other fluorinated substances resulting from these disposal processes are not well known and further research should be carried out in real industrial conditions to ascertain their efficiency. Also, the impact on the emissions of greenhouse gases has not been calculated.

The human health and environmental risks of fluorine-free foams are considered lower than when using PFAS-containing foams, even if required quantities are greater. The Clean Production Action organisation developed hazard assessment standards for firefighting foams under the GreenScreen® methodology⁷⁰ and several foam products assessed have been attributed bronze and silver level scores⁷¹. Besides these, alternatives based on siloxanes have been identified to be available on the market. However, it should be highlighted that there are concerns related to the PBT and/or vPvB properties of some siloxanes: cyclic D4, D5, D6 have been identified as substances of very high concern under REACH based on these endpoints and others (linear) are currently undergoing PBT-assessment (e.g. octamethyltrisiloxane). Furthermore, D4, D5, D6 are subject to an ongoing restriction process that would not allow their use in firefighting foams if adopted. The restriction is subject to decision making. For this reason, alternatives based on siloxanes have not been assessed further in this report (see Annex E.2 on risks and technical feasibility of alternatives).

The Dossier Submitter highlights the importance for manufacturers of alternatives to PFAS-containing foams to assess the overall human health and environmental safety profile of their products according to recognised methodologies.

⁷⁰ <https://www.greenscreenchemicals.org/certified/fff-standard>

⁷¹ <https://www.greenscreenchemicals.org/certified/products>

As noted in section 2.4 and 2.8, one expected impact of the reduced releases will be the avoided need for developing and implementing more appropriate drinking water purification techniques across the European drinking water suppliers. Although some of the current high-end techniques may clean PFASs from raw water to some extent (see section B.4.5 for details and a briefing note of EUREAU (2021)), costs of implementation would be expected to be very large in case releases and hence increase of drinking water resource contamination would not be prevented. It should be noted, however, that for such costs PFAS-containing firefighting foams are only one substantial use among several (see, e.g., for preliminary proportions the restriction proposal of PFHxA, its salts and related substances; ECHA, 2022).

Similar to above, but directly targetable to the use of PFASs in firefighting foams is the avoided need to change drinking water supply in future. It is currently expected that the immediate clean-up methods would not be sufficiently effective to clean up or remediate soil/groundwater contamination after firefighting in non-bunded areas (see discussion in Annex B.4.5 (see also the example in Table F.14 in Annexes to the proposal and Annex E.4.3.5)).

2.6. Other impacts

The Dossier Submitter has not identified any other significant impacts (e.g. on employment or trade) resulting from the proposed restriction. This is because many producers of firefighting foams manufacture both PFAS-containing and PFAS-free foams, sufficient time is provided to develop suitable alternatives (if not available already), and because export is proposed to be allowed until alternatives are available for all uses and industrial sectors. See Annex E.6 for a brief analysis.

2.7. Practicality and monitorability

ROs 1-3 are considered to be practical (in terms of implementability, enforceability and manageability) and monitorable.

In terms of implementability, there are already other regulations in place controlling the placing on the market and use of PFAS-containing firefighting foams. In most of the sectors (all others than tank farms), some users have already substituted to PFAS-free foams. Sufficient transitional periods are proposed to allow the practical implementation of alternatives.

RO4 is not considered to be practical due to the need to adapt national or sub-national legislation to include the derogation system for the continued use of PFAS-containing foams on the site operating with permits.

RO5 is not considered to be practical for industry to implement as full containment of foam fire run-off including for large fire accidents is in practice unlikely to be technically and economically feasible.

Enforcement authorities can set up efficient supervision mechanisms to monitor industry compliance with the proposed restriction (RO3). Methods can be adapted based on those used to analyse PFOA and long-chain PFASs. Several types of analytical methods exist.

Targeted PFAS analysis is used to quantify individual specific PFAS, for example for the comparison with a limit value for a specific PFAS in a product. To quantify a specific PFAS reliably (e.g., for enforcement), an analytical reference standard for the particular PFAS must be available. Laboratories can currently quantify around 40 different PFAS, but this number

is increasing as more reference standards become available. In addition to specific analysis methods, the total oxidizable precursor (TOP) assay has been used by several laboratories in recent years to analyse PFASs (usually PFCAs) in firefighting foam concentrates and foam container rinse water. This method simulates accelerated environmental degradation and reveals the presence of arrowhead precursors in a sample e.g., both PFOA and PFOA-related substances. These methods are typically able to quantify PFASs at concentrations well below the threshold of 1 ppm proposed by the Dossier Submitter.

Furthermore, 'total fluorine' methods measure the overall amount of (organic) fluorine in a sample: total fluorine (TF), total extractable organic fluorine (EOF) and total adsorbable organic fluorine (AOF). These methods do not identify/differentiate between different kinds of fluorine-containing organic substances. Therefore, the total fluorine methods will detect and quantify both PFAS and non-PFAS organofluorine substances if they present in the same sample. However, the advantage of total fluorine methods, compared to targeted PFAS analysis or TOP (see directly above), is that they detect and quantify PFASs for which no reference standards exist, including fluoropolymers. In this respect, using total fluorine methods to quantify PFASs in firefighting foams (e.g. for compliance and enforcement purposes) is more practical than using targeted or precursor analysis as they are more compatible with the scope of the restriction proposal (which encompasses all PFAS). However, a disadvantage of total fluorine methods is that they would also detect and quantify, where they are present, organic fluorine from non-PFAS (i.e. not restricted) organofluorine substances in firefighting foams that are outside of the scope of the proposed restriction. Therefore, and to facilitate the practicality and enforceability of the proposed restriction using total fluorine analytical methods, an additional ancillary requirement⁷² for labelling the presence (and concentration) of non-PFAS organochlorine at concentrations greater than 1 ppm in firefighting foams is included in the conditions of the restriction (paragraph 7). This condition would allow the restriction to be enforced without requiring targeted analysis of all PFASs. The utility and appropriateness of this ancillary requirement shall be re-assessed by the Dossier Submitter based on comments received in the consultation on the Annex XV report. As such, it is presented in the proposed conditions of the restriction in square brackets [].

Based on the above, the absence of a European (or internationally) standardised analytical method for PFASs in firefighting foams is not considered as a hindrance to the enforceability of the proposed restriction, even though the importance of developing such a standard method at EU level is recognised by the Dossier Submitter. Therefore, considering the availability of analytical methods on the market to measure the content of various PFASs in firefighting foams, the ROs are concluded to be enforceable as regards analytical methods. Besides the availability of analytical methods, a sampling strategy is needed to monitor the restriction in the environment and humans. Analytical methods are further described in Annex E.7.

Nevertheless, the enforceability of the additional RMMs required by the proposed restriction (RO3) may be challenging for enforcement authorities. This is because the Dossier Submitter cannot define them in detail due to sector/use and site-specific differences. This is especially relevant for the techniques to collect PFAS emissions. However, best practices exist in some sectors and countries and they can be used as a basis for developing additional guidance for

⁷² A similar ancillary requirement is included in Entry 75 of Annex XVII of REACH (restricted substances for tattooing)

the industry (see e.g. section 2.2.2.2 for examples). Therefore, enforceability of ROs as regards the additional RMMs is considered feasible. In any case, enforcement can be based on the presence of the 'PFAS-containing firefighting foams management plan' required under paragraph 4c of the conditions of the proposed restriction.

To monitor the effectiveness of the proposed restriction (RO3), time trend monitoring could be performed with relevant samples from the environment (i.e., those from around sites using firefighting foams) or humans (e.g., firefighters). A deduction of PFAS emissions to the environment (and human exposures) resulting from this restriction should result in a decreasing PFAS concentration in such a trend monitoring.

2.8. Proportionality to the risk (including comparison of options)

The starting point for comparing the appropriateness of the five ROs is the balance between their potential to reduce PFAS emissions and their socio-economic impacts. As the environmental/health benefits of reduced PFAS emissions could not be quantified, it is not possible to use cost-benefit analysis to directly assess whether any of the proposed restriction options is proportionate. In such cases, ECHA's approach to the "Evaluation of restriction reports and applications for authorisation for PBT and vPvB substances in SEAC" requests Dossier Submitters to report the cost per unit (e.g. kilogram) of emissions reduced as the starting point for the proportionality assessment.

Therefore, the approach adopted is to identify the uses/applications and restriction conditions (transition periods, concentration thresholds, other risk management measures) that would achieve high levels of effectiveness (i.e. large reductions of PFAS emissions) with relatively small socio-economic impacts. As discussed above, the proposed transitional periods are considered sufficient to develop alternatives and for the users to test alternatives and adapt the fire extinguishing systems to allow the same level of fire protection as in the baseline.

There are **potentially significant benefits in terms of the reduced remediation costs that will arise by using PFAS-free foams**. As a very high-level estimate for illustration, the order of magnitude of avoided remediation cost could be hundreds of millions of euros (assuming tens of sites across the EU requiring remediation at the cost of tens of millions of € per site) to billions of euros (assuming hundreds of sites across the EU requiring remediation at the cost of tens of millions of € per site) (see Annex E.4 for details). Better information, e.g. on the total number of sites, on the use of PFAS-containing foams per site or on the implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess to which extent remediation is likely to be required in the future as a result of current uses of PFAS-containing firefighting foams (and could therefore be avoided because of the restriction). It is not possible to provide estimates per RO, but any such benefits would be higher in RO3 (which results in the highest avoided emissions) than in the other ROs, given the quicker abatement of PFAS emissions.

These remediation costs are not included as savings in the assessment of economic impacts as they are considered to be covered by the quantitative estimate for reduced releases which is used as proxy of human health and environmental impacts. It could be argued that also clean-up savings should be reported as benefits. However, they are considered as economic impacts in this report as they are carried out as part of the actual use of the firefighting foams. It is not clear to what extent remediation or clean-up eventually removes PFASs from circulation, or simply reduces the risk by removing a site-specific concern. The baseline

release estimates used in this report assume that all PFASs used will be eventually released to the environment and no adaptations have been done due to possible clean-up or remediation.

Same applies at larger scale for savings resulting from avoided drinking water purification costs. Use of PFASs in firefighting foams contributes to the general PFAS exposure to relevant extent. Due to their properties, most PFASs are difficult to remove from drinking water with current techniques in a manner which would be feasible for normal drinking water purification facilities. To avoid exposure via drinking water it would be necessary to develop feasible purification techniques for use in normal drinking water preparation facilities in case the releases would not be minimised. Otherwise new local water resources/aquifers would need to be taken into drinking water use. Either of these options can be expected to be costly to society. These avoided costs have not been quantified due to lack of data.

The SEAC PBT/vPvB approach recognises that while weighting on the basis of (expected) damage is currently not possible in a systematic way using quantitative approaches, it is often feasible to describe factors or situations where the properties of a particular PBT or vPvB would be likely to cause damage. The following discusses the factors that are considered particularly relevant for this case to support the proportionality assessment.

- The size and dynamics of the stock of PFASs in the environment is one of the main factors. PFASs are very persistent and many of them are expected to stay in the environment for decades and even centuries. Exposure to PFASs is hardly reversible once effects are encountered (see further discussion on consequences of persistence in section 1.1.4 and 1.1.6).
- The environmental stock of PFASs consists of a highly complex, variable mixture of PFASs. This complexity of exposure hampers (in addition to the very persistent property) both the exposure assessment and the identification of effects (see section 1.1.4 for more details).
- PFASs have a high potential for long-range transport.
- PFAS exposure via drinking water and food cannot be avoided by any parts of the human population if releases are continued (see section 1.1.4 and 1.1.6 for details). Effects are highly likely to be triggered over time when the PFAS levels increase.
- General drinking water purification of PFASs as a consequence of widespread PFAS contamination in groundwater and surface water is currently technically and economically not feasible and is expected to be challenging also in future due to the properties of PFASs (see section 1.1.4 for details and the discussion above on the potential costs).
- Wastewater treatment plants are not effective in removing PFASs (see Annex B.4.2.4. and B.4.5).
- Releases from firefighting uses substantially contribute to the overall environmental concentrations of PFASs.
- Use of PFASs in firefighting foams causes locally contaminated sites. Current remediation and clean-up methods are not fully effective to remove PFASs from contaminated sites.

To propose the most appropriate RO, the following aspects are discussed in this section:

- **Comparison of different users** or industrial sectors to describe the possibilities to substitute PFAS-containing foams with alternatives
- Based on this comparison, the sectoral **transition periods** are derived
- Derivation of **concentration thresholds**
- **Cost-effectiveness estimates** to discuss proportionality.

2.8.1. Comparison of different users

The analysis of alternatives (see Annex E.2) has concluded that alternatives are generally considered to be technically feasible in most applications. Further testing is required to confirm the technical feasibility of alternatives for some specific applications, particularly large atmospheric storage tanks and sites using different types of flammable liquids.

The various use sectors and applications of firefighting foams vary significantly in terms of the potential for a restriction to reduce PFAS emissions to the environment ('PFAS risk reduction potential'), the current feasibility of transitioning to fluorine-free alternatives ('substitution potential') and the resulting potential socio-economic impacts of that transition. Therefore, it is appropriate to set different conditions for the different sectors and applications, to balance the effectiveness of the measure with considerations around feasibility of alternatives and socio-economic impacts.

A table summarising and comparing substitution potential, socio-economic impacts and risk profile across the main identified user sectors is provided below (Table 8). The comparison in the table suggests that training and testing should be the highest priority for a quick transition to fluorine-free foams, because the use of alternatives is well established and already recommended as industry best practice. According to the stakeholder survey conducted in preparation of this Annex XV report, many users have already transitioned to fluorine-free alternatives for training and testing and the potential for adverse socio-economic impacts is very low for these types of uses.

The oil/(petro-)chemical industry is by far the largest use sector. The costs of transitioning, but also the current emissions of PFASs, are higher than in other sectors. A longer transition period for this sector is needed due to the specific applications (notably large tank fires and installations using different types of flammable liquids) where further testing is required to determine the technical feasibility of alternatives and potential fire-safety risks resulting from using alternatives. In order to cover all the sites that are likely to face such particularly hazardous fire scenarios, the Dossier Submitter suggests defining them as the establishments subject to the Seveso III Directive (upper and lower tier) instead of using a threshold based on e.g. tank size or bund area size, which might be too restrictive and could omit several relevant industries and sites.

A rapid transition in marine applications should be a high priority due to the low potential for retention of run-off and clean-up after incidents, and established alternatives (e.g. two of the alternatives shortlisted in the analysis of alternatives were reported to be used in the marine sector) and no particular issues have been raised during the stakeholder surveys. The assessment conducted in this report relates to marine ships which are understood to be the most relevant types of civilian ships using PFAS-containing foams (no information has been received from stakeholders on non-marine ships). However, by extension, the restriction entry refers to ships in general (marine and non-marine civilian ships) since the substitution considerations are assumed to be similar.

Municipal fire services should also be prioritised for a quick transition because alternatives are well established and this sector is typically involved in fire incidents outside of specific industrial sites where retention of run-off and clean-up after incidents is more difficult.

Alternatives are less well established in the defence sector. They are considered by some stakeholders to be feasible, having been adopted in Europe by the Danish and Norwegian armed forces (IPEN, 2018). However, even though some of the applications are similar to those of other sectors (e.g. civilian aviation) where substitution has taken place, the defence sector entails specificities such as the storage and transportation of explosives and ammunition, leading to increased security risks and requiring the highest level of efficiency when extinguishing and preventing re-ignition. Transition to an acceptable alternative is likely possible in some cases but requires extra care because if the use of alternatives causes any fire-safety risks, the potential damages could be significant and could include danger to human life. During the stakeholder survey conducted in 2021, several Member State Ministries of Defence have called for longer transitional periods – from a minimum of six years up to twelve years – to ensure a transition without compromising fire safety, or even requesting an exemption. According to REACH Article 2(3), Member States may allow for exemptions from the REACH Regulation in the interests of defence. The European Defence Agency has published guidelines to follow in case an exemption needs to be applied for. However, stakeholders have highlighted potential problems associated with national exemptions in the consultations of the PFHxA restriction proposal. According to industry, the national approval of an exemption is associated with extensive effort and a legal act of the Union ensures more legitimacy and acceptance because of its transparency and legal certainty.

Likewise, in civilian aviation there is a concern that, if the use of alternatives caused any fire-safety risks, the potential damages could be significant and would likely include danger to human life. However, alternatives are considered feasible and have successfully been implemented by many users (e.g. the airports of Dubai, Dortmund, Stuttgart, London Heathrow, Manchester, Copenhagen, Schiphol, Australia and Auckland) and a relatively quick transition should be sought. The 2021 stakeholder survey – to which several airports responded – did not indicate that a transition within five years would not be possible.

Some alternatives to PFAS-containing portable fire extinguishers for class B fires already exist and are in use but suitable alternatives are not available yet for all types of extinguishers. Additional time is needed to develop such suitable alternatives and make them available to the entire market.

2.8.2. Transition periods

The starting assumption adopted for this restriction proposal is to allow sufficient transition time to allow for the testing and selection of the most appropriate foam product and the adaptation or replacement of the fire extinguishing system to ensure the same level of fire protection as that achieved currently with the PFAS-containing foams. Based on this assumption, the Dossier Submitter has not quantified or monetised the impacts of any reduced fire protection capacity related to the use of alternative foams, as there should be no difference in performance.

Based on the analysis of alternatives (see Annex E.2), their applicability to specific sectors, and the input provided by a range of stakeholders on their implementation, different transition periods have been considered appropriate for different uses.

Successful transition to fluorine-free foams for **training and testing** has been reported by stakeholders across sectors and is already recommended as industry best practice. Therefore, a short transition period should be sufficient for training and most testing currently performed with PFAS-containing foams. However, there are some specific types of testing that differ in terms of their substitution potential. According to (Eurofeu, 2020), the following types of testing can be distinguished:

- testing of foam agents during their development phase,
- testing of foam agents by users to evaluate product suitability on specific combustibles,
- testing of the correct proportioning of firefighting foam concentrates, and
- testing of firefighting systems for their function (i.e. testing the fire protection system in the same way as it would operate in case of emergency).

According to Eurofeu, all types of testing can be implemented with PFAS-foam surrogates (i.e. alternatives products) except the latter one as also the properties of the foam generated by the system are subject to a pass/fail criterion. Therefore, if training and testing activities could quickly transition to fluorine-free alternatives, testing of the firefighting systems for their function should remain possible with PFAS-containing foams as long as the industry sector may use PFAS-containing foams for fire incident management. The Dossier Submitter considers that the transition in training and testing applications to fluorine-free foams should be feasible in 18 months (with the exception for testing the function of firefighting systems mentioned above).

The Dossier Submitter concludes that technically feasible alternatives to PFAS-containing foams are available on the market for **municipal fire services** and that a quick transition should be feasible. An exception to this would be municipal fire services that also have responsibility for industrial fires at establishments covered by the Seveso-III Directive. In this specific case, the same transitional period as applicable for the Seveso establishments themselves would be warranted but limited to the use in these establishments only. The Dossier Submitter considers that the transition of municipal fire services to fluorine-free foams should be feasible in 18 months (with the exception mentioned above).

Ready-for-use applications include ready-for-use firefighting agents which are predominantly used in handheld portable extinguishers but also as pre-fill of so-called “wet systems” (firefighting systems where the pipework from the extinguishing agent feed stock to the actual applicator is pre-filled with an extinguishant). Based on the information collected, the Dossier Submitter considers that a transition of five years would be necessary for developing, certifying and supplying the whole market with suitable alternatives to PFAS-containing ready-for-use agents. To allow the availability of PFAS-containing portable fire extinguishers for five years also for sectors of use with shorter transitional periods (e.g. ships: three years), the restriction entry specifies that the transitional period for portable fire extinguishers is valid irrespective of the sector of use.

The oil/(petro-)chemical industry is the sector where users have argued that a longer transition period of up to 10 or 12 years is required to ensure that fire safety is not compromised. This time would be required to conduct further testing of the feasibility of

alternatives for large atmospheric storage tanks⁷³ (LAST) and for other types of challenging fire scenarios such as those involving different types of flammable liquids. This is broadly consistent with the reported duration of the transition by the Norwegian oil and gas company Equinor (see case study in Annex E.2.6), which took about eight years from development and testing to full operation of fluorine-free alternatives.

The collected information indicates that, even though fluorine-free foams seem to perform well against different types of fuels overall, different application rates and methods may be needed to achieve the desired effect, resulting in the need to implement several technical adaptations to the overall fire extinguishing system of a site, including foam storage tanks and bunds. Sufficient time would therefore be needed to finalise the testing of different foams, application methods and fuels as well as to allow users to implement the necessary technical adaptations (mainly to fixed systems) for the transition to PFAS-free alternatives while maintaining equivalent fire safety levels. Most stakeholders from the oil/(petro-)chemical industry having contributed to the surveys or the consultations related to the PFHxA restriction proposal called for transitional periods of 10 to 12 years to allow the development and testing of fluorine-free alternatives and to implement the necessary technical changes at their sites. To cover all the sites likely to face such hazardous fire scenarios, the Dossier Submitter suggest defining them as the establishments subject to the Seveso III Directive (tier 1 and tier 2) instead of using a threshold based on e.g. tank size or bund area size, which might be too restrictive and could omit several relevant industries and sites. A transition period of ten years seems appropriate for the implementation of the transition to fluorine-free alternatives for this sector of use defined as establishments subject to the Seveso III Directive.

Regarding the **defence sector**, the Dossier Submitter considers that, based on the information received so far, in most cases the transition to fluorine-free alternatives in the defence sector should not be significantly different from a technical point of view compared to other sectors like the civilian aviation sector where quick extinguishment is also required. Contrary to the downstream petrochemical sector, major equipment adaptations are not expected. Exceptions might apply for ships already built or ships under construction in countries where ship equipment adaptation would not be possible. However, this case has only been mentioned by one Ministry of Defence, therefore, a general exemption does not seem warranted. If necessary, each Ministry of Defence has the possibility to call for a national defence exemption under Article 2(3) of REACH. Therefore, the same transitional period as for civilian aviation is proposed for the defence sector (see below).

The **civilian marine sector** (and by extension all civilian ships) shows limited capability to contain foams during use. In addition, fluorine-free alternatives are technically feasible and available for this sector. On this basis, the Dossier Submitter considers that a short transition period should be considered for this use and that three years should be sufficient to implement the necessary changes⁷⁴.

⁷³ These are large-diameter (greater than 40m), open-top floating-roof storage tanks of flammable liquids.

⁷⁴ It should be noted that certain uses of firefighting foams in the civilian marine sector are regulated by International Maritime Organisation rules and fall under Directive 2014/90/EU on marine equipment. This directive itself transposes IMO requirements and makes them applicable on vessels flying the flag of an EU Member State. For applying the restriction under REACH on firefighting foams to all sea-going ships calling at EU ports, a similar measure at IMO level would be needed.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

For all **other sectors** (e.g., civilian aviation, offshore oil extraction platforms, etc.), shorter transition periods, between three and six years, have been suggested by stakeholders and are considered sufficient to allow an orderly substitution towards fluorine-free foams. Regarding airports, the stakeholder survey undertaken by the Dossier Submitter in Spring 2021 – to which several airports responded – did not indicate that a transition within five years would not be possible. The Dossier Submitter therefore concludes that technically feasible alternatives to PFAS-containing foams are available on the market for the use in civilian aviation and that a complete transition within five years should be feasible. In regard to offshore oil extraction platforms, the Dossier Submitter concludes that technically feasible alternatives to PFAS-containing foams are available on the market. Considering the low potential of containment of firefighting foams during their use and the experience likely gained on the market since the transition by Equinor, the Dossier Submitter considers that a transition within five years should be feasible for offshore platforms. In general, the Dossier Submitter considers that a transition within five years should be feasible for these other sectors.

Table 8 below summarises the substitution potential, socio-economic impacts and PFAS-related risk reduction potential across the identified main user sectors and the transitional periods proposed by the Dossier Submitter for this restriction proposal.

Table 8. Substitution potential, socio-economic impacts and PFAS-replated risk reduction potential across the main identified user sector and proposed transitional periods

Use / application	Substitution potential	Potential socio-economic impacts	PFAS-replated risk reduction potential	Transitional periods proposed by the Dossier Submitter (1)
Oil/(petro-) chemical industry	Low for some applications, medium/high for others: Sector includes many different and complex scenarios. Alternatives have successfully been implemented for some applications but may not be readily available for others. In particular, additional testing required to confirm feasibility of alternatives for large atmospheric storage tanks and fires with different types of flammable liquids.	High: By far the largest user (59 % of annual sales), so transition is large scale. Highest potential fire-safety risks from using alternatives, although relatively low risk of danger to human life.	High: By far the largest user (59 % of annual sales), average potential for retention of run-off and clean-up after incidents.	10 years
Civilian marine Applications (civilian ships)	High: Feasible alternatives considered to be available and have successfully been implemented by many users.	Medium: Average user (12 % of annual sales), average potential for fire-safety risks from using alternatives.	Very high: Average user (12 % of annual sales), likely lowest potential for retention of run-off and clean-up after incidents.	3 years
Defence	Low for some specific applications/Medium for others:	Medium/High: Relatively small user (6 % of annual sales), so relatively small scale of	Medium: Relatively small user (6 % of annual sales), average potential for retention of	5 years

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Use / application	Substitution potential	Potential socio-economic impacts	PFAS-replated risk reduction potential	Transitional periods proposed by the Dossier Submitter (1)
	Feasible alternatives considered to be available by some users but not by others. Not many alternatives have been certified or implemented by users yet.	transition. Average potential of fire-safety risks from using alternatives, which could result in a relatively high potential of danger to human life.	run-off and clean-up after incidents.	
Civilian Aviation	High: Feasible alternatives considered to be available and have successfully been implemented by many users.	Medium/High: Relatively small user (9 % of annual sales), so relatively small scale of transition. Average potential of fire-safety risks from using alternatives, but any risks would result in a relatively high potential of danger to human life.	Medium: Relatively small user (9 % of annual sales), average potential for retention of run-off and clean-up after incidents.	5 years
Municipal Fire Services	High: Feasible alternatives considered to be available and have successfully been implemented by many users.	Low: Average user (12 % of annual sales), so average scale of transition. Low potential of fire-safety risks from using alternatives.	High: Average user (12 % of annual sales), likely lower potential for retention of run-off and clean-up after incidents because not restricted to specific industrial sites.	18 months
Ready to use applications	Medium/High: Feasible alternatives considered to be available for some applications but not all (R&D, certification needed, staggered supply of the market to cope with manufacturing capacity).	Low/Medium: Relatively small user in terms of quantities (1 % of annual sales according to Eurofeu data) but large number of devices affected (15 million PFAS-containing fire extinguishers estimated). Medium potential of fire-safety risks from using alternatives.	Medium/High: Relatively small user, likely lower potential for retention of run-off and clean-up after incidents because not restricted to specific industrial sites.	5 years
Testing	Very high: Feasible alternatives considered to be available and have successfully been implemented by many users. No need for high performance foams.	Very low: Likely very small share of use across sectors of use, not the most expensive high-performance foams required. Very low risk of damages resulting from performance of alternatives.	Low: Likely very small share of use across sectors of use, relatively high potential for retention but collected waste are not necessarily treated adequately.	18 months
Training	Very high: Feasible alternatives considered to be available and have successfully been implemented by many users. Little need for high performance foams.	Low: Limited share of use. Likely not the most expensive high-performance foams required. Low risk of damages resulting from performance of alternatives.	Low/Medium: Limited share of use, relatively high potential for retention but collected waste are not necessarily treated adequately.	18 months

Use / application	Substitution potential	Potential socio-economic impacts	PFAS-replated risk reduction potential	Transitional periods proposed by the Dossier Submitter (1)
Other sectors or types of uses not listed above	Considered similar as the aviation sector			5 years

(1) Alternative transitional periods are proposed for specific cases within some of these categories. See the restriction entry and explanatory notes in section 2.2.5 for details.

2.8.3. Concentration thresholds

There are three main considerations to choose appropriate concentration thresholds for remaining PFAS-contamination in firefighting foam systems: residual releases from contaminated firefighting foams/systems, the costs of cleaning (or replacement) of equipment, and detection limits of testing methods. The first two points are discussed here and the last one in section 2.7 (practicality including enforceability).

Considering these elements, the Dossier Submitter proposes a concentration threshold of 1 ppm.

Remaining PFAS-contamination

It is not clear what impurity levels would be in the contaminated alternative foams without a clean-up of the equipment already used for PFAS-containing foams. After transition from C8-based foam to C6-based foam without a cleaning, 'high' concentration (no quantitative information) of PFOS has been reported by a stakeholder. Another stakeholder stated that after substitution from PFAS-containing to non-fluorine foam, follow-up measurements showed that PFASs were still detectable.

When adopting a certain threshold there is a trade-off between the amount of PFAS emissions remaining and the costs of cleaning to achieve that threshold. For example, if the concentration of PFASs in the foam concentrate is on average 2.5 %, i.e. 25 000 ppm or 25 000 000 ppb, a threshold of 1 ppm would lead to a minimum reduction of concentration (and hence emissions considering a similar use and RMM pattern) of 99.99 %, whereas a threshold of 50 000 ppb would represent a reduction in concentration and emissions of 99.80 %. A threshold of 1 ppm is 25 000 times lower than the average concentration of PFASs in the firefighting foams in use (2.5 %) and 1 000 times below the lowest concentration (0.1 %) that can be considered as providing any functionality, therefore the proposed limit would impede any intentional use of PFASs in the foam concentrate.

Cost of cleaning equipment

According to industry, the cleaning cost heavily depends on the thresholds to achieve. The lowest cost reported for cleaning of equipment (foam concentrate tank) is €4 000. For large, fixed installations cleaning is more complex and therefore more expensive. The lowest cost method is reported to result in low ppb concentrations for each of 13 standard PFASs measured in the final rinse water. Other methods are reported to cost between €20 000 and €200 000 per equipment. Available information suggests that they could achieve lower concentrations (see Annex E.4.3.6 for details).

Based on the available information, the Dossier Submitter assumes that the cost of reaching the proposed 1 ppm level varies between €20 000 and €200 000 per site depending on the sector of use. This estimate accounts for the need to clean-up several equipment/systems per site, and also the possibility that higher impurity levels in the foam are reached during their storage. This could happen due to remaining PFASs, adhering to the surface of the equipment and being released via the foam over time⁷⁵.

It is not possible to derive robust cost estimates for different concentration limits. However, it can be calculated that reducing the remaining PFAS concentration in possibly contaminated fluorine-free foams from 1 ppm to 1 ppb, would reduce the quantity of PFASs released in the EU by around 150 kg⁷⁶ per year (other parameters remaining constant).

If the cleaning methods needed for reaching the lower thresholds are more expensive (e.g., 10 times) than those described above, the cost of achieving each additional kg of emission reduction would become very high. Even if there is high uncertainty in the data, the Dossier Submitter considers it sufficient to conclude that a lower threshold would not be appropriate based on its limited risk reduction capacity of less than 150 kg. However, it is recognised that some cleaning methods seem to be able to reach lower concentrations than the proposed 1 ppm. If these are preferred by the users of the substance, the lower concentrations are achieved in practice, regardless of the concentration threshold in the restriction proposal.

More detailed information on the available techniques and associated costs for cleaning procedures is available in Annex E.4.3.6 and in Appendix 1.

2.8.4. Cost-effectiveness estimates

Table 9 summarises the cost-effectiveness estimates for different ROs and industry sectors or types of use.

Table 9. Estimated C-E ratios for each RO and sector or type of use

Sector/type of use	RO1 (€ per kg)	RO2 (€ per kg)	RO3 (€ per kg)	RO4 (€ per kg)	RO5 (€ per kg)
Seveso establishments	700 (300-3700)	800 (300-3900)	800 (300-3900)	560 (230-2800)	2300 (1200-12000)
Other industries	160 (40-680)	200 (60-850)	200 (60-840)	200 (60-850)	200 (60-850)
Civilian aviation	50 (0-190)	70 (5-290)	70 (6-290)	70 (5-290)	70 (5-290)
Defence	50 (0-190)	70 (4-290)	70 (5-280)	30 (1-110)	70 (4-290)
Municipal fire services	900 (310-3600)	840 (290-3500)	830 (290-3500)	840 (290-3500)	840 (290-3500)

⁷⁵ See Annex E.4 on cost of cleaning equipment to comply with the proposed concentration threshold for more details.

⁷⁶ $(\text{Stock of foams} \times \text{concentration}^{\text{high}}) - (\text{Stock of foams} \times \text{concentration}^{\text{low}}) = (150\,000\text{ t} \times 0.0001\%) - (150\,000\text{ t} \times 0.0000001\%) < 150\text{ kg}$.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Ready-to-use applications	30 (0-140)	60 (0-210)	60 (0-210)	60 (0-210)	60 (0-210)
Marine applications	320 (90-1300)	310 (90-1300)	310 (90-1300)	310 (90-1300)	310 (90-1300)
Training and testing	17 (0-60)	60 (0-140)	60 (0-140)	60 (0-140)	60 (0-140)
All sectors/types of use	500 (190-2000)	520 (180-2200)	515 (180-2100)	415 (150-1700)	1200 (500-5500)

Note: The results for two sectors (municipal fire services and marine applications) suggests that RO2 would be less cost-effective measure than RO1. This is because of assumptions made to estimate the emission reduction from banning the use (higher reduction in these sectors) and should not be interpreted to suggest that banning use of existing foams would be cheaper per kg than banning placing on the market of new foams.

Table 10 reports the incremental cost and incremental reduction in releases for RO2 compared to RO1, and RO3 compared to RO2, to allow for a comparison of the restriction options against each other (rather than against the baseline). RO4 and RO5 are not covered in this table as they are not building on the other options and not considered to be practical by the Dossier Submitter.

Table 10. Incremental cost-effectiveness (C/E) of RO1, RO2 and RO3

Restriction option	Total costs (€ over 30 years)	Emission reduction (tonnes over 30 years)	C/E-ratio (€ per kg)	Incremental cost (€ over 30 years)	Incremental release reduction (tonnes over 30 years)	Incremental C/E-ratio (€ per kg)
RO1	5.9 billion	11 800	498	5.9 billion	11 800	498
RO2	6.8 billion	13 000	520	900 million	1 200	734
RO3	6.8 billion	13 200	515	8 million	120	67

Note: These results are based on best estimate scenario

The results in Table 9 and Table 10 are derived for scenarios with additional RMMs during the transitional periods. Results without these additional RMMs are reported in section F.4 of the Annex. Recognising that the information on the effectiveness of these RMMs to reduce emissions and their costs is uncertain, the results suggest that the C/E ratio of requiring these RMMs independently from the ban on placing on the market, use or export would be €15-100 per kg of release avoided.

To assess the proportionality of the various restriction options with regard to the risk identified in the Annex XV report, the Dossier Submitter compared the cost-effectiveness ratios to those of former REACH actions to avoid PBT- or PBT-like substances. As shown in Table 11, the cost-effectiveness ratios of around €500/kg for RO1, RO2 and RO3 are similar compared to other recent REACH restrictions.

Table 11. Cost-effectiveness of recent REACH restrictions

Restriction under REACH	€/kg, central value
Lead in shot in wetlands	9

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

D4, D5 in wash-off cosmetics	415
DecaBDE	464
Phenylmercury compounds	649
PFOA-related substances	734
PFOA	1 649

(Oosterhuis and Brouwer, 2015) investigated this issue more closely. It was concluded that, although cost estimates of previously adopted actions do not allow the derivation of a value of society's willingness-to-pay for reductions in the presence of PBT substance presence, use and emissions, the available evidence suggests that measures costing less than €1 000 per kg of PBT substance use or emission reduction would usually not be rejected for reasons of disproportionate costs, whereas measures with costs above €50 000 per kilogram PBT substance are likely to be rejected. While ECHA (2016) did not establish specific benchmarks for cost-effectiveness, the Dossier Submitter considers that the proportionality of the proposed restriction of PFASs in firefighting foams is supported by the cost-effectiveness estimates as they are similar to other recent restrictions adopted by the Commission.

The Dossier Submitter considers RO3 to be the most appropriate restriction option. Even though regulating the use of existing stocks (covered by RO2 and RO3) is more expensive per kg of emissions reduced than regulating placing on the market (which is not covered by RO1), the estimated cost of €515 per kg of avoided release is still proportionate. RO4 and RO5 are not considered most appropriate as they entail lower risk reduction capacity, and they are also not considered to be practical.

2.8.5. Additional risk management measures

The proposed restriction includes the requirement for the implementation of additional risk management measures during the transition periods by means of a mandatory 'PFAS-containing firefighting foams management plan' and the use of best practice risk management measures during the whole life cycle of PFAS-containing foams.

Current practices by foam users vary and are not always appropriate to minimise emissions to the environment. Therefore, additional risk management measures are proposed as part of the restriction.

The cost of the requirement to minimise emissions to the environment as well as direct and indirect exposure of humans to firefighting foams is monetised in this report by using the incineration cost of the foams as a proxy for the cost. Recognising that this does not completely cover the requirement, it is considered sufficient by the Dossier Submitter in the absence of more accurate cost estimates as the requirement is to minimise the emissions to the extent that is technically and economically feasible for the industry. The cost of establishing a site-specific 'PFAS-containing firefighting foams management plan' is also covered by this cost estimate. The total cost of the requirement is estimated to be €60 million (NPV) over the 30 years assessment period.

The emission reduction of the additional RMM requirement is estimated to be around 1 900 tonnes over the 30-year assessment period for RO3 in the best-case scenario. This is relatively high due to the fact that the Dossier Submitter assumes that these measures are

currently not implemented, and the effectiveness of these measures is assumed to be relatively high⁷⁷.

Even though there is high uncertainty related to the cost and release reduction estimates, leading to possible overestimation of the cost-effectiveness of the requirement, the Dossier Submitter considers the information sufficient to conclude that additional risk management measures during the transition periods are justified.

3. Assumptions, uncertainties and sensitivities

The following are the main assumptions made in this restriction proposal:

- There is no trend in the amounts of PFAS-containing foams used, i.e. same amounts would be used each and every year during the 30 years assessment period without regulation. An increase could be justified due to an increase in GDP, and on the other hand, a decrease could be justified because alternative foams are under development. The latter seems more plausible and thus, we may overestimate the emissions and thus the costs of the restriction. Even though a trend is not accounted for in the quantitative calculations, the assumptions about foam stocks and annual sales are varied in the sensitivity analysis.
- Environmental/health benefits of the reduction of PFAS emissions cannot be quantified, primarily due to a lack of knowledge about the effects of PFASs to human health and the environment. The avoided releases are used as a proxy of the environmental and human health impacts. Possible avoided remediation costs and avoided drinking water purification costs are not counted as savings but described qualitatively as a benefit of the avoided releases.
- In the baseline, all the PFASs in firefighting foams will be released during the service life of the foam. No effective collection and safe disposal are assumed. Only if foams expire before their use (which takes place only in some sensitivity scenarios), safe disposal is assumed.
- The proposed sectoral transition periods allow the transition to fluorine-free alternatives without compromising fire safety.

The input parameters taken for the quantitative emissions and cost calculations are summarised in Table 12 and Table 13. These also report the sources of the data, level of uncertainty and the values used for the calculations in the so-called low, best and high scenarios. For the emissions estimates in the baseline, the same input parameters as in Table 12 for the best scenario have been applied, with the exception of the parameter for "Effectiveness of additional RMMs imposed by the ROs" which is not relevant in the baseline scenario.

For each RO, sensitivity analyses were carried out to describe the magnitude of uncertainty in the results and to understand the contribution of each input parameter to the overall uncertainty. The level of uncertainty for each parameter was labelled low, medium or high based on the Dossier Submitter's judgement. Based on this, reasonable assumptions for low

⁷⁷ See section 3. "Assumptions, uncertainties and sensitivities" for input parameters.

and high scenarios were made. However, the intention was not to determine the lowest and highest possible values for each parameter.

pre-publication – do not cite

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Table 12. Input parameters for the calculation of the emissions in the five scenarios R01 – R05 (“Low”, “Best” and “High” estimates).

Parameter	Source of best estimate	How parameters have been derived	Level of uncertainty (low, medium, high)	Values used		
				Low estimate “Low scenario”	Best estimate “Best scenario”	High estimate “High scenario”
Foam stock and annual sales	The foam stock in year 0 should be derived from the Excel sheet so that the annual use, based on (Wood et al., 2020) is obtained.	See description of mass balance calculation in Appendix 8.	Medium	Mass balance to obtain 14 000 t/y of annual sales	Mass balance to obtain 18 000 t/y of annual sales	Mass balance to obtain 20 000 t/y of annual sales
Concentration of PFAS-containing surfactants in foam	(Wood et al., 2020)	Wood’s stakeholders’ consultation	Low	2 %	2.5 %	3 %
Average foam life span	(Wood et al., 2020)	Literature and confirmed by stakeholders (note: the PFAS-containing foams normally do not have an indicated expiry date and in practice samples are taken from time to time and validity confirmed by lab. Can actually be used beyond 20 y)	Low	15 y	15 y	15 y
Sectoral breakdown (shares of industry sectors)	(Wood et al., 2020)	Based on Eurofeu’s data	Low (only the share of Seveso vs non-Seveso (“other industries”) of the oil/petrochemicals category is more uncertain, based on expert’s assumption)	Defence: 6 % Civilian Aviation: 9 % Municipal Fire Services: 13 % Chemical / Petrochemical: 59 % Marine Applications: 12 % Ready to use applications: 1 %	Defence: 6 % Civilian Aviation: 9 % Municipal Fire Services: 13 % Chemical / Petrochemical: 59 % Marine Applications: 12 % Ready to use applications: 1 %	Defence: 6 % Civilian Aviation: 9 % Municipal Fire Services: 13 % Chemical / Petrochemical: 59 % Marine Applications: 12 % Ready to use applications: 1 %

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

				Share of Seveso versus non-Seveso ("other industries") of the oil/petrochemicals category: 98 % versus 2 %	Share of Seveso versus non-Seveso ("other industries") of the oil/petrochemicals category: 98 % versus 2 %	Share of Seveso versus non-Seveso ("other industries") of the oil/petrochemicals category: 98 % versus 2 %
Sectoral transition period	Expert judgement		Not applicable	Defence: 5 y Civilian Aviation: 5 y Municipal Fire Services: 1.5 y Chemical / Petrochemical Seveso: 10 y Other industries: 5 y Marine Applications: 3 y Ready to use applications: 5 y Training and testing: 1.5 y	Defence: 5 y Civilian Aviation: 5 y Municipal Fire Services: 1.5 y Chemical / Petrochemical Seveso: 10 y Other industries: 5 y Marine Applications: 3 y Ready to use applications: 5 y Training and testing: 1.5 y	Defence: 5 y Civilian Aviation: 5 y Municipal Fire Services: 1.5 y Chemical / Petrochemical Seveso: 10 y Other industries: 5 y Marine Applications: 3 y Ready to use applications: 5 y Training and testing: 1.5 y
Use type breakdown (training/testing and fire incidents management): annual use (compared to stock)	Eurofeu and other stakeholders' consultation	Eurofeu's data and other stakeholders' consultation	Medium	13 % for fire incidents management 5 % for training and testing Except ready to use applications: only live incidents	10 % for fire incidents management 2 % for training and testing Except ready to use applications: only live incidents	5 % for fire incidents management 1 % for training and testing Except ready to use applications: only live incidents
Emissions parameters: - leakage during storage - emission formulation to WWT - emission formulation to air	Best scenario: Wood emission scenario spreadsheet High and low scenarios: leakage: OECD emission scenario document 10 for lubricants and	Best: Wood emission scenario spreadsheet (for formulation, equal to REACH default values for formulation) Low= best/2 in accordance with low and best for leakage	Medium	leakage during storage: 0.5 % emission formulation to WWT: 1 % emission formulation to air: 1.25 %	leakage during storage: 1 % emission formulation to WWT: 2 % emission formulation to air: 2.5 %	leakage during storage: 2 % emission formulation to WWT: 2 % emission formulation to air: 2.5 %

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

- emission formulation to soil - emission during incineration - share WWT to effluent - share WWT to soil/sludge - partitioning coefficient	additives: range, referenced in REACH guidance R16 page 78 Low= expert judgement	High = best *2 (leakage during storage)		emission formulation to soil: 0.005 % emission during incineration: 1 % share WWT to effluent: 0.375 share WWT to soil/sludge: 0.625 partitioning coefficient: 2.67	emission formulation to soil: 0.01 % emission during incineration: 1 % share WWT to effluent: 0.375 share WWT to soil/sludge: 0.625 partitioning coefficient: 2.67	emission formulation to soil: 0.01 % emission during incineration: 1 % share WWT to effluent: 0.375 share WWT to soil/sludge: 0.625 partitioning coefficient: 2.67
Releases to surface water, soil and sea during incidents (in absence of RMMs)	(Wood et al., 2020), based on PFOA Annex XV dossier		Medium	100 % releases: 50 %/50 %/0 % for all sectors of use except marine (0 %/0 %/100 %)	100 % releases: 50 %/50 %/0 % for all sectors of use except marine (0 %/0 %/100 %)	100 % releases: 50 %/50 %/0 % for all sectors of use except marine (0 %/0 %/100 %)
Effectiveness of bunding measures for training	(Wood et al., 2020)	Based on expert's judgment	Medium	97 % for all sectors except marine (0 %)	97 % for all sectors except marine (0 %)	97 % for all sectors except marine (0 %)
Effectiveness of WWTP for PFASs	(Wood et al., 2020) Low estimate: expert judgment	Based on expert's judgment	Medium	5 %	0 %	0 %
Effectiveness of additional RMMs imposed by the ROs: - collection to the extent feasible of the firewater from fire incidents and their incineration - incineration of all collected firewater from training/testing (collection already considered in place under the baseline scenario) - Only RO5: after 10 years for Seveso sites "full" collection and incineration of firewater from fire incidents (before that: collection to the extent feasible)	Ramboll's expert judgement		Medium	collection of firewater during incidents 97 % for all sectors except marine, ready to use and municipal fire services (0 %) 100 % incineration of all collected firewater from training	collection of firewater during incidents 50 % for all sectors except marine, ready to use and municipal fire services (0 %) Chemical / Petrochemical Seveso: 97 % 100 % incineration of all collected firewater from training	collection of firewater during incidents 0 % for all sectors Chemical / Petrochemical Seveso: 97 % 100 % incineration of all collected firewater from training

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Table 13. Input parameters for the calculation of the transition costs, sources and use (low, best and high scenarios)

Parameter		Source of best estimate	How parameters have been derived	Level of uncertainty (low, medium, high)	Values used in different cost scenarios			Calculations for which parameters have been used
					Low	Best	High	
Incineration/disposal costs €/tonne		(Wood et al., 2020) Table 8.14 p. 163	Range confirmed by stakeholders	Low	-10 %	€1 000/tonne	+25 %	Early disposal of legacy foams when replaced
Cost of using alternative foams	Average price €/tonne of PFAS-containing foam	(Wood et al., 2020) Table 8.4 p. 148	Range confirmed by stakeholders	Low	+25 %	€3 000/tonne	-10 %	Depreciation of stocks to be disposed of Additional costs of alternative foams due to price and/or volume differences
	Average price €/tonne of fluorine-free foam	(Wood et al., 2020) Table 8.4 p. 148	Range confirmed by stakeholders	Low	-10 %	€3 000/tonne	+25 %	Additional costs of alternative foams due to price and/or volume differences
	Additional volumes required % increase over PFAS-containing foams	(Wood et al., 2020) Table 8.4 p. 148	Range confirmed by stakeholders	Low	+25 % required	+50% required	+75 % required	Additional costs of alternative foams due to price and/or volume differences
Savings from avoided clean-up		(Wood et al., 2020) Section "Clean-up" pp. 155-156	Wood et al. (2020) estimate cost of €100 000 to a few million € per incident requiring clean-up. Assuming several tens of incidents per year requiring clean-up due to PFAS content of foam gives around €10 million per year. Average clean-up costs per PFAS-containing foams in	Medium	+100 %	Gradually increasing to €10 million per year for the sum of all sectors	-50 %	Clean-up (after use, training, leakage, spill) savings

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

			use (€ per tonne) derived to come to the results of the Wood study.					
Additional producer surplus due to exports excepted from the ban (only for RM3)	Tonnage of exports	FFFC (FFFC-Interview, 2021) and Eurofeu (Eurofeu, 2021)	25% of annual sales, i.e. 25% of 18 000 t/y = 4 500 t/y	Medium	10 % of revenues for five years	10% of revenues for two years	10 % of revenues for one year	Producer surplus due to exports excepted from the ban (RO3)
	Years with profit losses due to export ban (or additional profits due to exports exempted from the ban)	(Ramboll, 2021)	Profits assumed as 10% of the value of sales revenue Two years profit loss (best cost scenario) as a proxy of the changes in producer surplus					
Costs per site for implementation of RMMs to meet full containment (only for RO5 and Seveso sector)		ECHA survey 2021	Information from industry	Medium	-50 %	€2 000 000 per site	+200 %	Costs for the implementation of RMMs to meet full containment within the total site (RO5, Seveso sector)
Costs of technical means to contain releases and disposal of PFAS-contaminated water from the fire-water run-off from testing/training		(Wood et al., 2020) Table 8.14 p. 163	Incineration/ disposal costs used as a proxy to cover the whole requirement	Medium	-50 %	€1 000/tonne	+100 %	Cost of additional RMMs for training/testing
Costs of technical means to contain releases and disposal of PFAS-contaminated water from the fire-water run-off from incidents		(Wood et al., 2020) Table 8.14 p. 163	Incineration/ disposal costs used as a proxy to cover the whole requirement*	Medium	-50 %	€1 000/tonne	+100 %	Cost of additional RMMs for incidents
Sector-specific parameters								
Cleaning cost to comply with the proposed concentration threshold	Cleaning costs per site	(Ramboll, 2021), derived from estimations from stakeholders: Vehicles: WFVD (WFVD and Peltzer, 2021) (Plant Fire Brigade Association Germany), LfU (LfU-Gierig-Interview,	Dependent on vehicles versus installed systems and remaining PFAS levels	Medium	-50 % in total cleaning costs	SEVESO: €200 000 per site. Civilian aviation and military: €50 000 per site Other sectors: €20 000 per site. Training and testing and ready to use	+100 % in total cleaning costs	Costs for cleaning of equipment

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

		2021) (Bavarian State Ministry for the Environment and Consumer Protection); Cornelsen (Cornelsen-Interview, 2021) (supplier of PerfluorAd process) Installed systems: one large German chemical/Seveso company)				applications: not relevant (see footnote*)		
	Number of sites per sector(s)	(Wood et al., 2020) (A.2.3.4, p. 389).	One unit per site as an average that has to be cleaned	Medium	Same as for the best scenario (the total costs of cleaning are considered in the sensitivity analysis by varying the unit cost.	Seveso: 10 000 Other industries: 1 000 (not reported by Wood) Civilian aviation: 401 Military: 239 Municipal fire services: 50 000 marine applications: 15 000 (sea-going ships) Training and testing and ready to use applications: not relevant	Same as for the best scenario (the total costs of cleaning are considered in the sensitivity analysis by varying the unit cost.	Costs for cleaning of equipment Cost of technical changes needed to use alternative foams Costs for the implementation of RMMs to meet full containment within the total site (RO5, Seveso sector)
Cost of technical changes needed to use alternative foams	Cost of technical change per site	See Section F.4.3. (Cost of technical changes needed) in the Annex.	€500 000 assumed for Seveso sites who provided information on significant costs. For other sectors no information suggesting significant costs is available.	High	-50 %	Seveso: €500 000 Training and testing: €0 Ready-to-use applications: not relevant** Other sectors: €5 000	+200 %	Cost of technical changes needed to use alternative foams

* In the absence of better information, the incineration cost of the PFAS-containing foams is used to approximate the cost of the requirement. This may

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

significantly underestimate the cost of the requirement considering that there are currently tens of thousands of users of PFAS-containing firefighting foams.

** The estimated total cost of €7 million over 30 years for ready-to-use applications does not consider the possible need for early replacement of the existing fire extinguishers. According to industry, replacement of the device may be needed. In this case, the cost for this sector could be significantly higher as there are around 15 million PFAS-containing extinguishers in use in the EU. However, the five-year transition period proposed for this sector is indicated to be sufficient by the industry to replace also the devices when necessary (see Annex E.4.3 for further details).

The emission calculations are subject to a range of uncertain assumptions. Among them, the annual use rates, the nature and efficiency of the risk management measures already in place, and the efficiency of the RMMs proposed in the restriction have been identified as entailing the highest uncertainties which can potentially significantly affect the results. The most uncertain parameters used in the cost assessment are related to the cost of technical changes needed to use alternative foams. In addition, there is in-built uncertainty in using the reduced emissions as a proxy of the risk reduction and reduced negative human health and environmental impacts. As mentioned in section 2.8, potential savings from avoided clean-up could further be described as benefits of restriction (instead of savings as done in this report). Even if this assumption would be changed, the overall results would not change significantly as this cost element represents only less than 2% of the total cost of the proposed restriction. Only for some cost categories a sector/use-specific assessment was considered necessary based on available data. This simplifies the assessment but does not mean that other sector-specific issues could not exist.

The full results of the sensitivity analysis are reported in Appendix 8 and 9.

4. Conclusion

All PFASs are very persistent in the environment. Many PFASs are likely to persist in the environment longer than any other man-made organic substance. As a consequence, if releases are not minimised, humans and other organisms will be exposed to progressively increasing amounts of PFASs until such levels are reached where effects are likely. In such an event the exposures are practically irreversible. Even if further releases of PFASs were immediately prevented, existing environmental stocks would continue to be a source of exposure for generations. There are several additional concerns arising from the use of PFASs, e.g., that a ubiquitous contamination of drinking water resources is unavoidable unless releases are minimised. Human exposures occur efficiently via all exposure routes via environment and cannot be avoided or mitigated. Some PFASs can accumulate in plants, others have bioaccumulation potential in biota and humans. Exposures are also transmitted effectively to unborn and breastfeeding children.

Use of PFASs in firefighting foams is substantially contributing to long-term general human and environmental exposures of PFASs aside other uses. The proposed restriction is providing a partial solution to the need to prevent the increase of general PFAS exposures. However, specific to the use of PFASs in firefighting foams, the potential to contaminate local environments, where firefighting, equipment maintenance and training take place, is high. The proposed restriction directly prevents such contaminated sites to be formed in future.

Five Member States are in the process of preparing a restriction that would cover all uses of PFASs. Concurrently, the Commission requested ECHA on 20 July 2020 to prepare a restriction proposal on the use PFASs in firefighting foams, as there are many technically and economically feasible alternatives available with the same function. Furthermore, initiatives have been taken in non-EU countries such as in Australia and restrictions on use in several US states and Australia. This global trend of moving away from PFASs in firefighting foams also helps the implementation of the proposed EU-wide restriction.

Based on five main options considered, a restriction covering placing on the market, use and export is proposed in the EU with specific transitional periods. The assessment of risk

reduction capacity, costs and cost-effectiveness ratios supports this conclusion. The results are associated with significant uncertainties and ranges have been estimated.

The need for the restriction of PFASs in firefighting foams is based on the following considerations:

- Risks of PFASs are of the non-threshold nature.
- PFASs are very persistent. PFAS exposures are therefore likely to increase to such levels that effects are triggered. At that point of time, the exposures are hardly reversible.
- Many PFASs are mobile in water, and their potential for long-range transport is high. This in combination with high persistence mean that PFAS exposures cannot be avoided by humans.
- Humans and environmental organisms are exposed to a complex mixture of PFASs, many of which have so far not been subject of regular targeted monitoring. Combined effects are likely within the group.
- The continued use of PFAS-containing firefighting foams is estimated to result in about 14 000 tonnes of emissions to the environment in the EU in the next 30 years unless action is taken. The proposed restriction option would lead to an estimated reduction of emissions of 13 200 tonnes over 30 years, which corresponds to an emission reduction of PFAS of 440 tonnes per year.

A restriction under REACH on the placing on the market, use and export of PFAS-containing firefighting foams is justified because:

- Suitable alternatives are available for most applications (all except sites or sectors which could face with particularly challenging fire scenarios such as establishments subject to the Seveso Directive).
- Transition periods are proposed for each type of use or industrial sector. In this manner it will be possible to select and test the most appropriate alternative firefighting product and to adapt the fire extinguishing system if necessary, without jeopardising the fire safety.
- Risk management measures that could reduce the emissions of PFASs in the environment are available and may to unknown extent be applied, however, in absence of additional regulatory measures these appear unlikely to significantly reduce the emissions of PFASs from the use of firefighting foams. To minimise the emissions of PFASs in the environment and the exposure of humans during the transition periods, the restriction needs to include additional mandatory risk management measures.
- The net-present value of the cost related to the restriction was estimated at €6.8 billion for the assessment period of 30 years. The cost-effectiveness of emission reduction was estimated at €515 per kg. This is comparable to other restriction proposals adopted by the Commission on PBT and PBT-like substances.
- The concern should be addressed at EU-level due to the functioning of the internal market for firefighting foam products. Firefighting foams are traded over the borders and it would not be meaningful or possible to restrict them nationally due to internal market considerations. Furthermore, due to their high mobility and persistence (at least of some PFASs), PFAS emissions could lead to cross-border pollution.

Fluorine-free foams have characteristics which differ from PFAS-containing foams. Therefore, for each user, testing of the alternative foam product in conjunction with the foam application method and adaptation of the fire extinguishing installation and equipment will be required.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

For certain types of uses this transition is expected to be implementable in a relatively short term. For other uses, a longer time is likely to be needed. In addition, the potential for emission reduction depends on the type of use. For these reasons, different transitional periods are considered per type of use and described below.

The proposed transitional periods are based the information collected during the preparation of this restriction proposal, including several stakeholder consultations. They are based on the assumption that suitable alternatives are implementable for each type of use by the end of the corresponding transitional period, i.e. that the transition to alternative would not compromise the fire safety.

Sector/type of use or placing on the market	Transitional period from the entry into force
Seveso establishments	10 years
Other industries	5 years
Civilian aviation	5 years
Defence	5 years
Municipal fire services	18 months
Ready-to-use applications	5 years
Marine applications	3 years
Training and testing	18 months
Export	10 years

Regarding **concentration thresholds**, a balance would need to be struck between the amount of PFAS emissions remaining if a given threshold is adopted, versus the costs of cleaning imposed to achieve that threshold. Stakeholder input suggests that 1 ppm can be achieved with a relatively simple cleaning. Lower thresholds are achievable with more complex and costly processes. However, setting a lower concentration threshold would only lead to a small additional reduction in PFAS emissions, compared to the overall reduction achieved by the restriction.

Finally, the proposed restriction would oblige the users to prepare and implement a **PFAS-containing firefighting foams management plan** and **best practice risk management measures** during and after the use of PFAS- containing firefighting foam. This covers among others foam purchase, containment, treatment, proper disposal of PFAS-containing foams and fire water run-off, use of personal protective equipment. These measures provide relatively effective reduction of PFAS emissions and exposure of workers and professionals at relatively low cost during the transition periods when PFAS-containing foams continue to be used.

In conclusion, in response to the request made by the Commission on 20 July 2020, the restriction on the placing on the market, use and export of PFASs in firefighting foams is proposed. The proposed entry for the restriction is presented in section 2.2.5.

References

- BACKHAUS, T., ALTENBURGER, R., BOEDEKER, W., FAUST, M., SCHOLZE, M. & GRIMME, L. H. 2000. Predictability of the toxicity of a multiple mixture of dissimilarly acting chemicals to *Vibrio fischeri*. *Environmental Toxicology and Chemistry*, 19, 2348-2356.
- BACKHAUS, T. & FAUST, M. 2012. Predictive Environmental Risk Assessment of Chemical Mixtures: A Conceptual Framework. *Environmental Science & Technology*, 46, 2564-2573.
- BALAN, S. A., MATHRANI, V. C., GUO, D. F. M. & ALGAZI, A. M. 2021. Regulating PFAS as a Chemical Class under the California Safer Consumer Products Program. *Environmental Health Perspectives*, 129.
- BIPRO 2011. Study on waste related issues of newly listed POPs and candidate POPs, retrieved from <https://op.europa.eu/en/publication-detail/-/publication/ad438122-39ee-49d3-a771-a98cad48a20a>.
- BLAKE, B. E., COPE, H. A., HALL, S. M., KEYS, R. D., MAHLER, B. W., MCCORD, J., SCOTT, B., STAPLETON, H. M., STRYNAR, M. J., ELMORE, S. A. & FENTON, S. E. 2020. Evaluation of Maternal, Embryo, and Placental Effects in CD-1 Mice following Gestational Exposure to Perfluorooctanoic Acid (PFOA) or Hexafluoropropylene Oxide Dimer Acid (HFPO-DA or GenX). *Environmental Health Perspectives*, 128.
- BLUM, A., BALAN, S. A., SCHERINGER, M., TRIER, X., GOLDENMAN, G., COUSINS, I. T., DIAMOND, M., FLETCHER, T., HIGGINS, C., LINDEMAN, A. E., PEASLEE, G., DE VOOGT, P., WANG, Z. & WEBER, R. 2015. The Madrid Statement on Poly- and Perfluoroalkyl Substances (PFASs). *Environ Health Perspect*, 123, A107-11.
- CORNELSEN-INTERVIEW 2021. Interview with Martin Cornelesen concerning ECHA FWC: PFAS in AFFF, SR 4 waste disposal, and cleaning techniques. . In: SCHÖPEL, M. (ed.).
- COUSINS, I. T., NG, C. A., WANG, Z. & SCHERINGER, M. 2019. Why is high persistence alone a major cause of concern? *Environ Sci Process Impacts*, 21, 781-792.
- DARWIN, R. L. 2011. Estimated Inventory Of PFOS-based Aqueous Film Forming Foam (AFFF), retrieved from <https://www.informea.org/sites/default/files/imported-documents/UNEP-POPS-POPRC13FU-SUBM-PFOA-FFFC-3-20180112.En.pdf>.
- EFSA 2019. Guidance on harmonised methodologies for human health, animal health and ecological risk assessment of combined exposure to multiple chemicals. *European Food Safety Authority; EFSA Journal*, 17(3):5634; doi: 10.2903/j.efsa.2019.5634.
- EFSA 2020. Risk to human health related to the presence of perfluoroalkyl substances in food. *EFSA Journal*, 18(9):6223.
- EPA US 2021. Human Health Toxicity Assessments for GenX Chemicals. *U.S. Environmental Protection Agency Office of Water (4304T), Health and Ecological Criteria Division, Washington, DC 20460*, <https://www.epa.gov/chemical-research/human-health-toxicity-assessments-genx-chemicals>.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

- EUROFEU 2020. Comment #2983 to the PFHxA restriction Annex XV report; available in RCOM Part 2 at <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d>.
- EUROFEU 2021. Input to the study on "REACH restriction support – PFAS in firefighting foams (part 4)" - Provide a report on the manufacture, import and export of firefighting foams in the EEA.
- FELIZETER, S., MCLACHLAN, M. S. & DE VOOGT, P. 2014. Root uptake and translocation of perfluorinated alkyl acids by three hydroponically grown crops. *J Agric Food Chem*, 62, 3334-42.
- FFFC-INTERVIEW 2021. Interview with Tom Cortina; John Olav Ottesen, Dafo Fomtec AB; Gregg Ublacker, Johnson Controls (GU) and Mitch Hubert, Perimeter Solutions (MH) concerning ECHA FWC: PFAS in AFFF, SR 5 market data. In: SCHÖPEL, M. (ed.).
- FFFC 2016. Best Practice Guidance for Use of Class B Firefighting Foams.
- FFFC 2020. Comment #3010 on the Annex XV report on PFHxA, retrieved from RCOM Part 2 available at <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d>.
- FPA-AUS 2020. Selection and use of firefighting foams
- HENRY, B. J., CARLIN, J. P., HAMMERSCHMIDT, J. A., BUCK, R. C., BUXTON, L. W., FIEDLER, H., SEED, J. & HERNANDEZ, O. 2018. A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integr Environ Assess Manag*, 14, 316-334.
- IPEN 2018. Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams (AFFF), retrieved from https://ipen.org/sites/default/files/documents/IPEN_F3_Position_Paper_POPRC-14_12September2018d.pdf.
- JONES, C. E., BALLINGER, M. B., MATTIE, D. R., DELRASO, N. J., SECKEL, C. & VINEGAR, A. 1991. Effects of short-term oral dosing of polychlorotrifluoroethylene (polyCTFE) on the rhesus monkey. *J Appl Toxicol*, 11, 51-60.
- KEMI 2016. Strategy for reducing the use of highly fluorinated substances, PFASs. Swedish Chemicals Agency.
- LFU-GIERIG-INTERVIEW 2021. Interview with Dr. Michael Gierig concerning ECHA FWC: PFAS in AFFF, SR 4 waste disposal and cleaning techniques. .
- LI, F., DUAN, J., TIAN, S., JI, H., ZHU, Y., WEI, Z. & ZHAO, D. 2020. Short-chain per- and polyfluoroalkyl substances in aquatic systems: Occurrence, impacts and treatment. *Chemical Engineering Journal*, 380.
- LOHMANN, R., COUSINS, I. T., DEWITT, J. C., GLÜGE, J., GOLDENMAN, G., HERZKE, D., LINDSTROM, A. B., MILLER, M. F., NG, C. A., 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? *Environmental Science & Technology*, 54, 12820-12828.
- MARTIN, O., SCHOLZE, M., ERMILER, S., MCPHIE, J., BOPP, S. K., KIENZLER, A., PARISSIS, N. & KORTENKAMP, A. 2021. Ten years of research on synergisms and antagonisms in chemical mixtures: A systematic review and quantitative reappraisal of mixture studies. *Environment International*, 146, 17.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

- MUIR, D., BOSSI, R., CARLSSON, P., EVANS, M., DE SILVA, A., HALSALL, C., RAUERT, C., HERZKE, D., HUNG, H. & LETCHER, R. 2019. Levels and trends of poly-and perfluoroalkyl substances in the Arctic environment–An update. *Emerging contaminants*, 5, 240-271.
- OECD 2021a. Draft OECD Synthesis Report on Understanding Side-Chain Fluorinated Polymers and Their Life Cycle (v.3, from 9.12.2021).
- OECD 2021b. Reconciling terminology of the universe of per-and polyfluoroalkyl substances: recommendations and practical guidance. *Series on risk management*. Paris: Organisation for economic cooperation and development.
- OOSTERHUIS, F. & BROUWER, R. 2015. Benchmark development for the proportionality assessment of PBT and vPvB substances available at http://echa.europa.eu/documents/10162/13647/R15_11_pbt_benchmark_report_en.pdf.
- RAMBOLL 2021. ECHA FWC: PFAS in firefighting foams, SR 4 PFAS waste disposal methods and equipment cleaning methods, unpublished.
- SCHERINGER, M., TRIER, X., COUSINS, I. T., DE VOOGT, P., FLETCHER, T., WANG, Z. & WEBSTER, T. F. 2014. Helsingor statement on poly- and perfluorinated alkyl substances (PFASs). *Chemosphere*, 114, 337-9.
- US-CA 2020. SB-1044 Firefighting equipment and foam: PFAS chemicals, available at https://leginfo.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB1044.
- US-EPA 2019. EPA's Per- and Polyfluoroalkyl Substances (PFAS) Action Plan - retrieved from https://www.epa.gov/sites/default/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf.
- US-NDAA 2020. S.1790 - National Defense Authorization Act for Fiscal Year 2020, available at <https://www.congress.gov/bill/116th-congress/senate-bill/1790/text>.
- US-WA 2018. Engrossed substitute senate bill 6413 available at <http://lawfilesexternal.wa.gov/biennium/2017-18/Pdf/Bills/Senate%20Passed%20Legislature/6413-S.PL.pdf?q=20200413062702>.
- US-WA 2020. Engrossed substitute house bill 2265, available at: <https://lawfilesexternal.wa.gov/biennium/2019-20/Pdf/Bills/House%20Bills/2265-S.E.pdf?q=20211213081248>.
- WASHINGTON, J. W., RANKIN, K., LIBELO, E. L., LYNCH, D. G. & CYTERSKI, M. 2019. Determining global background soil PFAS loads and the fluorotelomer-based polymer degradation rates that can account for these loads. *Science of the Total Environment*, 651, 2444-2449.
- WFVD & PELTZER, E. 2021. Input to the study on "REACH restriction support – PFAS in firefighting foams".
- WOOD 2020. The use of PFAS and fluorine-free alternatives in textiles, upholstery, carpets, leather and apparel. Wednesday 15th January 2020 at the European Commission, Brussels: Wood Environment & Infrastructure Solutions UK Limited,.
- WOOD, RAMBOLL & COWI 2020. The use of PFAS and fluorine-free alternatives in firefighting foams.

YOO, H., WASHINGTON, J. W., JENKINS, T. M. & ELLINGTON, J. J. 2011. Quantitative determination of perfluorochemicals and fluorotelomer alcohols in plants from biosolid-amended fields using LC/MS/MS and GC/MS. *Environ Sci Technol*, 45, 7985-90.

Additional references

(to be sorted before the third party consultation. Might contain duplicates)

3M (1983): TWO YEAR ORAL (DIET) TOXICITY / CARCINOGENICITY STUDY OF FLUOROCEMICAL FC-143 IN RATS. RIKER Experiment No. 028]CR0012. Pathology and Toxicology, Riker Laboratories, Inc., St. Paul, MN, USA

3M 1983. TWO YEAR ORAL (DIET) TOXICITY / CARCINOGENICITY STUDY OF FLUOROCEMICAL FC-143 IN RATS. St. Paul, MN, USA: Pathology and Toxicology, Riker Laboratories, Inc.

Aas, C.B., Fuglei, E., Herzke, D., Yoccoz, N.G., Routti, H., 2014. Effect of body condition on tissue distribution of perfluoroalkyl substances (PFASs) in Arctic fox (*Vulpes lagopus*). *Environ. Sci. Technol.* 48, 11654-11661.

Abbott B.D., Wolf C.J., Schmid J.E., Das K.P., Zehr R.D., Helfant L., Nakayama S., Lindstrom A.B., Strynar M.J., and Lau C. (2007): Perfluorooctanoic acid-induced developmental toxicity in the mouse is dependent on expression of peroxisome proliferator-activated receptor- α . *Toxicological Sciences* 98 (2), 571-581. DOI: 10.1093/toxsci/kfm110

ABBOTT, B. D., WOLF, C. J., SCHMID, J. E., DAS, K. P., ZEHR, R. D., HELFANT, L., NAKAYAMA, S., LINDSTROM, A. B., STRYNAR, M. J. & LAU, C. 2007. Perfluorooctanoic acid-induced developmental toxicity in the mouse is dependent on expression of peroxisome proliferator-activated receptor- α . *Toxicological Sciences*, 98, 571-581.

Abercrombie, S.A., de Perre, C., Choi, Y.J., Tornabene, B.J., Sepúlveda, M.S., Lee, L.S., Hoverman, J.T., 2019. Larval amphibians rapidly bioaccumulate poly- and perfluoroalkyl substances. *Ecotoxicol. Environ. Saf.* 178, 137-145. <https://doi.org/10.1016/j.ecoenv.2019.04.022>

Abercrombie, S.A., de Perre, C., Choi, Y.J., Tornabene, B.J., Sepúlveda, M.S., Lee, L.S., Hoverman, J.T., 2019. Larval amphibians rapidly bioaccumulate poly- and perfluoroalkyl substances. *Ecotoxicol. Environ. Saf.* 178, 137-145. <https://doi.org/10.1016/j.ecoenv.2019.04.022>

Ahrens L, Norström K, Viktor T, Cousins AP, Josefsson S. Stockholm Arlanda Airport as a source of per- and polyfluoroalkyl substances to water, sediment and fish. *Chemosphere* 2015; 129: 33-38: <https://doi.org/10.1016/j.chemosphere.2014.03.136>.

Ahrens, L., 2011. Polyfluoroalkyl compounds in the aquatic environment: A review of their occurrence and fate. *Journal of Environmental Monitoring* 13, 20-31.

Ahrens, L., 2011. Polyfluoroalkyl compounds in the aquatic environment: A review of their occurrence and fate. *Journal of Environmental Monitoring* 13, 20-31.

Ahrens, L., Bundschuh, M., 2014a. Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. *Environ. Toxicol. Chem.* 33, 1921-1929. <https://doi.org/10.1002/etc.2663>

Ahrens, L., Bundschuh, M., 2014a. Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. *Environ. Toxicol. Chem.* 33, 1921–1929. <https://doi.org/10.1002/etc.2663>

Ahrens, L., Bundschuh, M., 2014b. Fate and effects of poly- and perfluoroalkyl substances in the aquatic environment: A review. *Environmental Toxicology and Chemistry* 33, 1921–1929. <https://doi.org/10.1002/etc.2663>

Ahrens, L., Gerwinski, W., Theobald, N., Ebinghaus, R., 2010a. Sources of polyfluoroalkyl compounds in the North Sea, Baltic Sea and Norwegian Sea: Evidence from their spatial distribution in surface water. *Mar. Pollut. Bull.* 60, 255.

Ahrens, L., Harner, T., Shoeib, M., Koblizkova, M., Reiner, E.J., 2013. Characterization of two passive air samplers for per- and polyfluoroalkyl substances. *Environ. Sci. Technol.* 47, 14024–14033.

Ahrens, L., Shoeib, M., Del Vento, S., Codling, G., Halsall, C., 2011. Polyfluoroalkyl compounds in the Canadian Arctic atmosphere. *Environmental Chemistry* 8, 399–406.

Ahrens, L., Shoeib, M., Harner, T., Lee, S.C., Guo, R., Reiner, E.J., 2011. Wastewater treatment plant and landfills as sources of polyfluoroalkyl compounds to the atmosphere. *Environ. Sci. Technol.* 45, 8098–8105.

Ahrens, L., Siebert, U., Ebinghaus, R., 2009. Total body burden and tissue distribution of polyfluorinated compounds in harbor seals (*Phoca vitulina*) from the German Bight. *Mar Pollut Bull* 58, 520–5. <https://doi.org/10.1016/j.marpolbul.2008.11.030>

Ahrens, L., Siebert, U., Ebinghaus, R., 2009. Total body burden and tissue distribution of polyfluorinated compounds in harbor seals (*Phoca vitulina*) from the German Bight. *Mar Pollut Bull* 58, 520–5. <https://doi.org/10.1016/j.marpolbul.2008.11.030>

AHRENS, L., TANIYASU, S., YEUNG, L. W., YAMASHITA, N., LAM, P. K. & EBINGHAUS, R. 2010. Distribution of polyfluoroalkyl compounds in water, suspended particulate matter and sediment from Tokyo Bay, Japan. *Chemosphere*, 79, 266–72.

Ahrens, L., Xie, Z., Ebinghaus, R., 2010b. Distribution of perfluoroalkyl compounds in seawater from Northern Europe, Atlantic Ocean, and Southern Ocean. *Chemosphere* 78, 1011–1016.

Alexandrino, D. A. M., Ribeiro, I., Pinto, L. M., Cambra, R., Oliveira, R. S., Pereira, F. & Carvalho, M. F. (2018): Biodegradation of mono-, di- and trifluoroacetate by microbial cultures with different origins. *New Biotechnology*, 43, 23–29.

Alexandrino, D. A. M., Ribeiro, I., Pinto, L. M., Cambra, R., Oliveira, R. S., Pereira, F. & Carvalho, M. F. (2018): Biodegradation of mono-, di- and trifluoroacetate by microbial cultures with different origins. *New Biotechnology*, 43, 23–29.

Allendorf, F., Berger, U., Goss, K.-U., Ulrich, N., 2019a. Partition coefficients of four perfluoroalkyl acid alternatives between bovine serum albumin (BSA) and water in comparison to ten classical perfluoroalkyl acids. *Environmental Science: Processes and Impacts* 21, 1852–1863. <https://doi.org/10.1039/c9em00290a>

Allendorf, F., Berger, U., Goss, K.-U., Ulrich, N., 2019a. Partition coefficients of four perfluoroalkyl acid alternatives between bovine serum albumin (BSA) and water in comparison to ten classical perfluoroalkyl acids. *Environmental Science: Processes and Impacts* 21, 1852–1863. <https://doi.org/10.1039/c9em00290a>

Allendorf, F., Berger, U., Goss, K.-U., Ulrich, N., 2019b. Partition coefficients of four perfluoroalkyl acid alternatives between bovine serum albumin (BSA) and water in comparison to ten classical perfluoroalkyl acids. *Environmental Science: Processes and Impacts* 21, 1852–1863. <https://doi.org/10.1039/c9em00290a>

Allendorf, F., Goss, K.-U., Ulrich, N., 2021. Estimating the Equilibrium Distribution of Perfluoroalkyl Acids and 4 of Their Alternatives in Mammals. *Environmental Toxicology and Chemistry* 40, 910–920. <https://doi.org/10.1002/etc.4954>

Allendorf, F., Goss, K.-U., Ulrich, N., 2021. Estimating the Equilibrium Distribution of Perfluoroalkyl Acids and 4 of Their Alternatives in Mammals. *Environmental Toxicology and Chemistry* 40, 910–920. <https://doi.org/10.1002/etc.4954>

Altenburger R., Backhaus T., Boedeker W., Faust M., and Scholze M. (2013): Simplifying complexity: Mixture toxicity assessment in the last 20 years. *Environmental Toxicology and Chemistry* 32 (8), 1685-1687. DOI: 10.1002/etc.2294

ALTENBURGER, R., BACKHAUS, T., BOEDEKER, W., FAUST, M. & SCHOLZE, M. 2013. Simplifying complexity: Mixture toxicity assessment in the last 20 years. *Environmental Toxicology and Chemistry*, 32, 1685-1687.

Amap, 2014. ArcRisk (arctic health risks: impacts on health in the arctic and Europe owing to climate-induced changes in contaminant cycling) results overview. Arctic Monitoring and Assessment Program Oslo, 62.

Andersen, M. P. S. & Nielsen, O. J. (2022): Tropospheric photolysis of CF₃CHO. *Atmospheric Environment*, 272, 118935.

Andersen, M. P. S., Kyte, M., Andersen, S. T., Nielsen, C. J. & Nielsen, O. J. (2017): Atmospheric Chemistry of (CF₃)₂CF-CN: A Replacement Compound for the Most Potent Industrial Greenhouse Gas, SF₆. *Environmental Science & Technology*, 51, 1321-1329.

Andersen, M.E., Butenhoff, J.L., Chang, S.C., Farrar, D.G., Kennedy, G.L., Lau, C., Olsen, G.W., Seed, J., Wallace, K.B., 2008. Perfluoroalkyl acids and related chemistries--toxicokinetics and modes of action. *Toxicol.Sci* 102, 3–14.

Andersen, M.E., Butenhoff, J.L., Chang, S.C., Farrar, D.G., Kennedy, G.L., Lau, C., Olsen, G.W., Seed, J., Wallace, K.B., 2008. Perfluoroalkyl acids and related chemistries--toxicokinetics and modes of action. *Toxicol.Sci* 102, 3–14.

Androulakis A, Alygizakis N, Gkotsis G, Nika M-C, Nikolopoulou V, Bizani E, et al. Determination of 56 per- and polyfluoroalkyl substances in top predators and their prey from Northern Europe by LC-MS/MS. *Chemosphere* 2022: 131775: <https://doi.org/10.1016/j.chemosphere.2021.131775>.

Ankley, G. T., Cureton, P., Hoke, R. A., Houde, M., Kumar, A., Kurias, J., . . . Valsecchi, S. (2020). Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward. *Environmental Toxicology and Chemistry*, 40(3), 564-605. doi:<https://doi.org/10.1002/etc.4869>

Ankley, G.T., Cureton, P., Hoke, R.A., Houde, M., Kumar, A., Kurias, J., Lanno, R., McCarthy, C., Newsted, J., Salice, C.J., Sample, B.E., Sepúlveda, M.S., Steevens, J., Valsecchi, S., 2021. Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward. *Environ. Toxicol. Chem.* 40, 564–605. <https://doi.org/10.1002/etc.4869>

Ankley, G.T., Cureton, P., Hoke, R.A., Houde, M., Kumar, A., Kurias, J., Lanno, R., McCarthy, C., Newsted, J., Salice, C.J., Sample, B.E., Sepúlveda, M.S., Steevens, J., Valsecchi, S., 2021.

Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward. *Environ. Toxicol. Chem.* 40, 564–605. <https://doi.org/10.1002/etc.4869>

Annunziato, K. M., Jantzen, C. E., Gronske, M. C., & Cooper, K. R. (2019). Subtle morphometric, behavioral and gene expression effects in larval zebrafish exposed to PFHxA, PFHxS and 6:2 FTOH. *Aquat Toxicol*, 208, 126-137. doi:10.1016/j.aquatox.2019.01.009

Armitage JM, Arnot JA, Wania F. Potential Role of Phospholipids in Determining the Internal Tissue Distribution of Perfluoroalkyl Acids in Biota. *Environmental Science & Technology* 2012; 46: 12285-12286: DOI: 10.1021/es304430r.

Armitage JM, MacLeod M, Cousins IT. Comparative Assessment of the Global Fate and Transport Pathways of Long-Chain Perfluorocarboxylic Acids (PFCAs) and Perfluorocarboxylates (PFCs) Emitted from Direct Sources. *Environmental Science & Technology* 2009a; 43: 5830-5836: DOI: 10.1021/es900753y.

Armitage JM, MacLeod M, Cousins IT. Modeling the Global Fate and Transport of Perfluorooctanoic Acid (PFOA) and Perfluorooctanoate (PFO) Emitted from Direct Sources Using a Multispecies Mass Balance Model. *Environmental Science & Technology* 2009b; 43: 1134-1140: DOI: 10.1021/es802900n.

Armitage, J., Cousins, I.T., Buck, R.C., Prevedouros, K., Russell, M.H., MacLeod, M., Korzeniowski, S.H., 2006. Modeling global-scale fate and transport of perfluorooctanoate emitted from direct sources. *Environ. Sci. Technol.* 40, 6969.

Armitage, J.M., Arnot, J.A., Wania, F., 2012a. Potential role of phospholipids in determining the internal tissue distribution of perfluoroalkyl acids in biota. *Environmental Science and Technology* 46, 12285–12286. <https://doi.org/10.1021/es304430r>

Armitage, J.M., Arnot, J.A., Wania, F., 2012a. Potential role of phospholipids in determining the internal tissue distribution of perfluoroalkyl acids in biota. *Environmental Science and Technology* 46, 12285–12286. <https://doi.org/10.1021/es304430r>

Armitage, J.M., Arnot, J.A., Wania, F., 2012b. Potential role of phospholipids in determining the internal tissue distribution of perfluoroalkyl acids in biota. *Environmental Science and Technology* 46, 12285–12286. <https://doi.org/10.1021/es304430r>

Armitage, J.M., Arnot, J.A., Wania, F., Mackay, D., 2013. Development and evaluation of a mechanistic bioconcentration model for ionogenic organic chemicals in fish. *Environmental Toxicology and Chemistry* 32, 115–128. <https://doi.org/10.1002/etc.2020>

Armitage, J.M., Arnot, J.A., Wania, F., Mackay, D., 2013. Development and evaluation of a mechanistic bioconcentration model for ionogenic organic chemicals in fish. *Environmental Toxicology and Chemistry* 32, 115–128. <https://doi.org/10.1002/etc.2020>

Armitage, J.M., Erickson, R.J., Luckenbach, T., Ng, C.A., Prosser, R.S., Arnot, J.A., Schirmer, K., Nichols, J.W., 2017. Assessing the bioaccumulation potential of ionizable organic compounds: Current knowledge and research priorities. *Environmental Toxicology and Chemistry* 36, 882–897. <https://doi.org/10.1002/etc.3680>

Armitage, J.M., Erickson, R.J., Luckenbach, T., Ng, C.A., Prosser, R.S., Arnot, J.A., Schirmer, K., Nichols, J.W., 2017. Assessing the bioaccumulation potential of ionizable organic compounds: Current knowledge and research priorities. *Environmental Toxicology and Chemistry* 36, 882–897. <https://doi.org/10.1002/etc.3680>

Arnot, J.A., Gobas, F.A., 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. *Environmental Toxicology and Chemistry* 23, 2343–55.

Arnot, J.A., Gobas, F.A., 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. *Environmental Toxicology and Chemistry* 23, 2343–55.

Arnot, J.A., Gobas, F.A., 2006. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environ. Rev.* 14, 257–297. <https://doi.org/10.1139/a06-005>

Arnot, J.A., Gobas, F.A., 2006. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environ. Rev.* 14, 257–297. <https://doi.org/10.1139/a06-005>

Aro R., Eriksson U., Kärrman A., Chen F., Wang T., and Yeung L.W.Y. (2021): Fluorine Mass Balance Analysis of Effluent and Sludge from Nordic Countries. *ACS ES&T Water* 1 (9), 2087–2096. DOI: 10.1021/acsestwater.1c00168

Arp, H. P. & Slinde, G. A., Norwegian Geotechnical Institute (NGI) (2018). PFBS in the Environment: Monitoring and Physical-Chemical Data Related to the Environmental Distribution of Perfluorobutanesulfonic Acid (M-1122). <http://www.miljodirektoratet.no/Documents/publikasjoner/M1122/M1122.pdf>

Arp, H. P. & Slinde, G. A., Norwegian Geotechnical Institute (NGI) (2018). PFBS in the Environment: Monitoring and Physical-Chemical Data Related to the Environmental Distribution of Perfluorobutanesulfonic Acid (M-1122). <http://www.miljodirektoratet.no/Documents/publikasjoner/M1122/M1122.pdf>

Arp, H. P. H. & Hale, S. E., UBA (2019). REACH: Improvement of guidance and methods for the identification and assessment of PMT/vPvM substances. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-11-29_texte_126-2019_reach-pmt.pdf

Arp, H. P. H. & Hale, S. E., UBA (2019). REACH: Improvement of guidance and methods for the identification and assessment of PMT/vPvM substances. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-11-29_texte_126-2019_reach-pmt.pdf

Arp, H.P.F.H., S.E., 2019. REACH: Improvement of guidance and methods for the identification and assessment of PM/PMT substances. UBA Texte 126/2019. Project number: FKZ 3716 67 416 0. ISSN: 1862-4804. German Environmental Agency (UBA), Dessau-Rosslau, Germany. 129 p. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-11-29_texte_126-2019_reach-pmt.pdf. .

Arvaniti O.S., Ventouri E.I., Stasinakis A.S., and Thomaidis N.S. (2012): Occurrence of different classes of perfluorinated compounds in Greek wastewater treatment plants and determination of their solid-water distribution coefficients. *J Hazard Mater* 239–240, 24–31. DOI: 10.1016/j.jhazmat.2012.02.015

Arvaniti OS, Andersen HR, Thomaidis NS, Stasinakis AS. Sorption of Perfluorinated Compounds onto different types of sewage sludge and assessment of its importance during wastewater treatment. *Chemosphere* 2014; 111: 405–411. <https://doi.org/10.1016/j.chemosphere.2014.03.087>.

Arvaniti, O.S., Andersen, H.R., Thomaidis, N.S., Stasinakis, A.S., 2014. Sorption of Perfluorinated Compounds onto different types of sewage sludge and assessment of its importance during wastewater treatment. *Chemosphere* 111, 405–411.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Assessment, C.f.R., 2021. ECHA's Committee for Risk Assessment (RAC). Opinion on an Annex XV dossier proposing restrictions on undecafluorohexanoic acid (PFHxA), its salts and related substances ECHA/RAC/RES-O-0000006976-57-01/F . Adopted 3 June 2021.

ATSDR (2021): Toxicological Profile for Perfluoroalkyls, date: 2021-05. Agency for Toxic Substances and Disease Registry. Registry A.f.T.S.a.D., Atlanta, GA, USA. <https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=1117&tid=237>

ATSDR 2021. Toxicological Profile for Perfluoroalkyls. In: REGISTRY, A. F. T. S. A. D. (ed.). Atlanta, GA, USA: Agency for Toxic Substances and Disease Registry.

Awad, E., Zhang, X., Bhavsar, S.P., Petro, S., Crozier, P.W., Reiner, E.J., Fletcher, R., Tittlemier, S.A., Braekevelt, E., 2011. Long-term environmental fate of perfluorinated compounds after accidental release at Toronto airport. *Environ Sci Technol* 45, 8081-8089.

Bach, C., Dauchy, X., Boiteux, V., Colin, A., Hemard, J., Sagres, V., Rosin, C., Munoz, J.F., 2016. The impact of two fluoropolymer manufacturing facilities on downstream contamination of a river and drinking water resources with per- and polyfluoroalkyl substances. *Environ Sci Pollut Res Int*.

Backhaus T. and Faust M. (2012): Predictive Environmental Risk Assessment of Chemical Mixtures: A Conceptual Framework. *Environmental Science & Technology* 46 (5), 2564-2573. DOI: 10.1021/es2034125

Backhaus T., Altenburger R., Boedeker W., Faust M., Scholze M., and Grimme L.H. (2000): Predictability of the toxicity of a multiple mixture of dissimilarly acting chemicals to *Vibrio fischeri*. *Environmental Toxicology and Chemistry* 19 (9), 2348-2356. DOI: 10.1002/etc.5620190927

BACKHAUS, T. & FAUST, M. 2012. Predictive Environmental Risk Assessment of Chemical Mixtures: A Conceptual Framework. *Environmental Science & Technology*, 46, 2564-2573.

BACKHAUS, T., ALTENBURGER, R., BOEDEKER, W., FAUST, M., SCHOLZE, M. & GRIMME, L. H. 2000. Predictability of the toxicity of a multiple mixture of dissimilarly acting chemicals to *Vibrio fischeri*. *Environmental Toxicology and Chemistry*, 19, 2348-2356.

Badry A, Treu G, Gkotsis G, Nika M-C, Alygizakis N, Thomaidis NS, et al. Ecological and spatial variations of legacy and emerging contaminants in white-tailed sea eagles from Germany: Implications for prioritisation and future risk management. *Environment International* 2022; 158: 106934: <https://doi.org/10.1016/j.envint.2021.106934>.

Baduel, C., Mueller, J. F., Rotander, A., Corfield, J., & Gomez-Ramos, M. J. (2017). Discovery of novel per- and polyfluoroalkyl substances (PFASs) at a fire fighting training ground and preliminary investigation of their fate and mobility. *Chemosphere*, 185, 1030-1038. doi:10.1016/j.chemosphere.2017.06.096

Baduel, C., Mueller, J.F., Rotander, A., Corfield, J., Gomez-Ramos, M.J., 2017. Discovery of novel per- and polyfluoroalkyl substances (PFASs) at a fire fighting training ground and preliminary investigation of their fate and mobility. *Chemosphere* 185, 1030-1038.

Balan S.A., Mathrani V.C., Guo D.F.M., and Algazi A.M. (2021): Regulating PFAS as a Chemical Class under the California Safer Consumer Products Program. *Environmental Health Perspectives* 129 (2). DOI: Artn 02500110.1289/Ehp7431

Bălan, S. A., Mathrani, V. C., Guo, D. F. & Algazi, A. M. (2021): Regulating PFAS as a Chemical Class under the California Safer Consumer Products Program. *Environmental Health Perspectives*, 129, 1-9.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Bălan, S. A., Mathrani, V. C., Guo, D. F. & Algazi, A. M. (2021): Regulating PFAS as a Chemical Class under the California Safer Consumer Products Program. *Environmental Health Perspectives*, 129, 1-9.

BALAN, S. A., MATHRANI, V. C., GUO, D. F. M. & ALGAZI, A. M. 2021. Regulating PFAS as a Chemical Class under the California Safer Consumer Products Program. *Environmental Health Perspectives*, 129.

Banerjee, S., Schmidt, J., Talmon, Y., Hori, H., Asai, T., & Ameduri, B. (2018): A degradable fluorinated surfactant for emulsion polymerization of vinylidene fluoride. *Chemical Communications*, 54, 11399–11402.

Banerjee, S., Schmidt, J., Talmon, Y., Hori, H., Asai, T., & Ameduri, B. (2018): A degradable fluorinated surfactant for emulsion polymerization of vinylidene fluoride. *Chemical Communications*, 54, 11399–11402.

Bao, J., Li, C.L., Liu, Y., Wang, X., Yu, W.J., Liu, Z.Q., Shao, L.X., Jin, Y.H., 2020. Bioaccumulation of perfluoroalkyl substances in greenhouse vegetables with long-term groundwater irrigation near fluorochemical plants in Fuxin, China. *Environ. Res.* 188.

Bao, J., Yu, W.J., Liu, Y., Wang, X., Jin, Y.H., Dong, G.H., 2019. Perfluoroalkyl substances in groundwater and home-produced vegetables and eggs around a fluorochemical industrial park in China. *Ecotoxicology and Environmental Safety* 171, 199-205.

Barmentlo, S. H., Stel, J. M., van Doorn, M., Eschauzier, C., de Voogt, P., & Kraak, M. H. S. (2015). Acute and chronic toxicity of short chained perfluoroalkyl substances to *Daphnia magna*. *Environmental Pollution*, 198(0), 47-53. doi:10.1016/j.envpol.2014.12.025

Barmentlo, S. H., Stel, J. M., Van Doorn, M., Eschauzier, C., De Voogt, P., & Kraak, M. H. S. (2015). Acute and chronic toxicity of short chained perfluoroalkyl substances to *Daphnia magna*. *Environmental Pollution*, 198, 47-53. doi:10.1016/j.envpol.2014.12.025

Barnes, I., Hjorth, J. & Mihalopoulos, N. (2006): Dimethyl Sulfide and Dimethyl Sulfoxide and Their Oxidation in the Atmosphere. *Chemical Reviews*, 106, 940–975.

Barrett H, Du X, Houde M, Lair S, Verreault J, Peng H. Suspect and Nontarget Screening Revealed Class-Specific Temporal Trends (2000–2017) of Poly- and Perfluoroalkyl Substances in St. Lawrence Beluga Whales. *Environmental Science & Technology* 2021; 55: 1659-1671: 10.1021/acs.est.0c05957.

Barry V., Winquist A., and Steenland K. (2013): Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. *Environ Health Perspect* 121 (11-12), 1313-1318. DOI: 10.1289/ehp.1306615

BARRY, V., WINQUIST, A. & STEENLAND, K. 2013. Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. *Environ Health Perspect*, 121, 1313-8.

Barton, C. A., Kaiser, M. A., & Russell, M. H. (2007). Partitioning and removal of perfluorooctanoate during rain events: The importance of physical-chemical properties. *Journal of Environmental Monitoring*, 9(8), 839-846. doi:10.1039/b703510a

Bassler J., Ducatman A., Elliott M., Wen S., Wahlang B., Barnett J., and Cave M.C. (2019): Environmental perfluoroalkyl acid exposures are associated with liver disease characterized by apoptosis and altered serum adipocytokines. *Environmental Pollution* 247, 1055-1063. DOI: 10.1016/j.envpol.2019.01.064

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

BASSLER, J., DUCATMAN, A., ELLIOTT, M., WEN, S., WAHLANG, B., BARNETT, J. & CAVE, M. C. 2019. Environmental perfluoroalkyl acid exposures are associated with liver disease characterized by apoptosis and altered serum adipocytokines. *Environ Pollut*, 247, 1055-1063.

BayerCropScience (2014): Summary of the toxicological and metabolism studies for Flurtamone. <https://www.cropscience.bayer.com/sites/cropscience/files/inline-files/M-482296-01-5.PDF>

BAYERCROPSCIENCE 2014. Summary of the toxicological and metabolism studies for Flurtamone. <https://www.cropscience.bayer.com/sites/cropscience/files/inline-files/M-482296-01-5.PDF>.

Beans C. (2021): News Feature: How “forever chemicals” might impair the immune system. *Proceedings of the National Academy of Sciences* 118 (15), e2105018118. DOI: 10.1073/pnas.2105018118

BEANS, C. 2021. News Feature: How “forever chemicals” might impair the immune system. *Proceedings of the National Academy of Sciences*, 118, e2105018118.

Behr A.-C., Lichtenstein D., Braeuning A., Lampen A., and Buhrke T. (2018): Perfluoroalkylated substances (PFAS) affect neither estrogen and androgen receptor activity nor steroidogenesis in human cells in vitro. *Toxicology Letters* 291, 51-60. DOI: <https://doi.org/10.1016/j.toxlet.2018.03.029>

Bengtson Nash, S., Rintoul, S.R., Kawaguchi, S., Staniland, I., Hoff, J.V.D., Tierney, M., Bossi, R., 2010. Perfluorinated compounds in the Antarctic region: Ocean circulation provides prolonged protection from distant sources. *Environmental Pollution* 158, 2985-2991.

Benninghoff A.D., Bisson W.H., Koch D.C., Ehresman D.J., Kolluri S.K., and Williams D.E. (2011): Estrogen-like activity of perfluoroalkyl acids in vivo and interaction with human and rainbow trout estrogen receptors in vitro. *Toxicol Sci* 120 (1), 42-58. DOI: 10.1093/toxsci/kfq379

Berg V., Nost T.H., Hansen S., Elverland A., Veyhe A.S., Jorde R., Odland J.O., and Sandanger T.M. (2015): Assessing the relationship between perfluoroalkyl substances, thyroid hormones and binding proteins in pregnant women; a longitudinal mixed effects approach. *Environ Int* 77, 63-69. DOI: 10.1016/j.envint.2015.01.007

BERG, V., NOST, T. H., HANSEN, S., ELVERLAND, A., VEYHE, A. S., JORDE, R., ODLAND, J. O. & SANDANGER, T. M. 2015. Assessing the relationship between perfluoroalkyl substances, thyroid hormones and binding proteins in pregnant women; a longitudinal mixed effects approach. *Environ Int*, 77, 63-9.

Bernard, F., Papanastasiou, D. K., Portmann, R. W., Papadimitriou, V. C. & Burkholder, J. B. (2020): Atmospheric lifetimes and global warming potentials of atmospherically persistent N(C_xF_{2x+1})₃, x = 2–4, perfluoroamines. *Chemical Physics Letters*, 744, 137089.

Bernard, F., Papanastasiou, D. K., Portmann, R. W., Papadimitriou, V. C. & Burkholder, J. B. (2020): Atmospheric lifetimes and global warming potentials of atmospherically persistent N(C_xF_{2x+1})₃, x = 2–4, perfluoroamines. *Chemical Physics Letters*, 744, 137089.

Bernard, F., Papanastasiou, D. K., Portmann, R. W., Papadimitriou, V. C. & Burkholder, J. B. (2020): Atmospheric lifetimes and global warming potentials of atmospherically persistent N(C_xF_{2x+1})₃, x = 2–4, perfluoroamines. *Chemical Physics Letters*, 744, 137089.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Bertrand, O.R., Halsall, C.J., Herzke, D., Huber, S., Nordstad, T., del Vento, S., Heimstad, E.S., 2014. Short-term fluctuations in the levels of poly- and perfluoroalkyl Substances (PFASs) in the seasonal Snowpack. *Arctic Frontiers*.

Biegel L.B., Hurtt M.E., Frame S.R., O'Connor J.C., and Cook J.C. (2001): Mechanisms of extrahepatic tumor induction by peroxisome proliferators in male CD rats. *Toxicol Sci* 60 (1), 44-55. DOI: 10.1093/toxsci/60.1.44

BIEGEL, L. B., HURTT, M. E., FRAME, S. R., O'CONNOR, J. C. & COOK, J. C. 2001. Mechanisms of extrahepatic tumor induction by peroxisome proliferators in male CD rats. *Toxicol Sci*, 60, 44-55.

Bil W, Zeilmaker M, Fragki S, Lijzen J, Verbruggen E, Bokkers B. Risk Assessment of Per- and Polyfluoroalkyl Substance Mixtures: A Relative Potency Factor Approach. *Environ Toxicol Chem*. 2021 Mar;40(3):859-870. doi: 10.1002/etc.4835. Epub 2020 Sep 8. PMID: 32729940.

Bil W., Zeilmaker M., Fragki S., Lijzen J., Verbruggen E., and Bokkers B. (2021): Risk Assessment of Per- and Polyfluoroalkyl Substance Mixtures: A Relative Potency Factor Approach. *Environmental Toxicology and Chemistry* 40 (3), 859-870. DOI: 10.1002/etc.4835

BIL, W., ZEILMAKER, M., FRAGKI, S., LIJZEN, J., VERBRUGGEN, E. & BOKKERS, B. 2021. Risk Assessment of Per- and Polyfluoroalkyl Substance Mixtures: A Relative Potency Factor Approach. *Environ Toxicol Chem*, 40, 859-870.

Bischel HN, MacManus-Spencer LA, Zhang C, Luthy RG. Strong associations of short-chain perfluoroalkyl acids with serum albumin and investigation of binding mechanisms. *Environmental Toxicology and Chemistry* 2011; 30: 2423-2430: <https://doi.org/10.1002/etc.647>.

Bischel, H.N., Macmanus-Spencer, L.A., Zhang, C., Luthy, R.G., 2011. Strong associations of short-chain perfluoroalkyl acids with serum albumin and investigation of binding mechanisms. *Environmental Toxicology and Chemistry* 30, 2423–2430. <https://doi.org/10.1002/etc.647>

Bischel, H.N., Macmanus-Spencer, L.A., Zhang, C., Luthy, R.G., 2011. Strong associations of short-chain perfluoroalkyl acids with serum albumin and investigation of binding mechanisms. *Environmental Toxicology and Chemistry* 30, 2423–2430. <https://doi.org/10.1002/etc.647>

Bizkarguenaga E., Zabaleta I., Prieto A., Fernández L.A., and 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.

BIZKARGUENAGA, E., ZABALETA, I., PRIETO, A., FERNÁNDEZ, L. A. & 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.

Bizkarguenaga, E., Zabaleta, I., Prieto, A., Fernández, L. A., & 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. doi:10.1016/j.chemosphere.2016.02.130

Björnsdotter, M. K., Yeung, L. W. Y., Kärrman, A., & Ericson Jogsten, I. (2020). Challenges in the analytical determination of ultra-short-chain perfluoroalkyl acids and implications for environmental and human health. *Analytical and Bioanalytical Chemistry*, 412(20), 4785-4796. doi:10.1007/s00216-020-02692-8

BLAINE, A. C., RICH, C. D., HUNDAL, L. S., LAU, C., MILLS, M. A., HARRIS, K. M. & HIGGINS, C. P. 2013. Uptake of perfluoroalkyl acids into edible crops via land applied biosolids: field and greenhouse studies. *Environ Sci Technol*, 47, 14062-9.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Blaine, A. C., Rich, C. D., Hundal, L. S., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2013). Uptake of perfluoroalkyl acids into edible crops via land applied biosolids: field and greenhouse studies. *Environ Sci Technol*, 47(24), 14062-14069. doi:10.1021/es403094q

BLAINE, A. C., RICH, C. D., SEDLACKO, E. M., HUNDAL, L. S., KUMAR, K., LAU, C., MILLS, M. A., HARRIS, K. M. & HIGGINS, C. P. 2014a. Perfluoroalkyl acid distribution in various plant compartments of edible crops grown in biosolids-amended soils. *Environ Sci Technol*, 48, 7858-65.

Blaine, A. C., Rich, C. D., Sedlacko, E. M., Hundal, L. S., Kumar, K., Lau, C., . . . Higgins, C. P. (2014). Perfluoroalkyl acid distribution in various plant compartments of edible crops grown in biosolids-amended soils. *Environ Sci Technol*, 48(14), 7858-7865. doi:10.1021/es500016s

BLAINE, A. C., RICH, C. D., SEDLACKO, E. M., HYLAND, K. C., STUSHNOFF, C., DICKENSON, E. R. & HIGGINS, C. P. 2014b. Perfluoroalkyl acid uptake in lettuce (*Lactuca sativa*) and strawberry (*Fragaria ananassa*) irrigated with reclaimed water. *Environ Sci Technol*, 48, 14361-8.

Blaine, A. C., Rich, C. D., Sedlacko, E. M., Hyland, K. C., Stushnoff, C., Dickenson, E. R., & Higgins, C. P. (2014). Perfluoroalkyl acid uptake in lettuce (*Lactuca sativa*) and strawberry (*Fragaria ananassa*) irrigated with reclaimed water. *Environ Sci Technol*, 48(24), 14361-14368. doi:10.1021/es504150h

Blaine, A.C., Rich, C.D., Sedlacko, E.M., Hundal, L.S., Kumar, K., Lau, C., Mills, M.A., Harris, K.M., Higgins, C.P., 2014. Perfluoroalkyl acid distribution in various plant compartments of edible crops grown in biosolids-amended soils. *Environ. Sci. Technol.* 48, 7858-7865.

Blake B.E., Cope H.A., Hall S.M., Keys R.D., Mahler B.W., McCord J., Scott B., Stapleton H.M., Strynar M.J., Elmore S.A., and Fenton S.E. (2020): Evaluation of Maternal, Embryo, and Placental Effects in CD-1 Mice following Gestational Exposure to Perfluorooctanoic Acid (PFOA) or Hexafluoropropylene Oxide Dimer Acid (HFPO-DA or GenX). *Environmental Health Perspectives* 128 (2). DOI: Artn 02700610.1289/Ehp6233

Blake B.E., Pinney S.M., Hines E.P., Fenton S.E., and Ferguson K.K. (2018): Associations between longitudinal serum perfluoroalkyl substance (PFAS) levels and measures of thyroid hormone, kidney function, and body mass index in the Fernald Community Cohort. *Environmental Pollution* 242, 894-904. DOI: 10.1016/j.envpol.2018.07.042

BLAKE, B. E., COPE, H. A., HALL, S. M., KEYS, R. D., MAHLER, B. W., MCCORD, J., SCOTT, B., STAPLETON, H. M., STRYNAR, M. J., ELMORE, S. A. & FENTON, S. E. 2020. Evaluation of Maternal, Embryo, and Placental Effects in CD-1 Mice following Gestational Exposure to Perfluorooctanoic Acid (PFOA) or Hexafluoropropylene Oxide Dimer Acid (HFPO-DA or GenX). *Environmental Health Perspectives*, 128.

BLAKE, B. E., PINNEY, S. M., HINES, E. P., FENTON, S. E. & FERGUSON, K. K. 2018. Associations between longitudinal serum perfluoroalkyl substance (PFAS) levels and measures of thyroid hormone, kidney function, and body mass index in the Fernald Community Cohort. *Environmental Pollution*, 242, 894-904.

Blum A., Balan S.A., Scheringer M., Trier X., Goldenman G., Cousins I.T., Diamond M., Fletcher T., Higgins C., Lindeman A.E., Peaslee G., de Voogt P., Wang Z., and Weber R. (2015): The Madrid Statement on Poly- and Perfluoroalkyl Substances (PFASs). *Environ Health Perspect* 123 (5), A107-111. DOI: 10.1289/ehp.1509934

BLUM, A., BALAN, S. A., SCHERINGER, M., TRIER, X., GOLDENMAN, G., COUSINS, I. T., DIAMOND, M., FLETCHER, T., HIGGINS, C., LINDEMAN, A. E., PEASLEE, G., DE VOOGT, P., WANG, Z. & WEBER, R. 2015. The Madrid Statement on Poly- and Perfluoroalkyl Substances (PFASs). *Environ Health Perspect*, 123, A107-11.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Blum, A., Balan, S. A., Scheringer, M., Trier, X., Goldenman, G., Cousins, I. T., Diamond, M., Fletcher, T., Higgins, C., Lindeman, A. E., Peaslee, G., Voogt, P. d., Wang, Z. & Weber, R. (2015): The Madrid Statement on Poly-and Perfluoroalkyl Substances (PFASs). *Environmental Health Perspectives*, 123, A107-A111.

Blum, A., Balan, S. A., Scheringer, M., Trier, X., Goldenman, G., Cousins, I. T., Diamond, M., Fletcher, T., Higgins, C., Lindeman, A. E., Peaslee, G., Voogt, P. d., Wang, Z. & Weber, R. (2015): The Madrid Statement on Poly-and Perfluoroalkyl Substances (PFASs). *Environmental Health Perspectives*, 123, A107-A111.

Blum, A., Balan, S.A., Scheringer, M., Trier, X., Goldenman, G., Cousins, I.T., Diamond, M., Fletcher, T., Higgins, C., Lindeman, A.E., 2015. The Madrid statement on poly-and perfluoroalkyl substances (PFASs). *Environmental health perspectives* 123, A107–A111.

Bogdanska, J., Borg, D., Bergström, U., Mellring, M., Bergman, Å., DePierre, J., Nobel, S., 2020. Tissue distribution of ¹⁴C-labelled perfluorooctanoic acid in adult mice after 1–5 days of dietary exposure to an experimental dose or a lower dose that resulted in blood levels similar to those detected in exposed humans. *Chemosphere* 239, 124755. <https://doi.org/10.1016/j.chemosphere.2019.124755>

Bolan, N., Sarkar, B., Vithanage, M., Singh, G., Tsang, D.C.W., Mukhopadhyay, R., Ramadass, K., Vinu, A., Sun, Y., Ramanayaka, S., Hoang, S.A., Yan, Y., Li, Y., Rinklebe, J., Li, H., Kirkham, M.B., 2021. Distribution, behaviour, bioavailability and remediation of poly- and per-fluoroalkyl substances (PFAS) in solid biowastes and biowaste-treated soil. *Environment International* 155.

Borg D. and Ivarsson J. (2017): Analysis of PFASs and TOF in Products. *TemaNord* 2017:543, ISSN 0908-6692. Nordic Council of Ministers, Copenhagen, DK. <http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A1118439&dswid=9615> (last accessed 2017-12-20)

Borg D., Lund B.O., Lindquist N.G., and Hakansson H. (2013): Cumulative health risk assessment of 17 perfluoroalkylated and polyfluoroalkylated substances (PFASs) in the Swedish population. *Environment International* 59, 112-123. DOI: 10.1016/j.envint.2013.05.009

BORG, D. & IVARSSON, J. 2017. Analysis of PFASs and TOF in Products. Copenhagen, DK: Nordic Council of Ministers.

Borg, D., Håkansson, H., 2012. Environmental and Health Risk Assessment of Perfluoroalkylated and Polyfluoroalkylated Substances (PFASs) in Sweden, in: *Book Environmental and Health Risk Assessment of Perfluoroalkylated and Polyfluoroalkylated Substances (PFASs) in Sweden* (Editor Ed. ^eds.), Vol. 6513. Swedish Environmental Protection Agency, City.

BORG, D., LUND, B. O., LINDQUIST, N. G. & HAKANSSON, H. 2013. Cumulative health risk assessment of 17 perfluoroalkylated and polyfluoroalkylated substances (PFASs) in the Swedish population. *Environment International*, 59, 112-123.

Borgert C.J., Quill T.F., McCarty L.S., and Mason A.M. (2004): Can mode of action predict mixture toxicity for risk assessment? *Toxicology and Applied Pharmacology* 201 (2), 85-96. DOI: 10.1016/j.taap.2004.05.005

BORGERT, C. J., QUILL, T. F., MCCARTY, L. S. & MASON, A. M. 2004. Can mode of action predict mixture toxicity for risk assessment? *Toxicology and Applied Pharmacology*, 201, 85-96.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Bossi R., Strand J., Sortkjær O., and Larsen M.M. (2008): Perfluoroalkyl compounds in Danish wastewater treatment plants and aquatic environments. *Environment International* 34 (4), 443-450. DOI: <http://dx.doi.org/10.1016/j.envint.2007.10.002>

Bossi, R., Dam, M., Rigét, F.F., 2015. Perfluorinated alkyl substances (PFAS) in terrestrial environments in Greenland and Faroe Islands. *Chemosphere* 129, 164-169.

Bossi, R., Vorkamp, K., Skov, H., 2016. Concentrations of organochlorine pesticides, polybrominated diphenyl ethers and perfluorinated compounds in the atmosphere of North Greenland. *Environmental Pollution* 217, 4-10.

Bradry, N.C.W., R.R., 2010. *Elements of the Nature and Properties of Soils*, 3rd Ed. Pearsons Education Limited, Harlow, UK.

Brambilla, G., D'Hollander, W., Oliaei, F., Stahl, T., Weber, R., 2015. Pathways and factors for food safety and food security at PFOS contaminated sites within a problem based learning approach. *Chemosphere* 129, 192-202.

BRANDSMA, S. H., KOEKKOEK, J. C., VAN VELZEN, M. J. M. & DE BOER, J. 2019. The PFOA substitute GenX detected in the environment near a fluoropolymer manufacturing plant in the Netherlands. *Chemosphere*, 220, 493-500.

Brandsma, S. H., Koekkoek, J. C., van Velzen, M. J. M., & de Boer, J. (2019). The PFOA substitute GenX detected in the environment near a fluoropolymer manufacturing plant in the Netherlands. *Chemosphere*, 220, 493-500. doi:<https://doi.org/10.1016/j.chemosphere.2018.12.135>

Brantsaeter A.L., Whitworth K.W., Ydersbond T.A., Haug L.S., Haugen M., Knutsen H.K., Thomsen C., Meltzer H.M., Becher G., Sabaredzovic A., Hoppin J.A., Eggesbo M., and Longnecker M.P. (2013): Determinants of plasma concentrations of perfluoroalkyl substances in pregnant Norwegian women. *Environ Int* 54, 74-84. DOI: 10.1016/j.envint.2012.12.014

BRANTSAETER, A. L., WHITWORTH, K. W., YDERSBOND, T. A., HAUG, L. S., HAUGEN, M., KNUTSEN, H. K., THOMSEN, C., MELTZER, H. M., BECHER, G., SABAREDZOVIC, A., HOPPIN, J. A., EGGESBO, M. & LONGNECKER, M. P. 2013. Determinants of plasma concentrations of perfluoroalkyl substances in pregnant Norwegian women. *Environ Int*, 54, 74-84.

Braune, B.M., Gaston, A.J., Elliott, K.H., Provencher, J.F., Woo, K.J., Chambellant, M., Ferguson, S.H., Letcher, R.J., 2014a. Organohalogen contaminants and total mercury in forage fish preyed upon by thick-billed murre in northern Hudson Bay. *Mar. Pollut. Bull.* 78, 258-266.

Braune, B.M., Gaston, A.J., Letcher, R.J., Grant Gilchrist, H., Mallory, M.L., Provencher, J.F., 2014b. A geographical comparison of chlorinated, brominated and fluorinated compounds in seabirds breeding in the eastern Canadian Arctic. *Environ. Res.* 134, 46-56.

Bräunig, J., Baduel, C., Barnes, C.M., Mueller, J.F., 2019. Leaching and bioavailability of selected perfluoroalkyl acids (PFAAs) from soil contaminated by firefighting activities. *Sci. Total Environ.* 646, 471-479.

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(1). doi:10.1186/s12302-018-0134-4

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.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Briels, N., Ciesielski, T. M., Herzke, D., & Jaspers, V. L. B. (2018a). Developmental Toxicity of Perfluorooctanesulfonate (PFOS) and Its Chlorinated Polyfluoroalkyl Ether Sulfonate Alternative F-53B in the Domestic Chicken. *Environ. Sci. Technol.*, 52(21), 12859.

Briels, N., Ciesielski, T. M., Herzke, D., & Jaspers, V. L. B. (2018b). Developmental Toxicity of Perfluorooctanesulfonate (PFOS) and Its Chlorinated Polyfluoroalkyl Ether Sulfonate Alternative F-53B in the Domestic Chicken. *Environ Sci Technol*, 52(21), 12859-12867. doi:10.1021/acs.est.8b04749

Brown, J.B., Conder, J.M., Arblaster, J.A., Higgins, C.P., 2020. Assessing Human Health Risks from Per- And Polyfluoroalkyl Substance (PFAS)-Impacted Vegetable Consumption: A Tiered Modeling Approach. *Environ. Sci. Technol.* 54, 15202-15214.

Brusseau, M. L., Anderson, R. H., & Guo, B. (2020). PFAS concentrations in soils: Background levels versus contaminated sites. *Science of The Total Environment*, 740, 140017. doi:<https://doi.org/10.1016/j.scitotenv.2020.140017>

Brusseau, M.L., 2018. Assessing the potential contributions of additional retention processes to PFAS retardation in the subsurface. *Science of the Total Environment* 613-614, 176-185.

Brusseau, M.L., Anderson, R.H., Guo, B., 2020. PFAS concentrations in soils: Background levels versus contaminated sites. *Science of the Total Environment* 740.

Buck RC, Franklin J, Berger U, Conder JM, Cousins IT, Voogt PD, Jensen AA, Kannan K, Mabury SA, van Leeuwen SPJ. 2011. Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management* 7:513-541.

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., Voogt, P. d., Jensen, A. A., Kannan, K., Mabury, S. A. & Leeuwen, S. P. J. v. (2011): Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins. *Integrated Environmental Assessment and Management*, 7, 513-541.

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., Voogt, P. D., . . . van Leeuwen, S. P. J. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management*, 7(4), 513-541. doi:10.1002/ieam.258

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., Voogt, P. d., Jensen, A. A., Kannan, K., Mabury, S. A. & Leeuwen, S. P. J. v. (2011): Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins. *Integrated Environmental Assessment and Management*, 7, 513-541.

Burkhard L. (2021): Evaluation of Published Bioconcentration Factor (BCF) and Bioaccumulation Factor (BAF) Data for Per- and Polyfluoroalkyl Substances Across Aquatic Species. *Environmental Toxicology and Chemistry* 40: 1530–1543

Burkhard L. (2021): Evaluation of Published Bioconcentration Factor (BCF) and Bioaccumulation Factor (BAF) Data for Per- and Polyfluoroalkyl Substances Across Aquatic Species. *Environmental Toxicology and Chemistry* 40: 1530–1543

Busch, J., Ahrens, L., Xie, Z., Sturm, R., Ebinghaus, R., 2010. Polyfluoroalkyl compounds in the East Greenland Arctic Ocean. *J. Environ. Monit.* 12, 1242.

Buszek, R. J. & Francisco, J. S. (2009): The Gas-Phase Decomposition of CF₃OH with Water: A Radical-Catalyzed Mechanism. *Journal of Physical Chemistry A*, 113, 5333–5337.

Butenhoff J.L., Chang S.C., Olsen G.W., and Thomford P.J. (2012): Chronic dietary toxicity and carcinogenicity study with potassium perfluorooctanesulfonate in Sprague Dawley rats. *Toxicology* 293 (1-3), 1-15. DOI: 10.1016/j.tox.2012.01.003

Butenhoff J.L., Kennedy G.L., Jr., Frame S.R., O'Connor J.C., and York R.G. (2004): The reproductive toxicology of ammonium perfluorooctanoate (APFO) in the rat. *Toxicology* 196 (1-2), 95-116. DOI: 10.1016/j.tox.2003.11.005

BUTENHOFF, J. L., CHANG, S. C., OLSEN, G. W. & THOMFORD, P. J. 2012. Chronic dietary toxicity and carcinogenicity study with potassium perfluorooctanesulfonate in Sprague Dawley rats. *Toxicology*, 293, 1-15.

BUTENHOFF, J. L., KENNEDY, G. L., JR., FRAME, S. R., O'CONNOR, J. C. & YORK, R. G. 2004. The reproductive toxicology of ammonium perfluorooctanoate (APFO) in the rat. *Toxicology*, 196, 95-116.

Butt C.M., Muir D.C.G., and Mabury S.A. (2014): Biotransformation pathways of fluorotelomer-based polyfluoroalkyl substances: A review. *Environmental Toxicology and Chemistry*, 33 (2), 243-267.

Butt C.M., Young C.J., Mabury S.A., Hurley M.D., and Wallington T.J. (2009): Atmospheric chemistry of 4:2 fluorotelomer acrylate [C₄F₉CH₂CH₂OC(O)CH=CH₂]: kinetics, mechanisms, and products of chlorine-atom- and OH-radical-initiated oxidation. *J Phys Chem A*, 113 (13), 3155-3161.

Butt CM, Muir DCG, Mabury SA. (2010): Elucidating the pathways of poly- and perfluorinated acid formation in rainbow trout. *Environ Sci Technol*, 44, 4973–4980.

Butt, C.M., Berger, U., Bossi, R., Tomy, G.T., 2010. Levels and trends of poly- and perfluorinated compounds in the arctic environment. *Sci. Total Environ.* 408, 2936-2965.

Butt, C.M., Muir, D.C.G., Mabury, S.A., 2014. Biotransformation pathways of fluorotelomer-based polyfluoroalkyl substances: A review. *Environ. Toxicol. Chem.* 33, 243-267.

C8 Science Panel (2012): Probable Link Evaluation of Thyroid disease. C8 Science Panel

C8 SCIENCE PANEL 2012. Probable Link Evaluation of Thyroid disease. C8 Science Panel.

Cai, M., Zhao, Z., Yang, H., Yin, Z., Hong, Q., Sturm, R., Ebinghaus, R., Ahrens, L., Cai, M., He, J. & Xie, Z. (2012b): Spatial distribution of per- and polyfluoroalkyl compounds in coastal waters from the East to South China Sea. *Environmental Pollution*, 161, 162-169.

Cai, M., Zhao, Z., Yang, H., Yin, Z., Hong, Q., Sturm, R., Ebinghaus, R., Ahrens, L., Cai, M., He, J., Xie, Z., 2012. Spatial distribution of per- and polyfluoroalkyl compounds in coastal waters from the East to South China Sea. *Environmental Pollution* 161, 162-169.

Cai, M., Zhao, Z., Yin, Z., Ahrens, L., Huang, P., Cai, M., Yang, H., He, J., Sturm, R., Ebinghaus, R., Xie, Z., 2012. Occurrence of perfluoroalkyl compounds in surface waters from the North Pacific to the Arctic Ocean. *Environ. Sci. Technol.* 46, 661-668.

Campbell S., Raza M., and Pollack A.Z. (2016): Perfluoroalkyl substances and endometriosis in US women in NHANES 2003-2006. *Reproductive Toxicology* 65, 230-235. DOI: 10.1016/j.reprotox.2016.08.009

Campbell, J. S., Kable, S. H. & Hansen, C. S. (2021): Photodissociation of CF₃CHO provides a new source of CHF₃ (HFC-23) in the atmosphere: implications for new refrigerants (PREPRINT). *Physical Sciences*.

CAMPBELL, S., RAZA, M. & POLLACK, A. Z. 2016. Perfluoroalkyl substances and endometriosis in US women in NHANES 2003-2006. *Reprod Toxicol*, 65, 230-235.

Campo J, Masiá A, Picó Y, Farré M, Barceló D. Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants. *Science of The Total Environment* 2014; 472: 912-922: <https://doi.org/10.1016/j.scitotenv.2013.11.056>.

Campo J., Masiá A., Picó Y., Farré M., and Barceló D. (2014): Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants. *Science of the Total Environment* 472, 912-922. DOI: <https://doi.org/10.1016/j.scitotenv.2013.11.056>

Campo, J., Lorenzo, M., Pérez, F., Picó, Y., Farré, M., Barceló, D., 2016. Analysis of the presence of perfluoroalkyl substances in water, sediment and biota of the Júcar River (E Spain). Sources, partitioning and relationships with water physical characteristics. *Environ. Res.* 147, 503–512. <https://doi.org/10.1016/j.envres.2016.03.010>

Campo, J., Pérez, F., Masia, A., Picó, Y., Farré, M., Barceló, D. 2015: Perfluoroalkyl substance contamination of the Llobregat River ecosystem (Mediterranean area, NE Spain). *Science of the Total Environment* 503–504: 48-57

Campo, J., Pérez, F., Masia, A., Picó, Y., Farré, M., Barceló, D. 2015: Perfluoroalkyl substance contamination of the Llobregat River ecosystem (Mediterranean area, NE Spain). *Science of the Total Environment* 503–504: 48-57

Campos Pereira, H., Ullberg, M., Kleja, D.B., Gustafsson, J.P., Ahrens, L., 2018. Sorption of perfluoroalkyl substances (PFASs) to an organic soil horizon – Effect of cation composition and pH. *Chemosphere* 207, 183-191.

Cáñez, T.T., Guo, B., McIntosh, J.C., Brusseau, M.L., 2021. Perfluoroalkyl and polyfluoroalkyl substances (PFAS) in groundwater at a reclaimed water recharge facility. *Science of the Total Environment* 791.

Cao X.Y., Liu J., Zhang Y.J., Wang Y., Xiong J.W., Wu J., and Chen L. (2020): Exposure of adult mice to perfluorobutanesulfonate impacts ovarian functions through hypothyroxinemia leading to down-regulation of Akt-mTOR signaling. *Chemosphere* 244. DOI: [10.1016/j.chemosphere.2019.125497](https://doi.org/10.1016/j.chemosphere.2019.125497)

CAO, X. Y., LIU, J., ZHANG, Y. J., WANG, Y., XIONG, J. W., WU, J. & CHEN, L. 2020. Exposure of adult mice to perfluorobutanesulfonate impacts ovarian functions through hypothyroxinemia leading to down-regulation of Akt-mTOR signaling. *Chemosphere*, 244.

Carpenter, L.J., Reimann, S., Burkholder, J.B., Clerbaux, C., Hall, B.D., Hossaini, R., Laube, J.C., Yvon-Lewis, S.A., 2014. Ozone-depleting substances (ODSs) and other gases of interest to the montreal protocol. *Scientific Assessment of Ozone Depletion: 2014*.

Casas, G., Martínez-Varela, A., Roscales, J.L., Vila-Costa, M., Dachs, J., Jiménez, B., 2020. Enrichment of perfluoroalkyl substances in the sea-surface microlayer and sea-spray aerosols in the Southern Ocean. *Environmental Pollution* 267.

Casson, R., & Chiang, S. Y. D. (2018). Integrating total oxidizable precursor assay data to evaluate fate and transport of PFASs. *Remediation*, 28(2), 71-87. doi:10.1002/rem.21551

Cassone C.G., Vongphachan V., Chiu S., Williams K.L., Letcher R.J., Pelletier E., Crump D., and Kennedy S.W. (2012): In Ovo Effects of Perfluorohexane Sulfonate and Perfluorohexanoate on Pipping Success, Development, mRNA Expression, and Thyroid Hormone Levels in Chicken Embryos. *Toxicological Sciences* 127 (1), 216-224. DOI: [10.1093/toxsci/kfs072](https://doi.org/10.1093/toxsci/kfs072) (last accessed 7/9/2021)

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Cassone, C. G., Vongphachan, V., Chiu, S., Williams, K. L., Letcher, R. J., Pelletier, E., . . . Kennedy, S. W. (2012). In Ovo Effects of Perfluorohexane Sulfonate and Perfluorohexanoate on Pipping Success, Development, mRNA Expression, and Thyroid Hormone Levels in Chicken Embryos. *Toxicological Sciences*, 127(1), 216-224. doi:10.1093/toxsci/kfs072

Caverly Rae J.M., Craig L., Slone T.W., Frame S.R., Buxton L.W., and Kennedy G.L. (2015): Evaluation of chronic toxicity and carcinogenicity of ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)-propanoate in Sprague-Dawley rats. *Toxicol Rep* 2, 939-949. DOI: 10.1016/j.toxrep.2015.06.001

CAVERLY RAE, J. M., CRAIG, L., SLONE, T. W., FRAME, S. R., BUXTON, L. W. & KENNEDY, G. L. 2015. Evaluation of chronic toxicity and carcinogenicity of ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)-propanoate in Sprague-Dawley rats. *Toxicol Rep*, 2, 939-949.

Charles River Laboratories (2007a): A 5-Day Repeat Dose Oral Toxicity Screening Study in Rats with a 7-Day Recovery Period with MTDID 6675, 7280, 7254 and 8799. 06-375 / ZXA00081. Charles River Laboratories Preclinical Services 640 North Elizabeth Street Spencerville, OH 45887

Charles River Laboratories (2007b): Oral (Gavage) Developmental Toxicity Screening Study of MTDID 6675 in Rats 06-376 / ZXA00077. Charles River Laboratories Preclinical Services 905 Sheely Drive, Building A Horsham, PA 19044

Charles River Laboratories (2017): A Combined 28-Day Whole Body Inhalation Toxicity Study with the Reproduction/Developmental Toxicity Screening Test of PPVE with a 14-Day Recovery in Rats study no 15-014 / WIL-272502. Charles River Laboratories Ashland, LLC 1407 George Road Ashland, OH 44805 United States

CHARLES RIVER LABORATORIES 2007a. A 5-Day Repeat Dose Oral Toxicity Screening Study in Rats with a 7-Day Recovery Period with MTDID 6675, 7280, 7254 and 8799. Charles River Laboratories Preclinical Services 640 North Elizabeth Street Spencerville, OH 45887.

CHARLES RIVER LABORATORIES 2007b. Oral (Gavage) Developmental Toxicity Screening Study of MTDID 6675 in Rats Charles River Laboratories Preclinical Services 905 Sheely Drive, Building A Horsham, PA 19044.

CHARLES RIVER LABORATORIES 2017. A Combined 28-Day Whole Body Inhalation Toxicity Study with the Reproduction/Developmental Toxicity Screening Test of PPVE with a 14-Day Recovery in Rats Charles River Laboratories Ashland, LLC 1407 George Road Ashland, OH 44805 United States.

Chen F., Gong Z., Kelly B.C. (2016): Bioavailability and bioconcentration potential of perfluoroalkyl-phosphinic and -phosphonic acids in zebrafish (*Danio rerio*): Comparison to perfluorocarboxylates and perfluorosulfonates. *Science of The Total Environment* 568: 33-41.

Chen F., Gong Z., Kelly B.C. (2016): Bioavailability and bioconcentration potential of perfluoroalkyl-phosphinic and -phosphonic acids in zebrafish (*Danio rerio*): Comparison to perfluorocarboxylates and perfluorosulfonates. *Science of The Total Environment* 568: 33-41.

Chen L., Hu C., Tsui M.M.P., Wan T., Peterson D.R., Shi Q., Lam P.K.S., Au D.W.T., Lam J.C.W., and Zhou B. (2018): Multigenerational Disruption of the Thyroid Endocrine System in Marine Medaka after a Life-Cycle Exposure to Perfluorobutanesulfonate. *Environmental Science & Technology* 52 (7), 4432-4439. DOI: 10.1021/acs.est.8b00700

Chen Y, Fu J, Ye T, Li X, Gao K, Xue Q, et al. Occurrence, profiles, and ecotoxicity of poly- and perfluoroalkyl substances and their alternatives in global apex predators: A critical review. *Journal of Environmental Sciences* 2021; 109: 219-236: <https://doi.org/10.1016/j.jes.2021.03.036>.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

- Chen Y., Li H., Mo J., Chen X., Wu K., Ge F., Ma L., Li X., Guo X., Zhao J., and Ge R.S. (2019): Perfluorododecanoic Acid Blocks Rat Leydig Cell Development during Prepuberty. *Chem Res Toxicol* 32 (1), 146-155. DOI: 10.1021/acs.chemrestox.8b00241
- Chen, C., Wang, J., Li, L., Xu, W., & Liu, J. (2020). Comparison of fluorotelomer alcohol emissions from wastewater treatment plants into atmospheric and aquatic environments. *Environment International*, 139. doi:10.1016/j.envint.2020.105718
- Chen, F., Gong, Z., Kelly, B.C., 2016a. Bioavailability and bioconcentration potential of perfluoroalkyl-phosphinic and -phosphonic acids in zebrafish (*Danio rerio*): Comparison to perfluorocarboxylates and perfluorosulfonates. *Science of the Total Environment* 568, 33–41. <https://doi.org/10.1016/j.scitotenv.2016.05.215>
- Chen, F., Gong, Z., Kelly, B.C., 2016b. Bioavailability and bioconcentration potential of perfluoroalkyl-phosphinic and -phosphonic acids in zebrafish (*Danio rerio*): Comparison to perfluorocarboxylates and perfluorosulfonates. *Science of the Total Environment* 568, 33–41. <https://doi.org/10.1016/j.scitotenv.2016.05.215>
- Chen, F., Gong, Z., Kelly, B.C., 2017. Bioaccumulation Behavior of Pharmaceuticals and Personal Care Products in Adult Zebrafish (*Danio rerio*): Influence of Physical-Chemical Properties and Biotransformation. *Environmental Science and Technology* 51, 11085–11095. <https://doi.org/10.1021/acs.est.7b02918>
- Chen, F., Gong, Z., Kelly, B.C., 2017. Bioaccumulation Behavior of Pharmaceuticals and Personal Care Products in Adult Zebrafish (*Danio rerio*): Influence of Physical-Chemical Properties and Biotransformation. *Environmental Science and Technology* 51, 11085–11095. <https://doi.org/10.1021/acs.est.7b02918>
- Chen, F., Wei, C., Chen, Q., Zhang, J., Wang, L., Zhou, Z., . . . Liang, Y. (2018). Internal concentrations of perfluorobutane sulfonate (PFBS) comparable to those of perfluorooctane sulfonate (PFOS) induce reproductive toxicity in *Caenorhabditis elegans*. *Ecotoxicol Environ Saf*, 158, 223-229. doi:10.1016/j.ecoenv.2018.04.032
- Chen, H., Yao, Y., Zhao, Z., Wang, Y., Wang, Q., Ren, C., Wang, B., Sun, H., Alder, A.C., Kannan, K., 2018. Multimedia Distribution and Transfer of Per- and Polyfluoroalkyl Substances (PFASs) Surrounding Two Fluorochemical Manufacturing Facilities in Fuxin, China. *Environ. Sci. Technol.* 52, 8263-8271.
- Chen, M., Wang, Q., Shan, G., Zhu, L., Yang, L., Liu, M., 2018. Occurrence, partitioning and bioaccumulation of emerging and legacy per- and polyfluoroalkyl substances in Taihu Lake, China. *Science of the Total Environment* 634, 251–259. <https://doi.org/10.1016/j.scitotenv.2018.03.301>
- Chen, M., Wang, Q., Shan, G., Zhu, L., Yang, L., Liu, M., 2018. Occurrence, partitioning and bioaccumulation of emerging and legacy per- and polyfluoroalkyl substances in Taihu Lake, China. *Science of the Total Environment* 634, 251–259. <https://doi.org/10.1016/j.scitotenv.2018.03.301>
- Chen, M., Zhu, L., Wang, Q., Shan, G., 2021. Tissue distribution and bioaccumulation of legacy and emerging per-and polyfluoroalkyl substances (PFASs) in edible fishes from Taihu Lake, China. *Environmental Pollution* 268. <https://doi.org/10.1016/j.envpol.2020.115887>
- Chen, M., Zhu, L., Wang, Q., Shan, G., 2021. Tissue distribution and bioaccumulation of legacy and emerging per-and polyfluoroalkyl substances (PFASs) in edible fishes from Taihu Lake, China. *Environmental Pollution* 268. <https://doi.org/10.1016/j.envpol.2020.115887>
- Chen, Y., Fu, J., Ye, T., Li, X., Gao, K., Xue, Q., Lv, J., Zhang, A., Fu, J., 2021. Occurrence, profiles, and ecotoxicity of poly- and perfluoroalkyl substances and their alternatives in global

apex predators: A critical review. J. Environ. Sci. 109, 219–236. <https://doi.org/10.1016/j.jes.2021.03.036>

Chen, Y., Fu, J., Ye, T., Li, X., Gao, K., Xue, Q., Lv, J., Zhang, A., Fu, J., 2021. Occurrence, profiles, and ecotoxicity of poly- and perfluoroalkyl substances and their alternatives in global apex predators: A critical review. J. Environ. Sci. 109, 219–236. <https://doi.org/10.1016/j.jes.2021.03.036>

CHEN, Y., LI, H., MO, J., CHEN, X., WU, K., GE, F., MA, L., LI, X., GUO, X., ZHAO, J. & GE, R. S. 2019. Perfluorododecanoic Acid Blocks Rat Leydig Cell Development during Prepuberty. Chem Res Toxicol, 32, 146-155.

Chengelis C.P., Kirkpatrick J.B., Radovsky A., and Shinohara M. (2009): A 90-day repeated dose oral (gavage) toxicity study of perfluorohexanoic acid (PFHxA) in rats (with functional observational battery and motor activity determinations). Reproductive Toxicology 27 (3-4), 342-351. DOI: 10.1016/j.reprotox.2009.01.006

CHENGELIS, C. P., KIRKPATRICK, J. B., RADOVSKY, A. & SHINOHARA, M. 2009. A 90-day repeated dose oral (gavage) toxicity study of perfluorohexanoic acid (PFHxA) in rats (with functional observational battery and motor activity determinations). Reproductive Toxicology, 27, 342-351.

Chengelis, C.P., Kirkpatrick, J.B., Myers, N.R., Shinohara, M., Stetson, P.L., Sved, D.W., 2009. Comparison of the toxicokinetic behavior of perfluorohexanoic acid (PFHxA) and nonafluorobutane-1-sulfonic acid (PFBS) in cynomolgus monkeys and rats. Reproductive Toxicology 27, 400–406. <https://doi.org/10.1016/j.reprotox.2009.01.013>

Chengelis, C.P., Kirkpatrick, J.B., Myers, N.R., Shinohara, M., Stetson, P.L., Sved, D.W., 2009. Comparison of the toxicokinetic behavior of perfluorohexanoic acid (PFHxA) and nonafluorobutane-1-sulfonic acid (PFBS) in cynomolgus monkeys and rats. Reproductive Toxicology 27, 400–406. <https://doi.org/10.1016/j.reprotox.2009.01.013>

Cluett R., Seshasayee S.M., Rokoff L.B., Rifas-Shiman S.L., Ye X.Y., Calafat A.M., Gold D.R., Coull B., Gordon C.M., Rosen C.J., Oken E., Sagiv S.K., and Fleisch A.F. (2019): Per- and Polyfluoroalkyl Substance Plasma Concentrations and Bone Mineral Density in Midchildhood: A Cross-Sectional Study (Project Viva, United States). Environmental Health Perspectives 127 (8). DOI: Artn 08700610.1289/Ehp4918

CLUETT, R., SESHASAYEE, S. M., ROKOFF, L. B., RIFAS-SHIMAN, S. L., YE, X. Y., CALAFAT, A. M., GOLD, D. R., COULL, B., GORDON, C. M., ROSEN, C. J., OKEN, E., SAGIV, S. K. & FLEISCH, A. F. 2019. Per- and Polyfluoroalkyl Substance Plasma Concentrations and Bone Mineral Density in Midchildhood: A Cross-Sectional Study (Project Viva, United States). Environmental Health Perspectives, 127.

Collins M.A., Rusch G.M., Sato F., Hext P.M., and Millischer R.-J. (1995): 1,1,1,2-Tetrafluoroethane: Repeat Exposure Inhalation Toxicity in the Rat, Developmental Toxicity in the Rabbit, and Genotoxicity in Vitro and in Vivo. Fundamental and Applied Toxicology 25 (2), 271-280. DOI: <https://doi.org/10.1006/faat.1995.1063>

Collins, C.D., Finnegan, E., 2010. Modeling the Plant Uptake of Organic Chemicals, Including the Soil–Air–Plant Pathway. Environmental Science & Technology 44, 998-1003.

COLLINS, M. A., RUSCH, G. M., SATO, F., HEXT, P. M. & MILLISCHER, R.-J. 1995. 1,1,1,2-Tetrafluoroethane: Repeat Exposure Inhalation Toxicity in the Rat, Developmental Toxicity in the Rabbit, and Genotoxicity in Vitro and in Vivo. Fundamental and Applied Toxicology, 25, 271-280.

Committee, M.S., 2019. ECHA'S MEMBER STATE COMMITTEE SUPPORT DOCUMENT FOR IDENTIFICATION OF PERFLUOROBUTANE SULFONIC ACID AND ITS SALTS AS SUBSTANCES OF VERY HIGH CONCERN BECAUSE OF THEIR HAZARDOUS PROPERTIES WHICH CAUSE PROBABLE SERIOUS EFFECTS TO HUMAN HEALTH AND THE ENVIRONMENT WHICH GIVE RISE TO AN EQUIVALENT LEVEL OF CONCERN TO THOSE OF CMR1 AND PBT/vPvB2 SUBSTANCES (ARTICLE 57F). Adopted on 11 December 2019.

Conder, J.M., Hoke, R.A., Wolf, W. de, Russell, M.H., Buck, R.C., 2008. Are PFCAs Bioaccumulative? A Critical Review and Comparison with Regulatory Criteria and Persistent Lipophilic Compounds. *Environ. Sci. Technol.* 42, 995–1003. <https://doi.org/10.1021/es070895g>

Conley J.M., Lambright C.S., Evans N., McCord J., Strynar M.J., Hill D., Medlock-Kakaley E., Wilson V.S., and Gray L.E., Jr. (2021): Hexafluoropropylene oxide-dimer acid (HFPO-DA or GenX) alters maternal and fetal glucose and lipid metabolism and produces neonatal mortality, low birthweight, and hepatomegaly in the Sprague-Dawley rat. *Environmental International* 146. DOI: 10.1016/j.envint.2020.106204

Conley J.M., Lambright C.S., Evans N., Strynar M.J., McCord J., McIntyre B.S., Travlos G.S., Cardon M.C., Medlock-Kakaley E., Hartig P.C., Wilson V.S., and Gray L.E., Jr. (2019): Adverse Maternal, Fetal, and Postnatal Effects of Hexafluoropropylene Oxide Dimer Acid (GenX) from Oral Gestational Exposure in Sprague-Dawley Rats. *Environmental Health Perspectives* 127 (3), 37008. DOI: 10.1289/EHP4372

Conley Justin M., Lambright Christy S., Evans N., Strynar Mark J., McCord J., McIntyre Barry S., Travlos Gregory S., Cardon Mary C., Medlock-Kakaley E., Hartig Phillip C., Wilson Vickie S., and Gray L.E. (2019): Adverse Maternal, Fetal, and Postnatal Effects of Hexafluoropropylene Oxide Dimer Acid (GenX) from Oral Gestational Exposure in Sprague-Dawley Rats. *Environmental health perspectives* 127 (3), 037008. DOI: 10.1289/EHP4372 (last accessed 2022/01/10)

CONLEY, J. M., LAMBRIGHT, C. S., EVANS, N., MCCORD, J., STRYNAR, M. J., HILL, D., MEDLOCK-KAKALEY, E., WILSON, V. S. & GRAY, L. E., JR. 2021. Hexafluoropropylene oxide-dimer acid (HFPO-DA or GenX) alters maternal and fetal glucose and lipid metabolism and produces neonatal mortality, low birthweight, and hepatomegaly in the Sprague-Dawley rat. *Environmental International*, 146.

CONLEY, J. M., LAMBRIGHT, C. S., EVANS, N., STRYNAR, M. J., MCCORD, J., MCINTYRE, B. S., TRAVLOS, G. S., CARDON, M. C., MEDLOCK-KAKALEY, E., HARTIG, P. C., WILSON, V. S. & GRAY, L. E., JR. 2019. Adverse Maternal, Fetal, and Postnatal Effects of Hexafluoropropylene Oxide Dimer Acid (GenX) from Oral Gestational Exposure in Sprague-Dawley Rats. *Environmental health perspectives*, 127, 37008.

Consoer, D.M., Hoffman, A.D., Fitzsimmons, P.N., Kosian, P.A., Nichols, J.W., 2014. Toxicokinetics of perfluorooctanoate (PFOA) in rainbow trout (*Oncorhynchus mykiss*). *Aquatic Toxicology* 156, 65–73. <https://doi.org/10.1016/j.aquatox.2014.07.022>

Consoer, D.M., Hoffman, A.D., Fitzsimmons, P.N., Kosian, P.A., Nichols, J.W., 2014. Toxicokinetics of perfluorooctanoate (PFOA) in rainbow trout (*Oncorhynchus mykiss*). *Aquatic Toxicology* 156, 65–73. <https://doi.org/10.1016/j.aquatox.2014.07.022>

Coperchini F., Croce L., Denegri M., Pignatti P., Agozzino M., Netti G.S., Imbriani M., Rotondi M., and Chiovato L. (2020): Adverse effects of in vitro GenX exposure on rat thyroid cell viability, DNA integrity and thyroid-related genes expression. *Environmental Pollution* 264, 114778. DOI: <https://doi.org/10.1016/j.envpol.2020.114778>

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Coperchini F., Croce L., Ricci G., Magri F., Rotondi M., Imbriani M., and Chiovato L. (2021): Thyroid Disrupting Effects of Old and New Generation PFAS. *Frontiers in Endocrinology* 11. DOI: ARTN 61232010.3389/fendo.2020.612320

Coperchini F., Croce L., Ricci G., Magri F., Rotondi M., Imbriani M., and Chiovato L. (2021): Thyroid Disrupting Effects of Old and New Generation PFAS. *Frontiers in Endocrinology* 11, 1077. <https://www.frontiersin.org/article/10.3389/fendo.2020.612320>

COPERCHINI, F., CROCE, L., RICCI, G., MAGRI, F., ROTONDI, M., IMBRIANI, M. & CHIOVATO, L. 2021. Thyroid Disrupting Effects of Old and New Generation PFAS. *Frontiers in Endocrinology*, 11.

COSTELLO, M. C. S. & LEE, L. S. 2020. Sources, Fate, and Plant Uptake in Agricultural Systems of Per- and Polyfluoroalkyl Substances. *Current Pollution Reports*.

Costello, M. C. S., & Lee, L. S. (2020). Sources, Fate, and Plant Uptake in Agricultural Systems of Per- and Polyfluoroalkyl Substances. *Current Pollution Reports*. doi:10.1007/s40726-020-00168-y

Cousins I.T., DeWitt J.C., Gluge J., Goldenman G., Herzke D., Lohmann R., Miller M., Ng C.A., Scheringer M., Vierke L., and Wang Z. (2020): Strategies for grouping per- and polyfluoroalkyl substances (PFAS) to protect human and environmental health. *Environ Sci Process Impacts* 22 (7), 1444-1460. DOI: 10.1039/d0em00147c

Cousins I.T., Ng C.A., Wang Z., and Scheringer M. (2019): Why is high persistence alone a major cause of concern? *Environ Sci Process Impacts* 21 (5), 781-792. DOI: 10.1039/c8em00515j

Cousins I.T., Vestergren R., Wang Z., Scheringer M., McLachlan M.S. (2016): The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater, *Environment International*, Volume 94, Pages 331 - 3401

Cousins, I. T., DeWitt, J. C., Gluege, J., Goldenman, G., Herzke, D., Lohmann, R., Ng, C., Scheringer, M., & Wang, Z. (2020a). The High Persistence of PFAS is Sufficient for their Management as a Chemical Class. *Environmental Science Processes & Impacts*, 22, 2307–2312.

Cousins, I. T., DeWitt, J. C., Gluege, J., Goldenman, G., Herzke, D., Lohmann, R., Ng, C., Scheringer, M., & Wang, Z. (2020a). The High Persistence of PFAS is Sufficient for their Management as a Chemical Class. *Environmental Science Processes & Impacts*, 22, 2307–2312.

COUSINS, I. T., DEWITT, J. C., GLUGE, J., GOLDENMAN, G., HERZKE, D., LOHMANN, R., MILLER, M., NG, C. A., SCHERINGER, M., VIERKE, L. & WANG, Z. 2020. Strategies for grouping per- and polyfluoroalkyl substances (PFAS) to protect human and environmental health. *Environ Sci Process Impacts*, 22, 1444-1460.

Cousins, I. T., DeWitt, J. C., Gluge, J., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C. A., Scheringer, M., Vierke, L. & Wang, Z. (2020b): Strategies for grouping per- and polyfluoroalkyl substances (PFAS) to protect human and environmental health. *Environmental Science: Processes & Impacts*, 22, 7

Cousins, I. T., DeWitt, J. C., Gluge, J., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C. A., Scheringer, M., Vierke, L. & Wang, Z. (2020b): Strategies for grouping per- and polyfluoroalkyl substances (PFAS) to protect human and environmental health. *Environmental Science: Processes & Impacts*, 22, 1444-1460.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Cousins, I. T., DeWitt, J. C., Lohmann, R., Glüge, J., Goldenman, G., Herzke, D., Miller, M., Ng, C. A., Scheringer, M. & Wang, Z. (2020): The High Persistence of PFAS is Sufficient for their Management as a Chemical Class. *Environmental Science: Processes & Impacts*, 22, 2307-2312.

Cousins, I. T., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C. A., . . . Dewitt, J. C. (2019). The concept of essential use for determining when uses of PFASs can be phased out. *Environmental Science: Processes and Impacts*, 21(11), 1803-1815. doi:10.1039/c9em00163h

Cousins, I. T., Ng, C. A., Wang, Z. & Scheringer, M. (2019): Why is High Persistence Alone a Major Cause of Concern? *Environmental Science Processes & Impacts*, 21, 781-792.

Cousins, I. T., Ng, C. A., Wang, Z. & Scheringer, M. (2019): Why is High Persistence Alone a Major Cause of Concern? *Environmental Science Processes & Impacts*, 21, 781-792.

COUSINS, I. T., NG, C. A., WANG, Z. & SCHERINGER, M. 2019. Why is high persistence alone a major cause of concern? *Environ Sci Process Impacts*, 21, 781-792.

Cousins, I. T., Ng, C. A., Wang, Z., & Scheringer, M. (2019). Why is high persistence alone a major cause of concern? *Environ Sci Process Impacts*, 21(5), 781-792. doi:10.1039/c8em00515j

Cousins, I. T., Vestergren, R., Wang, Z., Scheringer, M. & McLachlan, M. S. (2016): The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater. *Environment International*, 94, 331-340.

Cousins, I. T., Vestergren, R., Wang, Z., Scheringer, M. & McLachlan, M. S. (2016): The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater. *Environment International*, 94, 331-340.

Cousins, I., DeWitt, J. C., Lohmann, R., Glüge, J., Goldenman, G., Herzke, D., Miller, M., Ng, C. A., Scheringer, M. & Wang, Z. (2020): The High Persistence of PFAS is Sufficient for their Management as a Chemical Class. *Environmental Science: Processes & Impacts*, 22, 2307-2312.

Cousins, I.T., Ng, C.A., Wang, Z., Scheringer, M., 2019. Why is high persistence alone a major cause of concern? *Environ Sci Process Impacts* 21, 781-792.

Cousins, I.T., Vestergren, R., Wang, Z., Scheringer, M., McLachlan, M.S., 2016. The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater. *Environment International* 94, 331-340.

Covance Laboratories (2020a): Sodium Trifluoroacetate: Preliminary Study for Effects on Embryo-Fetal Development in the New Zealand White Rabbit by Oral Gavage Administration. YQ44HR. Covance Laboratories Limited, Eye Suffolk, IP23 7PX UK

Covance Laboratories (2020b): Sodium Trifluoroacetate: Study for Effects on Embryo-Fetal Development in the New Zealand White Rabbit by Oral Gavage Administration. 8437242. Covance Laboratories Limited, Eye Suffolk, IP23 7PX UK

COVANCE LABORATORIES 2020a. Sodium Trifluoroacetate: Preliminary Study for Effects on Embryo-Fetal Development in the New Zealand White Rabbit by Oral Gavage Administration. Covance Laboratories Limited, Eye Suffolk, IP23 7PX UK

COVANCE LABORATORIES 2020b. Sodium Trifluoroacetate: Study for Effects on Embryo-Fetal Development in the New Zealand White Rabbit by Oral Gavage Administration. Covance Laboratories Limited, Eye Suffolk, IP23 7PX UK

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Croce L., Coperchini F., Tonacchera M., Imbriani M., Rotondi M., and Chiovato L. (2019): Effect of long- and short-chain perfluorinated compounds on cultured thyroid cells viability and response to TSH. *Journal of Endocrinological Investigation* 42 (11), 1329-1335. DOI: 10.1007/s40618-019-01062-1

Crookes, M.J., Fisk, M., 2018. Evaluation of using mobility of chemicals in the environment to fulfil bioaccumulation criteria of the Stockholm Convention.

Crookes, M.J., Fisk, M., 2018. Evaluation of using mobility of chemicals in the environment to fulfil bioaccumulation criteria of the Stockholm Convention.

Cui L., Zhou Q.F., Liao C.Y., Fu J.J., and Jiang G.B. (2009): Studies on the toxicological effects of PFOA and PFOS on rats using histological observation and chemical analysis. *Arch Environ Contam Toxicol* 56 (2), 338-349. DOI: 10.1007/s00244-008-9194-6

CUI, L., ZHOU, Q. F., LIAO, C. Y., FU, J. J. & JIANG, G. B. 2009. Studies on the toxicological effects of PFOA and PFOS on rats using histological observation and chemical analysis. *Arch Environ Contam Toxicol*, 56, 338-49.

D. C. G. & Mabury, S. A. (2001): The fate and persistence of trifluoroacetic and chloroacetic acids in pond waters. *Chemosphere*, 42, 309-318.

Dai, Z., Xia, X., Guo, J., Jiang, X., 2013. Bioaccumulation and uptake routes of perfluoroalkyl acids in *Daphnia magna*. *Chemosphere* 90, 1589-1596. <https://doi.org/10.1016/j.chemosphere.2012.08.026>

Dai, Z., Xia, X., Guo, J., Jiang, X., 2013. Bioaccumulation and uptake routes of perfluoroalkyl acids in *Daphnia magna*. *Chemosphere* 90, 1589-1596. <https://doi.org/10.1016/j.chemosphere.2012.08.026>

DAL FERRO, N., PELLIZZARO, A., FANT, M., ZERLOTTIN, M. & BORIN, M. 2021. Uptake and translocation of perfluoroalkyl acids by hydroponically grown lettuce and spinach exposed to spiked solution and treated wastewaters. *Science of The Total Environment*, 772, 145523.

Dal Ferro, N., Pellizzaro, A., Fant, M., Zerlottin, M., & Borin, M. (2021). Uptake and translocation of perfluoroalkyl acids by hydroponically grown lettuce and spinach exposed to spiked solution and treated wastewaters. *Science of The Total Environment*, 772, 145523. doi:10.1016/j.scitotenv.2021.145523

Dalahmeh, S., Tirgani, S., Komakech, A.J., Niwagaba, C.B., Ahrens, L., 2018. Per- and polyfluoroalkyl substances (PFASs) in water, soil and plants in wetlands and agricultural areas in Kampala, Uganda. *Sci. Total Environ.* 631-632, 660-667.

Dalsager L., Christensen N., Halekoh U., Timmermann C.A.G., Nielsen F., Kyhl H.B., Husby S., Grandjean P., Jensen T.K., and Andersen H.R. (2021): Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in childhood: A study among 1,503 children from the Odense Child Cohort. *Environ Int* 149, 106395. DOI: 10.1016/j.envint.2021.106395

Dalsager L., Christensen N., Husby S., Kyhl H., Nielsen F., Host A., Grandjean P., and Jensen T.K. (2016): Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age 1-4 years among 359 children in the Odense Child Cohort. *Environment International* 96, 58-64. DOI: 10.1016/j.envint.2016.08.026

DALSAGER, L., CHRISTENSEN, N., HALEKOH, U., TIMMERMANN, C. A. G., NIELSEN, F., KYHL, H. B., HUSBY, S., GRANDJEAN, P., JENSEN, T. K. & ANDERSEN, H. R. 2021. Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in

childhood: A study among 1,503 children from the Odense Child Cohort. *Environ Int*, 149, 106395.

DALSAGER, L., CHRISTENSEN, N., HUSBY, S., KYHL, H., NIELSEN, F., HOST, A., GRANDJEAN, P. & JENSEN, T. K. 2016. Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age 1-4 years among 359 children in the Odense Child Cohort. *Environment International*, 96, 58-64.

Daly E.R., Chan B.P., Talbot E.A., Nassif J., Bean C., Cavallo S.J., Metcalf E., Simone K., and Woolf A.D. (2018): Per- and polyfluoroalkyl substance (PFAS) exposure assessment in a community exposed to contaminated drinking water, New Hampshire, 2015. *Int J Hyg Environ Health* 221 (3), 569-577. DOI: 10.1016/j.ijheh.2018.02.007

DALY, E. R., CHAN, B. P., TALBOT, E. A., NASSIF, J., BEAN, C., CAVALLO, S. J., METCALF, E., SIMONE, K. & WOOLF, A. D. 2018. Per- and polyfluoroalkyl substance (PFAS) exposure assessment in a community exposed to contaminated drinking water, New Hampshire, 2015. *Int J Hyg Environ Health*, 221, 569-577.

Danish Environmental Protection Agency, 2015. Short-chain Polyfluoroalkyl Substances (PFAS) -A literature review of information on human health effects and environmental fate and effect aspects of short-chain PFAS. Environmental project No. 1707, 2015.

Das K.P., Grey B.E., Rosen M.B., Wood C.R., Tatum-Gibbs K.R., Zehr R.D., Strynar M.J., Lindstrom A.B., and Lau C. (2015): Developmental toxicity of perfluorononanoic acid in mice. *Reproductive Toxicology* 51, 133-144. DOI: 10.1016/j.reprotox.2014.12.012

Das K.P., Grey B.E., Zehr R.D., Wood C.R., Butenhoff J.L., Chang S.C., Ehresman D.J., Tan Y.M., and Lau C. (2008): Effects of perfluorobutyrate exposure during pregnancy in the mouse. *Toxicological Sciences* 105 (1), 173-181. DOI: 10.1093/toxsci/kfn099

DAS, K. P., GREY, B. E., ROSEN, M. B., WOOD, C. R., TATUM-GIBBS, K. R., ZEHR, R. D., STRYNAR, M. J., LINDSTROM, A. B. & LAU, C. 2015. Developmental toxicity of perfluorononanoic acid in mice. *Reprod Toxicol*, 51, 133-44.

DAS, K. P., GREY, B. E., ZEHR, R. D., WOOD, C. R., BUTENHOFF, J. L., CHANG, S. C., EHRESMAN, D. J., TAN, Y. M. & LAU, C. 2008. Effects of perfluorobutyrate exposure during pregnancy in the mouse. *Toxicological Sciences*, 105, 173-181.

Dasu K. and Lee L.S. (2016): Aerobic biodegradation of toluene-2,4-di(8:2 fluorotelomer urethane) and hexamethylene-1,6-di(8:2 fluorotelomer urethane) monomers in soils. *Chemosphere*, 144, 2482-2488.

Dasu K., Lee L.S., Turco R.F., and Nies L.F. (2013): Aerobic biodegradation of 8:2 fluorotelomer stearate monoester and 8:2 fluorotelomer citrate triester in forest soil. *Chemosphere*, 91 (3), 399-405.

Dasu K., Liu J., and Lee L.S. (2012): Aerobic soil biodegradation of 8:2 fluorotelomer stearate monoester. *Environ Sci Technol*, 46 (7), 3831-3836.

Dauchy X, Boiteux V, Bach C, Colin A, Hemard J, Rosin C, et al. Mass flows and fate of per- and polyfluoroalkyl substances (PFASs) in the wastewater treatment plant of a fluorochemical manufacturing facility. *Science of The Total Environment* 2017; 576: 549-558: <https://doi.org/10.1016/j.scitotenv.2016.10.130>.

Dauchy, X., Boiteux, V., Bach, C., Rosin, C., Munoz, J.F., 2017. Per- and polyfluoroalkyl substances in firefighting foam concentrates and water samples collected near sites impacted by the use of these foams. *Chemosphere* 183, 53-61.

Dauchy, X., Boiteux, V., Colin, A., Hemard, J., Bach, C., Rosin, C., & Munoz, J. F. (2018). Deep seepage of per- and polyfluoroalkyl substances through the soil of a firefighter training site and subsequent groundwater contamination. *Chemosphere*, 214, 729-737. doi:10.1016/j.chemosphere.2018.10.003

Dauwe T, Van de Vijver K, De Coen W, Eens M. PFOS levels in the blood and liver of a small insectivorous songbird near a fluorochemical plant. *Environment International* 2007; 33: 357-361: <https://doi.org/10.1016/j.envint.2006.11.014>.

De Silva AO, Armitage JM, Bruton TA, Dassuncao C, Heiger-Bernays W, Hu XC, et al. PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding. *Environmental Toxicology and Chemistry* 2021; 40: 631-657: <https://doi.org/10.1002/etc.4935>.

De Silva AO, et al. 2021. PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding. *Environmental Toxicology and Chemistry* 40:631-657.

De Silva, A. O., Armitage, J.M., Bruton, T.A., Dassuncao, C., Heiger-Bernays, W., Hu, X.C., Kärman, A., Kelly, B., Ng, C., Robuck, A., Sun, M., Webster, T.F., Sunderland, E.M., 2021. PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding. *Environmental Toxicology and Chemistry* 40, 631-657. <https://doi.org/10.1002/etc.4935>

De Silva, A. O., Armitage, J.M., Bruton, T.A., Dassuncao, C., Heiger-Bernays, W., Hu, X.C., Kärman, A., Kelly, B., Ng, C., Robuck, A., Sun, M., Webster, T.F., Sunderland, E.M., 2021. PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding. *Environmental Toxicology and Chemistry* 40, 631-657. <https://doi.org/10.1002/etc.4935>

De Silva, A.O., Armitage, J.M., Bruton, T.A., Dassuncao, C., Heiger-Bernays, W., Hu, X.C., Kärman, A., Kelly, B., Ng, C., Robuck, A., Sun, M., Webster, T.F., Sunderland, E.M., 2021. PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding. *Environmental Toxicology and Chemistry* 40, 631-657. <https://doi.org/10.1002/etc.4935>

De Silva, A.O., Tseng, P.J., Mabury, S.A., 2008. Toxicokinetics of perfluorocarboxylate isomers in rainbow trout. *Environ.Toxicol.Chem* 1.

De Silva, A.O., Tseng, P.J., Mabury, S.A., 2008. Toxicokinetics of perfluorocarboxylate isomers in rainbow trout. *Environ.Toxicol.Chem* 1.

de Wit, C.A., Bossi, R., Dietz, R., Dreyer, A., Faxneld, S., Garbus, S.E., Hellström, P., Koschorreck, J., Lohmann, N., Roos, A., Sellström, U., Sonne, C., Treu, G., Vorkamp, K., Yuan, B., Eulaers, I., 2020. Organohalogen compounds of emerging concern in Baltic Sea biota: Levels, biomagnification potential and comparisons with legacy contaminants. *Environment International* 144, 106037. <https://doi.org/10.1016/j.envint.2020.106037>

de Wit, C.A., Bossi, R., Dietz, R., Dreyer, A., Faxneld, S., Garbus, S.E., Hellström, P., Koschorreck, J., Lohmann, N., Roos, A., Sellström, U., Sonne, C., Treu, G., Vorkamp, K., Yuan, B., Eulaers, I., 2020. Organohalogen compounds of emerging concern in Baltic Sea biota: Levels, biomagnification potential and comparisons with legacy contaminants. *Environment International* 144, 106037. <https://doi.org/10.1016/j.envint.2020.106037>

Death C, Bell C, Champness D, Milne C, Reichman S, Hagen T. Per- and polyfluoroalkyl substances (PFAS) in livestock and game species: A review. *Science of The Total Environment* 2021; 774: 144795: <https://doi.org/10.1016/j.scitotenv.2020.144795>.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

- Death, C., Bell, C., Champness, D., Milne, C., Reichman, S., Hagen, T., 2021. Per- and polyfluoroalkyl substances (PFAS) in livestock and game species: A review. *Sci. Total Environ.* 774. <https://doi.org/10.1016/j.scitotenv.2020.144795>
- Death, C., Bell, C., Champness, D., Milne, C., Reichman, S., Hagen, T., 2021. Per- and polyfluoroalkyl substances (PFAS) in livestock and game species: A review. *Sci. Total Environ.* 774. <https://doi.org/10.1016/j.scitotenv.2020.144795>
- deBruyn, A.M.H., Gobas, F.A.P.C., 2007. The sorptive capacity of animal protein. *Environ. Toxicol. Chem.* 26, 1803.
- deBruyn, A.M.H., Gobas, F.A.P.C., 2007. The sorptive capacity of animal protein. *Environ. Toxicol. Chem.* 26, 1803.
- Del Vento, S., Halsall, C., Gioia, R., Jones, K., Dachs, J., 2012. Volatile per- and polyfluoroalkyl compounds in the remote atmosphere of the western Antarctic Peninsula: An indirect source of perfluoroalkyl acids to Antarctic waters? *Atmos. Pollut. Res.* 3, 450-455.
- Deng M., Wu Y., Xu C., Jin Y., He X., Wan J., Yu X., Rao H., and Tu W. (2018): Multiple approaches to assess the effects of F-53B, a Chinese PFOS alternative, on thyroid endocrine disruption at environmentally relevant concentrations. *Science of the Total Environment* 624, 215-224. DOI: <https://doi.org/10.1016/j.scitotenv.2017.12.101>
- Dennis, N. M., Hossain, F., Subbiah, S., Karnjanapiboonwong, A., Dennis, M. L., McCarthy, C., . . . Anderson, T. A. (2022). Species- and Tissue-Specific Chronic Toxicity Values for Northern Bobwhite Quail (*Colinus virginianus*) Exposed to Perfluorohexane Sulfonic Acid and a Binary Mixture of Perfluorooctane Sulfonic Acid and Perfluorohexane Sulfonic Acid. *Environ Toxicol Chem*, 41(1), 219-229. doi:10.1002/etc.5238
- Dennis, N. M., Subbiah, S., Karnjanapiboonwong, A., Dennis, M. L., McCarthy, C., Salice, C. J., & Anderson, T. A. (2021). Species- and Tissue-Specific Avian Chronic Toxicity Values for Perfluorooctane Sulfonate (PFOS) and a Binary Mixture of PFOS and Perfluorohexane Sulfonate. *Environmental Toxicology and Chemistry*, 40(3), 899-909. doi:<https://doi.org/10.1002/etc.4937>
- D'Eon J.C. and Mabury S.A. (2007): Production of perfluorinated carboxylic acids (PFCAs) from the biotransformation of polyfluoroalkyl phosphate surfactants (PAPS): exploring routes of human contamination. *Environ Sci Technol*, 41 (13), 4799-4805.
- D'Eon J.C. and Mabury S.A. (2010): Uptake and elimination of perfluorinated phosphonic acids in the rat. *Environmental Toxicology and Chemistry* 29 (6), 1319-1329. DOI: 10.1002/etc.167
- D'Eon J.C. and Mabury S.A. (2011): Exploring indirect sources of human exposure to perfluoroalkyl carboxylates (PFCAs): evaluating uptake, elimination, and biotransformation of polyfluoroalkyl phosphate esters (PAPs) in the rat. *Environ Health Perspect*, 119 (3), 344-350.
- D'EON, J. C. & MABURY, S. A. 2010. Uptake and elimination of perfluorinated phosphonic acids in the rat. *Environ Toxicol Chem*, 29, 1319-29.
- D'Eon, J., Hurley, M., Wallington, T. & Mabury, S. (2006): Atmospheric chemistry of N-methyl perfluorobutane sulfonamidoethanol, C₄F₉SO₂N(CH₃)CH₂CH₂OH: kinetics and mechanism of reaction with OH. *Environmental Science and Technology*, 40 (6), 1862-8.
- DeWitt J.C., Blossom S.J., and Schaidler L.A. (2019): Exposure to per-fluoroalkyl and polyfluoroalkyl substances leads to immunotoxicity: epidemiological and toxicological evidence. *Journal of Exposure Science and Environmental Epidemiology* 29 (2), 148-156. DOI: 10.1038/s41370-018-0097-y

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

DeWitt J.C., Copeland C.B., and Luebke R.W. (2009): Suppression of Humoral Immunity by Perfluorooctanoic Acid is Independent of Elevated Serum Corticosterone Concentration in Mice. *Toxicological Sciences* 109 (1), 106-112. DOI: 10.1093/toxsci/kfp040

DeWitt J.C., Copeland C.B., Strynar M.J., and Luebke R.W. (2008): Perfluorooctanoic acid-induced immunomodulation in adult C57BL/6J or C57BL/6N female mice. *Environ Health Perspect* 116 (5), 644-650. DOI: 10.1289/ehp.10896

DeWitt J.C., Williams W.C., Creech N.J., and Luebke R.W. (2016): Suppression of antigen-specific antibody responses in mice exposed to perfluorooctanoic acid: Role of PPARalpha and T- and B-cell targeting. *J Immunotoxicol* 13 (1), 38-45. DOI: 10.3109/1547691X.2014.996682

DEWITT, J. C., BLOSSOM, S. J. & SCHAIER, L. A. 2019. Exposure to per-fluoroalkyl and polyfluoroalkyl substances leads to immunotoxicity: epidemiological and toxicological evidence. *Journal of Exposure Science and Environmental Epidemiology*, 29, 148-156.

DEWITT, J. C., COPELAND, C. B. & LUEBKE, R. W. 2009. Suppression of Humoral Immunity by Perfluorooctanoic Acid is Independent of Elevated Serum Corticosterone Concentration in Mice. *Toxicological Sciences*, 109, 106-112.

DEWITT, J. C., COPELAND, C. B., STRYNAR, M. J. & LUEBKE, R. W. 2008. Perfluorooctanoic acid-induced immunomodulation in adult C57BL/6J or C57BL/6N female mice. *Environ Health Perspect*, 116, 644-50.

DEWITT, J. C., WILLIAMS, W. C., CREECH, N. J. & LUEBKE, R. W. 2016. Suppression of antigen-specific antibody responses in mice exposed to perfluorooctanoic acid: Role of PPARalpha and T- and B-cell targeting. *J Immunotoxicol*, 13, 38-45.

Diamond, M.L., de Wit, C.A., Molander, S., Scheringer, M., Backhaus, T., Lohmann, R., Arvidsson, R., Bergman, Å., Hauschild, M., Holoubek, I., Persson, L., Suzuki, N., Vighi, M. & Zetzsch, C. 2015, 'Exploring the planetary boundary for chemical pollution', *Environment international*, vol. 78, pp. 8-15

Dinglasan M.J., Ye Y., Edwards E.A., and Mabury S.A. (2004): Fluorotelomer alcohol biodegradation yields poly- and perfluorinated acids. *Environ Sci Technol*, 38 (10), 2857-2864.

doi: 10.1016/0147-6513(77)90016-1

Domingo, J. L., & Nadal, M. (2017). Per- and polyfluoroalkyl substances (PFASs) in food and human dietary intake: A review of the recent scientific literature. *Journal of Agricultural and Food Chemistry*, 65(3), 533-543. doi:10.1021/acs.jafc.6b04683

Domingo, J.L., Nadal, M., 2017. Per- and polyfluoroalkyl substances (PFASs) in food and human dietary intake: A review of the recent scientific literature. *Journal of Agricultural and Food Chemistry* 65, 533-543.

Domínguez, A., Salazar, Z., Betancourt, M., Ducolomb, Y., Casas, E., Fernández, F., . . . Bonilla, E. (2019). Effect of perfluorodecanoic acid on pig oocyte viability, intracellular calcium levels and gap junction intercellular communication during oocyte maturation in vitro. *Toxicol In Vitro*, 58, 224-229. doi:10.1016/j.tiv.2019.03.041

Dow AgroSciences (2002a): XDE-007: 13-Week Dietary Toxicity with 4-Week Recovery Study in Fischer 344 Rats study no DECO HET DR-0355-2305-027 / 1241. Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48674

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Dow AgroSciences (2002b): XDE-007: 90-Day Dietary Toxicity Study in CD-1 Mice study no DECO HET DR-0355-2305-062 / 11096. Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48675

Dow AgroSciences (2004): XDE-007: Two-generation dietary reproduction toxicity study in CD rats study no DECO HET DR-0355-2305-063 / 21115. Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48679

Dow AgroSciences (2005a): XDE-007: 18-months oncogenicity study in CD-1 mice study no DECO HET DR-0355-2305-048 / 21038. Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48676

Dow AgroSciences (2005b): XDE-007: Two-Year Dietary Chronic Toxicity/Oncogenicity and Chronic Neurotoxicity Study in Fischer 344 Rats study no DECO HET DR-0355-2305-040 REV / 11168. Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48677

DOW AGROSCIENCES 2002a. XDE-007: 13-Week Dietary Toxicity with 4-Week Recovery Study in Fischer 344 Rats Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48674.

DOW AGROSCIENCES 2002b. XDE-007: 90-Day Dietary Toxicity Study in CD-1 Mice Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48675.

DOW AGROSCIENCES 2004. XDE-007: Two-generation dietary reproduction toxicity study in CD rats Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48679.

DOW AGROSCIENCES 2005a. XDE-007: 18-months oncogenicity study in CD-1 mice Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48676.

DOW AGROSCIENCES 2005b. XDE-007: Two-Year Dietary Chronic Toxicity/Oncogenicity and Chronic Neurotoxicity Study in Fischer 344 Rats Toxicology & Environmental Research and Consulting, The Dow Chemical; Company, Midland, Michigan 48677

Dreyer, A., Ebinghaus, R., 2009. Polyfluorinated compounds in ambient air from ship- and land-based measurements in northern Germany. *Atmospheric Environment* 43, 1527-1535.

Dreyer, A., Weinberg, I., Temme, C., Ebinghaus, R., 2009. Polyfluorinated compounds in the atmosphere of the Atlantic and Southern Oceans: Evidence for a global distribution. *Environ. Sci. Technol.* 43, 6507-6514.

Droge, S.T.J., 2019. Membrane-Water Partition Coefficients to Aid Risk Assessment of Perfluoroalkyl Anions and Alkyl Sulfates. *Environmental Science and Technology* 53, 760–770. <https://doi.org/10.1021/acs.est.8b05052>

Droge, S.T.J., 2019. Membrane-Water Partition Coefficients to Aid Risk Assessment of Perfluoroalkyl Anions and Alkyl Sulfates. *Environmental Science and Technology* 53, 760–770. <https://doi.org/10.1021/acs.est.8b05052>

Droge, S.T.J., Goss, K.U., 2013. Sorption of organic cations to phyllosilicate clay minerals: CEC-normalization, salt dependency, and the role of electrostatic and hydrophobic effects. *Environmental Science and Technology* 47, 14224-14232.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Du G., Hu J., Huang Z., Yu M., Lu C., Wang X., and Wu D. (2019): Neonatal and juvenile exposure to perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS): Advance puberty onset and kisspeptin system disturbance in female rats. *Ecotoxicology and Environmental Safety* 167, 412-421. DOI: 10.1016/j.ecoenv.2018.10.025

DU, G., HU, J., HUANG, Z., YU, M., LU, C., WANG, X. & WU, D. 2019. Neonatal and juvenile exposure to perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS): Advance puberty onset and kisspeptin system disturbance in female rats. *Ecotoxicology and Environmental Safety*, 167, 412-421.

Duan Y., Sun H., Yao Y., Meng Y., and Li Y. (2020): Distribution of novel and legacy per-/polyfluoroalkyl substances in serum and its associations with two glycemic biomarkers among Chinese adult men and women with normal blood glucose levels. *Environ Int* 134, 105295. DOI: 10.1016/j.envint.2019.105295

DUAN, Y., SUN, H., YAO, Y., MENG, Y. & LI, Y. 2020. Distribution of novel and legacy per-/polyfluoroalkyl substances in serum and its associations with two glycemic biomarkers among Chinese adult men and women with normal blood glucose levels. *Environ Int*, 134, 105295.

DuPont Haskell (2007a): Combined dose-toxicity study with a reproduction/developmental toxicity screening test (OECD 422). DUPONT-20813. DuPont Haskell Global Centers for Health & Environmental Sciences

DuPont Haskell (2007b): H-27450: One-Generation Reproduction Study in Rats. DuPont-20699. DuPont Haskell Global Centers for Health & Environmental Sciences

DuPont Haskell (2008): Repeated Dose Oral Toxicity 7-Day Gavage Study in Rats. DuPont-24009. DuPont Haskell Global Centers for Health & Environmental Sciences

DuPont Haskell (2009): H-29007: Repeated-Dose Oral Toxicity 28-Day Gavage Study in Rats. DuPont-18157-1023. DuPont Haskell Global Centers for Health & Environmental Sciences

DuPont Haskell (2010): FEA-1100: Inhalation Main Developmental Toxicity Study in Rats. DuPont-17453-731. DuPont Haskell Global Centers for Health & Environmental Sciences

DuPont Haskell (2011): H-29477: Subchronic Toxicity 90-Day Gavage Study in Rats. DuPont-18157-1026. DuPont Haskell Global Centers for Health & Environmental Sciences

DuPont Haskell (2014): H-30380: Multi-Generation Reproduction Study in Rats. DuPont-19976-904-1. DuPont Haskell Global Centers for Health & Environmental Sciences; Histo-Scientific Research Laboratories, Inc., Virginia, U.S.A.

DUPONT HASKELL 2007a. Combined dose-toxicity study with a reproduction/developmental toxicity screening test (OECD 422). DuPont Haskell Global Centers for Health & Environmental Sciences

DUPONT HASKELL 2007b. H-27450: One-Generation Reproduction Study in Rats. DuPont Haskell Global Centers for Health & Environmental Sciences.

DUPONT HASKELL 2008. Repeated Dose Oral Toxicity 7-Day Gavage Study in Rats. DuPont Haskell Global Centers for Health & Environmental Sciences.

DUPONT HASKELL 2009. H-29007: Repeated-Dose Oral Toxicity 28-Day Gavage Study in Rats. DuPont Haskell Global Centers for Health & Environmental Sciences

DUPONT HASKELL 2010. FEA-1100: Inhalation Main Developmental Toxicity Study in Rats. DuPont Haskell Global Centers for Health & Environmental Sciences.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

DUPONT HASKELL 2011. H-29477: Subchronic Toxicity 90-Day Gavage Study in Rats. DuPont Haskell Global Centers for Health & Environmental Sciences

DUPONT HASKELL 2014. H-30380: Multi-Generation Reproduction Study in Rats. DuPont Haskell Global Centers for Health & Environmental Sciences; Histo-Scientific Research Laboratories, Inc., Virginia, U.S.A.

Ebert, A., Allendorf, F., Berger, U., Goss, K.-U., Ulrich, N., 2020. Membrane/Water Partitioning and Permeabilities of Perfluoroalkyl Acids and Four of their Alternatives and the Effects on Toxicokinetic Behavior. *Environmental science & technology* 54, 5051–5061. <https://doi.org/10.1021/acs.est.0c00175>

Ebert, A., Allendorf, F., Berger, U., Goss, K.-U., Ulrich, N., 2020. Membrane/Water Partitioning and Permeabilities of Perfluoroalkyl Acids and Four of their Alternatives and the Effects on Toxicokinetic Behavior. *Environmental science & technology* 54, 5051–5061. <https://doi.org/10.1021/acs.est.0c00175>

ECHA (2012a). Member State Committee support document for identification of henicosafuoroundecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd43c>

ECHA (2012a). Member State Committee support document for identification of henicosafuoroundecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd43c>

ECHA (2012b). Member State Committee support document for identification of heptacosafuorotetradecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd647>

ECHA (2012b). Member State Committee support document for identification of heptacosafuorotetradecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd647>

ECHA (2012c). Member State Committee support document for identification of pentacosafuorotridecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd5ad>

ECHA (2012c). Member State Committee support document for identification of pentacosafuorotridecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd5ad>

ECHA (2012d). Member State Committee support document for identification of tricosafuorododecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd4ef>

ECHA (2012d). Member State Committee support document for identification of tricosafuorododecanoic acid as a substance of very high concern because of its vPvB properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807dd4ef>

ECHA (2013): Member State Committee support document for identification of pentadecafluorooctanoic acid (PFOA) as a substance of very high concern because of its CMR and PBT properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807db2ba>

ECHA (2013): Member State Committee support document for identification of pentadecafluorooctanoic acid (PFOA) as a substance of very high concern because of its CMR and PBT properties. <https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807db2ba>

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

ECHA (2015). Member State Committee support document for identification of perfluorononan-1-oic acid and its sodium and ammonium salts as a substance of very high concern because of its toxic for reproduction, PBT properties.

ECHA (2015). Member State Committee support document for identification of perfluorononan-1-oic acid and its sodium and ammonium salts as a substance of very high concern because of its toxic for reproduction, PBT properties.

ECHA (2016). Member State Committee support document for identification of nonadecafluorodecanoic acid and its sodium and ammonium salts as a substance of very high concern because of its toxic for reproduction, PBT properties.

ECHA (2016). Member State Committee support document for identification of nonadecafluorodecanoic acid and its sodium and ammonium salts as a substance of very high concern because of its toxic for reproduction, PBT properties.

ECHA (2017a). Guidance on Information Requirements and Chemical Safety Assessment Chapter R.11: PBT/vPvB assessment. https://echa.europa.eu/documents/10162/13632/information_requirements_r11_en.pdf

ECHA (2017a). Guidance on Information Requirements and Chemical Safety Assessment Chapter R.11: PBT/vPvB assessment. https://echa.europa.eu/documents/10162/13632/information_requirements_r11_en.pdf

ECHA (2017b). Member State Committee Support Document for the Identification of Perfluorohexane-1-sulphonic Acid and its Salts as Substances of Very High Concern Because of Their vPvB (Article 57e) Properties. <https://echa.europa.eu/candidatelist-table/-/dislist/details/0b0236e18184a0e1>

ECHA (2017b). Member State Committee Support Document for the Identification of Perfluorohexane-1-sulphonic Acid and its Salts as Substances of Very High Concern Because of Their vPvB (Article 57e) Properties. <https://echa.europa.eu/candidatelist-table/-/dislist/details/0b0236e18184a0e1>

ECHA (2018). RAC and SEAC Background document to the Opinion on the Annex XV dossier proposing restrictions on C9-C14 PFCAs including their salts and precursors. <https://echa.europa.eu/documents/10162/02d5672d-9123-8a8c-5898-ac68f81e5a72>

ECHA (2018). RAC and SEAC Background document to the Opinion on the Annex XV dossier proposing restrictions on C9-C14 PFCAs including their salts and precursors. <https://echa.europa.eu/documents/10162/02d5672d-9123-8a8c-5898-ac68f81e5a72>

ECHA (2018b). RAC and SEAC Background document to the Opinion on the Annex XV dossier proposing restrictions on perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances.

ECHA (2019a). Member State Committee Support Document for identification of Perfluorobutane sulfonic acid and its salts as substances of very high concern because of their hazardous properties which cause probable serious effects to human health and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB substances (Article 57f). <https://www.echa.europa.eu/documents/10162/891ab33d-d263-cc4b-0f2d-d84cfb7f424a>

ECHA (2019a). Member State Committee Support Document for identification of Perfluorobutane sulfonic acid and its salts as substances of very high concern because of their hazardous properties which cause probable serious effects to human health and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB

substances (Article 57f). <https://www.echa.europa.eu/documents/10162/891ab33d-d263-cc4b-0f2d-d84cfb7f424a>

ECHA (2019b). Member State Committee Support Document for identification of 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propionic acid, its salts and its acyl halides as substances of very high concern because of their hazardous properties which cause probable serious effects to human health and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB substances (Article 57f). <https://www.echa.europa.eu/documents/10162/53fa6a5b-e95f-3128-ea9d-fa27f43b18bc>

ECHA (2019b). Member State Committee Support Document for identification of 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propionic acid, its salts and its acyl halides as substances of very high concern because of their hazardous properties which cause probable serious effects to human health and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB substances (Article 57f). <https://www.echa.europa.eu/documents/10162/53fa6a5b-e95f-3128-ea9d-fa27f43b18bc>

ECHA (2019c). Annex XV restriction report on the restriction proposal for Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances. <https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19>

ECHA (2021). RAC and SEAC Background Document to the Opinion on the Annex XV dossier proposing restrictions on Undecafluorohexanoic acid (PFHxA), its salts and related substances. <https://echa.europa.eu/documents/10162/b1ac0e22-7991-2b29-e666-c390d86f503f>

ECHA (2021). RAC and SEAC Background Document to the Opinion on the Annex XV dossier proposing restrictions on Undecafluorohexanoic acid (PFHxA), its salts and related substances. <https://echa.europa.eu/documents/10162/b1ac0e22-7991-2b29-e666-c390d86f503f>

ECHA, 2017. Chapter R.7c: Endpoint specific guidance Version 3.0 – June 2017.

ECHA, 2019. European Chemicals Agency. Annex XV report for public consultation on the proposal for identification of 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid, its salts and its acyl halides (covering any of their individual isomers and combinations thereof) as a substance of very high concern on the basis of the criteria set out in REACH article 57. <https://echa.europa.eu/documents/10162/41086906-eeb6-a963-f0b9-af1d0e27efc2>

ECHA. (2016). Guidance on information requirements and Chemical Safety Assessment Chapter R.16: Environmental exposure assessment. Retrieved from https://echa.europa.eu/documents/10162/13632/information_requirements_r16_en.pdf/b9f0f406-ff5f-4315-908e-e5f83115d6af

ECOS - Environmental Coalition on Standards (2021). Briefing: One step forward, two steps back - A deep dive into the climate impact of modern fluorinated refrigerants. https://ecostandard.org/wp-content/uploads/2021/05/ECOS-briefing-on-HFO-production-and-degradation_final.pdf

EEA (2020). Emerging chemical risks in Europe - 'PFAS'.

EEA (2020). Emerging chemical risks in Europe - 'PFAS'. <https://www.eea.europa.eu/themes/human/chemicals/emerging-chemical-risks-in-europe>

EFSA (2014). Reasoned opinion on the setting of MRLs for saflufenacil in various crops, considering the risk related to the metabolite trifluoroacetic acid (TFA). EFSA Journal, 12 (2): 3585.

EFSA (2016). Conclusion on the peer review of the pesticide risk assessment of the active substance flurtamone. EFSA Journal, 14 (6): 4498.

EFSA (2017). Reasoned Opinion on the modification of the existing maximum residue levels for fluazinam in onions, shallots and garlic. EFSA Journal, 15 (7): 4904.

EFSA (2017b). Conclusion on the peer review of the pesticide risk assessment of the active substance trifloxystrobin. EFSA Journal, 15 (10): 4989.

EFSA (2018). <https://efsa.onlinelibrary.wiley.com/doi/10.2903/j.efsa.2018.5194>

EFSA (2019). Reasoned opinion on the review of the existing maximum residue levels for fluometuron according to Article 12 of Regulation (EC) No 396/2005. EFSA Journal, 17 (1): 5560.

EFSA (2019): Guidance on harmonised methodologies for human health, animal health and ecological risk assessment of combined exposure to multiple chemicals. European Food Safety Authority; EFSA Journal 17(3):5634; doi: 10.2903/j.efsa.2019.5634

EFSA (2020): Risk to human health related to the presence of perfluoroalkyl substances in food. EFSA Journal 18(9):6223

EFSA (2021). Reasoned Opinion on the modification of the existing maximum residue levels for cyflumetofen in various crops. EFSA Journal, 19 (2): 6373.

EFSA 2019. Guidance on harmonised methodologies for human health, animal health and ecological risk assessment of combined exposure to multiple chemicals. European Food Safety Authority; EFSA Journal, 17(3):5634; doi: 10.2903/j.efsa.2019.5634.

EFSA 2020. Risk to human health related to the presence of perfluoroalkyl substances in food. EFSA Journal, 18(9):6223.

EFSA, Knutsen H.K., Alexander J., Barregård L., Bignami M., Brüschweiler B., Ceccatelli S., Cottrill B., Dinovi M., Edler L., Grasl-Kraupp B., Hogstrand C., Hoogenboom L., Nebbia C.S., Oswald I.P., Petersen A., Rose M., Roudot A.-C., Vleminckx C., Vollmer G., Wallace H., Bodin L., Cravedi J.-P., Halldorsson T.I., Haug L.S., Johansson N., van Loveren H., Gergelova P., Mackay K., Levorato S., van Manen M., and Schwerdtle T. (2018): EFSA Panel on Contaminants in the Food Chain: Risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food. EFSA Journal 16 (12), e05194. DOI: <https://doi.org/10.2903/j.efsa.2018.5194>

EFSA, KNUTSEN, H. K., ALEXANDER, J., BARREGÅRD, L., BIGNAMI, M., BRÜSCHWEILER, B., CECCATELLI, S., COTTRILL, B., DINOVI, M., EDLER, L., GRASL-KRAUPP, B., HOGSTRAND, C., HOOGENBOOM, L., NEBBIA, C. S., OSWALD, I. P., PETERSEN, A., ROSE, M., ROUDOT, A.-C., VLEMINCKX, C., VOLLMER, G., WALLACE, H., BODIN, L., CRAVEDI, J.-P., HALLDORSSON, T. I., HAUG, L. S., JOHANSSON, N., VAN LOVEREN, H., GERGELOVA, P., MACKAY, K., LEVORATO, S., VAN MANEN, M. & SCHWERDTLE, T. 2018. EFSA Panel on Contaminants in the Food Chain: Risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food. EFSA Journal, 16, e05194.

Eggers Pedersen, K., Basu, N., Letcher, R., Greaves, A.K., Sonne, C., Dietz, R., Styrishave, B., 2015. Brain region-specific perfluoroalkylated sulfonate (PFSA) and carboxylic acid (PFCA) accumulation and neurochemical biomarker Responses in east Greenland polar Bears (*Ursus maritimus*). Environ. Res. 138, 22–31. <https://doi.org/10.1016/j.envres.2015.01.015>

Eggers Pedersen, K., Basu, N., Letcher, R., Greaves, A.K., Sonne, C., Dietz, R., Styrishave, B., 2015. Brain region-specific perfluoroalkylated sulfonate (PFSA) and carboxylic acid (PFCA) accumulation and neurochemical biomarker Responses in east Greenland polar Bears (*Ursus maritimus*). Environ. Res. 138, 22–31. <https://doi.org/10.1016/j.envres.2015.01.015>

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Ellis D.A., Martin J.W., De Silva A.O., Mabury S.A., Hurley M.D., Sulbaek Andersen M.P., and Wallington T.J. (2004): Degradation of fluorotelomer alcohols: a likely atmospheric source of perfluorinated carboxylic acids. *Environ Sci Technol*, 38 (12), 3316-3321.

Ellis, D. A. and Mabury, S. A. (2000): The aqueous photolysis of TFM and related trifluoromethylphenols. An alternate source of trifluoroacetic acid in the environment. *Environ Sci Technol*, 34, 632-637.

Ellis, D. A., Hanson, M. L., Sibley, P. K., Shahid, T., Fineberg, N. A., Solomon, K. R., Muir, D. C. G. & Mabury, S. A. (2001): The fate and persistence of trifluoroacetic and chloroacetic acids in pond waters. *Chemosphere*, 42, 309-318.

Ellis, D. A., Hanson, M. L., Sibley, P. K., Shahid, T., Fineberg, N. A., Solomon, K. R., Muir,

Ellis, D.A., Martin, J.W., De Silva, A.O., Mabury, S.A., Hurley, M.D., Sulbaek Andersen, M.P., Wallington, T.J., 2004. Degradation of fluorotelomer alcohols: A likely atmospheric source of perfluorinated carboxylic acids. *Environ. Sci. Technol.* 38, 3316-3321.

Elmoznino, J., Vlahos, P., Whitney, M., 2018. Occurrence and partitioning behavior of perfluoroalkyl acids in wastewater effluent discharging into the Long Island Sound. *Environmental Pollution* 243, 453-461.

Emeléus, H. J. & Smith, J. D. (1959): The heptafluoropropyl iodophosphines and their derivatives. *Journal of the Chemical Society* 375-381.

Emeléus, H. J. & Smith, J. D. (1959): The heptafluoropropyl iodophosphines and their derivatives. *Journal of the Chemical Society*, 375-381.

Emmett E.A., Shofer F.S., Zhang H., Freeman D., Desai C., and Shaw L.M. (2006): Community exposure to perfluorooctanoate: relationships between serum concentrations and exposure sources. *Journal of Occupational and Environmental Medicine* 48 (8), 759-770. DOI: 10.1097/01.jom.0000232486.07658.74

EMMETT, E. A., SHOFER, F. S., ZHANG, H., FREEMAN, D., DESAI, C. & SHAW, L. M. 2006. Community exposure to perfluorooctanoate: relationships between serum concentrations and exposure sources. *J Occup Environ Med*, 48, 759-70.

Environmental Coalition on Standards, ECOS (2021). Briefing: One step forward, two steps back - A deep dive into the climate impact of modern fluorinated refrigerants. https://ecostandard.org/wp-content/uploads/2021/05/ECOS-briefing-on-HFO-production-and-degradation_final.pdf

EPA US (2016a): Health Effects Support Document for Perfluorooctane Sulfonate (PFOS). U.S. Environmental Protection Agency, Office of Water (4304T) Health and Ecological Criteria Division, Washington, DC 20460 EPA Document Number: 822-R-16-002, May 2016

EPA US (2016b): Health Effects Support Document for Perfluorooctanoic Acid (PFOA). U.S. Environmental Protection Agency Office of Water (4304T), Health and Ecological Criteria Division, Washington, DC 20460 EPA Document Number: 822-R-16-003, May 2016

EPA US (2018): Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3), also known as "GenX Chemicals". U.S. Environmental Protection Agency, Office of Water (4304T) Health and Ecological Criteria Division, Washington, DC 20460 EPA Document Number: 823-P-18-001, NOVEMBER 2018

EPA US (2021): Human Health Toxicity Assessments for GenX Chemicals. U.S. Environmental Protection Agency Office of Water (4304T), Health and Ecological Criteria Division,

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Washington, DC 20460 <https://www.epa.gov/chemical-research/human-health-toxicity-assessments-genx-chemicals>

EPA US 2016a. Health Effects Support Document for Perfluorooctane Sulfonate (PFOS). U.S. Environmental Protection Agency, Office of Water (4304T) Health and Ecological Criteria Division, Washington, DC 20460, EPA Document Number: 822-R-16-002, May 2016.

EPA US 2016b. Health Effects Support Document for Perfluorooctanoic Acid (PFOA). U.S. Environmental Protection Agency Office of Water (4304T), Health and Ecological Criteria Division, Washington, DC 20460, EPA Document Number: 822-R-16-003, May 2016.

EPA US 2018. Human Health Toxicity Values for Hexafluoropropylene Oxide (HFPO) Dimer Acid and Its Ammonium Salt (CASRN 13252-13-6 and CASRN 62037-80-3), also known as "GenX Chemicals". U.S. Environmental Protection Agency, Office of Water (4304T) Health and Ecological Criteria Division, Washington, DC 20460, EPA Document Number: 823-P-18-001, NOVEMBER 2018.

Eriksson, U., Haglund, P. & Karrman, A. (2017): Contribution of precursor compounds to the release of per- and polyfluoroalkyl substances (PFASs) from waste water treatment plants (WWTPs). *J Environ Sci*, 61, 80-90.

Ernstgard L., Sjogren B., and Johanson G. (2012): Toxicokinetics in humans of hydrofluorocarbons (HFCs) used as refrigerants. *Toxicology Letters* 211, S139-S139. DOI: 10.1016/j.toxlet.2012.03.507

ERNSTGARD, L., SJOGREN, B. & JOHANSON, G. 2012. Toxicokinetics in humans of hydrofluorocarbons (HFCs) used as refrigerants. *Toxicology Letters*, 211, S139-S139.

EUROPEAN CHEMICALS AGENCY 2012a. Member State Committee support document for identification of heneicosafuoroundecanoic acid as a substance of very high concern because of its vPvB properties.

EUROPEAN CHEMICALS AGENCY 2012b. Member State Committee support document for identification of heptacosafuorotetradecanoic acid as a substance of very high concern because of its vPvB properties.

EUROPEAN CHEMICALS AGENCY 2012c. Member State Committee support document for identification of pentacosafuorotridecanoic acid as a substance of very high concern because of its vPvB properties.

EUROPEAN CHEMICALS AGENCY 2012d. Member State Committee support document for identification of tricosafuorododecanoic acid as a substance of very high concern because of its vPvB properties.

EUROPEAN CHEMICALS AGENCY 2013. Member State Committee support document for identification of pentadecafluorooctanoic acid (PFOA) as a substance of very high concern because of its CMR and PBT properties.

EUROPEAN CHEMICALS AGENCY 2015. Member State Committee support document for identification of perfluorononan-1-oic acid and its sodium and ammonium salts as a substance of very high concern because of its toxic for reproduction, PBT properties.

EUROPEAN CHEMICALS AGENCY 2016a. Guidance on information requirements and Chemical Safety Assessment Chapter R.16: Environmental exposure assessment.

EUROPEAN CHEMICALS AGENCY 2016b. Member State Committee support document for identification of nonadecafluorodecanoic acid and its sodium and ammonium salts as a substance of very high concern because of its toxic for reproduction, PBT properties.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

EUROPEAN CHEMICALS AGENCY 2019. Annex XV report for public consultation on the proposal for identification of 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid, its salts and its acyl halides (covering any of their individual isomers and combinations thereof) as a substance of very high concern on the basis of the criteria set out in REACH article 57. <https://echa.europa.eu/documents/10162/41086906-eeb6-a963-f0b9-af1d0e27efc2>.

European Chemicals Agency, 2012a. Member State Committee support document for identification of heptacosafuorotetradecanoic acid as a substance of very high concern because of its vPvB properties.

European Chemicals Agency, 2012b. Inclusion of substances of very high concern in the Candidate List (No. ED/169/2012).

European Chemicals Agency, 2012b. Inclusion of substances of very high concern in the Candidate List (No. ED/169/2012).

European Chemicals Agency, 2013a. Agreement of the Member State Committee on the identification of Pentadecafluorooctanoic acid (PFOA) as a substance of very high concern. <https://echa.europa.eu/documents/10162/86f13df6-a078-475c-b0b2-2eb9536ebc5d>.

European Chemicals Agency, 2013a. Agreement of the Member State Committee on the identification of Pentadecafluorooctanoic acid (PFOA) as a substance of very high concern. <https://echa.europa.eu/documents/10162/86f13df6-a078-475c-b0b2-2eb9536ebc5d>.

European Chemicals Agency, 2013b. Member State Committee support document for identification of pentadecafluorooctanoic acid (PFOA) as a substance of very high concern because of its CMR and PBT properties.

European Chemicals Agency, 2013b. Member State Committee support document for identification of pentadecafluorooctanoic acid (PFOA) as a substance of very high concern because of its CMR and PBT properties.

European Chemicals Agency, 2015. Background document to the Opinion on the Annex XV dossier proposing restrictions on Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances.

European Chemicals Agency, 2015. Background document to the Opinion on the Annex XV dossier proposing restrictions on Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances.

European Chemicals Agency, 2017. Member State Committee Support Document for Identification of Perfluorohexane-1-sulphonic acid and its salts as Substances of Very High Concern because of their vPvB (article 57e) properties.

European Chemicals Agency, 2017. Member State Committee Support Document for Identification of Perfluorohexane-1-sulphonic acid and its salts as Substances of Very High Concern because of their vPvB (article 57e) properties.

European Chemicals Agency, 2018. Background document to the Opinion on the Annex XV dossier proposing restrictions on C9-C14 PFCA including their salts and precursors.

European Chemicals Agency, 2018. Background document to the Opinion on the Annex XV dossier proposing restrictions on C9-C14 PFCA including their salts and precursors.

European Chemicals Agency, 2019a: Member State Committee support document for identification of perfluorobutane sulfonic acid and its salts as substances of very high concern because of their hazardous properties which cause probable serious effects to human health

and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB substances (Article 57f)

European Chemicals Agency, 2019a: Member State Committee support document for identification of perfluorobutane sulfonic acid and its salts as substances of very high concern because of their hazardous properties which cause probable serious effects to human health and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB substances (Article 57f)

European Chemicals Agency, 2019b: Member State Committee support document for identification of 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid, its salts and its acyl halides (covering any of their individual isomers and combinations thereof) as substances of very high concern because of their hazardous properties which cause probable serious effects to human health and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB substances (Article 57f)

European Chemicals Agency, 2019b: Member State Committee support document for identification of 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid, its salts and its acyl halides (covering any of their individual isomers and combinations thereof) as substances of very high concern because of their hazardous properties which cause probable serious effects to human health and the environment which give rise to an equivalent level of concern to those of CMR and PBT/vPvB substances (Article 57f)

European Chemicals Agency. (2019). Annex XV report for public consultation on the proposal for identification of 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid, its salts and its acyl halides (covering any of their individual isomers and combinations thereof) as a substance of very high concern on the basis of the criteria set out in REACH article 57. Retrieved from <https://echa.europa.eu/documents/10162/41086906-eeb6-a963-f0b9-af1d0e27efc2>:

European Commission (2020a). Staff Working Document on Poly- and perfluoroalkyl substances (PFAS). https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf

European Commission (2020a). Staff Working Document on Poly- and perfluoroalkyl substances (PFAS). https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf

European Commission (2020b). Chemicals Strategy for Sustainability. Towards a Toxic-Free Environment. <https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf>

European Commission (2020b). Chemicals Strategy for Sustainability. Towards a Toxic-Free Environment. <https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf>

EUROPEAN COMMISSION 2016. Synthesis Report on the Quality of Drinking Water in the Union examining Member States' reports for the 2011-2013 period, foreseen under Article 13(5) of Directive 98/83/EC. Brussels: European Commission.

European Commission, 2016. Synthesis Report on the Quality of Drinking Water in the Union examining Member States' reports for the 2011-2013 period, foreseen under Article 13(5) of Directive 98/83/EC. European Commission, Brussels.

Fair, P.A., Wolf, B., White, N.D., Arnott, S.A., Kannan, K., Karthikraj, R., Vena, J.E., 2019. Perfluoroalkyl substances (PFASs) in edible fish species from Charleston Harbor and tributaries, South Carolina, United States: Exposure and risk assessment. Environmental Research 171, 266–277. <https://doi.org/10.1016/j.envres.2019.01.021>

Fair, P.A., Wolf, B., White, N.D., Arnott, S.A., Kannan, K., Karthikraj, R., Vena, J.E., 2019. Perfluoroalkyl substances (PFASs) in edible fish species from Charleston Harbor and tributaries, South Carolina, United States: Exposure and risk assessment. *Environmental Research* 171, 266–277. <https://doi.org/10.1016/j.envres.2019.01.021>

Falk S, Brunn H, Schröter-Kermani C, Failing K, Georgii S, Tarricone K, et al. Temporal and spatial trends of perfluoroalkyl substances in liver of roe deer (*Capreolus capreolus*). *Environmental Pollution* 2012; 171: 1-8: <https://doi.org/10.1016/j.envpol.2012.07.022>.

Falk S, Stahl T, Fliedner A, Rüdel H, Tarricone K, Brunn H, et al. Levels, accumulation patterns and retrospective trends of perfluoroalkyl acids (PFAAs) in terrestrial ecosystems over the last three decades. *Environmental Pollution* 2019; 246: 921-931: <https://doi.org/10.1016/j.envpol.2018.12.095>.

Fang, S., Chen, X., Zhao, S., Zhang, Y., Jiang, W., Yang, L., Zhu, L., 2014. Trophic magnification and isomer fractionation of perfluoroalkyl substances in the food web of Taihu Lake, China. *Environmental Science and Technology* 48, 2173–2182. <https://doi.org/10.1021/es405018b>

Fang, S., Chen, X., Zhao, S., Zhang, Y., Jiang, W., Yang, L., Zhu, L., 2014. Trophic magnification and isomer fractionation of perfluoroalkyl substances in the food web of Taihu Lake, China. *Environmental Science and Technology* 48, 2173–2182. <https://doi.org/10.1021/es405018b>

Faxneld S, Berger U, Helander B, Danielsson S, Miller A, Nyberg E, et al. Temporal Trends and Geographical Differences of Perfluoroalkyl Acids in Baltic Sea Herring and White-Tailed Sea Eagle Eggs in Sweden. *Environmental Science & Technology* 2016; 50: 13070-13079: DOI: 10.1021/acs.est.6b03230.

Fei C., McLaughlin J.K., Lipworth L., and Olsen J. (2009): Maternal levels of perfluorinated chemicals and subfecundity. *Hum Reprod* 24 (5), 1200-1205. DOI: 10.1093/humrep/den490

FEI, C., MCLAUGHLIN, J. K., LIPWORTH, L. & OLSEN, J. 2009. Maternal levels of perfluorinated chemicals and subfecundity. *Hum Reprod*, 24, 1200-5.

FELIZETER, S., JÜRLING, H., KOTTHOFF, M., DE VOOGT, P. & MCLACHLAN, M. S. 2021. Uptake of perfluorinated alkyl acids by crops: results from a field study. *Environmental Science: Processes & Impacts*.

Felizeter, S., Jürling, H., Kotthoff, M., De Voogt, P., & McLachlan, M. S. (2021). Uptake of perfluorinated alkyl acids by crops: results from a field study. *Environmental Science: Processes & Impacts*. doi:10.1039/D1EM00166C

FELIZETER, S., MCLACHLAN, M. S. & DE VOOGT, P. 2012. Uptake of perfluorinated alkyl acids by hydroponically grown lettuce (*Lactuca sativa*). *Environ Sci Technol*, 46, 11735-43.

FELIZETER, S., MCLACHLAN, M. S. & DE VOOGT, P. 2014. Root uptake and translocation of perfluorinated alkyl acids by three hydroponically grown crops. *J Agric Food Chem*, 62, 3334-42.

Felizeter, S., McLachlan, M. S., & de Voogt, P. (2012). Uptake of perfluorinated alkyl acids by hydroponically grown lettuce (*Lactuca sativa*). *Environ Sci Technol*, 46(21), 11735-11743. doi:10.1021/es302398u

Felizeter, S., McLachlan, M. S., & De Voogt, P. (2014). Root uptake and translocation of perfluorinated alkyl acids by three hydroponically grown crops. *J Agric Food Chem*, 62(15), 3334-3342. doi:10.1021/jf500674j

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Feng X.J., Cao X.Y., Zhao S.S., Wang X.L., Hua X., Chen L., and Chen L. (2017): Exposure of pregnant mice to perfluorobutanesulfonate causes hypothyroxinemia and developmental abnormalities in female offspring. *Toxicological Sciences* 155 (2), 409-419. DOI: 10.1093/toxsci/kfw219

Feng Y., Fang X., Shi Z., Xu M., and Dai J. (2010): Effects of PFNA exposure on expression of junction-associated molecules and secretory function in rat Sertoli cells. *Reproductive Toxicology* 30 (3), 429-437. DOI: 10.1016/j.reprotox.2010.05.010

Feng Y., Shi Z., Fang X., Xu M., and Dai J. (2009): Perfluorononanoic acid induces apoptosis involving the Fas death receptor signaling pathway in rat testis. *Toxicol Lett* 190 (2), 224-230. DOI: 10.1016/j.toxlet.2009.07.020

FENG, X. J., CAO, X. Y., ZHAO, S. S., WANG, X. L., HUA, X., CHEN, L. & CHEN, L. 2017. Exposure of pregnant mice to perfluorobutanesulfonate causes hypothyroxinemia and developmental abnormalities in female offspring. *Toxicological Sciences*, 155, 409-419.

FENG, Y., FANG, X., SHI, Z., XU, M. & DAI, J. 2010. Effects of PFNA exposure on expression of junction-associated molecules and secretory function in rat Sertoli cells. *Reprod Toxicol*, 30, 429-37.

FENG, Y., SHI, Z., FANG, X., XU, M. & DAI, J. 2009. Perfluorononanoic acid induces apoptosis involving the Fas death receptor signaling pathway in rat testis. *Toxicol Lett*, 190, 224-30.

Fenton S.E., Ducatman A., Boobis A., DeWitt J.C., Lau C., Ng C., Smith J.S., and Roberts S.M. (2021): Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research. *Environmental Toxicology and Chemistry* 40 (3), 606-630. DOI: 10.1002/etc.4890

FENTON, S. E., DUCATMAN, A., BOOBIS, A., DEWITT, J. C., LAU, C., NG, C., SMITH, J. S. & ROBERTS, S. M. 2021. Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research. *Environ Toxicol Chem*, 40, 606-630.

Filgo A.J., Quist E.M., Hoenerhoff M.J., Brix A.E., Kissling G.E., and Fenton S.E. (2015): Perfluorooctanoic Acid (PFOA)-induced Liver Lesions in Two Strains of Mice Following Developmental Exposures: PPAR α Is Not Required. *Toxicol Pathol* 43 (4), 558-568. DOI: 10.1177/0192623314558463

FILGO, A. J., QUIST, E. M., HOENERHOFF, M. J., BRIX, A. E., KISSLING, G. E. & FENTON, S. E. 2015. Perfluorooctanoic Acid (PFOA)-induced Liver Lesions in Two Strains of Mice Following Developmental Exposures: PPAR α Is Not Required. *Toxicol Pathol*, 43, 558-68.

Filipovic, M., Woldegiorgis, A., Norström, K., Bibi, M., Lindberg, M., & Österås, A. H. (2015). Historical usage of aqueous film forming foam: A case study of the widespread distribution of perfluoroalkyl acids from a military airport to groundwater, lakes, soils and fish. *Chemosphere*, 129, 39-45. doi:10.1016/j.chemosphere.2014.09.005

Fleet, D., Hanlon, J., Osborne, K., Vedrine, M. L. & Ashford, P. (2018). Study on environmental and health effects of HFO refrigerants: 1-8.

Forhead A.J. and Fowden A.L. (2014): Thyroid hormones in fetal growth and parturition maturation. *J Endocrinol* 221 (3), R87-R103. DOI: 10.1530/JOE-14-0025

FORHEAD, A. J. & FOWDEN, A. L. 2014. Thyroid hormones in fetal growth and parturition maturation. *J Endocrinol*, 221, R87-R103.

Frank, H., Christoph, E. H., Holm-Hansen, O. & Bullister, J. L. (2002): Trifluoroacetate in Ocean Waters. *Environmental Science & Technology*, 36, 12-15.

Frauenhofer Institut für Toxikologie und experim. Medizin (2005): Two Generation Inhalation Reproduction Study with HFC-245fa in Sprague Dawley Rats. 12G04010. Frauenhofer Institut fuer Toxicology und Experim. Medizin, 30625 Hannover

FRAUENHOFER INSTITUT FÜR TOXIKOLOGIE UND EXPERIM. MEDIZIN 2005. Two Generation Inhalation Reproduction Study with HFC-245fa in Sprague Dawley Rats. Frauenhofer Institut fuer Toxicology und Experim. Medizin, 30625 Hannover

Frawley R.P., Smith M., Cesta M.F., Hayes-Bouknight S., Blystone C., Kissling G.E., Harris S., and Germolec D. (2018): Immunotoxic and hepatotoxic effects of perfluoro-n-decanoic acid (PFDA) on female Harlan Sprague-Dawley rats and B6C3F1/N mice when administered by oral gavage for 28 days. *J Immunotoxicol* 15 (1), 41-52. DOI: 10.1080/1547691X.2018.1445145

FRAWLEY, R. P., SMITH, M., CESTA, M. F., HAYES-BOUKNIGHT, S., BLYSTONE, C., KISSLING, G. E., HARRIS, S. & GERMOLEC, D. 2018. Immunotoxic and hepatotoxic effects of perfluoro-n-decanoic acid (PFDA) on female Harlan Sprague-Dawley rats and B6C3F1/N mice when administered by oral gavage for 28 days. *J Immunotoxicol*, 15, 41-52.

Freeling F, Behringer D, Heydel F, Scheurer M, Ternes TA, Nödler K. Trifluoroacetate in Precipitation: Deriving a Benchmark Data Set. *Environmental Science & Technology* 2020; 54: 11210-11219; DOI: 10.1021/acs.est.0c02910.

Freeling F, Scheurer M. Langzeittrends für Trifluoressigsäure in terrestrischen Umweltproben - Untersuchung von Pflanzenproben der Umweltprobenbank des Bundes (UPB) auf Trifluoressigsäure. Umweltbundesamt 2021: ISSN 1862-4804. UBA Text 177/2021.

Freeling, F., Behringer, D., Heydel, F., Scheurer, M., Ternes, T. A. & Nödler, K. (2020): Trifluoroacetate in Precipitation: Deriving a Benchmark Data Set. *Environmental Science & Technology*, 11210–11219.

Frömel, T., Knepper, T.P., 2010. Biodegradation of fluorinated alkyl substances. *Rev Environ Contam Toxicol* 208, 161-177.

Fromme H., Tittlemier S.A., Volkel W., Wilhelm M., and Twardella D. (2009): Perfluorinated compounds--exposure assessment for the general population in Western countries. *Int J Hyg Environ Health* 212 (3), 239-270. DOI: 10.1016/j.ijheh.2008.04.007

FROMME, H., TITTELMIER, S. A., VOLKEL, W., WILHELM, M. & TWARDELLA, D. 2009. Perfluorinated compounds--exposure assessment for the general population in Western countries. *Int J Hyg Environ Health*, 212, 239-70.

Furdui, V.I., Stock, N.L., Ellis, D.A., Butt, C.M., Whittle, D.M., Crozier, P.W., Reiner, E.J., Muir, D.C., Mabury, S.A., 2007. Spatial distribution of perfluoroalkyl contaminants in lake trout from the Great Lakes. *Environ.Sci Technol.* 41, 1554–1559.

Gannon, S.A., Johnson, T., Nabb, D.L., Serex, T.L., Buck, R.C., Loveless, S.E., 2011. Absorption, distribution, metabolism, and excretion of [1-14C]-perfluorohexanoate ([14C]-PFHx) in rats and mice. *Toxicology* 283, 55–62. <https://doi.org/10.1016/j.tox.2011.02.004>

Gannon, S.A., Johnson, T., Nabb, D.L., Serex, T.L., Buck, R.C., Loveless, S.E., 2011. Absorption, distribution, metabolism, and excretion of [1-14C]-perfluorohexanoate ([14C]-PFHx) in rats and mice. *Toxicology* 283, 55–62. <https://doi.org/10.1016/j.tox.2011.02.004>

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Gao, K., Miao, X., Fu, J., Chen, Y., Li, H., Pan, W., Fu, J., Zhang, Q., Zhang, A., Jiang, G., 2020. Occurrence and trophic transfer of per- and polyfluoroalkyl substances in an Antarctic ecosystem. *Environmental Pollution* 257.

Gao, K., Zhuang, T., Liu, X., Fu, Jianjie, Zhang, J., Fu, Jie, Wang, L., Zhang, A., Liang, Y., Song, M., Jiang, G., 2019. Prenatal Exposure to Per- and Polyfluoroalkyl Substances (PFASs) and Association between the Placental Transfer Efficiencies and Dissociation Constant of Serum Proteins–PFAS Complexes. *Environ. Sci. Technol.* 53, 6529–6538. <https://doi.org/10.1021/acs.est.9b00715>

GARCIA-VALCARCEL, A. I., MOLERO, E., ESCORIAL, M. C., CHUECA, M. C. & TADEO, J. L. 2014. Uptake of perfluorinated compounds by plants grown in nutrient solution. *Sci Total Environ*, 472, 20-6.

Garcia-Valcarcel, A. I., Molero, E., Escorial, M. C., Chueca, M. C., & Tadeo, J. L. (2014). Uptake of perfluorinated compounds by plants grown in nutrient solution. *Sci Total Environ*, 472, 20-26. doi:10.1016/j.scitotenv.2013.10.054

Garnett, J., Halsall, C., Thomas, M., Crabeck, O., France, J., Joerss, H., Ebinghaus, R., Kaiser, J., Leeson, A., Wynn, P.M., 2021a. Investigating the Uptake and Fate of Poly- And Perfluoroalkylated Substances (PFAS) in Sea Ice Using an Experimental Sea Ice Chamber. *Environ. Sci. Technol.* 55, 9601-9608.

Garnett, J., Halsall, C., Vader, A., Joerss, H., Ebinghaus, R., Leeson, A., Wynn, P.M., 2021b. High Concentrations of Perfluoroalkyl Acids in Arctic Seawater Driven by Early Thawing Sea Ice. *Environ. Sci. Technol.* 55, 11049-11059.

Gaspar T.R., Chi R.J., Parrow M.W., and Ringwood A.H. (2018): Cellular Bioreactivity of Micro- and Nano-Plastic Particles in Oysters. *Frontiers in Marine Science* 5 (345). DOI: 10.3389/fmars.2018.00345

GASPAR, T. R., CHI, R. J., PARROW, M. W. & RINGWOOD, A. H. 2018. Cellular Bioreactivity of Micro- and Nano-Plastic Particles in Oysters. *Frontiers in Marine Science*, 5.

Gauthier S.A. and Mabury S.A. (2005): Aqueous photolysis of 8:2 fluorotelomer alcohol. *Environ Toxicol Chem*, 24 (8), 1837-1846.

Gawor, A., Shunthirasingham, C., Hayward, S.J., Lei, Y.D., Gouin, T., Mmereki, B.T., Masamba, W., Ruepert, C., Castillo, L.E., Shoeib, M., Lee, S.C., Harner, T., Wania, F., 2014. Neutral polyfluoroalkyl substances in the global Atmosphere. *Environmental Sciences: Processes and Impacts* 16, 404-413.

Gebbink WA, Bignert A, Berger U. 2016. Perfluoroalkyl Acids (PFAAs) and Selected Precursors in the Baltic Sea Environment: Do Precursors Play a Role in Food Web Accumulation of PFAAs? *Environ Sci Technol* 50:6354-6362.

Gebbink, W.A., Bossi, R., Rig  t, F.F., Rosing-Asvid, A., Sonne, C., Dietz, R., 2016. Observation of emerging per- and polyfluoroalkyl substances (PFASs) in Greenland marine mammals. *Chemosphere* 144, 2384.

Geiser M., Schurch S., and Gehr P. (2003): Influence of surface chemistry and topography of particles on their immersion into the lung's surface-lining layer. *J Appl Physiol* (1985) 94 (5), 1793-1801. DOI: 10.1152/japplphysiol.00514.2002

GEISER, M., SCHURCH, S. & GEHR, P. 2003. Influence of surface chemistry and topography of particles on their immersion into the lung's surface-lining layer. *J Appl Physiol* (1985), 94, 1793-801.

Gellrich, V., 2014. Sorption und Verbreitung per und polyfluorierter Chemikalien (PFAS) in Wasser und Boden—Sorption and distribution of PFAS in water and soil.

Gellrich, V., Knepper, T.P., 2012. Sorption and leaching behavior of perfluorinated compounds in soil, Handbook of Environmental Chemistry, pp. 63-72.

German Environment Agency (2021). Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential. <https://www.umweltbundesamt.de/publikationen/persistent-degradation-products-of-halogenated>

GHISI, R., VAMERALI, T. & MANZETTI, S. 2019. Accumulation of perfluorinated alkyl substances (PFAS) in agricultural plants: A review. Environmental Research, 169, 326-341.

Ghisi, R., Vamerali, T., & Manzetti, S. (2019). Accumulation of perfluorinated alkyl substances (PFAS) in agricultural plants: A review. Environ Res, 169, 326-341. doi:10.1016/j.envres.2018.10.023

Ghisi, R., Vamerali, T., Manzetti, S., 2019. Accumulation of perfluorinated alkyl substances (PFAS) in agricultural plants: A review. Environ. Res. 169, 326-341.

Giesy, J.P., Kannan, K., 2001. Global distribution of perfluorooctane sulfonate in wildlife. Environmental Science and Technology 35, 1339–1342. <https://doi.org/10.1021/es001834k>

Giesy, J.P., Kannan, K., 2001. Global distribution of perfluorooctane sulfonate in wildlife. Environmental Science and Technology 35, 1339–1342. <https://doi.org/10.1021/es001834k>

Giesy, J.P., Kannan, K., 2001. Global distribution of perfluorooctane sulfonate in wildlife. Environ. Sci. Technol. 35, 1339-1342.

Gilliland F.D. and Mandel J.S. (1993): Mortality among Employees of a Perfluorooctanoic Acid Production Plant. Journal of Occupational and Environmental Medicine 35 (9), 950-954. DOI: Doi 10.1097/00043764-199309000-00020

GILLILAND, F. D. & MANDEL, J. S. 1993. Mortality among Employees of a Perfluorooctanoic Acid Production Plant. Journal of Occupational and Environmental Medicine, 35, 950-954.

Gobas, F., 2020. A framework for assessing bioaccumulation and exposure risks of per- and polyfluoroalkyl substances in threatened and endangered species on aqueous film forming foam (AFFF)-impacted sites. Strategic Environmental Research and Development Program, Alexandria, VA, USA. [cited 2020 June 21]. Available from: <https://www.serdpestcp.org/Program-Areas/Environmental-Restoration/ER18-1502>.

Gobas, F., 2020. A framework for assessing bioaccumulation and exposure risks of per- and polyfluoroalkyl substances in threatened and endangered species on aqueous film forming foam (AFFF)-impacted sites. Strategic Environmental Research and Development Program, Alexandria, VA, USA. [cited 2020 June 21]. Available from: <https://www.serdpestcp.org/Program-Areas/Environmental-Restoration/ER18-1502>.

Gobas, F.A.P.C., Mayer, P., Parkerton, T.F., Burgess, R.M., van de Meent, D., Gouin, T., 2018. A chemical activity approach to exposure and risk assessment of chemicals. Environmental Toxicology and Chemistry 37, 1235–1251. <https://doi.org/10.1002/etc.4091>

Gobas, F.A.P.C., Mayer, P., Parkerton, T.F., Burgess, R.M., van de Meent, D., Gouin, T., 2018. A chemical activity approach to exposure and risk assessment of chemicals. Environmental Toxicology and Chemistry 37, 1235–1251. <https://doi.org/10.1002/etc.4091>

Gobas, F.A.P.C., Otton, S.V., Tupper-Ring, L.F., Crawford, M.A., Clark, K.E., Ikonomou, M.G., 2017. Chemical activity-based environmental risk analysis of the plasticizer di-ethylhexyl phthalate and its main metabolite mono-ethylhexyl phthalate. *Environmental Toxicology and Chemistry* 36, 1483–1492. <https://doi.org/10.1002/etc.3689>

Gobas, F.A.P.C., Otton, S.V., Tupper-Ring, L.F., Crawford, M.A., Clark, K.E., Ikonomou, M.G., 2017. Chemical activity-based environmental risk analysis of the plasticizer di-ethylhexyl phthalate and its main metabolite mono-ethylhexyl phthalate. *Environmental Toxicology and Chemistry* 36, 1483–1492. <https://doi.org/10.1002/etc.3689>

Göckener B, Fliedner A, Rüdell H, Badry A, Koschorreck J. Long-Term Trends of Per- and Polyfluoroalkyl Substances (PFAS) in Suspended Particular Matter from German Rivers Using the Direct Total Oxidizable Precursor (dTOP) Assay. *Environmental Science & Technology* 2022; 56: 208-217; DOI: 10.1021/acs.est.1c04165.

Göckener B, Fliedner A, Rüdell H, Fettig I, Koschorreck J. Exploring unknown per- and polyfluoroalkyl substances in the German environment – The total oxidizable precursor assay as helpful tool in research and regulation. *Science of The Total Environment* 2021; 782: 146825: <https://doi.org/10.1016/j.scitotenv.2021.146825>.

Göckener, B., Eichhorn, M., Lammer, R., Kotthoff, M., Kowalczyk, J., Numata, J., Schafft, H., Lahrssen-Wiederholt, M., Bucking, M., 2020. Transfer of Per- and Polyfluoroalkyl Substances (PFAS) from Feed into the Eggs of Laying Hens. Part 1: Analytical Results Including a Modified Total Oxidizable Precursor Assay. *J. Agric. Food Chem.* 68, 12527.

Göckener, B., Eichhorn, M., Lammer, R., Kotthoff, M., Kowalczyk, J., Numata, J., Schafft, H., Lahrssen-Wiederholt, M., Bucking, M., 2020. Transfer of Per- and Polyfluoroalkyl Substances (PFAS) from Feed into the Eggs of Laying Hens. Part 1: Analytical Results Including a Modified Total Oxidizable Precursor Assay. *J. Agric. Food Chem.* 68, 12527.

Godfrey A., Hooser B., Abdelmoneim A., and Sepúlveda M.S. (2019): Sex-specific endocrine-disrupting effects of three halogenated chemicals in Japanese medaka. *Journal of Applied Toxicology* 39 (8), 1215-1223. DOI: <https://doi.org/10.1002/jat.3807> (last accessed 2021/07/06)

Godfrey A., Hooser B., Abdelmoneim A., Horzmann K.A., Freeman J.L., and Sepúlveda M.S. (2017): Thyroid disrupting effects of halogenated and next generation chemicals on the swim bladder development of zebrafish. *Aquatic Toxicology* 193, 228-235. DOI: <https://doi.org/10.1016/j.aquatox.2017.10.024>

Goldenman (2017): <https://ec.europa.eu/environment/chemicals/non-toxic/pdf/Sub-study%20d%20very%20persistent%20subst.%20NTE%20final.pdf>

Goldenman (2017): <https://ec.europa.eu/environment/chemicals/non-toxic/pdf/Sub-study%20d%20very%20persistent%20subst.%20NTE%20final.pdf>

Gomis M.I., Vestergren R., Borg D., and Cousins I.T. (2018): Comparing the toxic potency in vivo of long-chain perfluoroalkyl acids and fluorinated alternatives. *Environment International* 113, 1-9. DOI: 10.1016/j.envint.2018.01.011

Gomis M.I., Vestergren R., MacLeod M., Mueller J.F., and Cousins I.T. (2017): Historical human exposure to perfluoroalkyl acids in the United States and Australia reconstructed from biomonitoring data using population-based pharmacokinetic modelling. *Environ Int* 108, 92-102. DOI: 10.1016/j.envint.2017.08.002

GOMIS, M. I., VESTERGREN, R., BORG, D. & COUSINS, I. T. 2018. Comparing the toxic potency in vivo of long-chain perfluoroalkyl acids and fluorinated alternatives. *Environment International*, 113, 1-9.

GOMIS, M. I., VESTERGREN, R., MACLEOD, M., MUELLER, J. F. & COUSINS, I. T. 2017. Historical human exposure to perfluoroalkyl acids in the United States and Australia reconstructed from biomonitoring data using population-based pharmacokinetic modelling. *Environ Int*, 108, 92-102.

Gonsowski C.T., Laster M.J., Eger E.I., Ferrell L.D., and Kerschmann R.L. (1994a): Toxicity of Compound-a in Rats - Effect of a 3-Hour Administration. *Anesthesiology* 80 (3), 556-565. DOI: Doi 10.1097/00000542-199403000-00012

Gonsowski C.T., Laster M.J., Eger E.I., Ferrell L.D., and Kerschmann R.L. (1994b): Toxicity of Compound-a in Rats - Effect of Increasing Duration of Administration. *Anesthesiology* 80 (3), 566-573. DOI: Doi 10.1097/00000542-199403000-00013

GONSOWSKI, C. T., LASTER, M. J., EGER, E. I., FERRELL, L. D. & KERSCHMANN, R. L. 1994a. Toxicity of Compound-a in Rats - Effect of a 3-Hour Administration. *Anesthesiology*, 80, 556-565.

GONSOWSKI, C. T., LASTER, M. J., EGER, E. I., FERRELL, L. D. & KERSCHMANN, R. L. 1994b. Toxicity of Compound-a in Rats - Effect of Increasing Duration of Administration. *Anesthesiology*, 80, 566-573.

Goodband, T. 2019. 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propionic acid: Bioaccumulation in Common Carp (*Cyprinus carpio*): Aqueous Exposure. Harrogate UK: Smithers Viscient (ESG) Ltd.

Gooddy, D.C., Darling, W.G., Abesser, C., Lapworth, D.J.: Using chlorofluorocarbons (CFCs) and sulphur hexafluoride (SF₆) to characterise groundwater movement and residence time in a lowland Chalk catchment (2006), *Journal of Hydrology*, 330 (1-2), pp. 44-52. Cited 103 times. doi: 10.1016/j.jhydrol.2006.04.011

Gordon, S. C. (2011): Toxicological evaluation of ammonium 4,8-dioxa-3H perfluorononanoate, a new emulsifier to replace ammonium perfluorooctanoate in fluoropolymer manufacturing. *Regulatory Toxicology and Pharmacology*, 59, 64-80.

Gordon, S. C. (2011): Toxicological evaluation of ammonium 4,8-dioxa-3H perfluorononanoate, a new emulsifier to replace ammonium perfluorooctanoate in fluoropolymer manufacturing. *Regulatory Toxicology and Pharmacology*, 59, 64-80.

Gorrochategui, E., Perez-Albaladejo, E., Casas, J., Lacorte, S., & Porte, C. (2014). Perfluorinated chemicals: differential toxicity, inhibition of aromatase activity and alteration of cellular lipids in human placental cells. *Toxicol Appl Pharmacol*, 277(2), 124-130. doi:10.1016/j.taap.2014.03.012

Goudarzi H., Miyashita C., Okada E., Kashino I., Chen C.J., Ito S., Araki A., Kobayashi S., Matsuura H., and Kishi R. (2017): Prenatal exposure to perfluoroalkyl acids and prevalence of infectious diseases up to 4 years of age. *Environmental International* 104, 132-138. DOI: 10.1016/j.envint.2017.01.024

GOUDARZI, H., MIYASHITA, C., OKADA, E., KASHINO, I., CHEN, C. J., ITO, S., ARAKI, A., KOBAYASHI, S., MATSUURA, H. & KISHI, R. 2017. Prenatal exposure to perfluoroalkyl acids and prevalence of infectious diseases up to 4 years of age. *Environmental International*, 104, 132-138.

Graber J.M., Alexander C., Laumbach R.J., Black K., Strickland P.O., Georgopoulos P.G., Marshall E.G., Shendell D.G., Alderson D., Mi Z., Mascari M., and Weisel C.P. (2019): Per and polyfluoroalkyl substances (PFAS) blood levels after contamination of a community water supply and comparison with 2013–2014 NHANES. *Journal of Exposure Science and Environmental Epidemiology* 29 (2), 172-182. DOI: 10.1038/s41370-018-0096-z

GRABER, J. M., ALEXANDER, C., LAUMBACH, R. J., BLACK, K., STRICKLAND, P. O., GEORGOPOULOS, P. G., MARSHALL, E. G., SHENDELL, D. G., ALDERSON, D., MI, Z., MASCARI, M. & WEISEL, C. P. 2019. Per and polyfluoroalkyl substances (PFAS) blood levels after contamination of a community water supply and comparison with 2013–2014 NHANES. *Journal of Exposure Science and Environmental Epidemiology*, 29, 172–182.

Granum B., Haug L.S., Namork E., Stolevik S.B., Thomsen C., Aaberge I.S., van Loveren H., Lovik M., and Nygaard U.C. (2013): Pre-natal exposure to perfluoroalkyl substances may be associated with altered vaccine antibody levels and immune-related health outcomes in early childhood. *J Immunotoxicol* 10 (4), 373–379. DOI: 10.3109/1547691X.2012.755580

GRANUM, B., HAUG, L. S., NAMORK, E., STOLEVIK, S. B., THOMSEN, C., AABERGE, I. S., VAN LOVEREN, H., LOVIK, M. & NYGAARD, U. C. 2013. Pre-natal exposure to perfluoroalkyl substances may be associated with altered vaccine antibody levels and immune-related health outcomes in early childhood. *J Immunotoxicol*, 10, 373–9.

Griffith F.D. and Long J.E. (1980): Animal toxicity studies with ammonium perfluorooctanoate. *Am Ind Hyg Assoc J* 41 (8), 576–583. DOI: 10.1080/15298668091425301

GRIFFITH, F. D. & LONG, J. E. 1980. Animal toxicity studies with ammonium perfluorooctanoate. *Am Ind Hyg Assoc J*, 41, 576–83.

Groffen, T., Rijnders, J., Verbrigghe, N., Verbruggen, E., Prinsen, E., Eens, M., Bervoets, L., 2019. Influence of soil physicochemical properties on the depth profiles of perfluoroalkylated acids (PFAAs) in soil along a distance gradient from a fluorochemical plant and associations with soil microbial parameters. *Chemosphere* 236, 124407. <https://doi.org/10.1016/j.chemosphere.2019.124407>

Groffen, T., Rijnders, J., Verbrigghe, N., Verbruggen, E., Prinsen, E., Eens, M., Bervoets, L., 2019. Influence of soil physicochemical properties on the depth profiles of perfluoroalkylated acids (PFAAs) in soil along a distance gradient from a fluorochemical plant and associations with soil microbial parameters. *Chemosphere* 236, 124407. <https://doi.org/10.1016/j.chemosphere.2019.124407>

Grønnestad, R., Villanger, G.D., Polder, A., Kovacs, K.M., Lydersen, C., Jenssen, B.M., Borgå, K., 2017. Maternal transfer of perfluoroalkyl substances in hooded seals. *Environ. Toxicol. Chem.* 36, 763–770. <https://doi.org/10.1002/etc.3623>

Grønnestad, R., Villanger, G.D., Polder, A., Kovacs, K.M., Lydersen, C., Jenssen, B.M., Borgå, K., 2017. Maternal transfer of perfluoroalkyl substances in hooded seals. *Environ. Toxicol. Chem.* 36, 763–770. <https://doi.org/10.1002/etc.3623>

Guillette, T.C., McCord, J., Guillette, M., Polera, M.E., Rachels, K.T., Morgeson, C., Kotlarz, N., Knappe, D.R.U., Reading, B.J., Strynar, M., Belcher, S.M., 2020. Elevated levels of per- and polyfluoroalkyl substances in Cape Fear River Striped Bass (*Morone saxatilis*) are associated with biomarkers of altered immune and liver function. *Environment International* 136, 105358. <https://doi.org/10.1016/j.envint.2019.105358>

Guillette, T.C., McCord, J., Guillette, M., Polera, M.E., Rachels, K.T., Morgeson, C., Kotlarz, N., Knappe, D.R.U., Reading, B.J., Strynar, M., Belcher, S.M., 2020. Elevated levels of per- and polyfluoroalkyl substances in Cape Fear River Striped Bass (*Morone saxatilis*) are associated with biomarkers of altered immune and liver function. *Environment International* 136, 105358. <https://doi.org/10.1016/j.envint.2019.105358>

Guo, X., Zhang, S., Lu, S., Zheng, B., Xie, P., Chen, J., . . . Sang, N. (2018). Perfluorododecanoic acid exposure induced developmental neurotoxicity in zebrafish embryos. *Environ Pollut*, 241, 1018–1026. doi:10.1016/j.envpol.2018.06.013

Gyllenhammar I., Benskin J.P., Sandblom O., Berger U., Ahrens L., Lignell S., Wiberg K., and Glynn A. (2018): Perfluoroalkyl Acids (PFAAs) in Serum from 2-4-Month-Old Infants: Influence of Maternal Serum Concentration, Gestational Age, Breast-Feeding, and Contaminated Drinking Water. *Environ Sci Technol* 52 (12), 7101-7110. DOI: 10.1021/acs.est.8b00770

GYLLENHAMMAR, I., BENSKIN, J. P., SANDBLOM, O., BERGER, U., AHRENS, L., LIGNELL, S., WIBERG, K. & GLYNN, A. 2018. Perfluoroalkyl Acids (PFAAs) in Serum from 2-4-Month-Old Infants: Influence of Maternal Serum Concentration, Gestational Age, Breast-Feeding, and Contaminated Drinking Water. *Environ Sci Technol*, 52, 7101-7110.

Hale S., Arp H.P.H., Slinde G.A., Wade E.J., Bjørseth K., Breedveld G.D., Straith B.F., Grotthing Moe K., Jartun M., Høisæter Å (2017): Sorbent amendment as a remediation strategy to reduce PFAS mobility and leaching in a contaminated sandy soil from a Norwegian firefighting training facility. *Chemosphere* 171: 9-18

Hallberg, I., Kjellgren, J., Persson, S., Örn, S., & Sjunnesson, Y. (2019). Perfluorononanoic acid (PFNA) alters lipid accumulation in bovine blastocysts after oocyte exposure during in vitro maturation. *Reprod Toxicol*, 84, 1-8. doi:10.1016/j.reprotox.2018.11.005

Han, X., Snow, T.A., Kemper, R.A., Jepson, G.W., 2003. Binding of perfluorooctanoic acid to rat and human plasma proteins. *Chemical Research in Toxicology* 16, 775–781. <https://doi.org/10.1021/tx034005w>

Han, X., Snow, T.A., Kemper, R.A., Jepson, G.W., 2003. Binding of perfluorooctanoic acid to rat and human plasma proteins. *Chemical Research in Toxicology* 16, 775–781. <https://doi.org/10.1021/tx034005w>

Harada, K.H., Hashida, S., Kaneko, T., Takenaka, K., Minata, M., Inoue, K., Saito, N., Koizumi, A., 2007. Biliary excretion and cerebrospinal fluid partition of perfluorooctanoate and perfluorooctane sulfonate in humans. *Environmental Toxicology and Pharmacology* 24, 134–139. <https://doi.org/10.1016/j.etap.2007.04.003>

Harada, K.H., Hashida, S., Kaneko, T., Takenaka, K., Minata, M., Inoue, K., Saito, N., Koizumi, A., 2007. Biliary excretion and cerebrospinal fluid partition of perfluorooctanoate and perfluorooctane sulfonate in humans. *Environmental Toxicology and Pharmacology* 24, 134–139. <https://doi.org/10.1016/j.etap.2007.04.003>

Hardell E., Karrman A., van Bavel B., Bao J., Carlberg M., and Hardell L. (2014): Case-control study on perfluorinated alkyl acids (PFAAs) and the risk of prostate cancer. *Environ Int* 63, 35-39. DOI: 10.1016/j.envint.2013.10.005

HARDELL, E., KARRMAN, A., VAN BAVEL, B., BAO, J., CARLBERG, M. & HARDELL, L. 2014. Case-control study on perfluorinated alkyl acids (PFAAs) and the risk of prostate cancer. *Environ Int*, 63, 35-9.

Harding-Marjanovic K.C., Houtz E.F., Yi S., Field J.A., Sedlak D.L., and Alvarez-Cohen L. (2015): Aerobic Biotransformation of Fluorotelomer Thioether Amido Sulfonate (Lodyne) in AFFF-Amended Microcosms. *Environ Sci Technol*, 49 (13), 7666-7674.

Harris M.W. and Birnbaum L.S. (1989): Developmental toxicity of perfluorodecanoic acid in C57BL/6N mice. *Fundam Appl Toxicol* 12 (3), 442-448. DOI: 10.1016/0272-0590(89)90018-3

HARRIS, M. W. & BIRNBAUM, L. S. 1989. Developmental toxicity of perfluorodecanoic acid in C57BL/6N mice. *Fundam Appl Toxicol*, 12, 442-8.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Harsanyi, A. & Sandford, G. (2015): Organofluorine Chemistry: Applications, sources and sustainability. *Green Chemistry*, 17, 2081-2086.

Haskell (1994): Developmental Toxicity Study of H-20255 in Rats. HLR-255-94. Haskell Laboratory for Toxicology and Industrial Medicine

Haskell (1996): 90-Day Inhalation Toxicity Study with HFC-236fa in Rats. HLR 211-95 Laboratory for Toxicology and Industrial Medicine

Haskell (1997): Four-Week Inhalation Toxicity Study with PEVE in Rats. DuPont HLR 955-96. E.I. du Pont de Nemours and Company, Haskell Laboratory for Toxicology and Industrial Medicine, Elkton Road, P.O. Box 50, Newark, Delaware 19714

Haskell (2010): H-28548: Subchronic Toxicity 90-Day Gavage Study in Mice DuPont-18405-1307. DuPont Haskell Global Centers for Health & Environmental Sciences

HASKELL 1994. Developmental Toxicity Study of H-20255 in Rats. Haskell Laboratory for Toxicology and Industrial Medicine.

HASKELL 1996. 90-Day Inhalation Toxicity Study with HFC-236fa in Rats. Laboratory for Toxicology and Industrial Medicine.

HASKELL 1997. Four-Week Inhalation Toxicity Study with PEVE in Rats. E.I. du Pont de Nemours and Company, Haskell Laboratory for Toxicology and Industrial Medicine, Elkton Road, P.O. Box 50, Newark, Delaware 19714.

HASKELL 2010. H-28548: Subchronic Toxicity 90-Day Gavage Study in Mice DuPont Haskell Global Centers for Health & Environmental Sciences.

Hassell, K.L., Coggan, T.L., Cresswell, T., Kolobaric, A., Berry, K., Crosbie, N.D., Blackbeard, J., Pettigrove, V.J., Clarke, B.O., 2020. Dietary Uptake and Depuration Kinetics of Perfluorooctane Sulfonate, Perfluorooctanoic Acid, and Hexafluoropropylene Oxide Dimer Acid (GenX) in a Benthic Fish. *Environ. Toxicol. Chem.* 39, 595–603. <https://doi.org/10.1002/etc.4640>

Hassell, K.L., Coggan, T.L., Cresswell, T., Kolobaric, A., Berry, K., Crosbie, N.D., Blackbeard, J., Pettigrove, V.J., Clarke, B.O., 2020. Dietary Uptake and Depuration Kinetics of Perfluorooctane Sulfonate, Perfluorooctanoic Acid, and Hexafluoropropylene Oxide Dimer Acid (GenX) in a Benthic Fish. *Environ. Toxicol. Chem.* 39, 595–603. <https://doi.org/10.1002/etc.4640>

Hays H.L. and Spiller H. (2014): Fluoropolymer-associated illness. *Clin Toxicol (Phila)* 52 (8), 848-855. DOI: 10.3109/15563650.2014.946610

Hellsing, M.S., Josefsson, S., Hughes, A.V., Ahrens, L., 2016. Sorption of perfluoroalkyl substances to two types of minerals. *Chemosphere* 159, 385-391.

Helmick, L. S. & Jones, W. R. J. (1990): Determination of the Thermal Stability of Perfluoroalkylethers. NASA Technical Memorandum 102493.

Helmick, L. S. & Jones, W. R. J. (1990): Determination of the Thermal Stability of Perfluoroalkylethers. NASA Technical Memorandum 102493.

Henderson, W.M., Smith, M.A., 2007. Perfluorooctanoic acid and perfluorononanoic acid in fetal and neonatal mice following in utero exposure to 8-2 fluorotelomer alcohol. *Toxicol Sci* 95, 452–461. <https://doi.org/10.1093/toxsci/kfl162>

Henderson, W.M., Smith, M.A., 2007. Perfluorooctanoic acid and perfluorononanoic acid in fetal and neonatal mice following in utero exposure to 8-2 fluorotelomer alcohol. *Toxicol Sci* 95, 452–461. <https://doi.org/10.1093/toxsci/kfl162>

Henneberger, L., Goss, K.-U., Endo, S., 2016. Partitioning of Organic Ions to Muscle Protein: Experimental Data, Modeling, and Implications for in Vivo Distribution of Organic Ions. *Environmental Science and Technology* 50, 7029–7036. <https://doi.org/10.1021/acs.est.6b01417>

Henneberger, L., Goss, K.-U., Endo, S., 2016. Partitioning of Organic Ions to Muscle Protein: Experimental Data, Modeling, and Implications for in Vivo Distribution of Organic Ions. *Environmental Science and Technology* 50, 7029–7036. <https://doi.org/10.1021/acs.est.6b01417>

Henry B.J., Carlin J.P., Hammerschmidt J.A., Buck R.C., Buxton L.W., Fiedler H., Seed J., and Hernandez O. (2018): A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integr Environ Assess Manag* 14 (3), 316-334. DOI: 10.1002/ieam.4035

HENRY, B. J., CARLIN, J. P., HAMMERSCHMIDT, J. A., BUCK, R. C., BUXTON, L. W., FIEDLER, H., SEED, J. & HERNANDEZ, O. 2018. A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integr Environ Assess Manag*, 14, 316-334.

Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J. & Hernandez, O. (2018): A Critical Review of the Application of Polymer of Low Concern and Regulatory Criteria to Fluoropolymers. *Integrated Environmental Assessment and Management* 1-19.

Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J. & Hernandez, O. (2018): A Critical Review of the Application of Polymer of Low Concern and Regulatory Criteria to Fluoropolymers. *Integrated Environmental Assessment and Management* 1-19.

Herzke, D., 2013. Perfluorinated alkylated substances, brominated flame retardants and chlorinated paraffins in the Norwegian Environment - screening 2013. NILU.

Herzke, D., Huber, S., Bervoets, L., D'Hollander, W., Hajslova, J., Pulkrabova, J., Brambilla, G., De Filippis, S.P., Klenow, S., Heinemeyer, G., de Voogt, P., 2013. Perfluorinated alkylated substances in vegetables collected in four European countries; occurrence and human exposure estimations. *Environ. Sci. Pollut. Res.* 20, 7930-7939.

HIGGINS, C. P. & LUTHY, R. G. 2006. Sorption of perfluorinated surfactants on sediments. *Environ.Sci Technol.*, 40, 7251-7256.

Higgins, C.P., Luthy, R.G., 2006. Sorption of perfluorinated surfactants on sediments. *Environmental Science and Technology* 40, 7251-7256.

Hirata-Koizumi M., Fujii S., Furukawa M., Ono A., and Hirose A. (2012): Repeated dose and reproductive/developmental toxicity of perfluorooctadecanoic acid in rats. *J Toxicol Sci* 37 (1), 63-79. DOI: 10.2131/jts.37.63

Hirata-Koizumi M., Fujii S., Hina K., Matsumoto M., Takahashi M., Ono A., and Hirose A. (2015): Repeated dose and reproductive/developmental toxicity of long-chain perfluoroalkyl carboxylic acids in rats: perfluorohexadecanoic acid and perfluorotetradecanoic acid. *Fundamental Toxicological Sciences* 2 (4), 177-190. DOI: 10.2131/fts.2.177

HIRATA-KOIZUMI, M., FUJII, S., FURUKAWA, M., ONO, A. & HIROSE, A. 2012. Repeated dose and reproductive/developmental toxicity of perfluorooctadecanoic acid in rats. *J Toxicol Sci*, 37, 63-79.

HIRATA-KOIZUMI, M., FUJII, S., HINA, K., MATSUMOTO, M., TAKAHASHI, M., ONO, A. & HIROSE, A. 2015. Repeated dose and reproductive/developmental toxicity of long-chain perfluoroalkyl carboxylic acids in rats: perfluorohexadecanoic acid and perfluorotetradecanoic acid. *Fundamental Toxicological Sciences*, 2, 177-190.

Hita (1994): Twenty-eight-day repeated-dose oral toxicity study of C6H in rats. D-3840. Hita Research Laboratories, Chemical Biotesting Center, Chemicals Inspection and Testing Institute (Japan)

Hita (2004): Twenty-Eight-Day Repeated-Dose Oral Toxicity Study of T-7869 in Rats. B11-0769. Hita Laboratory Chemicals Evaluation and Research Institute Japan

Hita (2006): Twenty-eight-day repeated-dose oral toxicity study of EEA-NH4 in rats. B11-0800. Hita Laboratory, Chemicals Evaluation and research Institute, 822, 3-chome, Ishii-machi, Hita, oita 877-0061, Japan

Hita (2007): Twenty-eight-day repeated-dose oral toxicity study of C6-ethane in rats. B11-0823. Hita Laboratory, Chemicals Evaluation and Research Institute, 822, 3-chome, Ishii-machi, Hita, Oita 877-0061, Japan

HITA 1994. Twenty-eight-day repeated-dose oral toxicity study of C6H in rats. Hita Research Laboratories, Chemical Biotesting Center, Chemicals Inspection and Testing Institute (Japan)

HITA 2004. Twenty-Eight-Day Repeated-Dose Oral Toxicity Study of T-7869 in Rats. Hita Laboratory Chemicals Evaluation and Research Institute Japan.

HITA 2006. Twenty-eight-day repeated-dose oral toxicity study of EEA-NH4 in rats. Hita Laboratory, Chemicals Evaluation and research Institute, 822, 3-chome, Ishii-machi, Hita, oita 877-0061, Japan.

HITA 2007. Twenty-eight-day repeated-dose oral toxicity study of C6-ethane in rats. Hita Laboratory, Chemicals Evaluation and Research Institute, 822, 3-chome, Ishii-machi, Hita, Oita 877-0061, Japan.

Hodnebrog, Ø., Aamaas, B., Fuglestad, J. S., Marston, G., Myhre, G., Nielsen, C. J., Sandstad, M., Shine, K. P. & Wallington, T. J. (2020): Updated Global Warming Potentials and Radiative Efficiencies of Halocarbons and Other Weak Atmospheric Absorbers. *Reviews of Geophysics*, 58, 1-30.

Hoke, R.A., Ferrell, B.D., Ryan, T., Sloman, T.L., Green, J.W., Nabb, D.L., Mingoia, R., Buck, R.C., Korzeniowski, S.H., 2015. Aquatic hazard, bioaccumulation and screening risk assessment for 6:2 fluorotelomer sulfonate. *Chemosphere* 128, 258–265. <http://dx.doi.org/10.1016/j.chemosphere.2015.01.033>

Hoke, R.A., Ferrell, B.D., Ryan, T., Sloman, T.L., Green, J.W., Nabb, D.L., Mingoia, R., Buck, R.C., Korzeniowski, S.H., 2015. Aquatic hazard, bioaccumulation and screening risk assessment for 6:2 fluorotelomer sulfonate. *Chemosphere* 128, 258–265. <http://dx.doi.org/10.1016/j.chemosphere.2015.01.033>

Hoke, R.A., Ferrell, B.D., Sloman, T.L., Buck, R.C., Buxton, L.W., 2016. Aquatic hazard, bioaccumulation and screening risk assessment for ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)-propanoate. *Chemosphere* 149, 336–42. <https://doi.org/10.1016/j.chemosphere.2016.01.009>

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Hoover G., Kar S., Guffey S., Leszczynski J., and Sepulveda M.S. (2019): In vitro and in silico modeling of perfluoroalkyl substances mixture toxicity in an amphibian fibroblast cell line. *Chemosphere* 233, 25-33. DOI: 10.1016/j.chemosphere.2019.05.065

HOOVER, G., KAR, S., GUFFEY, S., LESZCZYNSKI, J. & SEPULVEDA, M. S. 2019. In vitro and in silico modeling of perfluoroalkyl substances mixture toxicity in an amphibian fibroblast cell line. *Chemosphere*, 233, 25-33.

Hori, H., Murayama, M. & Kutsuna, S. (2009): Oxygen-induced efficient mineralization of perfluoroalkylether sulfonates in subcritical water. *Chemosphere*, 77, 1400-1405.

Hori, H., Murayama, M. & Kutsuna, S. (2009): Oxygen-induced efficient mineralization of perfluoroalkylether sulfonates in subcritical water. *Chemosphere*, 77, 1400-1405.

Houde M, De Silva AO, Muir DCG, Letcher RJ. Monitoring of Perfluorinated Compounds in Aquatic Biota: An Updated Review. *Environmental Science & Technology* 2011; 45: 7962-7973; DOI: 10.1021/es104326w.

Houde M., Douville M., Giraudo M., Jean K., Lépine M., Spencer C., and De Silva A.O. (2016): Endocrine-disruption potential of perfluoroethylcyclohexane sulfonate (PFECBS) in chronically exposed *Daphnia magna*. *Environmental Pollution* 218, 950-956. DOI: <https://doi.org/10.1016/j.envpol.2016.08.043>

Houde, M., Czub, G., Small, J.M., Backus, S., Wang, X., Alaei, M., Muir, D.C.G., 2008. Fractionation and bioaccumulation of perfluorooctane sulfonate (PFOS) isomers in a lake ontario food web. *Environmental Science and Technology* 42, 9397-9403. <https://doi.org/10.1021/es800906r>

Houde, M., Czub, G., Small, J.M., Backus, S., Wang, X., Alaei, M., Muir, D.C.G., 2008. Fractionation and bioaccumulation of perfluorooctane sulfonate (PFOS) isomers in a lake ontario food web. *Environmental Science and Technology* 42, 9397-9403. <https://doi.org/10.1021/es800906r>

Houde, M., De Silva, A.O., Muir, D.C., Letcher, R.J., 2011. Monitoring of perfluorinated compounds in aquatic biota: an updated review. *Environ Sci Technol* 45, 7962-73. <https://doi.org/10.1021/es104326w>

Houde, M., De Silva, A.O., Muir, D.C., Letcher, R.J., 2011. Monitoring of perfluorinated compounds in aquatic biota: an updated review. *Environ Sci Technol* 45, 7962-73. <https://doi.org/10.1021/es104326w>

Houde, M., De Silva, A.O., Muir, D.C.G., Letcher, R.J., 2011. Monitoring of perfluorinated compounds in aquatic biota: An updated review. *Environ. Sci. Technol.* 45, 7962-7973.

<https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1808db499>

<https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1808db499>

<https://echa.europa.eu/de/candidate-list-table/-/dislist/details/0b0236e180e22a1a>

<https://echa.europa.eu/de/candidate-list-table/-/dislist/details/0b0236e180e22a1a>

<https://echa.europa.eu/documents/10162/e40425c6-590f-8df7-2cd9-0eef79527685>

<https://www.eea.europa.eu/themes/human/chemicals/emerging-chemical-risks-in-europe>

Huang Q.Y., Zhang J., Martin F.L., Peng S.Y., Tian M.P., Mu X.L., and Shen H.Q. (2013): Perfluorooctanoic acid induces apoptosis through the p53-dependent mitochondrial pathway

in human hepatic cells: A proteomic study. *Toxicology Letters* 223 (2), 211-220. DOI: 10.1016/j.toxlet.2013.09.002

HUANG, Q. Y., ZHANG, J., MARTIN, F. L., PENG, S. Y., TIAN, M. P., MU, X. L. & SHEN, H. Q. 2013. Perfluorooctanoic acid induces apoptosis through the p53-dependent mitochondrial pathway in human hepatic cells: A proteomic study. *Toxicology Letters*, 223, 211-220.

Huber S, Ahrens L, Bårdsen B-J, Siebert U, Bustnes JO, Víkingsson GA, et al. Temporal trends and spatial differences of perfluoroalkylated substances in livers of harbor porpoise (*Phocoena phocoena*) populations from Northern Europe, 1991–2008. *Science of The Total Environment* 2012; 419: 216-224: <https://doi.org/10.1016/j.scitotenv.2011.12.050>.

Huber, S., Warner, N.A., Nygård, T., Remberger, M., Harju, M., Uggerud, H.T., Kaj, L., Hanssen, L., 2015. A broad cocktail of environmental pollutants found in eggs of three seabird species from remote colonies in Norway. *Environ. Toxicol. Chem.* 34, 1296-1308.

Hudcová H., Vymazal J., and Rozkošný M. (2019): Present restrictions of sewage sludge application in agriculture within the European Union. *Soil and Water Research* 14 (2), 104-120

HUFF, D. K., MORRIS, L. A., SUTTER, L., COSTANZA, J. & PENNELL, K. D. 2020. Accumulation of six PFAS compounds by woody and herbaceous plants: potential for phytoextraction. *International Journal of Phytoremediation*, 22, 1538-1550.

Huff, D. K., Morris, L. A., Sutter, L., Costanza, J., & Pennell, K. D. (2020). Accumulation of six PFAS compounds by woody and herbaceous plants: potential for phytoextraction. *International Journal of Phytoremediation*, 22(14), 1538-1550. doi:10.1080/15226514.2020.1786004

Hui Z.G., Li R.J., and Chen L. (2017): The impact of exposure to environmental contaminant on hepatocellular lipid metabolism. *Gene* 622, 67-71. DOI: 10.1016/j.gene.2017.04.024

HUI, Z. G., LI, R. J. & CHEN, L. 2017. The impact of exposure to environmental contaminant on hepatocellular lipid metabolism. *Gene*, 622, 67-71.

Hunter Anderson, R., Adamson, D. T., & Stroo, H. F. (2019). Partitioning of poly- and perfluoroalkyl substances from soil to groundwater within aqueous film-forming foam source zones. *Journal of Contaminant Hydrology*, 220, 59-65. doi:<https://doi.org/10.1016/j.jconhyd.2018.11.011>

Huntingdon (1992): READ ACROSS: T-5333: 90-Day Inhalation Study in Rats
T-5333. Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England

Huntingdon (1996): T-6334 13-Week Repeat Dose Inhalation Toxicity Study in Rats. MIN 196/961181. Huntingdon Life Sciences Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE19 6ES ENGLAND

Huntingdon (1998a): HFCPA 90 days repeat dose inhalation toxicity study in rats (snout only exposure). ZCE 044/982077. Huntingdon Life Sciences Ltd, PO Box 2, Huntingdon, Cambridgeshire, PE186ES, England

Huntingdon (1998b): HFCPA a study for effects on embryofetal development by inhalation administration in the rat (whole body exposure). ZCE 032/982554. Huntingdon Life Sciences Ltd, PO Box 2, Huntingdon, Cambridgeshire, PE186ES, England

Huntingdon (N/A-a): N/A (HFC-365mfc-28-d-inhalation-rat). Huntingdon Life Sciences Ltd. Huntingdon, Cambridgeshire PE18 6ES

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Huntingdon (N/A-b): N/A (Tetraconazole-2-yr-oral-rat). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England

Huntingdon (N/A-c): N/A (Tetraconazole-28-d(2)-oral-rat). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England

Huntingdon (N/A-d): N/A (Tetraconazole-80-wk-oral-mouse). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England

Huntingdon (N/A-e): N/A (Tetraconazole-90-d-oral-rat). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England

HUNTINGDON 1992. READ ACROSS: T-5333: 90-Day Inhalation Study in Rats
Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England.

HUNTINGDON 1996. T-6334 13-Week Repeat Dose Inhalation Toxicity Study in Rats. Huntingdon Life Sciences Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE19 6ES ENGLAND

HUNTINGDON 1998a. HFCPA 90 days repeat dose inhalation toxicity study in rats (snout only exposure). Huntingdon Life Sciences Ltd, PO Box 2, Huntingdon, Cambridgeshire, PE186ES, England.

HUNTINGDON 1998b. HFCPA a study for effects on embryofetal development by inhalation administration in the rat (whole body exposure). Huntingdon Life Sciences Ltd, PO Box 2, Huntingdon, Cambridgeshire, PE186ES, England.

HUNTINGDON N/A-a. N/A (HFC-365mfc-28-d-inhalation-rat). Huntingdon Life Sciences Ltd. Huntingdon, Cambridgeshire PE18 6ES.

HUNTINGDON N/A-b. N/A (Tetraconazole-2-yr-oral-rat). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England.

HUNTINGDON N/A-c. N/A (Tetraconazole-28-d(2)-oral-rat). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England.

HUNTINGDON N/A-d. N/A (Tetraconazole-80-wk-oral-mouse). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England.

HUNTINGDON N/A-e. N/A (Tetraconazole-90-d-oral-rat). Huntingdon Research Centre Ltd., P.O. Box 2, Huntingdon, Cambridgeshire, PE18 6ES, England.

Hurley, M. D., Andersen, M. P. S., Wallington, T. J., Ellis, D. A., Martin, J. W., & Mabury, S. A. (2004). Atmospheric Chemistry of Perfluorinated Carboxylic Acids: Reaction with OH Radicals and Atmospheric Lifetimes. *Journal of Physical Chemistry*, 108, 615–620.

Hurley, M. D., Andersen, M. P. S., Wallington, T. J., Ellis, D. A., Martin, J. W., & Mabury, S. A. (2004). Atmospheric Chemistry of Perfluorinated Carboxylic Acids: Reaction with OH Radicals and Atmospheric Lifetimes. *Journal of Physical Chemistry*, 108, 615–620.

Hurley, M. D., Ball, J. C., Wallington, T. J., Sulbaek Andersen, M. P., Nielsen, O. J., Ellis, D. A. (2006). Atmospheric chemistry of $n\text{-C}_x\text{F}_{2x+1}\text{CHO}$ ($x = 1, 2, 3, 4$): fate of $n\text{-C}_x\text{F}_{2x+1}\text{C(O)}$ radicals. *J Phys Chem A*, 110, 12443–12447.

Hurley, M. D., Wallington, T. J., Sulbaek Andersen, M. P., Ellis, D. A., Martin, J. W., Mabury, S. A. (2004b). Atmospheric chemistry of fluorinated alcohols: reaction with Cl atoms and OH radicals and atmospheric lifetimes. *J Phys Chem A*, 108, 1973–1979.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

IARC (2017): Some chemicals used as solvents and in polymer manufacture. International Agency for Research on Cancer. Available online: <http://monographs.iarc.fr/ENG/Monographs/vol110/mono110-01.pdf>

IARC 2017. Some chemicals used as solvents and in polymer manufacture. IARC monographs on the evaluation of carcinogenic risks to humans. International Agency for Research on Cancer.

ICI (1979): Arcton 134a: subacute toxicity to the rat by inhalation. Unpublished report CTL/P/463. ICI Central Toxicology Laboratory, Alderley Park, Macclesfield, Cheshire, UK

ICI 1979. Arcton 134a: subacute toxicity to the rat by inhalation. ICI Central Toxicology Laboratory, Alderley Park, Macclesfield, Cheshire, UK

Impinen A., Longnecker M.P., Nygaard U.C., London S.J., Ferguson K.K., Haug L.S., and Granum B. (2019): Maternal levels of perfluoroalkyl substances (PFASs) during pregnancy and childhood allergy and asthma related outcomes and infections in the Norwegian Mother and Child (MoBa) cohort. *Environ Int* 124, 462-472. DOI: 10.1016/j.envint.2018.12.041

Impinen A., Nygaard U.C., Lødrup Carlsen K.C., Mowinckel P., Carlsen K.H., Haug L.S., and Granum B. (2018): Prenatal exposure to perfluoroalkyl substances (PFASs) associated with respiratory tract infections but not allergy- and asthma-related health outcomes in childhood. *Environmental Research* 160, 518-523. DOI: 10.1016/j.envres.2017.10.012

IMPINEN, A., LONGNECKER, M. P., NYGAARD, U. C., LONDON, S. J., FERGUSON, K. K., HAUG, L. S. & GRANUM, B. 2019. Maternal levels of perfluoroalkyl substances (PFASs) during pregnancy and childhood allergy and asthma related outcomes and infections in the Norwegian Mother and Child (MoBa) cohort. *Environ Int*, 124, 462-472.

IMPINEN, A., NYGAARD, U. C., LØDRUP CARLSEN, K. C., MOWINCKEL, P., CARLSEN, K. H., HAUG, L. S. & GRANUM, B. 2018. Prenatal exposure to perfluoroalkyl substances (PFASs) associated with respiratory tract infections but not allergy- and asthma-related health outcomes in childhood. *Environmental Research*, 160, 518-523.

Ingelido A.M., Abballe A., Gemma S., Dellatte E., Iacovella N., De Angelis G., Zampaglioni F., Marra V., Miniero R., Valentini S., Russo F., Vazzoler M., Testai E., and De Felip E. (2018): Biomonitoring of perfluorinated compounds in adults exposed to contaminated drinking water in the Veneto Region, Italy. *Environ Int* 110, 149-159. DOI: 10.1016/j.envint.2017.10.026

INGELIDO, A. M., ABBALLE, A., GEMMA, S., DELLATTE, E., IACOVELLA, N., DE ANGELIS, G., ZAMPAGLIONI, F., MARRA, V., MINIERO, R., VALENTINI, S., RUSSO, F., VAZZOLER, M., TESTAI, E. & DE FELIP, E. 2018. Biomonitoring of perfluorinated compounds in adults exposed to contaminated drinking water in the Veneto Region, Italy. *Environ Int*, 110, 149-159.

Inoue, Y., Hashizume, N., Yakata, N., Murakami, H., Suzuki, Y., Kikushima, E., Otsuka, M., 2012. Unique physicochemical properties of perfluorinated compounds and their bioconcentration in common carp *Cyprinus carpio* L. *Arch Environ Contam Toxicol* 62, 672-80. <https://doi.org/10.1007/s00244-011-9730-7>

Inoue, Y., Hashizume, N., Yakata, N., Murakami, H., Suzuki, Y., Kikushima, E., Otsuka, M., 2012. Unique physicochemical properties of perfluorinated compounds and their bioconcentration in common carp *Cyprinus carpio* L. *Arch Environ Contam Toxicol* 62, 672-80. <https://doi.org/10.1007/s00244-011-9730-7>

Ishibashi H., Ishida H., Matsuoka M., Tominaga N., and Arizono K. (2007): Estrogenic effects of fluorotelomer alcohols for human estrogen receptor isoforms alpha and beta in vitro. *Biol.Pharm.Bull.* 30 (7), 1358-1359. DOI: 10.1248/bpb.30.1358

Ishibashi H., Kim E.Y., and Iwata H. (2011): Transactivation potencies of the Baikal seal (*Pusa sibirica*) peroxisome proliferator-activated receptor alpha by perfluoroalkyl carboxylates and sulfonates: estimation of PFOA induction equivalency factors. *Environ Sci Technol* 45 (7), 3123-3130. DOI: 10.1021/es103748s

Iwai H. and Hoberman A.M. (2014): Oral (Gavage) Combined Developmental and Perinatal/Postnatal Reproduction Toxicity Study of Ammonium Salt of Perfluorinated Hexanoic Acid in Mice. *International Journal of Toxicology* 33 (3), 219-237. DOI: 10.1177/1091581814529449

IWAI, H. & HOBERMAN, A. M. 2014. Oral (Gavage) Combined Developmental and Perinatal/Postnatal Reproduction Toxicity Study of Ammonium Salt of Perfluorinated Hexanoic Acid in Mice. *Int J Toxicol*, 33, 219-237.

Jackson D.A. and Mabury S.A. (2013): Polyfluorinated amides as a historical PFCA source by electrochemical fluorination of alkyl sulfonyl fluorides. *Environ Sci Technol*, 47 (1), 382-389.

Jackson D.A., Wallington T.J., and Mabury S.A. (2013): Atmospheric oxidation of polyfluorinated amides: historical source of perfluorinated carboxylic acids to the environment. *Environ Sci Technol*, 47 (9), 4317-4324.

Jain R.B. and Ducatman A. (2019a): Perfluoroalkyl substances follow inverted U-shaped distributions across various stages of glomerular function: Implications for future research. *Environ Res* 169, 476-482. DOI: 10.1016/j.envres.2018.11.033

Jain R.B. and Ducatman A. (2019b): Selective Associations of Recent Low Concentrations of Perfluoroalkyl Substances With Liver Function Biomarkers: NHANES 2011 to 2014 Data on US Adults Aged ≥ 20 Years. *Journal of Occupational and Environmental Medicine* 61 (4), 293-302. DOI: 10.1097/JOM.0000000000001532

JAIN, R. B. & DUCATMAN, A. 2019a. Perfluoroalkyl substances follow inverted U-shaped distributions across various stages of glomerular function: Implications for future research. *Environ Res*, 169, 476-482.

JAIN, R. B. & DUCATMAN, A. 2019b. Selective Associations of Recent Low Concentrations of Perfluoroalkyl Substances With Liver Function Biomarkers: NHANES 2011 to 2014 Data on US Adults Aged ≥ 20 Years. *J Occup Environ Med*, 61, 293-302.

Janda, J., Nödler, K., Brauch, H. J., Zwiener, C., & Lange, F. T. (2019). Robust trace analysis of polar (C2-C8) perfluorinated carboxylic acids by liquid chromatography-tandem mass spectrometry: method development and application to surface water, groundwater and drinking water. *Environmental Science and Pollution Research*, 26(8), 7326-7336. doi:10.1007/s11356-018-1731-x

Jaspers VLB, Herzke D, Eulaers I, Gillespie BW, Eens M. Perfluoroalkyl substances in soft tissues and tail feathers of Belgian barn owls (*Tyto alba*) using statistical methods for left-censored data to handle non-detects. *Environment International* 2013; 52: 9-16: <https://doi.org/10.1016/j.envint.2012.11.002>.

Jian, J.M., Guo, Y., Zeng, L., Liang-Ying, L., Lu, X., Wang, F., Zeng, E.Y., 2017. Global distribution of perfluorochemicals (PFCs) in potential human exposure source—A review. *Environment International* 108, 51-62.

Jian, J.-M., Guo, Y., Zeng, L., Liang-Ying, L., Lu, X., Wang, F., & Zeng, E. Y. (2017). Global distribution of perfluorochemicals (PFCs) in potential human exposure source—A review. *Environment International*, 108, 51-62. doi:10.1016/j.envint.2017.07.024

JIAO, X., SHI, Q. & GAN, J. 2020. Uptake, accumulation and metabolism of PFASs in plants and health perspectives: A critical review. *Critical Reviews in Environmental Science and Technology*, 1-32.

Jiao, X., Shi, Q., & Gan, J. (2020). Uptake, accumulation and metabolism of PFASs in plants and health perspectives: A critical review. *Critical Reviews in Environmental Science and Technology*, 1-32. doi:10.1080/10643389.2020.1809219

Jiao, X., Shi, Q., & Gan, J. (2020). Uptake, accumulation and metabolism of PFASs in plants and health perspectives: A critical review. *Critical Reviews in Environmental Science and Technology*. doi:10.1080/10643389.2020.1809219

Jin, H., Shan, G., Zhu, L., Sun, H., Luo, Y., 2018. Perfluoroalkyl Acids Including Isomers in Tree Barks from a Chinese Fluorochemical Manufacturing Park: Implication for Airborne Transportation. *Environ. Sci. Technol.* 52, 2016-2024.

Jin, Q., Shi, Y., Cai, Y., 2020. Occurrence and risk of chlorinated polyfluoroalkyl ether sulfonic acids (Cl-PFESAs) in seafood from markets in Beijing, China. *Science of The Total Environment* 726, 138538. <https://doi.org/10.1016/j.scitotenv.2020.138538>

Jin, Q., Shi, Y., Cai, Y., 2020. Occurrence and risk of chlorinated polyfluoroalkyl ether sulfonic acids (Cl-PFESAs) in seafood from markets in Beijing, China. *Science of The Total Environment* 726, 138538. <https://doi.org/10.1016/j.scitotenv.2020.138538>

Joensen U.N., Bossi R., Leffers H., Jensen A.A., Skakkebaek N.E., and Jorgensen N. (2009): Do Perfluoroalkyl Compounds Impair Human Semen Quality? *Environmental Health Perspectives* 117 (6), 923-927. DOI: 10.1289/ehp.0800517

JOENSEN, U. N., BOSSI, R., LEFFERS, H., JENSEN, A. A., SKAKKEBAEK, N. E. & JORGENSEN, N. 2009. Do Perfluoroalkyl Compounds Impair Human Semen Quality? *Environmental Health Perspectives*, 117, 923-927.

Joerss, H., Xie, Z., Wagner, C.C., von Appen, W.-J., Sunderland, E.M., Ebinghaus, R., 2020. Transport of Legacy Perfluoroalkyl Substances and the Replacement Compound HFPO-DA through the Atlantic Gateway to the Arctic Ocean—Is the Arctic a Sink or a Source? *Environmental Science & Technology* 54, 9958-9967.

Johansson, J.H., Salter, M.E., Acosta Navarro, J.C., Leck, C., Nilsson, E.D., Cousins, I.T., 2019. Global transport of perfluoroalkyl acids via sea spray aerosol. *Environmental Science: Processes & Impacts* 21, 635-649.

Johnson P.I., Sutton P., Atchley D.S., Koustas E., Lam J., Sen S., Robinson K.A., Axelrad D.A., and Woodruff T.J. (2014): The Navigation Guide - evidence-based medicine meets environmental health: systematic review of human evidence for PFOA effects on fetal growth. *Environ Health Perspect* 122 (10), 1028-1039. DOI: 10.1289/ehp.1307893

Johnson W. (2018a): Safety Assessment of Fluoropolymers as Used in Cosmetics - Draft Report for Panel Review. Draft Report for Panel Review. Cosmetic Ingredient Review Expert Panel (CIR)

Johnson W. (2018b): Safety Assessment of Fluoropolymers as Used in Cosmetics - Scientific Literature Review for Public Comment. Scientific Literature Review for Public Comment. Cosmetic Ingredient Review Expert Panel (CIR)

Johnson W. and Zhu J. (2018): Safety Assessment of Fluoropolymers as Used in Cosmetics - Final Report. Final Report. Cosmetic Ingredient Review Expert Panel (CIR)

JOHNSON, P. I., SUTTON, P., ATCHLEY, D. S., KOUSTAS, E., LAM, J., SEN, S., ROBINSON, K. A., AXELRAD, D. A. & WOODRUFF, T. J. 2014. The Navigation Guide - evidence-based medicine meets environmental health: systematic review of human evidence for PFOA effects on fetal growth. *Environ Health Perspect*, 122, 1028-39.

Jones C.E., Ballinger M.B., Mattie D.R., DelRaso N.J., Seckel C., and Vinegar A. (1991): Effects of short-term oral dosing of polychlorotrifluoroethylene (polyCTFE) on the rhesus monkey. *J Appl Toxicol* 11 (1), 51-60. DOI: 10.1002/jat.2550110110

Jones C.E., Ballinger M.B., Mattie D.R., DelRaso N.J., Seckel C., and Vinegar A. (1991): Effects of short-term oral dosing of polychlorotrifluoroethylene (polyCTFE) on the rhesus monkey. *J Appl Toxicol* 11 (1), 51-60. DOI: 10.1002/jat.2550110110

Jouanneau W, Bårdsen B-J, Herzke D, Johnsen TV, Eulaers I, Bustnes JO. Spatiotemporal Analysis of Perfluoroalkyl Substances in White-Tailed Eagle (*Haliaeetus albicilla*) Nestlings from Northern Norway—A Ten-Year Study. *Environmental Science & Technology* 2020; 54: 5011-5020. DOI: 10.1021/acs.est.9b06818.

Jouanneau, W., Léandri-Breton, D.-J., Corbeau, A., Herzke, D., Moe, B., Nikiforov, V.A., Gabrielsen, G.W., Chastel, O., 2021. A Bad Start in Life? Maternal Transfer of Legacy and Emerging Poly- and Perfluoroalkyl Substances to Eggs in an Arctic Seabird. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.1c03773>

Jouanneau, W., Léandri-Breton, D.-J., Corbeau, A., Herzke, D., Moe, B., Nikiforov, V.A., Gabrielsen, G.W., Chastel, O., 2021. A Bad Start in Life? Maternal Transfer of Legacy and Emerging Poly- and Perfluoroalkyl Substances to Eggs in an Arctic Seabird. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.1c03773>

Joudan S., Yeung L.W.Y., and Mabury S.A. (2017): Biological Cleavage of the C-P Bond in Perfluoroalkyl Phosphinic Acids in Male Sprague-Dawley Rats and the Formation of Persistent and Reactive Metabolites. *Environ Health Perspect* 125 (11), 117001. DOI: 10.1289/EHP1841

Joudan, S., Yeung, L. W. Y. & Mabury, S. A. (2017): Biological Cleavage of the C-P Bond in Perfluoroalkyl Phosphinic Acids in Male Sprague-Dawley Rats and the Formation of Persistent and Reactive Metabolites. *Environmental Health Perspectives*, 125, 117001.

Joudan, S., Yeung, L. W. Y. & Mabury, S. A. (2017): Biological Cleavage of the C-P Bond in Perfluoroalkyl Phosphinic Acids in Male Sprague-Dawley Rats and the Formation of Persistent and Reactive Metabolites. *Environmental Health Perspectives*, 125, 117001.

JOUDAN, S., YEUNG, L. W. Y. & MABURY, S. A. 2017. Biological Cleavage of the C-P Bond in Perfluoroalkyl Phosphinic Acids in Male Sprague-Dawley Rats and the Formation of Persistent and Reactive Metabolites. *Environ Health Perspect*, 125, 117001.

Kaboré, H.A., Vo Duy, S., Munoz, G., Méité, L., Desrosiers, M., Liu, J., Sory, T.K., Sauvé, S., 2018. Worldwide drinking water occurrence and levels of newly-identified perfluoroalkyl and polyfluoroalkyl substances. *Science of the Total Environment* 616-617, 1089-1100.

Kacprzak M., Neczaj E., Fijałkowski K., Grobelak A., Grosser A., Worwag M., Rorat A., Brattebo H., Almås Å., and Singh B.R. (2017): Sewage sludge disposal strategies for sustainable development. *Environmental Research* 156, 39-46. DOI: <https://doi.org/10.1016/j.envres.2017.03.010>

Kaiser, M. A., Larsen, B. S., Kao, C.-P. C., & Buck, R. C. (2005). Vapor Pressures of Perfluorooctanoic, -nonanoic, -decanoic, -undecanoic, and -dodecanoic Acids. *Journal of Chemical & Engineering Data*, 50(6), 1841-1843. doi:10.1021/je050070r

Kallenborn R. (2004): Perfluorinated alkylated substances (PFAS) in the Nordic environment. Nordic Council of Ministers. ISBN: 9289310510

Kannan, K., 2011. Perfluoroalkyl and polyfluoroalkyl substances: current and future perspectives. *Environmental Chemistry* 8, 333.

Karnjanapiboonwong, A., Deb, S. K., Subbiah, S., Wang, D., & Anderson, T. A. (2018). Perfluoroalkylsulfonic and carboxylic acids in earthworms (*Eisenia fetida*): Accumulation and effects results from spiked soils at PFAS concentrations bracketing environmental relevance. *Chemosphere*, 199, 168-173. doi:10.1016/j.chemosphere.2018.02.027

Kärrman A, Thanh W, Kallenborn R. 2019. PFASs in the Nordic environment Screening of Poly- and Perfluoroalkyl Substances (PFASs) and Extractable Organic Fluorine (EOF) in the Nordic Environment: Nordic Council of Ministers 2019.

Kärrman, A., Thanh, W., Kallenborn, R., 2019. PFASs in the Nordic environment Screening of Poly- and Perfluoroalkyl Substances (PFASs) and Extractable Organic Fluorine (EOF) in the Nordic Environment. Nordic Council of Ministers 2019.

Kato H., Fujii S., Takahashi M., Matsumoto M., Hirata-Koizumi M., Ono A., and Hirose A. (2015): Repeated dose and reproductive/developmental toxicity of perfluorododecanoic acid in rats. *Environ Toxicol* 30 (11), 1244-1263. DOI: 10.1002/tox.21996

KATO, H., FUJII, S., TAKAHASHI, M., MATSUMOTO, M., HIRATA-KOIZUMI, M., ONO, A. & HIROSE, A. 2015. Repeated dose and reproductive/developmental toxicity of perfluorododecanoic acid in rats. *Environ Toxicol*, 30, 1244-63.

Kelly BC, Ikonomou MG, Blair JD, Surridge B, Hoover D, Grace R, et al. Perfluoroalkyl Contaminants in an Arctic Marine Food Web: Trophic Magnification and Wildlife Exposure. *Environmental Science & Technology* 2009; 43: 4037-4043: DOI: 10.1021/es9003894.

Kelly, B.C., Gobas, F.A., McLachlan, M.S., 2004. Intestinal absorption and biomagnification of organic contaminants in fish, wildlife, and humans. *Environ Toxicol Chem* 23, 2324–2336.

Kelly, B.C., Gobas, F.A., McLachlan, M.S., 2004. Intestinal absorption and biomagnification of organic contaminants in fish, wildlife, and humans. *Environ Toxicol Chem* 23, 2324–2336.

Kelly, B.C., Ikonomou, M.G., Blair, J.D., Surridge, B., Hoover, D., Grace, R., 2009. Perfluoroalkyl contaminants in an arctic marine food web: trophic magnification and wildlife exposure. *Environ Sci Technol* 43. <https://doi.org/10.1021/es9003894>

Kelly, B.C., Ikonomou, M.G., Blair, J.D., Surridge, B., Hoover, D., Grace, R., 2009. Perfluoroalkyl contaminants in an arctic marine food web: trophic magnification and wildlife exposure. *Environ Sci Technol* 43. <https://doi.org/10.1021/es9003894>

KEMI, Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives (7/15). <https://www.kemi.se/global/rapporter/2015/report-7-15-occurrence-and-use-of-highly-fluorinated-substances-and-alternatives.pdf>

Key, B. D., Howell, R. D. & Criddle, C. S. (1998): Defluorination of Organofluorine Sulfur Compounds by *Pseudomonas* Sp. Strain D2. *Environmental Science & Technology*, 32, 2283-2287.

Key, B. D., Howell, R. D. & Criddle, C. S. (1998): Defluorination of Organofluorine Sulfur Compounds by *Pseudomonas* Sp. Strain D2. *Environmental Science & Technology*, 32, 2283-2287.

Khan, M. F. and Murphy, C. D. (2021): Bacterial degradation of the anti-depressant drug fluoxetine produces trifluoroacetic acid and fluoride ion. *Applied Microbiology and Biotechnology*, 105 (6).

Khazaei, M., Ng, C.A., 2018. Evaluating parameter availability for physiologically based pharmacokinetic (PBPK) modeling of perfluorooctanoic acid (PFOA) in zebrafish. *Environmental Science: Processes and Impacts* 20, 105–119. <https://doi.org/10.1039/c7em00474e>

Khazaei, M., Ng, C.A., 2018. Evaluating parameter availability for physiologically based pharmacokinetic (PBPK) modeling of perfluorooctanoic acid (PFOA) in zebrafish. *Environmental Science: Processes and Impacts* 20, 105–119. <https://doi.org/10.1039/c7em00474e>

Kim M.S., Kim S.K., Lee J.Y., Cho S.H., Lee K.-H., Kim J., and Lee S.-S. (2008): Synthesis of polystyrene nanoparticles with monodisperse size distribution and positive surface charge using metal stearates. *Macromolecular Research* 16 (2), 178-181. DOI: 10.1007/BF03218848

Kim S., Stroski K.M., Killeen G., Smitherman C., Simcik M.F., and Brooks B.W. (2020): 8:8 Perfluoroalkyl phosphinic acid affects neurobehavioral development, thyroid disruption, and DNA methylation in developing zebrafish. *Science of the Total Environment* 736, 139600. DOI: <https://doi.org/10.1016/j.scitotenv.2020.139600>

Kim, B. R., Suidan, M. T., Wallington, T. J., & Du, X. (2000). Biodegradability of Trifluoroacetic Acid. *Environmental Engineering Science*. 17, 337-342.

Kim, B. R., Suidan, M. T., Wallington, T. J., & Du, X. (2000). Biodegradability of Trifluoroacetic Acid. *Environmental Engineering Science*. 17, 337-342.

Kim, H., Ekpe, O.D., Lee, J.H., Kim, D.H., Oh, J.E., 2019. Field-scale evaluation of the uptake of Perfluoroalkyl substances from soil by rice in paddy fields in South Korea. *Sci. Total Environ.* 671, 714-721.

KIM, M. S., KIM, S. K., LEE, J. Y., CHO, S. H., LEE, K.-H., KIM, J. & LEE, S.-S. 2008. Synthesis of polystyrene nanoparticles with monodisperse size distribution and positive surface charge using metal stearates. *Macromolecular Research*, 16, 178-181.

Kirkpatrick J.B. (2005): A combined 28-day repeated dose oral toxicity study with the reproduction/developmental toxicity screening test of perfluorhexanoic acid and 1H,1H,2H,2H-tridecafluoro-1-octanol in rats, with recovery. WIL-534001, date: 2005-09-02. WIL Research Laboratories. Chemical A., Asahi Glass Company L., 10 Goikaigan I.-s., and Chiba 290-8566 J.

KIRKPATRICK, J. B. 2005. A combined 28-day repeated dose oral toxicity study with the reproduction/developmental toxicity screening test of perfluorhexanoic acid and 1H,1H,2H,2H-tridecafluoro-1-octanol in rats, with recovery. WIL Research Laboratories.

Kissa, E. (2001). *Fluorinated Surfactants and Repellents*. CRC, New York, Basel.

Kissa, E. & Dekker, M. (2001). *Fluorinated Surfactants and Repellents*. CRC, New York, Basel.

Kissa, E. (2001). *Fluorinated Surfactants and Repellents*. CRC, New York, Basel.

Klaunig J.E., Shinohara M., Iwai H., Chengelis C.P., Kirkpatrick J.B., Wang Z.M., and Bruner R.H. (2015): Evaluation of the Chronic Toxicity and Carcinogenicity of Perfluorohexanoic Acid (PFHxA) in Sprague-Dawley Rats. *Toxicologic Pathology* 43 (2), 209-220. DOI: 10.1177/0192623314530532

KLAUNIG, J. E., SHINOHARA, M., IWAI, H., CHENGELIS, C. P., KIRKPATRICK, J. B., WANG, Z. M. & BRUNER, R. H. 2015. Evaluation of the Chronic Toxicity and Carcinogenicity of Perfluorohexanoic Acid (PFHxA) in Sprague-Dawley Rats. *Toxicologic Pathology*, 43, 209-220.

Klein A. Halogenierte Essigsäuren in der Umwelt. Fakultät für Biologie, Chemie und Geowissenschaften. <https://eref.uni-bayreuth.de/27534/>. Dissertation. Universität Bayreuth, Aachen, 1997.

Klöpffer, W: Environmental Hazard- Assessment of chemicals and products: Part II: Persistence and degradability of organic chemicals (1994) *Environmental Science and Pollution Research*, 1 (2), pp. 108-116. doi: 10.1007/BF02986520

Kotamarthi, V.R., Rodriguez, J.M., Ko, M.K.W., Tromp, T.K., Sze, N.D., Prather, M.J., 1998. Trifluoroacetic acid from degradation of HCFCs and HFCs: A three-dimensional modeling study. *Journal of Geophysical Research: Atmospheres* 103, 5747-5758.

Koustaas E., Lam J., Sutton P., Johnson P.I., Atchley D.S., Sen S., Robinson K.A., Axelrad D.A., and Woodruff T.J. (2014): The Navigation Guide - evidence-based medicine meets environmental health: systematic review of nonhuman evidence for PFOA effects on fetal growth. *Environ Health Perspect* 122 (10), 1015-1027. DOI: 10.1289/ehp.1307177

KOUSTAS, E., LAM, J., SUTTON, P., JOHNSON, P. I., ATCHLEY, D. S., SEN, S., ROBINSON, K. A., AXELRAD, D. A. & WOODRUFF, T. J. 2014. The Navigation Guide - evidence-based medicine meets environmental health: systematic review of nonhuman evidence for PFOA effects on fetal growth. *Environ Health Perspect*, 122, 1015-27.

Kowalczyk, J., Göckener, B., Eichhorn, M., Kotthoff, M., Bücking, M., Schafft, H., Lahrssen-Wiederholt, M., Numata, J., 2020. Transfer of Per- And Polyfluoroalkyl Substances (PFAS) from Feed into the Eggs of Laying Hens. Part 2: Toxicokinetic Results including the Role of Precursors. *J. Agric. Food Chem.* <https://doi.org/10.1021/acs.jafc.0c04485>

Kowalczyk, J., Göckener, B., Eichhorn, M., Kotthoff, M., Bücking, M., Schafft, H., Lahrssen-Wiederholt, M., Numata, J., 2020. Transfer of Per- And Polyfluoroalkyl Substances (PFAS) from Feed into the Eggs of Laying Hens. Part 2: Toxicokinetic Results including the Role of Precursors. *J. Agric. Food Chem.* <https://doi.org/10.1021/acs.jafc.0c04485>

Krafft, M. P., & Riess, J. G. (2015). Per- and polyfluorinated substances (PFASs): Environmental challenges. *Current Opinion in Colloid & Interface Science*, 20(3), 192-212. doi:<https://doi.org/10.1016/j.cocis.2015.07.004>

KRIPPNER, J., BRUNN, H., FALK, S., GEORGII, S., SCHUBERT, S. & STAHL, T. 2014. Effects of chain length and pH on the uptake and distribution of perfluoroalkyl substances in maize (*Zea mays*). *Chemosphere*, 94, 85-90.

Krippner, J., Brunn, H., Falk, S., Georgii, S., Schubert, S., & Stahl, T. (2014). Effects of chain length and pH on the uptake and distribution of perfluoroalkyl substances in maize (*Zea mays*). *Chemosphere*, 94, 85-90. doi:10.1016/j.chemosphere.2013.09.018

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, 3646-53.

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(14), 3646-3653. doi:10.1021/acs.jafc.5b00012

Kudo, N., 2015. Metabolism and Pharmacokinetics, in: DeWitt, J.C. (Ed.), *Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances*, Molecular and Integrative Toxicology.

Springer International Publishing, Cham, pp. 151–175. https://doi.org/10.1007/978-3-319-15518-0_6

Kudo, N., 2015. Metabolism and Pharmacokinetics, in: DeWitt, J.C. (Ed.), Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances, Molecular and Integrative Toxicology. Springer International Publishing, Cham, pp. 151–175. https://doi.org/10.1007/978-3-319-15518-0_6

Kudo, N., Kawashima, Y., 2003. Toxicity and Toxicokinetics of Perfluorooctanoic Acid in Humans and Animals. The Journal of Toxicological Sciences 28, 49–57. <https://doi.org/10.2131/jts.28.49>

Kudo, N., Kawashima, Y., 2003. Toxicity and Toxicokinetics of Perfluorooctanoic Acid in Humans and Animals. The Journal of Toxicological Sciences 28, 49–57. <https://doi.org/10.2131/jts.28.49>

Kwadijk, C.J.A.F., Korytaľür, P., Koelmans, A.A., 2010. Distribution of Perfluorinated Compounds in Aquatic Systems in The Netherlands. Environmental Science & Technology 44, 3746–3751. <https://doi.org/doi:10.1021/es100485e>

Kwadijk, C.J.A.F., Korytaľür, P., Koelmans, A.A., 2010. Distribution of Perfluorinated Compounds in Aquatic Systems in The Netherlands. Environmental Science & Technology 44, 3746–3751. <https://doi.org/doi:10.1021/es100485e>

Kwiatkowski, C. F., Andrews, D. Q., Birnbaum, L. S., Bruton, T. A., DeWitt, J. C., Knappe, D. R. U., Maffini, M. V., Miller, M. F., Pelch, K. E., Reade, A., Soehl, A., Trier, X., Venier, M., Wagner, C. C., Wang, Z. & Blum, A. (2020): Scientific Basis for Managing PFAS as a Chemical Class. Environmental Science & Technology Letters. 7, 532-543.

Kwiatkowski, C. F., Andrews, D. Q., Birnbaum, L. S., Bruton, T. A., DeWitt, J. C., Knappe, D. R. U., Maffini, M. V., Miller, M. F., Pelch, K. E., Reade, A., Soehl, A., Trier, X., Venier, M., Wagner, C. C., Wang, Z. & Blum, A. (2021): Response to "Comment on Scientific Basis for Managing PFAS as a Chemical Class". Environmental Science & Technology Letters, 8, 195-197.

Kwiatkowski, C. F., Andrews, D. Q., Birnbaum, L. S., Bruton, T. A., DeWitt, J. C., Knappe, D. R. U., Maffini, M. V., Miller, M. F., Pelch, K. E., Reade, A., Soehl, A., Trier, X., Venier, M., Wagner, C. C., Wang, Z. & Blum, A. (2020): Scientific Basis for Managing PFAS as a Chemical Class. Environmental Science & Technology Letters. 7, 532-543.

Kwiatkowski, C. F., Andrews, D. Q., Birnbaum, L. S., Bruton, T. A., DeWitt, J. C., Knappe, D. R. U., Maffini, M. V., Miller, M. F., Pelch, K. E., Reade, A., Soehl, A., Trier, X., Venier, M., Wagner, C. C., Wang, Z. & Blum, A. (2021): Response to "Comment on Scientific Basis for Managing PFAS as a Chemical Class". Environmental Science & Technology Letters, 8, 195-197.

Kwok, K.Y., Yamazaki, E., Yamashita, N., Taniyasu, S., Murphy, M.B., Horii, Y., Petrick, G., Kallerborn, R., Kannan, K., Murano, K., Lam, P.K.S., 2013. Transport of Perfluoroalkyl substances (PFAS) from an arctic glacier to downstream locations: Implications for sources. Sci. Total Environ. 447, 46-55.

Labadie, P., Chevreuil, M., 2011. Partitioning behaviour of perfluorinated alkyl contaminants between water, sediment and fish in the Orge River (nearby Paris, France). Environ Pollut 159, 391–7. <https://doi.org/10.1016/j.envpol.2010.10.039>

Labadie, P., Chevreuil, M., 2011. Partitioning behaviour of perfluorinated alkyl contaminants between water, sediment and fish in the Orge River (nearby Paris, France). Environ Pollut 159, 391–7. <https://doi.org/10.1016/j.envpol.2010.10.039>

Lam J., Koustas E., Sutton P., Johnson P.I., Atchley D.S., Sen S., Robinson K.A., Axelrad D.A., and Woodruff T.J. (2014): The Navigation Guide - evidence-based medicine meets environmental health: integration of animal and human evidence for PFOA effects on fetal growth. *Environ Health Perspect* 122 (10), 1040-1051. DOI: 10.1289/ehp.1307923

LAM, J., KOUSTAS, E., SUTTON, P., JOHNSON, P. I., ATCHLEY, D. S., SEN, S., ROBINSON, K. A., AXELRAD, D. A. & WOODRUFF, T. J. 2014. The Navigation Guide - evidence-based medicine meets environmental health: integration of animal and human evidence for PFOA effects on fetal growth. *Environ Health Perspect*, 122, 1040-51.

LAN, Z., ZHOU, M., YAO, Y. & SUN, H. 2018. Plant uptake and translocation of perfluoroalkyl acids in a wheat-soil system. *Environmental Science and Pollution Research*, 25, 30907-30916.

Lan, Z., Zhou, M., Yao, Y., & Sun, H. (2018). Plant uptake and translocation of perfluoroalkyl acids in a wheat-soil system. *Environmental Science and Pollution Research*, 25(31), 30907-30916. doi:10.1007/s11356-018-3070-3

Land M, de Wit CA, Bignert A, Cousins IT, Herzke D, Johansson JH, et al. What is the effect of phasing out long-chain per- and polyfluoroalkyl substances on the concentrations of perfluoroalkyl acids and their precursors in the environment? A systematic review. *Environmental Evidence* 2018; 7: 4: DOI: 10.1186/s13750-017-0114-y.

Langberg HA, Arp HPH, Breedveld GD, Slinde GA, Høiseter Å, Grønning HM, et al. Paper product production identified as the main source of per- and polyfluoroalkyl substances (PFAS) in a Norwegian lake: Source and historic emission tracking. *Environmental Pollution* 2021; 273: 116259: <https://doi.org/10.1016/j.envpol.2020.116259>.

Lanza, H.A., Cochran, R.S., Mudge, J.F., Olson, A.D., Blackwell, B.R., Maul, J.D., Salice, C.J., Anderson, T.A., 2017. Temporal monitoring of perfluorooctane sulfonate accumulation in aquatic biota downstream of historical aqueous film forming foam use areas. *Environmental Toxicology and Chemistry* 36, 2022–2029. <https://doi.org/10.1002/etc.3726>

Lanza, H.A., Cochran, R.S., Mudge, J.F., Olson, A.D., Blackwell, B.R., Maul, J.D., Salice, C.J., Anderson, T.A., 2017. Temporal monitoring of perfluorooctane sulfonate accumulation in aquatic biota downstream of historical aqueous film forming foam use areas. *Environmental Toxicology and Chemistry* 36, 2022–2029. <https://doi.org/10.1002/etc.3726>

Larson, E.S., Conder, J.M., Arblaster, J.A., 2018. Modeling avian exposures to perfluoroalkyl substances in aquatic habitats impacted by historical aqueous film forming foam releases. *Chemosphere* 201, 335–341. <https://doi.org/10.1016/j.chemosphere.2018.03.004>

Larson, E.S., Conder, J.M., Arblaster, J.A., 2018. Modeling avian exposures to perfluoroalkyl substances in aquatic habitats impacted by historical aqueous film forming foam releases. *Chemosphere* 201, 335–341. <https://doi.org/10.1016/j.chemosphere.2018.03.004>

Lau C., Thibodeaux J.R., Hanson R.G., Narotsky M.G., Rogers J.M., Lindstrom A.B., and Strynar M.J. (2006): Effects of perfluorooctanoic acid exposure during pregnancy in the mouse. *Toxicol Sci* 90 (2), 510-518. DOI: 10.1093/toxsci/kfj105

Lau C., Thibodeaux J.R., Hanson R.G., Rogers J.M., Grey B.E., Stanton M.E., Butenhoff J.L., and Stevenson L.A. (2003): Exposure to perfluorooctane sulfonate during pregnancy in rat and mouse. II: postnatal evaluation. *Toxicol Sci* 74 (2), 382-392. DOI: 10.1093/toxsci/kfg122

LAU, C., THIBODEAUX, J. R., HANSON, R. G., NAROTSKY, M. G., ROGERS, J. M., LINDSTROM, A. B. & STRYNAR, M. J. 2006. Effects of perfluorooctanoic acid exposure during pregnancy in the mouse. *Toxicol Sci*, 90, 510-8.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

LAU, C., THIBODEAUX, J. R., HANSON, R. G., ROGERS, J. M., GREY, B. E., STANTON, M. E., BUTENHOFF, J. L. & STEVENSON, L. A. 2003. Exposure to perfluorooctane sulfonate during pregnancy in rat and mouse. II: postnatal evaluation. *Toxicol Sci*, 74, 382-92.

Lee H., D'Eon J., and Mabury S.A. (2010): Biodegradation of polyfluoroalkyl phosphates as a source of perfluorinated acids to the environment. *Environ Sci Technol*, 44 (9), 3305-3310.

Lee H., Tevlin A.G., Mabury S.A., and Mabury S.A. (2014): Fate of polyfluoroalkyl phosphate diesters and their metabolites in biosolids-applied soil: biodegradation and plant uptake in greenhouse and field experiments. *Environ Sci Technol* 48 (1), 340-349. DOI: 10.1021/es403949z

Lee H., Tevlin A.G., Mabury S.A., and Mabury S.A. (2014): Fate of polyfluoroalkyl phosphate diesters and their metabolites in biosolids-applied soil: biodegradation and plant uptake in greenhouse and field experiments. *Environ Sci Technol*, 48 (1), 340-349.

Lee J.W., Lee J.-W., Shin Y.-J., Kim J.-E., Ryu T.-K., Ryu J., Lee J., Kim P., Choi K., and Park K. (2017): Multi-generational xenoestrogenic effects of Perfluoroalkyl acids (PFAAs) mixture on *Oryzias latipes* using a flow-through exposure system. *Chemosphere* 169, 212-223. DOI: <https://doi.org/10.1016/j.chemosphere.2016.11.035>

Lee Y.Y., Wong C.K., Oger C., Durand T., Galano J.M., and Lee J.C. (2015): Prenatal exposure to the contaminant perfluorooctane sulfonate elevates lipid peroxidation during mouse fetal development but not in the pregnant dam. *Free Radic Res* 49 (8), 1015-1025. DOI: 10.3109/10715762.2015.1027199

Lee, H., De Silva, A.O., Mabury, S.A., 2012. Dietary bioaccumulation of perfluorophosphonates and perfluorophosphinates in juvenile rainbow trout: evidence of metabolism of perfluorophosphinates. *Environ Sci Technol* 46, 3489-97. <https://doi.org/10.1021/es204533m>

Lee, H., Mabury, S.A., 2017. Sorption of Perfluoroalkyl Phosphonates and Perfluoroalkyl Phosphinates in Soils. *Environ Sci Technol* 51, 3197-3205.

LEE, H., TEVLIN, A. G., MABURY, S. A. & MABURY, S. A. 2014. Fate of polyfluoroalkyl phosphate diesters and their metabolites in biosolids-applied soil: biodegradation and plant uptake in greenhouse and field experiments. *Environ Sci Technol*, 48, 340-9.

Lee, H., Tevlin, A. G., Mabury, S. A., & Mabury, S. A. (2014). Fate of polyfluoroalkyl phosphate diesters and their metabolites in biosolids-applied soil: biodegradation and plant uptake in greenhouse and field experiments. *Environ Sci Technol*, 48(1), 340-349. doi:10.1021/es403949z

LEE, Y. Y., WONG, C. K., OGER, C., DURAND, T., GALANO, J. M. & LEE, J. C. 2015. Prenatal exposure to the contaminant perfluorooctane sulfonate elevates lipid peroxidation during mouse fetal development but not in the pregnant dam. *Free Radic Res*, 49, 1015-25.

Lenka SP, Kah M, Padhye LP. A review of the occurrence, transformation, and removal of poly- and perfluoroalkyl substances (PFAS) in wastewater treatment plants. *Water Research* 2021; 199: 117187: <https://doi.org/10.1016/j.watres.2021.117187>.

Leranth, C., Szigeti-Buck, K., MacLusky, N.J., Hajszan, T., 2008. Bisphenol A Prevents the Synaptogenic Response to Testosterone in the Brain of Adult Male Rats. *Endocrinology* 149, 988-994.

Leranth, C., Szigeti-Buck, K., MacLusky, N.J., Hajszan, T., 2008. Bisphenol A Prevents the Synaptogenic Response to Testosterone in the Brain of Adult Male Rats. *Endocrinology* 149, 988-994.

Lescord, G.L., Kidd, K.A., De Silva, A.O., Williamson, M., Spencer, C., Wang, X., Muir, D.C.G., 2015. Perfluorinated and Polyfluorinated Compounds in Lake Food Webs from the Canadian High Arctic. *Environmental Science & Technology* 49, 2694-2702.

LESMEISTER, L., LANGE, F. T., BREUER, J., BIEGEL-ENGLER, A., GIESE, E. & SCHEURER, M. 2021. Extending the knowledge about PFAS bioaccumulation factors for agricultural plants – A review. *Science of The Total Environment*, 766, 142640.

Lesmeister, L., Lange, F. T., Breuer, J., Biegel-Engler, A., Giese, E., & Scheurer, M. (2021). Extending the knowledge about PFAS bioaccumulation factors for agricultural plants – A review. *Science of The Total Environment*, 766, 142640. doi:10.1016/j.scitotenv.2020.142640

Letcher, R., Chu, S. & McKinney, M. (2014): Comparative hepatic in vitro depletion and metabolite formation of major perfluorooctane sulfonate precursors in arctic polar bear, beluga whale, and ringed seal. *Chemosphere*, 112, 225–231.

Letcher, R.J., Bustnes, J.O., Dietz, R., Jenssen, B.M., Jørgensen, E.H., Sonne, C., Verreault, J., Vijayan, M.M., Gabrielsen, G.W., 2010. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. *Sci. Total Environ.* 408, 2995-3043.

Letcher, R.J., Chu, S., McKinney, M.A., Tomy, G.T., Sonne, C., Dietz, R., 2014. Comparative hepatic in vitro depletion and metabolite formation of major perfluorooctane sulfonate precursors in arctic polar bear, beluga whale, and ringed seal. *Chemosphere* 112, 225-231.

Letcher, R.J., Morris, A.D., Dyck, M., Sverko, E., Reiner, E.J., Blair, D.A.D., Chu, S.G., Shen, L., 2018. Legacy and new halogenated persistent organic pollutants in polar bears from a contamination hotspot in the Arctic, Hudson Bay Canada. *Sci. Total Environ.* 610-611, 121-136.

Lewis M., Kim M.H., Liu E.J., Wang N., and Chu K.H. (2016): Biotransformation of 6:2 polyfluoroalkyl phosphates (6:2 PAPs): Effects of degradative bacteria and co-substrates. *Journal of Hazardous Materials*, 320, 479-486.

Lewis, K. A., Tzilivakis, J., Warner, D. J., & Green, A. (2016). An international database for pesticide risk assessments and management. *Human and Ecological Risk Assessment: An International Journal*, 22(4), 1050-1064. doi:10.1080/10807039.2015.1133242

Li C.-H., Ren X.-M., Ruan T., Cao L.-Y., Xin Y., Guo L.-H., and Jiang G. (2018): Chlorinated Polyfluorinated Ether Sulfonates Exhibit Higher Activity toward Peroxisome Proliferator-Activated Receptors Signaling Pathways than Perfluorooctanesulfonate. *Environmental Science & Technology* 52 (5), 3232-3239. DOI: 10.1021/acs.est.7b06327

Li F., Duan J., Tian S.T., Ji H.D., Zhu Y.M., Wei Z.S., and Zhao D.Y. (2020): Short-chain per- and polyfluoroalkyl substances in aquatic systems: Occurrence, impacts and treatment. *Chemical Engineering Journal* 380. DOI: 10.1016/j.cej.2019.122506

Li F., Su Q., Zhou Z., Liao X., Zou J., Yuan B., and Sun W. (2018): Anaerobic biodegradation of 8:2 fluorotelomer alcohol in anaerobic activated sludge: Metabolic products and pathways. *Chemosphere*, 200, 124-132.

Li K., Gao P., Xiang P., Zhang X., Cui X., and Ma L.Q. (2017): Molecular mechanisms of PFOA-induced toxicity in animals and humans: Implications for health risks. *Environment International* 99, 43-54. DOI: 10.1016/j.envint.2016.11.014

Li Y., Li J., Zhang L., Huang Z., Liu Y., Wu N., He J., Zhang Z., Zhang Y., and Niu Z. (2019): Perfluoroalkyl acids in drinking water of China in 2017: Distribution characteristics, influencing

factors and potential risks. *Environment International* 123, 87-95. DOI: <https://doi.org/10.1016/j.envint.2018.11.036>

Li, B. B., Hu, L. X., Yang, Y. Y., Wang, T. T., Liu, C., & Ying, G. G. (2020). Contamination profiles and health risks of PFASs in groundwater of the Maozhou River basin. *Environmental Pollution*, 260. doi:10.1016/j.envpol.2020.113996

LI, F., DUAN, J., TIAN, S., JI, H., ZHU, Y., WEI, Z. & ZHAO, D. 2020. Short-chain per- and polyfluoroalkyl substances in aquatic systems: Occurrence, impacts and treatment. *Chemical Engineering Journal*, 380.

LI, F., SUN, H., HAO, Z., HE, N., ZHAO, L., ZHANG, T. & SUN, T. 2011. Perfluorinated compounds in Haihe River and Dagou Drainage Canal in Tianjin, China. *Chemosphere*, 84, 265-71.

Li, J., J. Sun, und P. Li. „Exposure Routes, Bioaccumulation and Toxic Effects of per- and Polyfluoroalkyl Substances (PFASs) on Plants: A Critical Review“. *Environment International* 158 (2022). <https://doi.org/10.1016/j.envint.2021.106891>

Li, J., Sun, J., & Li, P. (2022). Exposure routes, bioaccumulation and toxic effects of per- and polyfluoroalkyl substances (PFASs) on plants: A critical review. *Environment International*, 158, 106891. doi:10.1016/j.envint.2021.106891

Li, J., Sun, J., & Li, P. (2022). Exposure routes, bioaccumulation and toxic effects of per- and polyfluoroalkyl substances (PFASs) on plants: A critical review. *Environment International*, 158, 106891. doi:<https://doi.org/10.1016/j.envint.2021.106891>

Li, J., Sun, J., Li, P., 2022. Exposure routes, bioaccumulation and toxic effects of per- and polyfluoroalkyl substances (PFASs) on plants: A critical review. *Environment International* 158, 106891.

LI, K., GAO, P., XIANG, P., ZHANG, X., CUI, X. & MA, L. Q. 2017. Molecular mechanisms of PFOA-induced toxicity in animals and humans: Implications for health risks. *Environment International*, 99, 43-54.

Li, P., Oyang, X., Zhao, Y., Tu, T., Tian, X., Li, L., Zhao, Y., Li, J., Xiao, Z., 2019. Occurrence of perfluorinated compounds in agricultural environment, vegetables, and fruits in regions influenced by a fluorine-chemical industrial park in China. *Chemosphere* 225, 659-667.

Li, P., Xiao, Z., Xie, X., Li, Z., Yang, H., Ma, X., Sun, J., Li, J., 2021. Perfluorooctanoic acid (PFOA) changes nutritional compositions in lettuce (*Lactuca sativa*) leaves by activating oxidative stress. *Environmental Pollution* 285.

Li, Y., Yao, J., Zhang, J., Pan, Y., Dai, J., Ji, C., Tang, J., 2021. First Report on the Bioaccumulation and Trophic Transfer of Perfluoroalkyl Ether Carboxylic Acids in Estuarine Food Web. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.1c00965>

Li, Y., Yao, J., Zhang, J., Pan, Y., Dai, J., Ji, C., Tang, J., 2021. First Report on the Bioaccumulation and Trophic Transfer of Perfluoroalkyl Ether Carboxylic Acids in Estuarine Food Web. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.1c00965>

Lieder P.H., Chang S.C., York R.G., and Butenhoff J.L. (2009): Toxicological evaluation of potassium perfluorobutanesulfonate in a 90-day oral gavage study with Sprague-Dawley rats. *Toxicology* 255 (1-2), 45-52. DOI: 10.1016/j.tox.2008.10.002

LIEDER, P. H., CHANG, S. C., YORK, R. G. & BUTENHOFF, J. L. 2009. Toxicological evaluation of potassium perfluorobutanesulfonate in a 90-day oral gavage study with Sprague-Dawley rats. *Toxicology*, 255, 45-52.

Lin Y, Ruan T, Jiang G. 2017. Progress on analytical methods and environmental behavior of emerging per- and polyfluoroalkyl substances. *Kexue Tongbao/Chinese Science Bulletin* 62:2724-2733.

Lin, Q., Zhou, C., Chen, L., Li, Y., Huang, X., Wang, S., . . . Tang, C. (2020). Accumulation and associated phytotoxicity of novel chlorinated polyfluorinated ether sulfonate in wheat seedlings. *Chemosphere*, 249, 126447. doi:10.1016/j.chemosphere.2020.126447

LIN, Q., ZHOU, C., CHEN, L., LI, Y., HUANG, X., WANG, S., QIU, R. & TANG, C. 2020. Accumulation and associated phytotoxicity of novel chlorinated polyfluorinated ether sulfonate in wheat seedlings. *Chemosphere*, 249, 126447.

Lindstrom, A. B., Strynar, M. J., Delinsky, A. D., Nakayama, S. F., McMillan, L., Libelo, E. L., . . . Thomas, L. (2011). Application of WWTP biosolids and resulting perfluorinated compound contamination of surface and well water in Decatur, Alabama, USA. *Environmental Science and Technology*, 45(19), 8015-8021. doi:10.1021/es1039425

Liou, J. S. C., Szostek, B., DeRito, C. M., & Madsen, E. L. (2010). Investigating the biodegradability of perfluorooctanoic acid. *Chemosphere*, 80(2), 176–183.

Liou, J. S. C., Szostek, B., DeRito, C. M., & Madsen, E. L. (2010). Investigating the biodegradability of perfluorooctanoic acid. *Chemosphere*, 80(2), 176–183.

Liu C. and Liu J. (2016): Aerobic biotransformation of polyfluoroalkyl phosphate esters (PAPs) in soil. *Environ Pollut*, 212, 230-237.

Liu C., Deng J., Yu L., Ramesh M., and Zhou B. (2010): Endocrine disruption and reproductive impairment in zebrafish by exposure to 8:2 fluorotelomer alcohol. *Aquat Toxicol* 96 (1), 70-76. DOI: 10.1016/j.aquatox.2009.09.012

Liu C., Du Y., and Zhou B. (2007): Evaluation of estrogenic activities and mechanism of action of perfluorinated chemicals determined by vitellogenin induction in primary cultured tilapia hepatocytes. *Aquat.Toxicol.* 85 (4), 267-277. DOI: 10.1016/j.aquatox.2007.09.009

Liu C., Yu L., Deng J., Lam P.K., Wu R.S., and Zhou B. (2009a): Waterborne exposure to fluorotelomer alcohol 6:2 FTOH alters plasma sex hormone and gene transcription in the hypothalamic-pituitary-gonadal (HPG) axis of zebrafish. *Aquat Toxicol* 93 (2-3), 131-137. DOI: 10.1016/j.aquatox.2009.04.005

Liu C., Yu L., Deng J., Lam P.K.S., Wu R.S.S., and Zhou B. (2009b): Waterborne exposure to fluorotelomer alcohol 6:2 FTOH alters plasma sex hormone and gene transcription in the hypothalamic-pituitary-gonadal (HPG) axis of zebrafish. *Aquatic Toxicology* 93 (2), 131-137. DOI: https://doi.org/10.1016/j.aquatox.2009.04.005

Liu J. and Mejia Avendano S. (2013): Microbial degradation of polyfluoroalkyl chemicals in the environment: A review. *Environ Int*, 61, 98-114.

Liu J., Wang N., Buck R.C., Wolstenholme B.W., Folsom P.W., Sulecki L.M., and Bellin C.A. (2010a): Aerobic biodegradation of [14C] 6:2 fluorotelomer alcohol in a flow-through soil incubation system. *Chemosphere*, 80 (7), 716-723.

Liu J., Wang N., Szostek B., Buck R.C., Panciroli P.K., Folsom P.W., Sulecki L.M., and Bellin C.A. (2010b): 6-2 Fluorotelomer alcohol aerobic biodegradation in soil and mixed bacterial culture. *Chemosphere*, 78 (4), 437-444.

Liu M., Yi S., Chen P., Chen M., Zhong W., Yang J., Sun B., and Zhu L. (2019): Thyroid endocrine disruption effects of perfluoroalkyl phosphinic acids on zebrafish at early

development. *Science of the Total Environment* 676, 290-297. DOI: <https://doi.org/10.1016/j.scitotenv.2019.04.177>

Liu W, He W, Wu J, Qin N, He Q, Xu F. 2018. Residues, bioaccumulations and biomagnification of perfluoroalkyl acids (PFAAs) in aquatic animals from Lake Chaohu, China. *Environmental Pollution* 240:607-614.

Liu Y, Qian M, Ma X, Zhu L, Martin JW. Nontarget Mass Spectrometry Reveals New Perfluoroalkyl Substances in Fish from the Yangtze River and Tangxun Lake, China. *Environmental Science & Technology* 2018; 52: 5830-5840; DOI: 10.1021/acs.est.8b00779.

Liu, C., Chang, V. W., Gin, K. Y., & Nguyen, V. T. (2014). Genotoxicity of perfluorinated chemicals (PFCs) to the green mussel (*Perna viridis*). *Sci Total Environ*, 487, 117-122. doi:10.1016/j.scitotenv.2014.04.017

Liu, J., Zhong, G., Li, W. & Avendaño, S. (2019): Isomer-specific biotransformation of perfluoroalkyl sulfonamide compounds in aerobic soil. *Science of the Total Environment*, 651 (1), 766-774.

Liu, Y.e.a., 2018. Y. Liu, E.S. Richardson, A.E. Derocher, N.J. Lunn, H.-J. Lehmler, X. Li, Y. Zhang, J.Y. Cui, L. Cheng, J.W. Martin. Hundreds of unrecognized halogenated contaminants discovered in polar bear serum. *Angew. Chem. Int. Ed.*, 57 (2018), pp. 16401-16406.

Liu, Z., Lu, Y., Shi, Y., Wang, P., Jones, K., Sweetman, A.J., Johnson, A.C., Zhang, M., Zhou, Y., Lu, X., Su, C., Sarvajayakesavalu, S., Khan, K., 2017. Crop bioaccumulation and human exposure of perfluoroalkyl acids through multi-media transport from a mega fluorochemical industrial park, China. *Environment International* 106, 37-47.

Liu, Z., Lu, Y., Song, X., Jones, K., Sweetman, A. J., Johnson, A. C., . . . Su, C. (2019). Multiple crop bioaccumulation and human exposure of perfluoroalkyl substances around a mega fluorochemical industrial park, China: Implication for planting optimization and food safety. *Environment International*, 127, 671-684. doi:10.1016/j.envint.2019.04.008

Liu, Z., Lu, Y., Song, X., Jones, K., Sweetman, A.J., Johnson, A.C., Zhang, M., Lu, X., Su, C., 2019. Multiple crop bioaccumulation and human exposure of perfluoroalkyl substances around a mega fluorochemical industrial park, China: Implication for planting optimization and food safety. *Environment International* 127, 671-684.

Liu, Z., Lu, Y., Wang, P., Wang, T., Liu, S., Johnson, A. C., . . . Baninla, Y. (2017). Pollution pathways and release estimation of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in central and eastern China. *Science of The Total Environment*, 580, 1247-1256. doi:10.1016/j.scitotenv.2016.12.085

Liu, Z., Lu, Y., Wang, P., Wang, T., Liu, S., Johnson, A.C., Sweetman, A.J., Baninla, Y., 2017. Pollution pathways and release estimation of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in central and eastern China. *Science of the Total Environment* 580, 1247–1256. <https://doi.org/10.1016/j.scitotenv.2016.12.085>

Liu, Z., Lu, Y., Wang, P., Wang, T., Liu, S., Johnson, A.C., Sweetman, A.J., Baninla, Y., 2017. Pollution pathways and release estimation of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in central and eastern China. *Science of the Total Environment* 580, 1247–1256. <https://doi.org/10.1016/j.scitotenv.2016.12.085>

Liu, Z., Lu, Y., Wang, T., Wang, P., Li, Q., Johnson, A.C., Sarvajayakesavalu, S., Sweetman, A.J., 2016. Risk assessment and source identification of perfluoroalkyl acids in surface and ground water: Spatial distribution around a mega-fluorochemical industrial park, China. *Environment International* 91, 69-77.

Llorca, M., Farré, M., Tavano, M.S., Alonso, B., Koremblit, G., Barceló, D., 2012. Fate of a broad spectrum of perfluorinated compounds in soils and biota from Tierra del Fuego and Antarctica. *Environmental Pollution* 163, 158-166.

Llorca-Casamayor, M. (2012). Analysis of perfluoroalkyl substances in food and environmental matrices, University of Barcelona. PhD: 423. <https://www.tdx.cat/handle/10803/97204>

Llorca-Casamayor, M. (2012). Analysis of perfluoroalkyl substances in food and environmental matrices, University of Barcelona. PhD: 423. <https://www.tdx.cat/handle/10803/97204>

Lohmann R., Cousins I.T., DeWitt J.C., Glüge J., Goldenman G., Herzke D., Lindstrom A.B., Miller M.F., Ng C.A., Patton S., Scheringer M., Trier X., and Wang Z. (2020): Are Fluoropolymers Really of Low Concern for Human and Environmental Health and Separate from Other PFAS? *Environmental Science & Technology* 54 (20), 12820-12828. DOI: 10.1021/acs.est.0c03244

LOHMANN, R., COUSINS, I. T., DEWITT, J. C., GLÜGE, J., GOLDENMAN, G., HERZKE, D., LINDSTROM, A. B., MILLER, M. F., NG, C. A., 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? *Environmental Science & Technology*, 54, 12820-12828.

Lohmann, R., Jurado, E., Dijkstra, H.A., Dachs, J., 2013. Vertical eddy diffusion as a key mechanism for removing perfluorooctanoic acid (PFOA) from the global surface oceans. *Environ. Pollut.* 179, 88.

Loi, E.I.H., Yeung, L.W.Y., Taniyasu, S., Lam, P.K.S., Kannan, K., Yamashita, N., 2011. Trophic magnification of poly- and perfluorinated compounds in a subtropical food web. *Environmental Science and Technology* 45, 5506–5513. <https://doi.org/10.1021/es200432n>

Loi, E.I.H., Yeung, L.W.Y., Taniyasu, S., Lam, P.K.S., Kannan, K., Yamashita, N., 2011. Trophic magnification of poly- and perfluorinated compounds in a subtropical food web. *Environmental Science and Technology* 45, 5506–5513. <https://doi.org/10.1021/es200432n>

Lopez-Antia, A., Kavelaars, M.M., Müller, W., Bervoets, L., Eens, M., 2021. Understanding PFAAs exposure in a generalist seabird species breeding in the vicinity of a fluorochemical plant: Influence of maternal transfer and diet. *Environ Pollut* 271, 116355. <https://doi.org/10.1016/j.envpol.2020.116355>

Lopez-Antia, A., Kavelaars, M.M., Müller, W., Bervoets, L., Eens, M., 2021. Understanding PFAAs exposure in a generalist seabird species breeding in the vicinity of a fluorochemical plant: Influence of maternal transfer and diet. *Environ Pollut* 271, 116355. <https://doi.org/10.1016/j.envpol.2020.116355>

LÓPEZ-FONTÁN, J. L., SARMIENTO, F. & SCHULZ, P. C. 2005. The aggregation of sodium perfluorooctanoate in water. *Colloid and Polymer Science*, 283, 862-871.

Lou Q.Q., Zhang Y.F., Zhou Z., Shi Y.L., Ge Y.N., Ren D.K., Xu H.M., Zhao Y.X., Wei W.J., and Qin Z.F. (2013): Effects of perfluorooctanesulfonate and perfluorobutanesulfonate on the growth and sexual development of *Xenopus laevis*. *Ecotoxicology* 22 (7), 1133-1144. DOI: 10.1007/s10646-013-1100-y

Louis G.M., Peterson C.M., Chen Z., Hediger M.L., Croughan M.S., Sundaram R., Stanford J.B., Fujimoto V.Y., Varner M.W., Giudice L.C., Kennedy A., Sun L., Wu Q., and Kannan K. (2012): Perfluorochemicals and endometriosis: the ENDO study. *Epidemiology* 23 (6), 799-805. DOI: 10.1097/EDE.0b013e31826cc0cf

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

LOUIS, G. M., PETERSON, C. M., CHEN, Z., HEDIGER, M. L., CROUGHAN, M. S., SUNDARAM, R., STANFORD, J. B., FUJIMOTO, V. Y., VARNER, M. W., GIUDICE, L. C., KENNEDY, A., SUN, L., WU, Q. & KANNAN, K. 2012. Perfluorochemicals and endometriosis: the ENDO study. *Epidemiology*, 23, 799-805.

Loveless S.E., Finlay C., Everds N.E., Frame S.R., Gillies P.J., O'Connor J.C., Powley C.R., and Kennedy G.L. (2006): Comparative responses of rats and mice exposed to linear/branched, linear, or branched ammonium perfluorooctanoate (APFO). *Toxicology* 220 (2-3), 203-217. DOI: 10.1016/j.tox.2006.01.003

Loveless S.E., Hoban D., Sykes G., Frame S.R., and Everds N.E. (2008): Evaluation of the immune system in rats and mice administered linear ammonium perfluorooctanoate. *Toxicol Sci* 105 (1), 86-96. DOI: 10.1093/toxsci/kfn113

Loveless S.E., Slezak B., Serex T., Lewis J., Mukerji P., O'Connor J.C., Donner E.M., Frame S.R., Korzeniowski S.H., and Buck R.C. (2009): Toxicological evaluation of sodium perfluorohexanoate. *Toxicology* 264 (1-2), 32-44. DOI: 10.1016/j.tox.2009.07.011

LOVELESS, S. E., FINLAY, C., EVERDS, N. E., FRAME, S. R., GILLIES, P. J., O'CONNOR, J. C., POWLEY, C. R. & KENNEDY, G. L. 2006. Comparative responses of rats and mice exposed to linear/branched, linear, or branched ammonium perfluorooctanoate (APFO). *Toxicology*, 220, 203-17.

LOVELESS, S. E., HOBAN, D., SYKES, G., FRAME, S. R. & EVERDS, N. E. 2008. Evaluation of the immune system in rats and mice administered linear ammonium perfluorooctanoate. *Toxicol Sci*, 105, 86-96.

LOVELESS, S. E., SLEZAK, B., SEREX, T., LEWIS, J., MUKERJI, P., O'CONNOR, J. C., DONNER, E. M., FRAME, S. R., KORZENIOWSKI, S. H. & BUCK, R. C. 2009. Toxicological evaluation of sodium perfluorohexanoate. *Toxicology*, 264, 32-44.

Luebker D.J., Case M.T., York R.G., Moore J.A., Hansen K.J., and Butenhoff J.L. (2005a): Two-generation reproduction and cross-foster studies of perfluorooctanesulfonate (PFOS) in rats. *Toxicology* 215 (1-2), 126-148. DOI: 10.1016/j.tox.2005.07.018

Luebker D.J., York R.G., Hansen K.J., Moore J.A., and Butenhoff J.L. (2005b): Neonatal mortality from in utero exposure to perfluorooctanesulfonate (PFOS) in Sprague-Dawley rats: Dose-response, and biochemical and pharmacokinetic parameters. *Toxicology* 215 (1-2), 149-169. DOI: 10.1016/j.tox.2005.07.019

LUEBKER, D. J., CASE, M. T., YORK, R. G., MOORE, J. A., HANSEN, K. J. & BUTENHOFF, J. L. 2005a. Two-generation reproduction and cross-foster studies of perfluorooctanesulfonate (PFOS) in rats. *Toxicology*, 215, 126-148.

LUEBKER, D. J., YORK, R. G., HANSEN, K. J., MOORE, J. A. & BUTENHOFF, J. L. 2005b. Neonatal mortality from in utero exposure to perfluorooctanesulfonate (PFOS) in Sprague-Dawley rats: Dose-response, and biochemical and pharmacokinetic parameters. *Toxicology*, 215, 149-169.

Luebker, D.J., Hansen, K.J., Bass, N.M., Butenhoff, J.L., Seacat, A.M., 2002. Interactions of fluorochemicals with rat liver fatty acid-binding protein. *Toxicology* 176, 175-185. [https://doi.org/10.1016/S0300-483X\(02\)00081-1](https://doi.org/10.1016/S0300-483X(02)00081-1)

Luebker, D.J., Hansen, K.J., Bass, N.M., Butenhoff, J.L., Seacat, A.M., 2002. Interactions of fluorochemicals with rat liver fatty acid-binding protein. *Toxicology* 176, 175-185. [https://doi.org/10.1016/S0300-483X\(02\)00081-1](https://doi.org/10.1016/S0300-483X(02)00081-1)

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Lundin J.I., Alexander B.H., Olsen G.W., and Church T.R. (2009): Ammonium perfluorooctanoate production and occupational mortality. *Epidemiology* 20 (6), 921-928. DOI: 10.1097/EDE.0b013e3181b5f395

LUNDIN, J. I., ALEXANDER, B. H., OLSEN, G. W. & CHURCH, T. R. 2009. Ammonium perfluorooctanoate production and occupational mortality. *Epidemiology*, 20, 921-8.

MacInnis, J.J., French, K., Muir, D.C.G., Spencer, C., Criscitiello, A., De Silva, A.O., Young, C.J., 2017. Emerging investigator series: a 14-year depositional ice record of perfluoroalkyl substances in the High Arctic. *Environ. Sci.: Processes Impacts* 19, 22.

MacInnis, J.J., Lehnher, I., Muir, D.C.G., St Pierre, K.A., St Louis, V.L., Spencer, C., De Silva, A.O., 2019. Fate and transport of perfluoroalkyl substances from snowpacks into a lake in the high Arctic of Canada. *Environ. Sci. Technol.* 53, 10753.

Mackay, D., Hughes, D.M., Romano, M.L., Bonnell, M.: The role of persistence in chemical evaluations (2014) *Integrated Environmental Assessment and Management*, 10 (4), pp. 588-594. doi: 10.1002/ieam.1545

Macon M.B., Villanueva L.R., Tatum-Gibbs K., Zehr R.D., Strynar M.J., Stanko J.P., White S.S., Helfant L., and Fenton S.E. (2011): Prenatal perfluorooctanoic acid exposure in CD-1 mice: low-dose developmental effects and internal dosimetry. *Toxicol Sci* 122 (1), 134-145. DOI: 10.1093/toxsci/kfr076

MACON, M. B., VILLANUEVA, L. R., TATUM-GIBBS, K., ZEHR, R. D., STRYNAR, M. J., STANKO, J. P., WHITE, S. S., HELFANT, L. & FENTON, S. E. 2011. Prenatal perfluorooctanoic acid exposure in CD-1 mice: low-dose developmental effects and internal dosimetry. *Toxicol Sci*, 122, 134-45.

Maestri L., Negri S., Ferrari M., Ghittori S., Fabris F., Danesino P., and Imbriani M. (2006): Determination of perfluorooctanoic acid and perfluorooctanesulfonate in human tissues by liquid chromatography/single quadrupole mass spectrometry. *Rapid Commun Mass Spectrom* 20 (18), 2728-2734. DOI: 10.1002/rcm.2661

MAESTRI, L., NEGRI, S., FERRARI, M., GHITTORI, S., FABRIS, F., DANESINO, P. & IMBRIANI, M. 2006. Determination of perfluorooctanoic acid and perfluorooctanesulfonate in human tissues by liquid chromatography/single quadrupole mass spectrometry. *Rapid Commun Mass Spectrom*, 20, 2728-34.

Mahmood, T. & Shreeve, J. n. M. (1986): New perfluoroalkylphosphonic and bis(perfluoroalkyl)phosphinic acids and their precursors. *Inorganic Chemistry*, 25, 3128-3131.

Mahmood, T. & Shreeve, J. n. M. (1986): New perfluoroalkylphosphonic and bis(perfluoroalkyl)phosphinic acids and their precursors. *Inorganic Chemistry*, 25, 3128-3131.

Małoszewski, P., Zuber, A., 1982. Determining the turnover time of groundwater systems with the aid of environmental tracers. 1. Models and their applicability. *Journal of Hydrology* 57, 207-231.

Małoszewski, P., Zuber, A.: Determining the turnover time of groundwater systems with the aid of environmental tracers. 1. Models and their applicability (1982), *Journal of Hydrology*, 57 (3-4), pp. 207-231. doi: 10.1016/0022-1694(82)90147-0

Maras M., Vanparys C., Muylle F., Robbins J., Berger U., Barber J.L., Blust R., and De C.W. (2006): Estrogen-like properties of fluorotelomer alcohols as revealed by mcf-7 breast cancer cell proliferation. *Environ. Health Perspect.* 114 (1), 100-105. DOI: 10.1289/ehp.8149

Martin J.W., Ellis D.A., Mabury S.A., Hurley M.D., and Wallington T.J. (2006): Atmospheric chemistry of perfluoroalkanesulfonamides: kinetic and product studies of the OH radical and Cl atom initiated oxidation of N-ethyl perfluorobutanesulfonamide. *Environ Sci Technol*, 40 (3), 864-872.

Martin O., Scholze M., Ermler S., McPhie J., Bopp S.K., Kienzler A., Parissis N., and Kortenkamp A. (2021): Ten years of research on synergisms and antagonisms in chemical mixtures: A systematic review and quantitative reappraisal of mixture studies. *Environment International* 146, 17. DOI: 10.1016/j.envint.2020.106206

Martin, J. W., Mabury, S.A., Solomon, K.R., Muir, D.C., 2003a. Dietary accumulation of perfluorinated acids in juvenile rainbow trout (*Oncorhynchus mykiss*). *Environ.Toxicol.Chem.* 22, 189–195.

Martin, J. W., Mabury, S.A., Solomon, K.R., Muir, D.C.G., 2003b. Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (*Oncorhynchus mykiss*). *Environ Toxicol Chem* 22. <https://doi.org/10.1002/etc.5620220126>

Martin, J. W., Mabury, S.A., Solomon, K.R., Muir, D.C.G., 2003b. Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (*Oncorhynchus mykiss*). *Environ Toxicol Chem* 22. <https://doi.org/10.1002/etc.5620220126>

Martin, J.W., Ellis, D.A., Mabury, S.A., Hurley, M.D., Wallington, T.J., 2006. Atmospheric chemistry of perfluoroalkanesulfonamides: Kinetic and product studies of the OH radical and Cl atom initiated oxidation of N-ethyl perfluorobutanesulfonamide. *Environ. Sci. Technol.* 40, 864-872.

Martin, J.W., Mabury, S.A., Solomon, K.R., Muir, D.C.G., 2003. Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (*Oncorhynchus mykiss*). *Environmental Toxicology and Chemistry* 22, 196–204. <https://doi.org/10.1002/etc.5620220126>

Martin, J.W., Mabury, S.A., Solomon, K.R., Muir, D.C.G., 2003. Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (*Oncorhynchus mykiss*). *Environmental Toxicology and Chemistry* 22, 196–204. <https://doi.org/10.1002/etc.5620220126>

Martin, J.W., Whittle, D.M., Muir, D.C., Mabury, S.A., 2004. Perfluoroalkyl contaminants in a food web from Lake Ontario. *Environ.Sci Technol.* 38, 5379–5385. <https://doi.org/10.1021/es049331s>

Martin, J.W., Whittle, D.M., Muir, D.C., Mabury, S.A., 2004. Perfluoroalkyl contaminants in a food web from Lake Ontario. *Environ.Sci Technol.* 38, 5379–5385. <https://doi.org/10.1021/es049331s>

MARTIN, O., SCHOLZE, M., ERMLER, S., MCPHIE, J., BOPP, S. K., KIENZLER, A., PARISSIS, N. & KORTENKAMP, A. 2021. Ten years of research on synergisms and antagonisms in chemical mixtures: A systematic review and quantitative reappraisal of mixture studies. *Environment International*, 146, 17.

Marziali, L., Rosignoli, F., Valsecchi, S., Polesello, S., & Stefani, F. (2019). Effects of Perfluoroalkyl Substances on a Multigenerational Scale: A Case Study with *Chironomus riparius* (Diptera, Chironomidae). *Environ Toxicol Chem*, 38(5), 988-999. doi:10.1002/etc.4392

Matsubara, E., Harada, K., Inoue, K., & Koizumi, A. (2006). Effects of perfluorinated amphiphiles on backward swimming in *Paramecium caudatum*. *Biochem.Biophys.Res.Comm.*, 339(2), 554-561. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/16300727>

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

McDonough C.A., Ward C., Hu Q., Vance S., Higgins C.P., and DeWitt J.C. (2020): Immunotoxicity of an Electrochemically Fluorinated Aqueous Film-Forming Foam. *Toxicological Sciences* 178 (1), 104-114. DOI: 10.1093/toxsci/kfaa138

MCDONOUGH, A. M., BIRD, A. W., FREEMAN, L. M., LUCIANI, M. A. & TODD, A. K. 2021. Fate and budget of poly- and perfluoroalkyl substances in three common garden plants after experimental additions with contaminated river water. *Environmental Pollution*, 285, 117115.

McDonough, A. M., Bird, A. W., Freeman, L. M., Luciani, M. A., & Todd, A. K. (2021). Fate and budget of poly- and perfluoroalkyl substances in three common garden plants after experimental additions with contaminated river water. *Environmental Pollution*, 285, 117115. doi:10.1016/j.envpol.2021.117115

MCDONOUGH, C. A., WARD, C., HU, Q., VANCE, S., HIGGINS, C. P. & DEWITT, J. C. 2020. Immunotoxicity of an Electrochemically Fluorinated Aqueous Film-Forming Foam. *Toxicological Sciences*, 178, 104-114.

McGuire, K.J., McDonnell, J.J., Weiler, M., Kendall, C., McGlynn, B.L., Welker, J.M., Seibert, J.: The role of topography on catchment-scale water residence time (2005), *Water Resources Research*, 41 (5), pp. 1-14. doi: 10.1029/2004WR003657

McGuire, K.J., McDonnell, J.J., Weiler, M., Kendall, C., McGlynn, B.L., Welker, J.M., Seibert, J., 2005. The role of topography on catchment-scale water residence time. *Water Resources Research* 41, 1-14.

Mei, W., Sun, H., Song, M., Jiang, L., Li, Y., Lu, W., . . . Zhang, G. (2021). Per- and polyfluoroalkyl substances (PFASs) in the soil–plant system: Sorption, root uptake, and translocation. *Environment International*, 156, 106642. doi:10.1016/j.envint.2021.106642

MEI, W., SUN, H., SONG, M., JIANG, L., LI, Y., LU, W., YING, G.-G., LUO, C. & ZHANG, G. 2021. Per- and polyfluoroalkyl substances (PFASs) in the soil–plant system: Sorption, root uptake, and translocation. *Environment International*, 156, 106642.

Merino, N., Qu, Y., Deeb, R. A., Hawley, E. L., Hoffmann, M. R., & Mahendra, S. (2016): Degradation and Removal Methods for Perfluoroalkyl and Polyfluoroalkyl Substances in Water. *Environmental Engineering Science*, 33(9), 615–649.

Merino, N., Qu, Y., Deeb, R. A., Hawley, E. L., Hoffmann, M. R., & Mahendra, S. (2016): Degradation and Removal Methods for Perfluoroalkyl and Polyfluoroalkyl Substances in Water. *Environmental Engineering Science*, 33(9), 615–649.

Meyer J, Jaspers VLB, Eens M, de Coen W. The relationship between perfluorinated chemical levels in the feathers and livers of birds from different trophic levels. *Science of The Total Environment* 2009; 407: 5894-5900: <https://doi.org/10.1016/j.scitotenv.2009.07.032>.

Mhadhbi, L., Rial, D., Pérez, S., & Beiras, R. (2012). Ecological risk assessment of perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) in marine environment using *Isochrysis galbana*, *Paracentrotus lividus*, *Siriella armata* and *Psetta maxima*. *Journal of Environmental Monitoring*, 14(5), 1375-1382. doi:10.1039/C2EM30037K

Milinic, J., Lacorte, S., Vidal, M., Rigol, A., 2015. Sorption behaviour of perfluoroalkyl substances in soils. *Science of the Total Environment* 511, 63-71.

Ministry of Health, Welfare and Sport, Bilthoven, Netherlands. DOI: 10.21945/RIVM-2018-0070

Ministry of Health, Welfare and Sport.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Mitsubishi (1996): Toxicity Study of T-6333 by Oral Administration to Rats for 28 Days. 5L590. Mitsubishi Chemical Safety Institute Ltd., Kashima Laboratory 14 Sunayama, Hasaki-machi, Kshima-fun, Ibaraki, Japan

MITSUBISHI 1996. Toxicity Study of T-6333 by Oral Administration to Rats for 28 Days. Mitsubishi Chemical Safety Institute Ltd., Kashima Laboratory 14 Sunayama, Hasaki-machi, Kshima-fun, Ibaraki, Japan.

Mokra K. (2021): Endocrine Disruptor Potential of Short- and Long-Chain Perfluoroalkyl Substances (PFASs)—A Synthesis of Current Knowledge with Proposal of Molecular Mechanism. *International Journal of Molecular Sciences* 22 (4). DOI: 10.3390/ijms22042148

Moody, C.A., Martin, J.W., Kwan, W.C., Muir, D.C., Mabury, S.A., 2002. Monitoring perfluorinated surfactants in biota and surface water samples following an accidental release of fire-fighting foam into Etobicoke Creek. *Environ.Sci Technol.* 36, 545-551.

MOROI, Y., YANO, H., SHIBATA, O. & YONEMITSU, T. 2001. Determination of acidity constants of perfluoroalkanoic acids. *Bulletin of the Chemical Society of Japan*, 74, 667-672.

Mourier B, Labadie P, Desmet M, Grosbois C, Raux J, Debret M, et al. Combined spatial and retrospective analysis of fluoroalkyl chemicals in fluvial sediments reveal changes in levels and patterns over the last 40 years. *Environmental Pollution* 2019; 253: 1117-1125: <https://doi.org/10.1016/j.envpol.2019.07.079>.

MPI Research Inc. (2013): H:28548: Combined Chronic Toxicity/Oncogenicity Study 2-Year Oral Gavage Study in Rats DuPont-18405-1238 (US) / 125-141. MPI Research, Inc., Michigan, USA

MPI RESEARCH INC. 2013. H:28548: Combined Chronic Toxicity/Oncogenicity Study 2-Year Oral Gavage Study in Rats MPI Research, Inc., Michigan, USA.

Muir D, Bossi R, Carlsson P, Evans M, De Silva A, Halsall C, et al. Levels and trends of poly- and perfluoroalkyl substances in the Arctic environment – An update. *Emerging Contaminants* 2019; 5: 240-271: <https://doi.org/10.1016/j.emcon.2019.06.002>.

Muir D, Miaz LT. Spatial and Temporal Trends of Perfluoroalkyl Substances in Global Ocean and Coastal Waters. *Environmental Science & Technology* 2021; 55: 9527-9537: DOI: 10.1021/acs.est.0c08035.

Muir, D., 2015a. Community based seawater monitoring for organic contaminants and mercury in the Canadian Arctic. Synopsis of Research Conducted under the 2014-2015, Northern Contaminants Program, Aboriginal Affairs and Northern Development Canada, Ottawa., Aboriginal Affairs and Northern Development Canada, Ottawa, ON (2015), pp. 289-296.

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>

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>

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.

Muir, D.W., X; Houde, M., 2015b. Temporal trends of persistent organic pollutants and metals in ringed seals from the Canadian Arctic. Synopsis of Research Conducted under the 2014-2015, Northern Contaminants Program, Aboriginal Affairs and Northern Development Canada, Ottawa, ON (2015), pp. 189-198.

Müller CE, De Silva AO, Small J, Williamson M, Wang X, Morris A, et al. Biomagnification of Perfluorinated Compounds in a Remote Terrestrial Food Chain: Lichen–Caribou–Wolf. *Environmental Science & Technology* 2011; 45: 8665-8673: DOI: 10.1021/es201353v.

MÜLLER, C. E., LEFEVRE, G. H., TIMOFTE, A. E., HUSSAIN, F. A., SATTELY, E. S. & LUTHY, R. G. 2016. Competing mechanisms for perfluoroalkyl acid accumulation in plants revealed using an Arabidopsis model system. *Environmental Toxicology and Chemistry*, 35, 1138-1147.

Müller, C. E., LeFevre, G. H., Timofte, A. E., Hussain, F. A., Sattely, E. S., & Luthy, R. G. (2016). Competing mechanisms for perfluoroalkyl acid accumulation in plants revealed using an Arabidopsis model system. *Environmental Toxicology and Chemistry*, 35(5), 1138-1147. doi:10.1002/etc.3251

Müller, C.E., De Silva, A.O., Small, J., Williamson, M., Wang, X., Morris, A., Katz, S., Gamberg, M., Muir, D.C.G., 2011. Biomagnification of perfluorinated compounds in a remote terrestrial food chain: Lichen-Caribou-Wolf. *Environ. Sci. Technol.* 45, 8665-8673.

Müller, C.E., Gerecke, A.C., Bogdal, C., Wang, Z., Scheringer, M., Hungerbühler, K., 2012. Atmospheric fate of poly- and perfluorinated alkyl substances (PFASs): I. Day-night patterns of air concentrations in summer in Zurich, Switzerland. *Environmental Pollution* 169, 196-203.

Munoz G, Budzinski H, Babut M, Lobry J, Selleslagh J, Tapie N, et al. Temporal variations of perfluoroalkyl substances partitioning between surface water, suspended sediment, and biota in a macrotidal estuary. *Chemosphere* 2019; 233: 319-326: <https://doi.org/10.1016/j.chemosphere.2019.05.281>.

Munoz G, Budzinski H, Labadie P. Influence of Environmental Factors on the Fate of Legacy and Emerging Per- and Polyfluoroalkyl Substances along the Salinity/Turbidity Gradient of a Macrotidal Estuary. *Environmental Science & Technology* 2017; 51: 12347-12357: DOI: 10.1021/acs.est.7b03626.

Munoz, G., Budzinski, H., Babut, M., Drouineau, H., Lauzent, M., Menach, K.L., Lobry, J., Selleslagh, J., Simonnet-Laprade, C., Labadie, P., 2017. Evidence for the Trophic Transfer of Perfluoroalkylated Substances in a Temperate Macrotidal Estuary. *Environmental Science and Technology* 51, 8450–8459. <https://doi.org/10.1021/acs.est.7b02399>

Munoz, G., Budzinski, H., Babut, M., Drouineau, H., Lauzent, M., Menach, K.L., Lobry, J., Selleslagh, J., Simonnet-Laprade, C., Labadie, P., 2017. Evidence for the Trophic Transfer of Perfluoroalkylated Substances in a Temperate Macrotidal Estuary. *Environmental Science and Technology* 51, 8450–8459. <https://doi.org/10.1021/acs.est.7b02399>

Myers A.L. and Mabury S.A. (2010): Fate of fluorotelomer acids in a soil-water microcosm. *Environ Toxicol Chem*, 29 (8), 1689-1695.

Navarro I., de la Torre A., Sanz P., Pro J., Carbonell G., and de los Ángeles Martínez M. (2016): Bioaccumulation of emerging organic compounds (perfluoroalkyl substances and halogenated flame retardants) by earthworm in biosolid amended soils. *Environmental Research* 149, 32-39 norman database (2021): <https://www.norman-network.com/nds/>

NAVARRO, I., DE LA TORRE, A., SANZ, P., PORCEL, M. A., PRO, J., CARBONELL, G. & MARTINEZ, M. L. 2017. Uptake of perfluoroalkyl substances and halogenated flame retardants by crop plants grown in biosolids-amended soils. *Environ Res*, 152, 199-206.

Navarro, I., de la Torre, A., Sanz, P., Porcel, M. A., Pro, J., Carbonell, G., & Martinez, M. L. (2017). Uptake of perfluoroalkyl substances and halogenated flame retardants by crop plants grown in biosolids-amended soils. *Environ Res*, 152, 199-206. doi:10.1016/j.envres.2016.10.018

Neumann M, Schliebner (2017): Protecting the sources of our drinking water from mobile chemicals—a revised proposal for implementing criteria and an assessment procedure to identify Persistent, Mobile and Toxic (PMT) and very Persistent, very Mobile (vPvM) substances registered under REACH. German Environmental Agency, Dessau-Rosslau, Germany. ISSN: 2363-8273. 20 pages
https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/171027_u ba_pos_pmt_substances_engl_2aufl_bf.pdf

Newsted J.L., Beach S.A., Gallagher S.P., and Giesy J.P. (2008): Acute and chronic effects of perfluorobutane sulfonate (PFBS) on the mallard and northern bobwhite quail. *Arch Environ Contam Toxicol* 54 (3), 535-545. DOI: 10.1007/s00244-007-9039-8

Newton S, McMahan R, Stoeckel JA, Chislock M, Lindstrom A, Strynar M. 2017. Novel Polyfluorinated Compounds Identified Using High Resolution Mass Spectrometry Downstream of Manufacturing Facilities near Decatur, Alabama. *Environ Sci Technol*.

NG, C. A. & HUNGERBÜHLER, K. 2014. Bioaccumulation of perfluorinated alkyl acids: observations and models. *Environmental Science and Technology*, 48, 4637-48.

Ng, C.A., Hungerbühler, K., 2013. Bioconcentration of perfluorinated alkyl acids: how important is specific binding? *Environmental Science and Technology* 47, 7214-23. <https://doi.org/10.1021/es400981a>

Ng, C.A., Hungerbühler, K., 2014. Bioaccumulation of perfluorinated alkyl acids: observations and models. *Environ. Sci. Technol.* 48, 4637.

Ng, C.A., Hungerbühler, K., 2014a. Bioaccumulation of perfluorinated alkyl acids: Observations and models. *Environmental Science and Technology* 48, 4637-4648. <https://doi.org/10.1021/es404008g>

Ng, C.A., Hungerbühler, K., 2014a. Bioaccumulation of perfluorinated alkyl acids: Observations and models. *Environmental Science and Technology* 48, 4637-4648. <https://doi.org/10.1021/es404008g>

Ng, C.A., Hungerbühler, K., 2014b. Bioaccumulation of perfluorinated alkyl acids: Observations and models. *Environmental Science and Technology* 48, 4637-4648. <https://doi.org/10.1021/es404008g>

Ng, C.A., Hungerbühler, K., 2015. Exploring the Use of Molecular Docking to Identify Bioaccumulative Perfluorinated Alkyl Acids (PFAAs). *Environ Sci Technol* 49, 12306-14. <https://doi.org/10.1021/acs.est.5b03000>

Ng, C.A., Hungerbühler, K., 2015. Exploring the Use of Molecular Docking to Identify Bioaccumulative Perfluorinated Alkyl Acids (PFAAs). *Environ Sci Technol* 49, 12306-14. <https://doi.org/10.1021/acs.est.5b03000>

Nguyen, H.T., Kaserzon, S.L., Thai, P.K., Vijayasarathy, S., Bräunig, J., Crosbie, N.D., Bignert, A., Mueller, J.F., 2019. Temporal trends of per- and polyfluoroalkyl substances (PFAS) in the influent of two of the largest wastewater treatment plants in Australia. *Emerging Contaminants* 5, 211-218.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Nielsen C.J. (2014): Potential PFOA Precursors - Literature study and theoretical assessment of abiotic degradation pathways leading to PFOA. CTCC, Department of Chemistry, University of Oslo.

Nielsen, C. J. (2017): Potential PFBS and PFHxS Precursors, s.l.: Norwegian Environment Agency. M 792.

Nilsson H., Karrman A., Rotander A., van Bavel B., Lindstrom G., and Westberg H. (2013a): Biotransformation of fluorotelomer compound to perfluorocarboxylates in humans. *Environ Int* 51, 8-12. DOI: 10.1016/j.envint.2012.09.001

Nilsson H., Karrman A., Rotander A., van Bavel B., Lindstrom G., and Westberg H. (2013b): Professional ski waxers' exposure to PFAS and aerosol concentrations in gas phase and different particle size fractions. *Environmental Science-Processes & Impacts* 15 (4), 814-822. DOI: 10.1039/c3em30739e

Nilsson, E. J. K., Nielsen, O. J., Johnson, M. S., Hurley, M. D. & Wallington, T. J. (2009): Atmospheric chemistry of cis-CF₃CH=CHF: Kinetics of reactions with OH radicals and O₃ and products of OH radical initiated oxidation. *Chemical Physics Letters*, 473, 233-237.

NILSSON, H., KARRMAN, A., ROTANDER, A., VAN BAVEL, B., LINDSTROM, G. & WESTBERG, H. 2013a. Biotransformation of fluorotelomer compound to perfluorocarboxylates in humans. *Environ Int*, 51, 8-12.

NILSSON, H., KARRMAN, A., ROTANDER, A., VAN BAVEL, B., LINDSTROM, G. & WESTBERG, H. 2013b. Professional ski waxers' exposure to PFAS and aerosol concentrations in gas phase and different particle size fractions. *Environmental Science-Processes & Impacts*, 15, 814-822.

Nilu, 2015. Monitoring of environmental contaminants in air and precipitation, annual report 2014. M-368. NILU, 90.

NILU. F-gases in the remote region of Svalbard for the time period 2001-2020. Norwegian Institute for Air Research 2021.

Nohara, K., Toma, M., Kutsuna, S., Takeuchi, K. & Ibusuki, T. (2001): Cl Atom-Initiated Oxidation of Three Homologous Methyl Perfluoroalkyl Ethers. *Environmental Science & Technology*, 35, 114-120.

Non-Clinical Saftey (2017): 4 week oral toxicity study in rats plus a 2 week treatment-free recovery period. 15-DA128-N0 / 15-DA128-N0. Non-Clinical Saftey, Merck KGaA, Darmstadt, Germany

NON-CLINICAL SAFTEY 2017. 4 week oral toxicity study in rats plus a 2 week treatment-free recovery period. Non-Clinical Saftey, Merck KGaA, Darmstadt, Germany.

Norwegian Institute for Air Research, NILU (2009). Emissions from incineration of fluoropolymer materials. <https://nilu.brage.unit.no/nilu-xmlui/bitstream/handle/11250/2561710/NILU%20BOR%20B12-2009.pdf?sequence=1&isAllowed=y>

Norwegian Institute for Water Research (NIVA) (2017): Environmental Contaminants in an Urban Fjord - 2016,. NIVA Report no. 7199-2017, date: 2017. The Norwegian Environment Agency. <http://www.miljodirektoratet.no/Documents/publikasjoner/M812/M812.pdf>

Nøst T.H., Helgason L.B., Harju M., Heimstad E.S., Gabrielsen G.W., and Jenssen B.M. (2012): Halogenated organic contaminants and their correlations with circulating thyroid hormones in

developing Arctic seabirds. *Science of the Total Environment* 414, 248-256. DOI: <https://doi.org/10.1016/j.scitotenv.2011.11.051>

NTP (2016): CASRN Index in MS Excel. Report on carcinogens, Fourteenth Edition. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program. <https://ntp.niehs.nih.gov/whatwestudy/assessments/cancer/roc/index.html#P>

NTP (2019a): NTP Technical Report on the Toxicity Studies of Perfluoroalkyl Carboxylates (Perfluorohexanoic Acid, Perfluorooctanoic Acid, Perfluorononanoic Acid, and Perfluorodecanoic Acid) Administered by Gavage to Sprague Dawley (Hsd:Sprague Dawley SD) Rats. NTP TOX 97, date: August 2019. National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services. Services U.S.D.o.H.a.H., Research Triangle Park, North Carolina, USA, Toxicity Report. https://ntp.niehs.nih.gov/ntp/htdocs/st_rpts/tox097_508.pdf?utm_source=direct&utm_medium=prod&utm_campaign=ntpgolinks&utm_term=tox097

NTP (2019b): NTP Technical Report on the Toxicity Studies of Perfluoroalkyl Sulfonates (Perfluorobutane Sulfonic Acid, Perfluorohexane Sulfonate Potassium Salt, and Perfluorooctane Sulfonic Acid) Administered by Gavage to Sprague Dawley (Hsd:Sprague Dawley SD) Rats. Toxicity Report 96. National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services, Research Triangle Park, North Carolina, USA

NTP (2019c): NTP Technical Report on the Toxicology and Carcinogenesis Studies of Perfluorooctanoic Acid (CAS No. 335-67-1) Administered in Feed to Sprague Dawley (Hsd:Sprague Dawley® SD®) Rats. National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services, ISSN: 2473-4756 Technical Report 598

NTP 2016. CASRN Index in MS Excel. Report on carcinogens, Fourteenth Edition. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.

NTP 2019a. NTP Technical Report on the Toxicity Studies of Perfluoroalkyl Carboxylates (Perfluorohexanoic Acid, Perfluorooctanoic Acid, Perfluorononanoic Acid, and Perfluorodecanoic Acid) Administered by Gavage to Sprague Dawley (Hsd:Sprague Dawley SD) Rats. Toxicity Report 97. Research Triangle Park, North Carolina, USA: National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services.

NTP 2019b. NTP Technical Report on the Toxicity Studies of Perfluoroalkyl Sulfonates (Perfluorobutane Sulfonic Acid, Perfluorohexane Sulfonate Potassium Salt, and Perfluorooctane Sulfonic Acid) Administered by Gavage to Sprague Dawley (Hsd:Sprague Dawley SD) Rats. Research Triangle Park, North Carolina, USA: National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services.

NTP 2019c. NTP Technical Report on the Toxicology and Carcinogenesis Studies of Perfluorooctanoic Acid (CAS No. 335-67-1) Administered in Feed to Sprague Dawley (Hsd:Sprague Dawley® SD®) Rats. National Toxicology Program, Public Health Service, U.S. Department of Health and Human Services, ISSN: 2473-4756, Technical Report 598.

Numata, J., Kowalczyk, J., Adolphs, J., Ehlers, S., Schafft, H., Fuerst, P., Müller-Graf, C., Lahrssen-Wiederholt, M., Greiner, M., 2014. Toxicokinetics of Seven Perfluoroalkyl Sulfonic and Carboxylic Acids in Pigs Fed a Contaminated Diet. *Journal of Agricultural and Food Chemistry* 62, 6861–6870. <https://doi.org/10.1021/jf405827u>

Numata, J., Kowalczyk, J., Adolphs, J., Ehlers, S., Schafft, H., Fuerst, P., Müller-Graf, C., Lahrssen-Wiederholt, M., Greiner, M., 2014. Toxicokinetics of Seven Perfluoroalkyl Sulfonic and Carboxylic Acids in Pigs Fed a Contaminated Diet. *Journal of Agricultural and Food Chemistry* 62, 6861–6870. <https://doi.org/10.1021/jf405827u>

O'Hagan, David. „Understanding organofluorine chemistry. An introduction to the C–F bond“. Chemical Society Reviews 37, Nr. 2 (2008): 308–19. <https://doi.org/10.1039/B711844A>

OECD (2021). Series on Risk Management No. 61, 2021. [https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO\(2021\)25&docLanguage=En](https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO(2021)25&docLanguage=En)

OECD (2021). Series on Risk Management No. 61, 2021. [https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO\(2021\)25&docLanguage=En](https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO(2021)25&docLanguage=En)

OECD (2021). Series on Risk Management No. 61, 2021. [https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO\(2021\)25&docLanguage=En](https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/CBC/MONO(2021)25&docLanguage=En)

OECD/UNEP Global PFC Group (2013). Synthesis paper on per- and polyfluorinated chemicals (PFCs). <http://www.oecd.org/chemicalsafety/risk-management/synthesis-paper-on-per-and-polyfluorinated-chemicals.htm>

OECD/UNEP Global PFC Group (2013). Synthesis paper on per- and polyfluorinated chemicals (PFCs). <http://www.oecd.org/chemicalsafety/risk-management/synthesis-paper-on-per-and-polyfluorinated-chemicals.htm>

OECD/UNEP Global PFC Group (2018), Comprehensive Global Database of PFAS, <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/>

O'Hagan, D. & Harper, D. B. (1999): Fluorine-containing natural products. Journal of Fluorine Chemistry, 100, 127-133.

O'Hagan, D. (2008). Understanding organofluorine chemistry. An introduction to the C–F bond, Chemical Society Review, 37, 308–319

O'Hagan, D. (2008). Understanding organofluorine chemistry. An introduction to the C–F bond, Chemical Society Review, 37, 308–319

Ojo A.F., Peng C., and Ng J.C. (2021): Assessing the human health risks of per- and polyfluoroalkyl substances: A need for greater focus on their interactions as mixtures. Journal of Hazardous Materials 407, 14. DOI: 10.1016/j.jhazmat.2020.124863

OJO, A. F., PENG, C. & NG, J. C. 2021. Assessing the human health risks of per- and polyfluoroalkyl substances: A need for greater focus on their interactions as mixtures. Journal of Hazardous Materials, 407, 14.

Olsen G.W. (2015): PFAS Biomonitoring in Higher Exposed Populations. Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances, 77-125. DOI: 10.1007/978-3-319-15518-0_4

OLSEN, G. W. 2015. PFAS Biomonitoring in Higher Exposed Populations. Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances, 77-125.

Orsi, A.H., Whitworth Iii, T., Nowlin Jr, W.D., 1995. On the meridional extent and fronts of the Antarctic Circumpolar Current. Deep-Sea Research Part I 42, 641-673.

Pan, Y., Zhang, H., Cui, Q., Sheng, N., Yeung, L. W. Y., Sun, Y., Guo, Y. & Dai, J. (2018): Worldwide Distribution of Novel Perfluoroether Carboxylic and Sulfonic Acids in Surface Water. Environmental Science & Technology, 52, 7621–7629.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Pan, Y., Zhang, H., Cui, Q., Sheng, N., Yeung, L. W. Y., Sun, Y., Guo, Y. & Dai, J. (2018): Worldwide Distribution of Novel Perfluoroether Carboxylic and Sulfonic Acids in Surface Water. *Environmental Science & Technology*, 52, 7621–7629.

Parsons J.R., Saez M., Dolfig J., and de Voogt P. (2008): Biodegradation of perfluorinated compounds. *Rev Environ Contam Toxicol* 196, 53-71. DOI: 10.1007/978-0-387-78444-1_2

Parsons J.R., Saez M., Dolfig J., and de Voogt P. (2008): Biodegradation of perfluorinated compounds. *Rev Environ Contam Toxicol* 196, 53-71. DOI: 10.1007/978-0-387-78444-1_2

Paterson, S., Mackay, D., McFarlane, C., 1994. A Model of Organic Chemical Uptake by Plants from Soil and the Atmosphere. *Environmental Science & Technology* 28, 2259-2266.

Paul, A.G., Jones, K.C., Sweetman, A.J., 2009. A first global production, emission, and environmental inventory for perfluorooctane sulfonate. *Environ. Sci. Technol.* 43, 386-392.

Pelch, K. E., Reade, A., Wolffe, T. A. M., & Kwiatkowski, C. F. (2019). PFAS health effects database: Protocol for a systematic evidence map. *Environment International*, 130, 104851. doi:<https://doi.org/10.1016/j.envint.2019.05.045>

Penland, T.N., Cope, W.G., Kwak, T.J., Strynar, M.J., Grieshaber, C.A., Heise, R.J., Sessions, F.W., 2020. Trophodynamics of Per-and Polyfluoroalkyl Substances in the Food Web of a Large Atlantic Slope River. *Environmental Science and Technology* 54, 6800–6811. <https://doi.org/10.1021/acs.est.9b05007>

Penland, T.N., Cope, W.G., Kwak, T.J., Strynar, M.J., Grieshaber, C.A., Heise, R.J., Sessions, F.W., 2020. Trophodynamics of Per-and Polyfluoroalkyl Substances in the Food Web of a Large Atlantic Slope River. *Environmental Science and Technology* 54, 6800–6811. <https://doi.org/10.1021/acs.est.9b05007>

Pereira MG, Lacorte S, Walker LA, Shore RF. Contrasting long term temporal trends in perfluoroalkyl substances (PFAS) in eggs of the northern gannet (*Morus bassanus*) from two UK colonies. *Science of The Total Environment* 2021; 754: 141900: <https://doi.org/10.1016/j.scitotenv.2020.141900>.

Perez F., Nadal M., Navarro-Ortega A., Fabrega F., Domingo J.L., Barcelo D., and Farre M. (2013): Accumulation of perfluoroalkyl substances in human tissues. *Environment International* 59, 354-362. DOI: 10.1016/j.envint.2013.06.004

Pérez, F., Llorca, M., Köck-Schulmeyer, M., Škrbić, B., Silva, L.F.O., da Boit Martinello, K., Al-Dhabi, N.A., Antić, I., Farré, M., Barceló, D., 2014. Assessment of perfluoroalkyl substances in food items at global scale. *Environ. Res.* 135, 181-189.

PEREZ, F., NADAL, M., NAVARRO-ORTEGA, A., FABREGA, F., DOMINGO, J. L., BARCELO, D. & FARRE, M. 2013. Accumulation of perfluoroalkyl substances in human tissues. *Environment International*, 59, 354-362.

Pérez, F., Nadal, M., Navarro-Ortega, A., Fàbrega, F., Domingo, J.L., Barceló, D., Farré, M., 2013. Accumulation of perfluoroalkyl substances in human tissues. *Environment International* 59, 354–362. <https://doi.org/10.1016/j.envint.2013.06.004>

Pérez, F., Nadal, M., Navarro-Ortega, A., Fàbrega, F., Domingo, J.L., Barceló, D., Farré, M., 2013. Accumulation of perfluoroalkyl substances in human tissues. *Environment International* 59, 354–362. <https://doi.org/10.1016/j.envint.2013.06.004>

Persson, L.M., Breitholtz, M., Cousins, I.T., De Wit, C.A., MacLeod, M., McLachlan, M.S.: Confronting unknown planetary boundary threats from chemical pollution (2013) *Environmental Science and Technology*, 47 (22), pp. 12619-12622. doi: 10.1021/es402501c

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Persson, L.M., Breitholtz, M., Cousins, I.T., de Wit, C.A., MacLeod, M. & McLachlan, M.S. 2013, 'Confronting Unknown Planetary Boundary Threats from Chemical Pollution', *Environmental science & technology*, vol. 47, no. 22, pp. 12619-12622

Peschka, M., Fichtner, N., Hierse, W., Kirsch, P., Montenegro, E., Seidel, M., Wilken, R. D., & Knepper, T.P. (2008): Synthesis and analytical follow-up of the mineralization of a new fluorosurfactant prototype, *Chemosphere*, 72, 1534–1540.

Peschka, M., Fichtner, N., Hierse, W., Kirsch, P., Montenegro, E., Seidel, M., Wilken, R. D., & Knepper, T.P. (2008): Synthesis and analytical follow-up of the mineralization of a new fluorosurfactant prototype, *Chemosphere*, 72, 1534–1540.

PFAS-TOX-DATABASE (2021): PFAS-Tox-Database. <https://pfastoxdatabase.org/> (last accessed 2021-08-12)

PFAS-TOX-DATABASE. 2021. PFAS-Tox-Database [Online]. Available: <https://pfastoxdatabase.org/> [Accessed 2021-08-12].

Pi N., Ng J.Z, Kelly B.C (2017): Uptake and elimination kinetics of perfluoroalkyl substances in submerged and free-floating aquatic macrophytes: Results of mesocosm experiments with *Echinodorus horemanii* and *Eichhornia crassipes*. *Water Research*, Volume 117, 15 June 2017, Pages 167-174.

PI, N., NG, J. Z. & KELLY, B. C. 2017. Uptake and elimination kinetics of perfluoroalkyl substances in submerged and free-floating aquatic macrophytes: Results of mesocosm experiments with *Echinodorus horemanii* and *Eichhornia crassipes*. *Water Research*, 117, 167-174.

Pi, N., Ng, J. Z., & Kelly, B. C. (2017). Uptake and elimination kinetics of perfluoroalkyl substances in submerged and free-floating aquatic macrophytes: Results of mesocosm experiments with *Echinodorus horemanii* and *Eichhornia crassipes*. *Water Res*, 117, 167-174. doi:10.1016/j.watres.2017.04.003

Pickard HM, Criscitiello AS, Spencer C, Sharp MJ, Muir DCG, De Silva AO, et al. Continuous non-marine inputs of per- and polyfluoroalkyl substances to the High Arctic: a multi-decadal temporal record. *Atmos. Chem. Phys.* 2018; 18: 5045-5058: DOI: 10.5194/acp-18-5045-2018.

Pickard, H. M., Criscitiello, A. S., Persaud, D., Spencer, C., Muir, D. C. G., Lehnher, I., et al. (2020). Ice core record of persistent short-chain fluorinated alkyl acids: Evidence of the impact from global environmental regulations. *Geophysical Research Letters*, 47, e2020GL087535. <https://doi.org/10.1029/2020GL087535>

Pickard, H.M., Criscitiello, A.S., Persaud, D., Spencer, C., Muir, D.C.G., Lehnher, I., Sharp, M.J., De Silva, A.O., Young, C.J., 2020. Ice Core Record of Persistent Short-Chain Fluorinated Alkyl Acids: Evidence of the Impact From Global Environmental Regulations. *Geophys. Res. Lett.* 47.

Piekarski D.J., Diaz K.R., and McNerney M.W. (2020): Perfluoroalkyl chemicals in neurological health and disease: Human concerns and animal models. *Neurotoxicology* 77, 155-168. DOI: 10.1016/j.neuro.2020.01.001

PIEKARSKI, D. J., DIAZ, K. R. & MCNERNEY, M. W. 2020. Perfluoroalkyl chemicals in neurological health and disease: Human concerns and animal models. *Neurotoxicology*, 77, 155-168.

Pizzurro D.M., Seeley M., Kerper L.E., and Beck B.D. (2019): Interspecies differences in perfluoroalkyl substances (PFAS) toxicokinetics and application to health-based criteria. *Regul Toxicol Pharmacol* 106, 239-250. DOI: 10.1016/j.yrtph.2019.05.008

PIZZURRO, D. M., SEELEY, M., KERPER, L. E. & BECK, B. D. 2019. Interspecies differences in perfluoroalkyl substances (PFAS) toxicokinetics and application to health-based criteria. *Regul Toxicol Pharmacol*, 106, 239-250.

Pizzurro, D.M., Seeley, M., Kerper, L.E., Beck, B.D., 2019. Interspecies differences in perfluoroalkyl substances (PFAS) toxicokinetics and application to health-based criteria. *Regul. Toxicol. Pharmacol.* 106, 239–250. <https://doi.org/10.1016/j.yrtph.2019.05.008>

Prevedouros, K., Cousins, I.T., Buck, R.C., & Korzeniowski, S.H. (2006): Sources, fate and transport of perfluorocarboxylates, *Environmental Science & Technology*, 40, 32–44

Prevedouros, K., Cousins, I.T., Buck, R.C., & Korzeniowski, S.H. (2006): Sources, fate and transport of perfluorocarboxylates, *Environmental Science & Technology*, 40, 32–44

Qing, F., Guo, Q., Chen, L., Quan, H. & Mizukado, J. (2018): Atmospheric chemistry of E-CF₃CH=CHCF₃: Reaction kinetics of OH radicals and products of OH-initiated oxidation. *Chemical Physics Letters*, 706, 93-98.

Qiu Z., Qu K., Luan F., Liu Y., Zhu Y., Yuan Y., Li H., Zhang H., Hai Y., and Zhao C. (2020): Binding specificities of estrogen receptor with perfluorinated compounds: A cross species comparison. *Environment International* 134, 105284. DOI: <https://doi.org/10.1016/j.envint.2019.105284>

Qu, R., Liu, J., Li, C., Wang, L., Wang, Z. & Wu, J. (2016): Experimental and theoretical insights into the photochemical decomposition of environmentally persistent perfluorocarboxylic acids. *Water Research*, 104, 34-43.

Qu, R., Liu, J., Li, C., Wang, L., Wang, Z. & Wu, J. (2016): Experimental and theoretical insights into the photochemical decomposition of environmentally persistent perfluorocarboxylic acids. *Water Research*, 104, 34-43.

RAC (2020): Committee for Risk Assessment (RAC) and Committee for Socio-economic Analysis (SEAC): Opinion of the Committee for Risk Assessment and Opinion of the Committee for Socio-economic Analysis on an Annex XV dossier proposing restrictions on intentionally-added microplastics. <https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366>

Ramhøj L., Hass U., Gilbert M.E., Wood C., Svingen T., Usai D., Vinggaard A.M., Mandrup K., and Axelstad M. (2020): Evaluating thyroid hormone disruption: investigations of long-term neurodevelopmental effects in rats after perinatal exposure to perfluorohexane sulfonate (PFHxS). *Scientific Reports* 10 (1), 2672. DOI: 10.1038/s41598-020-59354-z

Rankin K., Lee H., Tseng P.J., and Mabury S.A. (2014): Investigating the biodegradability of a fluorotelomer-based acrylate polymer in a soil-plant microcosm by indirect and direct analysis. *Environ Sci Technol*, 48 (21), 12783-12790.

Rankin, K., Mabury, S. A., Jenkins, T. M., & Washington, J. W. (2016). A North American and global survey of perfluoroalkyl substances in surface soils: Distribution patterns and mode of occurrence. *Chemosphere*, 161, 333-341. doi:10.1016/j.chemosphere.2016.06.109

Rappazzo K.M., Coffman E., and Hines E.P. (2017): Exposure to perfluorinated alkyl substances and health outcomes in children: A systematic review of the epidemiologic literature. *International Journal of Environmental Research and Public Health* 14 (7). DOI: ARTN 69110.3390/ijerph14070691

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

RAPPAZZO, K. M., COFFMAN, E. & HINES, E. P. 2017. Exposure to perfluorinated alkyl substances and health outcomes in children: A systematic review of the epidemiologic literature. *International Journal of Environmental Research and Public Health*, 14.

Rashid F., Ramakrishnan A., Fields C., and Irudayaraj J. (2020): Acute PFOA exposure promotes epigenomic alterations in mouse kidney tissues. *Toxicology Reports* 7, 125-132. DOI: 10.1016/j.toxrep.2019.12.010

RASHID, F., RAMAKRISHNAN, A., FIELDS, C. & IRUDAYARAJ, J. 2020. Acute PFOA exposure promotes epigenomic alterations in mouse kidney tissues. *Toxicology Reports*, 7, 125-132.

Rauert, C., Shoieb, M., Schuster, J.K., 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.

Ravishankara, A. R., Solomon, S., Turnipseed, A. A. & Warren, R. F. (1993): Atmospheric Lifetimes of Long-Lived Halogenated Species. *Science*, 259, 194-199.

Ravishankara, A. R., Solomon, S., Turnipseed, A. A. & Warren, R. F. (1993): Atmospheric Lifetimes of Long-Lived Halogenated Species. *Science*, 259, 194-199.

Rayne S. and Forest K. (2010): Modeling the hydrolysis of perfluorinated compounds containing carboxylic and phosphoric acid ester functions and sulfonamide groups. *J Environ Sci Health A Tox Hazard Subst Environ Eng*, 45 (4), 432-446.

Reemtsma T, Berger U, Arp HPH, Gallard H, Knepper TP, Neumann M, Quintana JB, de Voogt P (2016) Mind the Gap: persistent and mobile organic compounds—water contaminants that slip through. *Environ Sci Technol* 50:10308–10315

Reemtsma T, Berger U, Arp HPH, Gallard H, Knepper TP, Neumann M, Quintana JB, de Voogt P (2016) Mind the Gap: persistent and mobile organic compounds—water contaminants that slip through. *Environ Sci Technol* 50:10308–10315

Reemtsma T, Berger U, Arp HPH, Gallard H, Knepper TP, Neumann M, Quintana JB, de Voogt P (2016) Mind the Gap: persistent and mobile organic compounds—water contaminants that slip through. *Environ Sci Technol* 50:10308–10315

Reemtsma, T., Berger, U., Arp, H.P.H., Gallard, H., Knepper, T.P., Neumann, M., Quintana, J.B., Voogt, P.D., 2016. Mind the Gap: Persistent and Mobile Organic Compounds - Water Contaminants That Slip Through. *Environmental Science and Technology* 50, 10308-10315.

Reiner, J.L., O'Connell, S.G., Moors, A.J., Kucklick, J.R., Becker, P.R., Keller, J.M., 2011. Spatial and temporal trends of perfluorinated compounds in Beluga Whales (*Delphinapterus leucas*) from Alaska. *Environ Sci Technol* 45, 8129–36. <https://doi.org/10.1021/es103560q>

Reiner, J.L., O'Connell, S.G., Moors, A.J., Kucklick, J.R., Becker, P.R., Keller, J.M., 2011. Spatial and temporal trends of perfluorinated compounds in Beluga Whales (*Delphinapterus leucas*) from Alaska. *Environ Sci Technol* 45, 8129–36. <https://doi.org/10.1021/es103560q>

Remaining references moved here from specific sections

Ren X.-M., Qin W.-P., Cao L.-Y., Zhang J., Yang Y., Wan B., and Guo L.-H. (2016): Binding interactions of perfluoroalkyl substances with thyroid hormone transport proteins and potential toxicological implications. *Toxicology* 366-367, 32-42. DOI: <https://doi.org/10.1016/j.tox.2016.08.011>

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Ren X.M., Qin W.P., Cao L.Y., Zhang J., Yang Y., Wan B., and Guo L.H. (2016): Binding interactions of perfluoroalkyl substances with thyroid hormone transport proteins and potential toxicological implications. *Toxicology* 366, 32-42. DOI: 10.1016/j.tox.2016.08.011

REN, X. M., QIN, W. P., CAO, L. Y., ZHANG, J., YANG, Y., WAN, B. & GUO, L. H. 2016. Binding interactions of perfluoroalkyl substances with thyroid hormone transport proteins and potential toxicological implications. *Toxicology*, 366, 32-42.

Rericha, Y., Cao, D., Truong, L., Simonich, M., Field, J. A., & Tanguay, R. L. (2021). Behavior Effects of Structurally Diverse Per- and Polyfluoroalkyl Substances in Zebrafish. *Chemical Research in Toxicology*, 34(6), 1409-1416. doi:10.1021/acs.chemrestox.1c00101

Research Toxicology Centre (2011): cC604 4 week oral toxicity study in rats followed by a 4 week recovery period. 82340. Research Toxicology Centre S.p.A., Via Tito Speri, 12/14, 00040 Pomezia (Roma), Italy

Research Toxicology Centre (2012): cC604 Reproduction/Development toxicity screening test in rats. 82350. Research Toxicology Centre S.p.A. - Via Tito Speri 12/14 00040 Pomezia RM Italy

Research Toxicology Centre (2013): cC604 13 week oral toxicity study in rats followed by a 6-week recovery period. 89720. Research Toxicology Centre S.p.A., Via Tito Speri, 12/14, 00040 Pomezia (Roma), Italy

RESEARCH TOXICOLOGY CENTRE 2011. cC604 4 week oral toxicity study in rats followed by a 4 week recovery period. Research Toxicology Centre S.p.A., Via Tito Speri, 12/14, 00040 Pomezia (Roma), Italy.

RESEARCH TOXICOLOGY CENTRE 2012. cC604 Reproduction/Development toxicity screening test in rats. Research Toxicology Centre S.p.A. - Via Tito Speri 12/14 00040 Pomezia RM Italy.

RESEARCH TOXICOLOGY CENTRE 2013. cC604 13 week oral toxicity study in rats followed by a 6-week recovery period. Research Toxicology Centre S.p.A., Via Tito Speri, 12/14, 00040 Pomezia (Roma), Italy.

Rhoads, K. R., Janssen, E. M.-L., Luthy, R. G. & Criddle, C. S. (2008): Aerobic Biotransformation and Fate of N-Ethyl Perfluorooctane Sulfonamidoethanol (N-EtFOSE) in Activated Sludge. *Environ Sci Technol*, 42 (8), 2873–2878.

Rice P.A., Cooper J., Koh-Fallet S.E., and Kabadi S.V. (2021): Comparative analysis of the physicochemical, toxicokinetic, and toxicological properties of ether-PFAS. *Toxicol Appl Pharmacol* 422, 115531. DOI: 10.1016/j.taap.2021.115531

RICE, P. A., COOPER, J., KOH-FALLET, S. E. & KABADI, S. V. 2021. Comparative analysis of the physicochemical, toxicokinetic, and toxicological properties of ether-PFAS. *Toxicol Appl Pharmacol*, 422, 115531.

Rigét F, Bossi R, Sonne C, Vorkamp K, Dietz R. Trends of perfluorochemicals in Greenland ringed seals and polar bears: Indications of shifts to decreasing trends. *Chemosphere* 2013; 93: 1607-1614: <https://doi.org/10.1016/j.chemosphere.2013.08.015>.

RIVM, 2017. Water quality standards for PFOA.

RIVM, Zeilmaker M.J., Fragki S., Verbruggen E.M.J., Bokkers B.G.H., and Lijzen J.P.A. (2018): Mixture exposure to PFAS: A relative potency factor approach. RIVM Report 2018-0070, date: 2018. National Institute for Public Health and the Environment (RIVM)

RIVM, ZEILMAKER, M. J., FRAGKI, S., VERBRUGGEN, E. M. J., BOKKERS, B. G. H. & LIJZEN, J. P. A. 2018. Mixture exposure to PFAS: A relative potency factor approach. In: PFAS, H. (ed.). Bilthoven, Netherlands: National Institute for Public Health and the Environment (RIVM)

Roos A, Berger U, Järnberg U, van Dijk J, Bignert A. Increasing Concentrations of Perfluoroalkyl Acids in Scandinavian Otters (*Lutra lutra*) between 1972 and 2011: A New Threat to the Otter Population? *Environmental Science & Technology* 2013; 47: 11757-11765: DOI: 10.1021/es401485t.

Roos AM, Gamberg M, Muir D, Kärrman A, Carlsson P, Cuyler C, et al. Perfluoroalkyl substances in circum-Arctic Rangifer: caribou and reindeer. *Environmental Science and Pollution Research* 2021: DOI: 10.1007/s11356-021-16729-7.

Rosen M.B., Das K.P., Rooney J., Abbott B., Christopher Lau, and Corton J.C. (2017): PPAR α -independent transcriptional targets of perfluoroalkyl acids revealed by transcript profiling. *Toxicology* 387, 95-107. DOI: <https://doi.org/10.1016/j.tox.2017.05.013>

Rosen M.B., Das K.P., Rooney J., Abbott B., Lau C., and Corton J.C. (2017): PPAR α -independent transcriptional targets of perfluoroalkyl acids revealed by transcript profiling. *Toxicology* 387, 95-107. DOI: 10.1016/j.tox.2017.05.013

ROSEN, M. B., DAS, K. P., ROONEY, J., ABBOTT, B., LAU, C. & CORTON, J. C. 2017. PPAR α -independent transcriptional targets of perfluoroalkyl acids revealed by transcript profiling. *Toxicology*, 387, 95-107.

Rosenmai A.K., Ahrens L., le Godec T., Lundqvist J., and Oskarsson A. (2018): Relationship between peroxisome proliferator-activated receptor α activity and cellular concentration of 14 perfluoroalkyl substances in HepG2 cells. *Journal of Applied Toxicology* 38 (2), 219-226. DOI: <https://doi.org/10.1002/jat.3515>

Rosenmai A.K., Nielsen F.K., Pedersen M., Hadrup N., Trier X., Christensen J.H., and Vinggaard A.M. (2013): Fluorochemicals used in food packaging inhibit male sex hormone synthesis. *Toxicol Appl Pharmacol* 266 (1), 132-142. DOI: 10.1016/j.taap.2012.10.022

Rosenmai A.K., Taxvig C., Svingen T., Trier X., van Vugt-Lussenburg B.M.A., Pedersen M., Lesné L., Jégou B., and Vinggaard A.M. (2016): Fluorinated alkyl substances and technical mixtures used in food paper-packaging exhibit endocrine-related activity in vitro. *Andrology* 4 (4), 662-672. DOI: <https://doi.org/10.1111/andr.12190>

Rotander, A., Kärrman, A., Bavel, B.V., Polder, A., Rigét, F., Audunsson, G.A., Víkingsson, G., Gabrielsen, G.W., Bloch, D., Dam, M., 2012. Increasing levels of long-chain perfluorocarboxylic acids (PFCAs) in Arctic and North Atlantic marine mammals, 1984-2009. *Chemosphere* 86, 278-285.

Routti H, Aars J, Fuglei E, Hanssen L, Lone K, Polder A, et al. Emission Changes Dwarf the Influence of Feeding Habits on Temporal Trends of Per- and Polyfluoroalkyl Substances in Two Arctic Top Predators. *Environmental Science & Technology* 2017; 51: 11996-12006: DOI: 10.1021/acs.est.7b03585.

Routti H, Gabrielsen GW, Herzke D, Kovacs KM, Lydersen C. Spatial and temporal trends in perfluoroalkyl substances (PFASs) in ringed seals (*Pusa hispida*) from Svalbard. *Environmental Pollution* 2016; 214: 230-238: <https://doi.org/10.1016/j.envpol.2016.04.016>.

Routti, H., Aars, J., Fuglei, E., Hanssen, L., Lone, K., Polder, A., Pedersen, Å.Ø., Tartu, S., Welker, J.M., Yoccoz, N.G., 2017. Emission Changes Dwarf the Influence of Feeding Habits on Temporal Trends of Per- and Polyfluoroalkyl Substances in Two Arctic Top Predators. *Environmental Science & Technology* 51, 11996-12006.

Routti, H., Krafft, B.A., Herzke, D., Eisert, R., Oftedal, O., 2015. Perfluoroalkyl substances detected in the world's southernmost marine mammal, the Weddell seal (*Leptonychotes weddellii*). *Environ Pollut* 197, 62-67.

Royer L.A., Lee L.S., Russell M.H., Nies L.F., and Turco R.F. (2015): Microbial transformation of 8:2 fluorotelomer acrylate and methacrylate in aerobic soils. *Chemosphere*, 129, 54-61.

Ruan T., Wang Y., Wang T., Zhang Q., Ding L., Liu J., Wang C., Qu G., and Jiang G. (2010): Presence and partitioning behavior of polyfluorinated iodine alkanes in environmental matrices around a fluorochemical manufacturing plant: another possible source for perfluorinated carboxylic acids? *Environ Sci Technol*, 44 (15), 5755-5761.

Rüdel, H., Körner, W., Letzel, T., Neumann, M., Nödler, K., Reemtsma, T., 2020. Persistent, mobile and toxic substances in the environment: a spotlight on current research and regulatory activities. *Environmental Sciences Europe* 32.

Russell M.H., Berti W.R., Szostek B., and Buck R.C. (2008): Investigation of the biodegradation potential of a fluoroacrylate polymer product in aerobic soils. *Environ Sci Technol*, 42 (3), 800-807.

Russell M.H., Berti W.R., Szostek B., Wang N., and Buck R.C. (2010): Evaluation of PFO formation from the biodegradation of a fluorotelomer-based urethane polymer product in aerobic soils. *Polymer Degradation and Stability*, 95 (1), 79-85.

Russell, M.H., Nilsson, H., Buck, R.C., 2013. Elimination kinetics of perfluorohexanoic acid in humans and comparison with mouse, rat and monkey. *Chemosphere* 93, 2419–25. <https://doi.org/10.1016/j.chemosphere.2013.08.060>

Russell, M.H., Nilsson, H., Buck, R.C., 2013. Elimination kinetics of perfluorohexanoic acid in humans and comparison with mouse, rat and monkey. *Chemosphere* 93, 2419–25. <https://doi.org/10.1016/j.chemosphere.2013.08.060>

Šabović I., Cosci I., De Toni L., Ferramosca A., Stornaiuolo M., Di Nisio A., Dall'Acqua S., Garolla A., and Foresta C. (2020): Perfluoro-octanoic acid impairs sperm motility through the alteration of plasma membrane. *Journal of Endocrinological Investigation* 43 (5), 641-652. DOI: 10.1007/s40618-019-01152-0

ŠABOVIĆ, I., COSCI, I., DE TONI, L., FERRAMOSCA, A., STORNAIUOLO, M., DI NISIO, A., DALL'ACQUA, S., GAROLLA, A. & FORESTA, C. 2020. Perfluoro-octanoic acid impairs sperm motility through the alteration of plasma membrane. *Journal of Endocrinological Investigation*, 43, 641-652.

Sáez, M., Voogt, P. d. & Parsons, J. R. (2008): Persistence of perfluoroalkylated substances in closed bottle tests with municipal sewage sludge. *Environmental Science and Pollution Research*, 15, 472-477.

Sáez, M., Voogt, P. d. & Parsons, J. R. (2008): Persistence of perfluoroalkylated substances in closed bottle tests with municipal sewage sludge. *Environmental Science and Pollution Research*, 15, 472-477.

Sakai, T. T. and Santi, D. V. (1973): Hydrolysis of hydroxybenzotrifluorides and fluorinated uracil derivatives. A general mechanism for carbon-fluorine bond labilization. *J Med Chem*, 16 (10), 1079–1084.

Sakuma A., Ochi H.W., Yoshioka M., Yamanaka N., Ikezawa M., and Guruge K.S. (2019): Changes in hepato-renal gene expression in microminipigs following a single exposure to a mixture of perfluoroalkyl acids. *PLoS One* 14 (1). DOI: 10.1371/journal.pone.0210110

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

SAKUMA, A., OCHI, H. W., YOSHIOKA, M., YAMANAKA, N., IKEZAWA, M. & GURUGE, K. S. 2019. Changes in hepato-renal gene expression in microminipigs following a single exposure to a mixture of perfluoroalkyl acids. *PLoS ONE*, 14.

Sant K.E., Venezia O.L., Sinno P.P., and Timme-Laragy A.R. (2019): Perfluorobutanesulfonic Acid Disrupts Pancreatic Organogenesis and Regulation of Lipid Metabolism in the Zebrafish, *Danio rerio*. *Toxicological sciences : an official journal of the Society of Toxicology* 167 (1), 258-268. DOI: 10.1093/toxsci/kfy237

SAVU, P. M. 2000. Fluorinated Higher Carboxylic Acids. *Kirk-Othmer Encyclopedia of Chemical Technology*. John Wiley & Sons, Inc.

Say, D., Manning, A. J., Western, L. M., Young, D., Wisher, A., Rigby, M., Reimann, S., Vollmer, M. K., Maione, M., Arduini, J., Krummel, P. B., Mühle, J., Harth, C. M., Evans, B., Weiss, R. F., Prinn, R. G. & O'Doherty, S. (2021): Global trends and European emissions of tetrafluoromethane (CF₄), hexafluoroethane (C₂F₆) and octafluoropropane (C₃F₈). *Atmospheric Chemistry and Physics*, 21, 2149–2164.

Say, D., Manning, A. J., Western, L. M., Young, D., Wisher, A., Rigby, M., Reimann, S., Vollmer, M. K., Maione, M., Arduini, J., Krummel, P. B., Mühle, J., Harth, C. M., Evans, B., Weiss, R. F., Prinn, R. G. & O'Doherty, S. (2021): Global trends and European emissions of tetrafluoromethane (CF₄), hexafluoroethane (C₂F₆) and octafluoropropane (C₃F₈). *Atmospheric Chemistry and Physics*, 21, 2149–2164.

Schenker, U., Scheringer, M., Macleod, M., Martin, J.W., Cousins, I.T., Hungerbühler, K., 2008. Contribution of volatile precursor substances to the flux of perfluorooctanoate to the arctic. *Environ. Sci. Technol.* 42, 3710-3716.

Scher, D.P., Kelly, J.E., Huset, C.A., Barry, K.M., Hoffbeck, R.W., Yingling, V.L., Messing, R.B., 2018. Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. *Chemosphere* 196, 548-555.

Scher, D.P., Kelly, J.E., Huset, C.A., Barry, K.M., Hoffbeck, R.W., Yingling, V.L., Messing, R.B., 2018. Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. *Chemosphere* 196, 548-555.

Scheringer M., Trier X., Cousins I.T., de Voogt P., Fletcher T., Wang Z., and Webster T.F. (2014): Helsingør statement on poly- and perfluorinated alkyl substances (PFASs). *Chemosphere* 114, 337-339. DOI: 10.1016/j.chemosphere.2014.05.044

Scheringer, M., 2009. Long-range transport of organic chemicals in the environment. *Environ. Toxicol. Chem.* 28, 677.

SCHERINGER, M., TRIER, X., COUSINS, I. T., DE VOOGT, P., FLETCHER, T., WANG, Z. & WEBSTER, T. F. 2014. Helsingør statement on poly- and perfluorinated alkyl substances (PFASs). *Chemosphere*, 114, 337-9.

Scheringer, M., Trier, X., Cousins, I. T., Voogt, P. d., Fletcher, T., Wang, Z. & Webster, T. F. (2014): Helsingør Statement on poly- and perfluorinated alkyl substances (PFASs). *Chemosphere*, 114, 337-339.

Scheringer, M., Trier, X., Cousins, I. T., Voogt, P. d., Fletcher, T., Wang, Z. & Webster, T. F. (2014): Helsingør Statement on poly- and perfluorinated alkyl substances (PFASs). *Chemosphere*, 114, 337-339.

Scheurer, M., Nodler, K., Freeling, F., Janda, J., Happel, O., Riegel, M., Müller, U., Storck, F. R., Fleig, M., Lange, F. T., Brunsch, A. & Brauch, H.-J. (2017): Small, mobile, persistent:

Trifluoroacetate in the water cycle - Overlooked sources, pathways, and consequences for drinking water supply. *Water Research*, 126, 460-471.

Scheurer, M., Nodler, K., Freeling, F., Janda, J., Happel, O., Riegel, M., Müller, U., Storck, F. R., Fleig, M., Lange, F. T., Brunsch, A. & Brauch, H.-J. (2017): Small, mobile, persistent: Trifluoroacetate in the water cycle - Overlooked sources, pathways, and consequences for drinking water supply. *Water Research*, 126, 460-471.

Schiavone, A., Corsolini, S., Kannan, K., Tao, L., Trivelpiece, W., Torres Jr, D., Focardi, S., 2009. Perfluorinated contaminants in fur seal pups and penguin eggs from South Shetland, Antarctica. *Sci. Total Environ.* 407, 3899-3904.

Schlabach, M., van Bavel, B., Baz Lomba, J.A., Borgen, A., Gabrielsen, G.W., Götsch, A., Halse, A.K., Hanssen, L., Sunde Krogseth, I., Nikiforov, V., Nygård, T., Bohlin Nizzetto, P., Reid, M., Rostkowski, P., Samanipour, S., Screening, P., 2018. AMAP Assessment Compounds. M-1080. 93.

Schultes L, Sandblom O, Broeg K, Bignert A, Benskin JP. Temporal Trends (1981–2013) of Per- and Polyfluoroalkyl Substances and Total Fluorine in Baltic cod (*Gadus morhua*). *Environmental Toxicology and Chemistry* 2020a; 39: 300-309: <https://doi.org/10.1002/etc.4615>.

Schultes L, van Noordenburg C, Spaan KM, Plassmann MM, Simon M, Roos A, et al. High Concentrations of Unidentified Extractable Organofluorine Observed in Blubber from a Greenland Killer Whale (*Orcinus orca*). *Environmental Science & Technology Letters* 2020b; 7: 909-915: DOI: 10.1021/acs.estlett.0c00661.

Schultz M.M., Higgins C.P., Huset C.A., Luthy R.G., Barofsky D.F., and Field J.A. (2006): Fluorochemical mass flows in a municipal wastewater treatment facility. *Environ Sci Technol* 40 (23), 7350-7357. <http://www.ncbi.nlm.nih.gov/pubmed/17180988>

Schulz, K., Silva, M. R., & Klaper, R. (2020). Distribution and effects of branched versus linear isomers of PFOA, PFOS, and PFHxS: A review of recent literature. *Science of The Total Environment*, 733. doi:10.1016/j.scitotenv.2020.139186

Schuster P., Bertermann R., Rusch G.M., and Dekant W. (2010): Biotransformation of 2,3,3,3-tetrafluoropropene (HFO-1234yf) in rabbits. *Toxicol Appl Pharmacol* 244 (3), 247-253. DOI: 10.1016/j.taap.2009.12.022

SCHUSTER, P., BERTERMANN, R., RUSCH, G. M. & DEKANT, W. 2010. Biotransformation of 2,3,3,3-tetrafluoropropene (HFO-1234yf) in rabbits. *Toxicol Appl Pharmacol*, 244, 247-53.

Scott, B. F., Macdonald, R. W., Kannan, K., Fisk, A., Witter, A., Yamashita, N., Durham, L., Spencer, C. & Muir, D. C. G. (2005): Trifluoroacetate Profiles in the Arctic, Atlantic, and Pacific Oceans. *Environmental Science & Technology*, 39, 6555-6560.

Scott, B.F., Spencer, C., Mabury, S.A., Muir, D.C.G., 2006. Poly and perfluorinated carboxylates in north American precipitation. *Environ. Sci. Technol.* 40, 7167-7174.

Semerád J., Hatasová N., Grassarová A., Černá T., Filipová A., Hanč A., Innemanová P., Pivokonský M., and Cajthaml T. (2020): Screening for 32 per- and polyfluoroalkyl substances (PFAS) including GenX in sludges from 43 WWTPs located in the Czech Republic - Evaluation of potential accumulation in vegetables after application of biosolids. *Chemosphere* 261, 128018. DOI: <https://doi.org/10.1016/j.chemosphere.2020.128018>

SEPULVADO, J. G., BLAINE, A. C., HUNDAL, L. S. & HIGGINS, C. P. 2011. Occurrence and fate of perfluorochemicals in soil following the land application of municipal biosolids. *Environ Sci Technol*, 45, 8106-12.

- Sepulvado, J. G., Blaine, A. C., Hundal, L. S., & Higgins, C. P. (2011). Occurrence and fate of perfluorochemicals in soil following the land application of municipal biosolids. *Environ Sci Technol*, 45(19), 8106-8112. doi:10.1021/es103903d
- Sha, B., Johansson, J.H., Tunved, P., Bohlin-Nizzetto, P., Cousins, I.T., Salter, M.E., 2022. Sea Spray Aerosol (SSA) as a Source of Perfluoroalkyl Acids (PFAAs) to the Atmosphere: Field Evidence from Long-Term Air Monitoring. *Environmental Science & Technology* 56, 228-238.
- Shan, G., Wei, M., Zhu, L., Liu, Z., Zhang, Y., 2014. Concentration profiles and spatial distribution of perfluoroalkyl substances in an industrial center with condensed fluorochemical facilities. *Sci. Total Environ.* 490, 351-359.
- Sharpe, R.L., Benskin, J.P., Laarman, A.H., MacLeod, S.L., Martin, J.W., Wong, C.S., Goss, G.G., 2010. Perfluorooctane sulfonate toxicity, isomer-specific accumulation, and maternal transfer in zebrafish (*Danio rerio*) and rainbow trout (*Oncorhynchus mykiss*). *Environmental Toxicology and Chemistry* 29, 1957–1966. <https://doi.org/10.1002/etc.257>
- Sharpe, R.L., Benskin, J.P., Laarman, A.H., MacLeod, S.L., Martin, J.W., Wong, C.S., Goss, G.G., 2010. Perfluorooctane sulfonate toxicity, isomer-specific accumulation, and maternal transfer in zebrafish (*Danio rerio*) and rainbow trout (*Oncorhynchus mykiss*). *Environmental Toxicology and Chemistry* 29, 1957–1966. <https://doi.org/10.1002/etc.257>
- Sheng, N., Li, J., Liu, H., Zhang, A., Dai, J., 2016. Interaction of perfluoroalkyl acids with human liver fatty acid-binding protein. *Archives of Toxicology* 90, 217–227. <https://doi.org/10.1007/s00204-014-1391-7>
- Sheng, N., Li, J., Liu, H., Zhang, A., Dai, J., 2016. Interaction of perfluoroalkyl acids with human liver fatty acid-binding protein. *Archives of Toxicology* 90, 217–227. <https://doi.org/10.1007/s00204-014-1391-7>
- Shi G., Guo H., Sheng N., Cui Q., Pan Y., Wang J., Guo Y., and Dai J. (2018): Two-generational reproductive toxicity assessment of 6:2 chlorinated polyfluorinated ether sulfonate (F-53B, a novel alternative to perfluorooctane sulfonate) in zebrafish. *Environmental Pollution* 243, 1517-1527. DOI: <https://doi.org/10.1016/j.envpol.2018.09.120>
- Shi Z., Ding L., Zhang H., Feng Y., Xu M., and Dai J. (2009): Chronic exposure to perfluorododecanoic acid disrupts testicular steroidogenesis and the expression of related genes in male rats. *Toxicol Lett* 188 (3), 192-200. DOI: 10.1016/j.toxlet.2009.04.014
- Shi Z.M., Zhang H.X., Liu Y., Xu M., and Dai J.Y. (2007): Alterations in gene expression and testosterone synthesis in the testes of male rats exposed to perfluorododecanoic acid. *Toxicological Sciences* 98 (1), 206-215. DOI: 10.1093/toxsci/kfm070
- Shi, G., Cui, Q., Pan, Y., Sheng, N., Sun, S., Guo, Y., & Dai, J. (2017). 6:2 Chlorinated polyfluorinated ether sulfonate, a PFOS alternative, induces embryotoxicity and disrupts cardiac development in zebrafish embryos. *Aquat Toxicol*, 185, 67-75. doi:10.1016/j.aquatox.2017.02.002
- Shi, G., Cui, Q., Wang, J., Guo, H., Pan, Y., Sheng, N., . . . Dai, J. (2019). Chronic exposure to 6:2 chlorinated polyfluorinated ether sulfonate acid (F-53B) induced hepatotoxic effects in adult zebrafish and disrupted the PPAR signaling pathway in their offspring. *Environ Pollut*, 249, 550-559. doi:10.1016/j.envpol.2019.03.032
- Shi, Y., Song, X., Jin, Q., Li, W., He, S., Cai, Y., 2020. Tissue distribution and bioaccumulation of a novel polyfluoroalkyl benzenesulfonate in crucian carp. *Environ. Int.* 135. <https://doi.org/10.1016/j.envint.2019.105418>

Shi, Y., Song, X., Jin, Q., Li, W., He, S., Cai, Y., 2020. Tissue distribution and bioaccumulation of a novel polyfluoroalkyl benzenesulfonate in crucian carp. *Environ. Int.* 135. <https://doi.org/10.1016/j.envint.2019.105418>

Shi, Y., Vestergren, R., Nost, T.H., Zhou, Z., Cai, Y., 2018. Probing the Differential Tissue Distribution and Bioaccumulation Behavior of Per- and Polyfluoroalkyl Substances of Varying Chain-Lengths, Isomeric Structures and Functional Groups in Crucian Carp. *Environmental Science & Technology* 52, 4592–4600. <https://doi.org/10.1021/acs.est.7b06128>

Shi, Y., Vestergren, R., Nost, T.H., Zhou, Z., Cai, Y., 2018. Probing the Differential Tissue Distribution and Bioaccumulation Behavior of Per- and Polyfluoroalkyl Substances of Varying Chain-Lengths, Isomeric Structures and Functional Groups in Crucian Carp. *Environmental Science & Technology* 52, 4592–4600. <https://doi.org/10.1021/acs.est.7b06128>

Shi, Y., Vestergren, R., Zhou, Z., Song, X., Xu, L., Liang, Y., Cai, Y., 2015. Tissue Distribution and Whole Body Burden of the Chlorinated Polyfluoroalkyl Ether Sulfonic Acid F-53B in Crucian Carp (*Carassius carassius*): Evidence for a Highly Bioaccumulative Contaminant of Emerging Concern. *Environmental Science and Technology* 49, 14156–14165. <https://doi.org/10.1021/acs.est.5b04299>

SHI, Z. M., ZHANG, H. X., LIU, Y., XU, M. & DAI, J. Y. 2007. Alterations in gene expression and testosterone synthesis in the testes of male rats exposed to perfluorododecanoic acid. *Toxicological Sciences*, 98, 206-215.

SHI, Z., DING, L., ZHANG, H., FENG, Y., XU, M. & DAI, J. 2009. Chronic exposure to perfluorododecanoic acid disrupts testicular steroidogenesis and the expression of related genes in male rats. *Toxicol Lett*, 188, 192-200.

Shoeib, M., Harner, T., Vlahos, P., 2006. Perfluorinated chemicals in the arctic atmosphere. *Environ. Sci. Technol.* 40, 7577-7583.

Siegemund, G., Schwertfeger, W., Feiring, A., Smart, B., Behr, F., Vogel, H. & McKusick, B. (2012). Fluorine Compounds, Organic. *Ullmann's Encyclopedia of Industrial Chemistry* Wiley-VCH Verlag GmbH & Co. KGaA. 15: 443-494.

Siegemund, G., Schwertfeger, W., Feiring, A., Smart, B., Behr, F., Vogel, H. & McKusick, B. (2012). Fluorine Compounds, Organic. *Ullmann's Encyclopedia of Industrial Chemistry* Wiley-VCH Verlag GmbH & Co. KGaA. 15: 443-494.

Silva E., Rajapakse N., and Kortenkamp A. (2002): Something from "nothing" - Eight weak estrogenic chemicals combined at concentrations below NOECs produce significant mixture effects. *Environmental Science & Technology* 36 (8), 1751-1756. DOI: 10.1021/es0101227

SILVA, E., RAJAPAKSE, N. & KORTENKAMP, A. 2002. Something from "nothing" - Eight weak estrogenic chemicals combined at concentrations below NOECs produce significant mixture effects. *Environmental Science & Technology*, 36, 1751-1756.

Sima, M. W., & Jaffé, P. R. (2021). A critical review of modeling Poly- and Perfluoroalkyl Substances (PFAS) in the soil-water environment. *Science of The Total Environment*, 757, 143793. doi:<https://doi.org/10.1016/j.scitotenv.2020.143793>

Sims, J. L., Stroski, K. M., Kim, S., Killeen, G., Ehalt, R., Simcik, M. F., & Brooks, B. W. (2021). Global occurrence and probabilistic environmental health hazard assessment of per- and polyfluoroalkyl substances (PFASs) in groundwater and surface waters. *Science of The Total Environment*, 151535. doi:<https://doi.org/10.1016/j.scitotenv.2021.151535>

Sinclair, G. M., Long, S. M., & Jones, O. A. H. (2020). What are the effects of PFAS exposure at environmentally relevant concentrations? *Chemosphere*, 258. doi:10.1016/j.chemosphere.2020.127340

Singh S. and Singh S.K. (2019a): Chronic exposure to perfluorononanoic acid impairs spermatogenesis, steroidogenesis and fertility in male mice. *J Appl Toxicol* 39 (3), 420-431. DOI: 10.1002/jat.3733

Singh S. and Singh S.K. (2019b): Prepubertal exposure to perfluorononanoic acid interferes with spermatogenesis and steroidogenesis in male mice. *Ecotoxicol Environ Saf* 170, 590-599. DOI: 10.1016/j.ecoenv.2018.12.034

Singh, R. R. & Papanastasiou, D. K. (2021): Comment on "Scientific Basis for Managing PFAS as a Chemical Class". *Environmental Science & Technology Letters*, 8, 192-194.

Singh, R. R. & Papanastasiou, D. K. (2021): Comment on "Scientific Basis for Managing PFAS as a Chemical Class". *Environmental Science & Technology Letters*, 8, 192-194.

SINGH, S. & SINGH, S. K. 2019a. Chronic exposure to perfluorononanoic acid impairs spermatogenesis, steroidogenesis and fertility in male mice. *J Appl Toxicol*, 39, 420-431.

SINGH, S. & SINGH, S. K. 2019b. Prepubertal exposure to perfluorononanoic acid interferes with spermatogenesis and steroidogenesis in male mice. *Ecotoxicol Environ Saf*, 170, 590-599.

Skov, H., Massling, A., Nielsen, I.E., Nordstrøm, C., Bossi, R., Vorkamp, K., Christensen, J., Larsen, M.M., Hansen, K.M., Liisberg, J., Poulsen, M.B., 2017. AMAP CORE - atmospheric part. Results from Villum Research Station. Technical report from DCE - Danish centre for environment and energy No. 101. Aarhus University, DCE - Danish Centre for Environment and Energy, 77.

Solomon, K. R., Velders, G. J. M., Wilson, S. R., Madronich, S., Longstreth, J., Aucamp, P. J., & Bornman, J. F. (2016). Sources, fates, toxicity, and risks of trifluoroacetic acid and its salts: Relevance to substances regulated under the Montreal and Kyoto Protocols. *Journal of Toxicology and Environmental Health, Part B*, 19(7), 289-304. doi:10.1080/10937404.2016.1175981

Solomon, S. (1999): Stratospheric Ozone Depletion: A Review of Concepts and History. *Reviews of Geophysics*, 37, 275-316.

Solomon, S. (1999): Stratospheric Ozone Depletion: A Review of Concepts and History. *Reviews of Geophysics*, 37, 275-316.

Song P., Li D., Wang X., and Zhong X. (2018a): Effects of perfluorooctanoic acid exposure during pregnancy on the reproduction and development of male offspring mice. *Andrologia* 50 (8), e13059. DOI: 10.1111/and.13059

Song X., Tang S., Zhu H., Chen Z., Zang Z., Zhang Y., Niu X., Wang X., Yin H., Zeng F., and He C. (2018b): Biomonitoring PFAAs in blood and semen samples: Investigation of a potential link between PFAAs exposure and semen mobility in China. *Environ Int* 113, 50-54. DOI: 10.1016/j.envint.2018.01.010

SONG, P., LI, D., WANG, X. & ZHONG, X. 2018a. Effects of perfluorooctanoic acid exposure during pregnancy on the reproduction and development of male offspring mice. *Andrologia*, 50, e13059.

SONG, X., TANG, S., ZHU, H., CHEN, Z., ZANG, Z., ZHANG, Y., NIU, X., WANG, X., YIN, H., ZENG, F. & HE, C. 2018b. Biomonitoring PFAAs in blood and semen samples: Investigation of

a potential link between PFAAs exposure and semen mobility in China. *Environ Int*, 113, 50-54.

Sovacool, B. K., Griffiths, S., Kim, J. & Bazilian, M. (2021): Climate change and industrial F-gases: A critical and systematic review of developments, sociotechnical systems and policy options for reducing synthetic greenhouse gas emissions *Renewable and Sustainable Energy Reviews*, 141, 1-55.

Spaan KM, van Noordenburg C, Plassmann MM, Schultes L, Shaw S, Berger M, et al. Fluorine Mass Balance and Suspect Screening in Marine Mammals from the Northern Hemisphere. *Environmental Science & Technology* 2020; 54: 4046-4058; DOI: 10.1021/acs.est.9b06773.

Spaan, K.M., van Noordenburg, C., Plassmann, M.M., Schultes, L., Shaw, S., Berger, M., Heide-Jørgensen, M.P., Rosing-Asvid, A., Granquist, S.M., Dietz, R., Sonne, C., Rigét, F., Roos, A., Benskin, J.P., 2020. Fluorine Mass Balance and Suspect Screening in Marine Mammals from the Northern Hemisphere. *Environ. Sci. Technol.* 54, 4046–4058. <https://doi.org/10.1021/acs.est.9b06773>

Spaan, K.M., van Noordenburg, C., Plassmann, M.M., Schultes, L., Shaw, S., Berger, M., Heide-Jørgensen, M.P., Rosing-Asvid, A., Granquist, S.M., Dietz, R., Sonne, C., Rigét, F., Roos, A., Benskin, J.P., 2020. Fluorine Mass Balance and Suspect Screening in Marine Mammals from the Northern Hemisphere. *Environ. Sci. Technol.* 54, 4046–4058. <https://doi.org/10.1021/acs.est.9b06773>

Stalter D., O'Malley E., von Gunten U., and Escher B.I. (2020): Mixture effects of drinking water disinfection by-products: implications for risk assessment. *Environmental Science-Water Research & Technology* 6 (9), 2341-2351. DOI: 10.1039/c9ew00988d

STALTER, D., O'MALLEY, E., VON GUNTEN, U. & ESCHER, B. I. 2020. Mixture effects of drinking water disinfection by-products: implications for risk assessment. *Environmental Science-Water Research & Technology*, 6, 2341-2351.

Stanifer J.W., Stapleton H.M., Souma T., Wittmer A., Zhao X., and Boulware L.E. (2018): Perfluorinated chemicals as emerging environmental threats to kidney health: A scoping review. *Clinical Journal of the American Society of Nephrology* 13 (10), 1479-1492. DOI: 10.2215/CJN.04670418

STANIFER, J. W., STAPLETON, H. M., SOUMA, T., WITTMER, A., ZHAO, X. & BOULWARE, L. E. 2018. Perfluorinated chemicals as emerging environmental threats to kidney health: A scoping review. *Clinical Journal of the American Society of Nephrology*, 13, 1479-1492.

Stanley, K. M., Say, D., Mühle, J., Harth, C. M., Krummel, P. B., Young, D., O'Doherty, S. J., Salameh, P. K., Simmonds, P. G., Weiss, R. F., Prinn, R. G., Fraser, P. J. & Rigby, M. (2020): Increase in global emissions of HFC-23 despite near-total expected reductions. *Nature Communications*, 11, 1-6.

Stasinakis A.S., Thomaidis N.S., Arvaniti O.S., Asimakopoulos A.G., Samaras V.G., Ajibola A., Mamais D., and Lekkas T.D. (2013): Contribution of primary and secondary treatment on the removal of benzothiazoles, benzotriazoles, endocrine disruptors, pharmaceuticals and perfluorinated compounds in a sewage treatment plant. *Science of the Total Environment* 463-464, 1067-1075. DOI: <https://doi.org/10.1016/j.scitotenv.2013.06.087>

STATISTISCHES BUNDESAMT 2015. Öffentliche Wasserversorgung und öffentliche Abwasserentsorgung - Öffentliche Wasserversorgung. Fachserie 19, Reihe 2.1.1 - 2013. Wiesbaden (Germany): Statistisches Bundesamt.

Steenland K. and Winquist A. (2021): PFAS and cancer, a scoping review of the epidemiologic evidence. *Environmental Research* 194. DOI: 10.1016/j.envres.2020.110690

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Steenland K. and Woskie S. (2012): Cohort mortality study of workers exposed to perfluorooctanoic acid. *Am J Epidemiol* 176 (10), 909-917. DOI: 10.1093/aje/kws171 (last accessed 5/12/2021)

STEENLAND, K. & WINQUIST, A. 2021. PFAS and cancer, a scoping review of the epidemiologic evidence. *Environmental Research*, 194.

STEENLAND, K. & WOSKIE, S. 2012. Cohort mortality study of workers exposed to perfluorooctanoic acid. *Am J Epidemiol*, 176, 909-17.

Stemmler, I., Lammel, G., 2010. Pathways of PFOA to the Arctic: variabilities and contributions of oceanic currents and atmospheric transport and chemistry sources. *Atmos. Chem. Phys.* 10, 9965.

Stephenson, M.E.: An approach to the identification of organic compounds hazardous to the environment and human health (1977) *Ecotoxicology and Environmental Safety*, 1 (1), pp. 39-48.

Stevenson, C. N., Manus-Spencer, L. A., Luckenbach, T., Luthy, R. G., & Epel, D. (2006). New perspectives on perfluorochemical ecotoxicology: inhibition and induction of an efflux transporter in the marine mussel, *Mytilus californianus*. *Environ Sci Technol*, 40(17), 5580-5585. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/16999143>

Stock, N.L., Furdui, V.I., Muir, D.C.G., Mabury, S.A., 2007. Perfluoroalkyl contaminants in the Canadian arctic: Evidence of atmospheric transport and local contamination. *Environ. Sci. Technol.* 41, 3529-3536.

Stoiber, T., Evans, S. & Naidenko, O. V. (2020): Disposal of products and materials containing per- and polyfluoroalkyl substances (PFAS): A cyclical problem. *Chemosphere*, 260, 127659.

Strøm E. and Alexandersen O. (1990): [Pulmonary damage caused by ski waxing]. *Tidsskr Nor Laegeforen* 110 (28), 3614-3616

Strynar M, Dagnino S, McMahan R, Liang S, Lindstrom A, Andersen E, McMillan L, Thurman M, Ferrer I, Ball C. 2015. Identification of Novel Perfluoroalkyl Ether Carboxylic Acids (PFECAs) and Sulfonic Acids (PFESAs) in Natural Waters Using Accurate Mass Time-of-Flight Mass Spectrometry (TOFMS). *Environ Sci Technol* 49:11622-11630.

Strynar, M. J., Lindstrom, A. B., Nakayama, S. F., Egeghy, P. P., & Helfant, L. J. (2012). Pilot scale application of a method for the analysis of perfluorinated compounds in surface soils. *Chemosphere*, 86(3), 252-257. doi:10.1016/j.chemosphere.2011.09.036

Styler S.A., Myers A.L., and Donaldson D.J. (2013): Heterogeneous photooxidation of fluorotelomer alcohols: a new source of aerosol-phase perfluorinated carboxylic acids. *Environ Sci Technol*, 47 (12), 6358-6367.

Sulbaek Andersen M.P., Nielsen O.J., Toft A., Nakayama T., Matsumi Y., Waterland R.L., Buck R.C., Hurley M.D., and Wallington T.J. (2005): Atmospheric chemistry of $C_xF_{2x+1}CH=CH_2$ ($x = 1, 2, 4, 6$, and 8): Kinetics of gas-phase reactions with Cl atoms, OH radicals, and O₃. *Journal of Photochemistry and Photobiology A: Chemistry*, 176 (1-3), 124-128.

Sulbaek-Andersen, M. P., Schmidt, J. A., Volkova, A. & Wuebbles, D. J. (2018): A three-dimensional model of the atmospheric chemistry of E and Z- $CF_3CH=CHCl$ (HCFO-1233(zd) (E/Z)). *Atmospheric Environment*, 179, 250-259.

Sun J, Bossi R, Bustnes JO, Helander B, Boertmann D, Dietz R, et al. White-Tailed Eagle (*Haliaeetus albicilla*) Body Feathers Document Spatiotemporal Trends of Perfluoroalkyl

Substances in the Northern Environment. *Environmental Science & Technology* 2019; 53: 12744-12753; DOI: 10.1021/acs.est.9b03514.

Sun, J., Bossi, R., Bustnes, J.O., Helander, B., Boertmann, D., Dietz, R., Herzke, D., Jaspers, V.L.B., Labansen, A.L., Lepoint, G., Schulz, R., Sonne, C., Thorup, K., Tøttrup, A.P., Zubrod, J.P., Eens, M., Eulaers, I., 2019. White-Tailed Eagle (*Haliaeetus albicilla*) Body Feathers Document Spatiotemporal Trends of Perfluoroalkyl Substances in the Northern Environment. *Environ. Sci. Technol.* 53, 12744-12753.

Sun, M., Cui, J., Guo, J., Zhai, Z., Zuo, P., Zhang, J. (2020): Fluorochemicals biodegradation as a potential source of trifluoroacetic acid (TFA) to the environment. *Chemosphere*, 254, 1-9.

Suo C., Fan Z., Zhou L., and Qiu J. (2017): Perfluorooctane sulfonate affects intestinal immunity against bacterial infection. *Sci Rep* 7 (1), 5166. DOI: 10.1038/s41598-017-04091-z

SUO, C., FAN, Z., ZHOU, L. & QIU, J. 2017. Perfluorooctane sulfonate affects intestinal immunity against bacterial infection. *Sci Rep*, 7, 5166.

Sznajder, K., ska, K., Surma, M., Cie, lik, E., Wiczkowski, W., 2018. The perfluoroalkyl substances (PFASs) contamination of fruits and vegetables. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment* 35, 1776-1786.

Takahashi M., Ishida S., Hirata-Koizumi M., Ono A., and Hirose A. (2014): Repeated dose and reproductive/developmental toxicity of perfluoroundecanoic acid in rats. *J Toxicol Sci* 39 (1), 97-108. DOI: 10.2131/jts.39.97

TAKAHASHI, M., ISHIDA, S., HIRATA-KOIZUMI, M., ONO, A. & HIROSE, A. 2014. Repeated dose and reproductive/developmental toxicity of perfluoroundecanoic acid in rats. *J Toxicol Sci*, 39, 97-108.

Taniguchi, N., Wallington, T. J., Hurley, M. D., Guschin, A. G., Molina, L. T. & Molina, M. J. (2003): Atmospheric Chemistry of C₂F₅C(O)CF(CF₃)₂: Photolysis and Reaction with Cl Atoms, OH Radicals, and Ozone. *Journal of Physical Chemistry A*, 107, 2674-2679.

Taniyasu, S., Yamashita, N., Moon, H.B., Kwok, K.Y., Lam, P.K.S., Horii, Y., Petrick, G., Kannan, K., 2013. Does wet precipitation represent local and regional atmospheric transportation by perfluorinated alkyl substances? *Environment International* 55, 25-32.

Taniyasu, S., Yamashita, N., Yamazaki, E., Petrick, G. & Kannan, K. (2013): The environmental photolysis of perfluorooctanesulfonate, perfluorooctanoate, and related fluorochemicals. *Chemosphere*, 90, 1686-1692.

Taniyasu, S., Yamashita, N., Yamazaki, E., Petrick, G. & Kannan, K. (2013): The environmental photolysis of perfluorooctanesulfonate, perfluorooctanoate, and related fluorochemicals. *Chemosphere*, 90, 1686-1692.

Tao, L., Kannan, K., Kajiwara, N., Costa, M.M., Fillmann, G., Takahashi, S., Tanabe, S., 2006. Perfluorooctanesulfonate and related fluorochemicals in albatrosses, elephant seals, penguins, and polar skuas from the southern ocean. *Environ. Sci. Technol.* 40, 7642-7648.

Tartu, S., Gabrielsen, G.W., Blévin, P., Ellis, H., Bustnes, J.O., Herzke, D., Chastel, O., 2014. Endocrine and fitness correlates of long-chain perfluorinated carboxylates exposure in arctic breeding black-legged kittiwakes. *Environ. Sci. Technol.* 48, 13504-13510.

Temkin A.M., Hocevar B.A., Andrews D.Q., Naidenko O.V., and Kamendulis L.M. (2020): Application of the key characteristics of carcinogens to per and polyfluoroalkyl substances.

International Journal of Environmental Research and Public Health 17 (5). DOI: 10.3390/ijerph17051668

TEMKIN, A. M., HOCEVAR, B. A., ANDREWS, D. Q., NAIDENKO, O. V. & KAMENDULIS, L. M. 2020. Application of the key characteristics of carcinogens to per and polyfluoroalkyl substances. International Journal of Environmental Research and Public Health, 17.

TERC (2002): XDE-007: Limited Pharmacokinetics and Metabolism of 14C-Labelled XDE-007 Following a Single Oral Administration in Fischer 344 Rats. DR-0355-2305-039 / 11151. Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674

TERC (2003): XDE-007: Pharmacokinetics and Metabolism in Fischer 344 Rats (Part A). DR-0355-2305-064 / 21110. Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674

TERC (2004): XDE-007: Pharmacokinetics and metabolism in Fischer 344 rats (Part B). DR-0355-2305-064B / 021110B. Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674

TERC (2005): XDE-007: Mechanistic Study to Evaluate Possible Cause of Toxicity Differences Among Species. DR-0355-2305-065 / 21125. Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674

TERC 2002. XDE-007: Limited Pharmacokinetics and Metabolism of 14C-Labelled XDE-007 Following a Single Oral Administration in Fischer 344 Rats. Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674.

TERC 2003. XDE-007: Pharmacokinetics and Metabolism in Fischer 344 Rats (Part A). Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674.

TERC 2004. XDE-007: Pharmacokinetics and metabolism in Fischer 344 rats (Part B). Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674.

TERC 2005. XDE-007: Mechanistic Study to Evaluate Possible Cause of Toxicity Differences Among Species. Toxicology & Environmental Research and Consulting, The Dow Chemical Company, Midland, Michigan 48674.

Tian, Y., Yao, Y., Chang, S., Zhao, Z., Zhao, Y., Yuan, X., Wu, F., Sun, H., 2018. Occurrence and Phase Distribution of Neutral and Ionizable Per- and Polyfluoroalkyl Substances (PFASs) in the Atmosphere and Plant Leaves around Landfills: A Case Study in Tianjin, China. Environ. Sci. Technol. 52, 1301.

Tian, Y., Yao, Y., Chang, S., Zhao, Z., Zhao, Y., Yuan, X., Wu, F., Sun, H., 2018. Occurrence and Phase Distribution of Neutral and Ionizable Per- and Polyfluoroalkyl Substances (PFASs) in the Atmosphere and Plant Leaves around Landfills: A Case Study in Tianjin, China. Environ. Sci. Technol. 52, 1301.

TNO (N/A): N/A (HDC-365mfc-90-d-inhalation-rat). TNO Civo Institutes 3700 AJ Zeist

TNO N/A. N/A (HDC-365mfc-90-d-inhalation-rat). TNO Civo Institutes 3700 AJ Zeist

Tomy, G. T., Tittlemier, S. A., Palace, V. P., Budakowski, W. R., Braekevelt, E., Brinkworth, L., and Friesen, K. (2004). Biotransformation of N-Ethyl Perfluorooctanesulfonamide by Rainbow Trout (*Onchorhynchus mykiss*) Liver Microsomes. Environ Sci Technol, 38 (3), 758-762.

Toxicology Centre S.p.A. (2011): cC6O4 4 week oral toxicity study in rats followed by a 4 week recovery period

TOXICOLOGY CENTRE S.P.A. 2011. cC6O4 4 week oral toxicity study in rats followed by a 4 week recovery period.

Trimmel S, Vike-Jonas K, Gonzalez SV, Ciesielski TM, Lindstrøm U, Jenssen BM, et al. Rapid Determination of Per- and Polyfluoroalkyl Substances (PFAS) in Harbour Porpoise Liver Tissue by HybridSPE®–UPLC®–MS/MS. *Toxics* 2021; 9: 183: <https://doi.org/10.3390/toxics9080183>.

Triskelion (2016): Inhalation prenatal developmental toxicity study with HFO-1336mzz-E in rats. V20685. Triskelion, P.O. Box 844, 3700 AV Zeist, The Netherlands

Triskelion (2017): Combined repeated dose inhalation toxicity study and reproduction/developmental toxicity screening test in rats with MOVE 3. V20810/02. Triskelion B.V.

Triskelion (2019): Inhalation extended one generation reproduction toxicity study with hexafluoropropene (hexafluoropropylene) (HFP) in rats V21072. Triskelion B.V., Utrechtseweg 48, 3704 HE Zeist, The Netherlands

TRISKELION 2016. Inhalation prenatal developmental toxicity study with HFO-1336mzz-E in rats. Triskelion, P.O. Box 844, 3700 AV Zeist, The Netherlands.

TRISKELION 2017. Combined repeated dose inhalation toxicity study and reproduction/developmental toxicity screening test in rats with MOVE 3. Triskelion B.V.

TRISKELION 2019. Inhalation extended one generation reproduction toxicity study with hexafluoropropene (hexafluoropropylene) (HFP) in rats Triskelion B.V., Utrechtseweg 48, 3704 HE Zeist, The Netherlands

Tsai, W.-T. (2005): Environmental risk assessment of hydrofluoroethers (HFEs). *Journal of Hazardous Materials*, A119, 69-78.

Tsai, W.-T. (2017): Environmental implications of perfluorotributylamine - a potent greenhouse gas. *Mitigation and Adaptation Strategies for Global Change*, 22, 225-231. B.5. Human health hazard assessment1

Tucker D.K., Macon M.B., Strynar M.J., Dagnino S., Andersen E., and Fenton S.E. (2015): The mammary gland is a sensitive pubertal target in CD-1 and C57Bl/6 mice following perinatal perfluorooctanoic acid (PFOA) exposure. *Reproductive Toxicology* 54, 26-36. DOI: 10.1016/j.reprotox.2014.12.002

TUCKER, D. K., MACON, M. B., STRYNAR, M. J., DAGNINO, S., ANDERSEN, E. & FENTON, S. E. 2015. The mammary gland is a sensitive pubertal target in CD-1 and C57Bl/6 mice following perinatal perfluorooctanoic acid (PFOA) exposure. *Reproductive Toxicology*, 54, 26-36.

Tveit A., Rusch G.M., Muijser H., and Tegelenbosch-Schouten M.M. (2013): The acute, developmental, genetic and inhalation toxicology of 2,3,3,3-tetrafluoropropene (HFO-1234yf). *Drug Chem Toxicol* 36 (4), 412-420. DOI: 10.3109/01480545.2012.749273

TVEIT, A., RUSCH, G. M., MUIJSER, H. & TEGELENBOSCH-SCHOUTEN, M. M. 2013. The acute, developmental, genetic and inhalation toxicology of 2,3,3,3-tetrafluoropropene (HFO-1234yf). *Drug Chem Toxicol*, 36, 412-20.

U.S. EPA (2019), PFAS Master List of PFAS Substances (Version 2), https://comptox.epa.gov/dashboard/chemical_lists/pfasmaster

U.S.EPA, 2020. [https://comptox.epa.gov/dashboard/chemical_lists/pfasmaster].

UBA, German Environment Agency (2021). Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential. <https://www.umweltbundesamt.de/publikationen/persistent-degradation-products-of-halogenated>

Ulhaq, M., Carlsson, G., Orn, S., & Norrgren, L. (2013). Comparison of developmental toxicity of seven perfluoroalkyl acids to zebrafish embryos. *Environ Toxicol Pharmacol*, 36(2), 423-426. doi:10.1016/j.etap.2013.05.004

Ulrich H., Freier K.P., and Gierig M. (2016): Getting on with persistent pollutants: Decreasing trends of perfluoroalkyl acids (PFAAs) in sewage sludge. *Chemosphere* 161, 527-535. DOI: 10.1016/j.chemosphere.2016.07.048

VanNoy B.N., Lam J., and Zota A.R. (2018): Breastfeeding as a Predictor of Serum Concentrations of Per- and Polyfluorinated Alkyl Substances in Reproductive-Aged Women and Young Children: A Rapid Systematic Review. *Curr Environ Health Rep* 5 (2), 213-224. DOI: 10.1007/s40572-018-0194-z

VANNOY, B. N., LAM, J. & ZOTA, A. R. 2018. Breastfeeding as a Predictor of Serum Concentrations of Per- and Polyfluorinated Alkyl Substances in Reproductive-Aged Women and Young Children: A Rapid Systematic Review. *Curr Environ Health Rep*, 5, 213-224.

Veillette, J., Muir, D.C.G., Antoniadou, D., Small, J.M., Spencer, C., Loewen, T.N., Babaluk, J.A., Reist, J.D., Vincent, W.F., 2012. Perfluorinated chemicals in meromictic lakes on the northern coast of Ellesmere Island, High Arctic Canada. *Arctic* 65, 245-256.

Verreault, J., Houde, M., Gabrielsen, G.W., Berger, U., Haukas, M., Letcher, R.J., Muir, D.C., 2005. Perfluorinated alkyl substances in plasma, liver, brain, and eggs of glaucous gulls (*Larus hyperboreus*) from the Norwegian arctic. *Environ. Sci. Technol.* 39, 7439.

Verreault, J., Houde, M., Gabrielsen, G.W., Berger, U., Haukas, M., Letcher, R.J., Muir, D.C., 2005. Perfluorinated alkyl substances in plasma, liver, brain, and eggs of glaucous gulls (*Larus hyperboreus*) from the Norwegian arctic. *Environ. Sci. Technol.* 39, 7439.

Versieren L., Evers S., De Schamphelaere K., Blust R., and Smolders E. (2016): Mixture toxicity and interactions of copper, nickel, cadmium, and zinc to barley at low effect levels: Something from nothing? *Environmental Toxicology and Chemistry* 35 (10), 2483-2492. DOI: 10.1002/etc.3380

VERSIEREN, L., EVERS, S., DE SCHAMPHELAERE, K., BLUST, R. & SMOLDERS, E. 2016. Mixture toxicity and interactions of copper, nickel, cadmium, and zinc to barley at low effect levels: Something from nothing? *Environmental Toxicology and Chemistry*, 35, 2483-2492.

Vested A., Ramlau-Hansen C.H., Olsen S.F., Bonde J.P., Kristensen S.L., Halldorsson T.I., Becher G., Haug L.S., Ernst E.H., and Toft G. (2013): Associations of in utero exposure to perfluorinated alkyl acids with human semen quality and reproductive hormones in adult men. *Environ Health Perspect* 121 (4), 453-458. DOI: 10.1289/ehp.1205118

VESTED, A., RAMLAU-HANSEN, C. H., OLSEN, S. F., BONDE, J. P., KRISTENSEN, S. L., HALLDORSSON, T. I., BECHER, G., HAUG, L. S., ERNST, E. H. & TOFT, G. 2013. Associations of in utero exposure to perfluorinated alkyl acids with human semen quality and reproductive hormones in adult men. *Environ Health Perspect*, 121, 453-8.

Vestergren, R., Orata, F., Berger, U., Cousins, I.T., 2013. Bioaccumulation of perfluoroalkyl acids in dairy cows in a naturally contaminated environment. *Environ. Sci. Pollut. Res.* 20, 7959-7969.

Vetvicka V. and Vetvickova J. (2013): Reversal of perfluorooctanesulfonate-induced immunotoxicity by a glucan-resveratrol-vitamin C combination. *Oriental Pharmacy and Experimental Medicine* 13 (1), 77-84. DOI: 10.1007/s13596-013-0105-7

VETVICKA, V. & VETVICKOVA, J. 2013. Reversal of perfluorooctanesulfonate-induced immunotoxicity by a glucan-resveratrol-vitamin C combination. *Oriental Pharmacy and Experimental Medicine*, 13, 77-84.

Vieira V.M., Hoffman K., Shin H.M., Weinberg J.M., Webster T.F., and Fletcher T. (2013): Perfluorooctanoic acid exposure and cancer outcomes in a contaminated community: a geographic analysis. *Environ Health Perspect* 121 (3), 318-323. DOI: 10.1289/ehp.1205829

VIEIRA, V. M., HOFFMAN, K., SHIN, H. M., WEINBERG, J. M., WEBSTER, T. F. & FLETCHER, T. 2013. Perfluorooctanoic acid exposure and cancer outcomes in a contaminated community: a geographic analysis. *Environ Health Perspect*, 121, 318-23.

VIERKE, L. 2014. Environmental Mobility of Short Chain Perfluoroalkyl Carboxylic Acids- Partition Behaviour and Resulting Environmental Concern. *Universitätsbibliothek der Leuphana Universität Lüneburg*.

Vierke, L., Berger, U., & Cousins, I. T. (2013). Estimation of the acid dissociation constant of perfluoroalkyl carboxylic acids through an experimental investigation of their water-to-air transport. *Environ Sci Technol*, 47(19), 11032-11039. doi:10.1021/es402691z

Visscher, P., Culbertson, C. & Oremland, R. (1994): Degradation of trifluoroacetate in oxic and anoxic sediments. *Nature* 369, 729-731

Visscher, P., Culbertson, C. & Oremland, R. (1994): Degradation of trifluoroacetate in oxic and anoxic sediments. *Nature* 369, 729-731

Vongphachan V., Cassone C.G., Wu D., Chiu S., Crump D., and Kennedy S.W. (2011a): Effects of perfluoroalkyl compounds on mRNA expression levels of thyroid hormone-responsive genes in primary cultures of avian neuronal cells. *Toxicol Sci* 120 (2), 392-402. DOI: 10.1093/toxsci/kfq395

Vongphachan V., Cassone C.G., Wu D., Chiu S., Crump D., and Kennedy S.W. (2011b): Effects of perfluoroalkyl compounds on mRNA expression levels of thyroid hormone-responsive genes in primary cultures of avian neuronal cells. *Toxicological Sciences* 120 (2), 392-402. DOI: 10.1093/toxsci/kfq395

Wågbo A.M., Cangialosi M.V., Cicero N., Letcher R.J., and Arukwe A. (2012): Perfluorooctane Sulfonamide-Mediated Modulation of Hepatocellular Lipid Homeostasis and Oxidative Stress Responses in Atlantic Salmon Hepatocytes. *Chemical Research in Toxicology* 25 (6), 1253-1264. DOI: 10.1021/tx300110u

Wallington, T. J., Schneider, W. F., Worsnop, D. R., Nielsen, O. J., Sehested, J., Debruyne, W. J. & Shorter, J. A. (1994): The Environmental Impact of CFC Replacements HFCs and HCFCs. *Environmental Science & Technology*, 28, 320A-326A.

Wallington, T.J., Sulbaek Andersen, M.P. & Nielsen, O.J. (2015): Atmospheric chemistry of short-chain haloolefins: Photochemical ozone creation potentials (POCPs), global warming potentials (GWPs), and ozone depletion potentials (ODPs). *Chemosphere*, 129, 135-141, Wang, S., Huang, J., Yang, Y., Hui, Y., Ge, Y., Larssen, T., Yu, G., Deng, S., Wang, B. & Harman, C. (2013): First Report of a Chinese PFOS Alternative Overlooked for 30 Years: Its

Toxicity, Persistence, and Presence in the Environment. *Environmental Science & Technology*, 47, 10163–10170.

Wallington, T.J., Sulbaek Andersen, M.P. & Nielsen, O.J. (2015): Atmospheric chemistry of short-chain haloolefins: Photochemical ozone creation potentials (POCPs), global warming potentials (GWPs), and ozone depletion potentials (ODPs). *Chemosphere*, 129, 135-141.

Wan H.T., Zhao Y.G., Wei X., Hui K.Y., Giesy J.P., and Wong C.K. (2012): PFOS-induced hepatic steatosis, the mechanistic actions on beta-oxidation and lipid transport. *Biochim Biophys Acta* 1820 (7), 1092-1101. DOI: 10.1016/j.bbagen.2012.03.010

WAN, H. T., ZHAO, Y. G., WEI, X., HUI, K. Y., GIESY, J. P. & WONG, C. K. 2012. PFOS-induced hepatic steatosis, the mechanistic actions on beta-oxidation and lipid transport. *Biochim Biophys Acta*, 1820, 1092-101.

Wang B., Zhang R., Jin F., Lou H., Mao Y., Zhu W., Zhou W., Zhang P., and Zhang J. (2017): Perfluoroalkyl substances and endometriosis-related infertility in Chinese women. *Environ Int* 102, 207-212. DOI: 10.1016/j.envint.2017.03.003

Wang I.J., Hsieh W.S., Chen C.Y., Fletcher T., Lien G.W., Chiang H.L., Chiang C.F., Wu T.N., and Chen P.C. (2011): The effect of prenatal perfluorinated chemicals exposures on pediatric atopy. *Environ Res* 111 (6), 785-791. DOI: 10.1016/j.envres.2011.04.006

Wang N., Buck R.C., Szostek B., Sulecki L.M., and Wolstenholme B.W. (2012): 5:3 Polyfluorinated acid aerobic biotransformation in activated sludge via novel "one-carbon removal pathways". *Chemosphere*, 87 (5), 527-534.

Wang N., Liu J., Buck R.C., Korzeniowski S.H., Wolstenholme B.W., Folsom P.W., and Sulecki L.M. (2011): 6:2 fluorotelomer sulfonate aerobic biotransformation in activated sludge of waste water treatment plants. *Chemosphere*, 82 (6), 853-858.

Wang N., Szostek B., Buck R.C., Folsom P.W., Sulecki L.M., and Gannon J.T. (2009): 8-2 fluorotelomer alcohol aerobic soil biodegradation: pathways, metabolites, and metabolite yields. *Chemosphere*, 75 (8), 1089-1096.

Wang N., Szostek B., Buck R.C., Folsom P.W., Sulecki L.M., Capka V., Berti W.R., and Gannon J.T. (2005a): Fluorotelomer alcohol biodegradation-direct evidence that perfluorinated carbon chains breakdown. *Environ Sci Technol*, 39 (19), 7516-7528.

Wang N., Szostek B., Folsom P.W., Sulecki L.M., Capka V., Buck R.C., Berti W.R., and Gannon J.T. (2005b): Aerobic biotransformation of 14C-labeled 8-2 telomer B alcohol by activated sludge from a domestic sewage treatment plant. *Environ Sci Technol*, 39 (2), 531-538.

WANG, B., ZHANG, R., JIN, F., LOU, H., MAO, Y., ZHU, W., ZHOU, W., ZHANG, P. & ZHANG, J. 2017. Perfluoroalkyl substances and endometriosis-related infertility in Chinese women. *Environ Int*, 102, 207-212.

WANG, I. J., HSIEH, W. S., CHEN, C. Y., FLETCHER, T., LIEN, G. W., CHIANG, H. L., CHIANG, C. F., WU, T. N. & CHEN, P. C. 2011a. The effect of prenatal perfluorinated chemicals exposures on pediatric atopy. *Environ Res*, 111, 785-91.

Wang, P., Zhang, M., Li, Q., Lu, Y., 2021. Atmospheric diffusion of perfluoroalkyl acids emitted from fluorochemical industry and its associated health risks. *Environment International* 146.

Wang, S., Huang, J., Yang, Y., Hui, Y., Ge, Y., Larssen, T., . . . Harman, C. (2013). First report of a Chinese PFOS alternative overlooked for 30 years: its toxicity, persistence, and presence in the environment. *Environ Sci Technol*, 47(18), 10163-10170. doi:10.1021/es401525n

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Wang, S., Huang, J., Yang, Y., Hui, Y., Ge, Y., Larssen, T., Yu, G., Deng, S., Wang, B. & Harman, C. (2013): First Report of a Chinese PFOS Alternative Overlooked for 30 Years: Its Toxicity, Persistence, and Presence in the Environment. *Environmental Science & Technology*, 47, 10163–10170.

WANG, W., RHODES, G., GE, J., YU, X. & LI, H. 2020. Uptake and accumulation of per- and polyfluoroalkyl substances in plants. *Chemosphere*, 261, 127584.

Wang, W., Rhodes, G., Ge, J., Yu, X., & Li, H. (2020). Uptake and accumulation of per- and polyfluoroalkyl substances in plants. *Chemosphere*, 261, 127584. doi:10.1016/j.chemosphere.2020.127584

Wang, W., Rhodes, G., Ge, J., Yu, X., Li, H., 2020. Uptake and accumulation of per- and polyfluoroalkyl substances in plants. *Chemosphere* 261.

Wang, Y., Chang, W., Wang, L., Zhang, Y., Zhang, Y., Wang, M., Wang, Y., & Li, P. (2019). A review of sources, multimedia distribution and health risks of novel fluorinated alternatives. *Ecotoxicology and Environmental Safety*, 182, 1–9.

Wang, Y., Chang, W., Wang, L., Zhang, Y., Zhang, Y., Wang, M., Wang, Y., Li, P., 2019. A review of sources, multimedia distribution and health risks of novel fluorinated alternatives. *Ecotoxicology and Environmental Safety* 182.

Wang, Y., Chang, W., Wang, L., Zhang, Y., Zhang, Y., Wang, M., Wang, Y., & Li, P. (2019). A review of sources, multimedia distribution and health risks of novel fluorinated alternatives. *Ecotoxicology and Environmental Safety*, 182, 1–9.

Wang, Y., Niu, J., Zhang, L., & Shi, J. (2014). Toxicity assessment of perfluorinated carboxylic acids (PFCAs) towards the rotifer *Brachionus calyciflorus*. *Science of The Total Environment*, 491-492, 266-270. doi:10.1016/j.scitotenv.2014.02.028

Wang, Y., Vestergren, R., Shi, Y., Cao, D., Xu, L., Cai, Y., Zhao, X., Wu, F., 2016. Identification, Tissue Distribution, and Bioaccumulation Potential of Cyclic Perfluorinated Sulfonic Acids Isomers in an Airport Impacted Ecosystem. *Environmental Science and Technology* 50, 10923–10932. <https://doi.org/10.1021/acs.est.6b01980>

Wang, Y., Vestergren, R., Shi, Y., Cao, D., Xu, L., Cai, Y., Zhao, X., Wu, F., 2016. Identification, Tissue Distribution, and Bioaccumulation Potential of Cyclic Perfluorinated Sulfonic Acids Isomers in an Airport Impacted Ecosystem. *Environmental Science and Technology* 50, 10923–10932. <https://doi.org/10.1021/acs.est.6b01980>

Wang, Z., Cousins, I. T. & Scheringer, M. (2015b): Comment on “The environmental photolysis of perfluorooctanesulfonate, perfluorooctanoate, and related fluorochemicals”. *Chemosphere*, 122, 301-303.

Wang, Z., Cousins, I. T. & Scheringer, M. (2015b): Comment on “The environmental photolysis of perfluorooctanesulfonate, perfluorooctanoate, and related fluorochemicals”. *Chemosphere*, 122, 301-303.

Wang, Z., Cousins, I. T., Berger, U., Hungerbühler, K. & Scheringer, M. (2016): Comparative assessment of the environmental hazards of and exposure to perfluoroalkyl phosphonic and phosphinic acids (PFPAs and PFPIAs): Current knowledge, gaps, challenges and research needs. *Environment International*, 89-90, 235-247.

Wang, Z., Cousins, I. T., Berger, U., Hungerbühler, K. & Scheringer, M. (2016): Comparative assessment of the environmental hazards of and exposure to perfluoroalkyl phosphonic and phosphinic acids (PFPAs and PFPIAs): Current knowledge, gaps, challenges and research needs. *Environment International*, 89-90, 235-247.

Wang, Z., Cousins, I. T., Scheringer, M. & 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.

Wang, Z., Cousins, I. T., Scheringer, M. & 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.

Wang, Z., Cousins, I.T., Scheringer, M., Buck, R.C., Hungerbühler, K., 2014. Global emission inventories for C4–C14 perfluoroalkyl carboxylic acid (PFCA) homologues from 1951 to 2030, Part I: production and emissions from quantifiable sources. *Environ. Int.* 70, 62.

Wang, Z., Cousins, I.T., Scheringer, M., 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.

Wang, Z., Cousins, I.T., Scheringer, M., Buck, R.C., Hungerbühler, K. (2014). Global emission inventories for C4–C14 perfluoroalkyl carboxylic acid homologues from 1951 to 2030, Part II: the remaining pieces of the puzzle. *Environ Int.*, 69, 166–176.

Wang, Z., DeWitt, J.C., Higgins, C.P. & Cousins, I.T. (2017): A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environmental Science and Technology*, 51, 2508-2518

Wang, Z., DeWitt, J.C., Higgins, C.P. & Cousins, I.T. (2017): A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environmental Science and Technology*, 51, 2508-2518

WANG, Z., MACLEOD, M., COUSINS, I. T., SCHERINGER, M. & HUNGERBÜHLER, K. 2011b. Using COSMOtherm to predict physicochemical properties of poly- and perfluorinated alkyl substances (PFASs). *Environmental Chemistry*, 8, 389-398.

Wang, Z., MacLeod, M., Cousins, I.T., Scheringer, M., Hungerbühler, K., 2011. Using COSMOtherm to predict physicochemical properties of poly- and perfluorinated alkyl substances (PFASs). *Environmental Chemistry* 8, 389–398. <https://doi.org/10.1071/EN10143>

Wang, Z., MacLeod, M., Cousins, I.T., Scheringer, M., Hungerbühler, K., 2011. Using COSMOtherm to predict physicochemical properties of poly- and perfluorinated alkyl substances (PFASs). *Environmental Chemistry* 8, 389–398. <https://doi.org/10.1071/EN10143>

Wania, F., 2007a. A global mass balance analysis of the source of perfluorocarboxylic acids in the Arctic Ocean. *Environ. Sci. Technol.* 41, 4529.

Wania, F., 2007b. A global mass balance analysis of the source of perfluorocarboxylic acids in the Arctic Ocean. *Environ. Sci. Technol.* 41, 4529-4535.

Washington J.W. and Jenkins T.M. (2015): Abiotic hydrolysis of fluorotelomer-based polymers as a source of perfluorocarboxylates at the global scale. *Environmental Science & Technology*, 49 (24), 14129-14135.

Washington J.W., Ellington J.J., Jenkins T.M., Evans J.J., Yoo H., and Hafner S.C. (2009): Degradability of an Acrylate-Linked, Fluorotelomer Polymer in Soil. *Environmental Science & Technology*, 43 (17), 6617-6623.

Washington J.W., Rankin K., Libelo E.L., Lynch D.G., and Cyterski M. (2019): Determining global background soil PFAS loads and the fluorotelomer-based polymer degradation rates that can account for these loads. *Science of the Total Environment* 651, 2444-2449. DOI: 10.1016/j.scitotenv.2018.10.071

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Washington J.W., Yoo H., Ellington J.J., Jenkins T.M., and Libelo E.L. (2010): Concentrations, distribution, and persistence of perfluoroalkylates in sludge-applied soils near Decatur, Alabama, USA. *Environ Sci Technol* 44 (22), 8390-8396. DOI: 10.1021/es1003846

WASHINGTON, J. W., RANKIN, K., LIBELO, E. L., LYNCH, D. G. & CYTERSKI, M. 2019. Determining global background soil PFAS loads and the fluorotelomer-based polymer degradation rates that can account for these loads. *Science of the Total Environment*, 651, 2444-2449.

Washington, J. W., Rankin, K., Libelo, E. L., Lynch, D. G., & Cyterski, M. (2019). Determining global background soil PFAS loads and the fluorotelomer-based polymer degradation rates that can account for these loads. *Sci Total Environ*, 651(Pt 2), 2444-2449. doi:10.1016/j.scitotenv.2018.10.071

Washington, J. W., Yoo, H., Ellington, J. J., Jenkins, T. M., & Libelo, E. L. (2010). Concentrations, distribution, and persistence of perfluoroalkylates in sludge-applied soils near Decatur, Alabama, USA. *Environ Sci Technol*, 44(22), 8390-8396. doi:10.1021/es1003846

Wassenaar, P.N.H., Verbruggen, E.M.J., Cieraad, E., Peijnenburg, W.J.G.M., Vijver, M.G., 2020. Variability in fish bioconcentration factors: Influences of study design and consequences for regulation. *Chemosphere* 239, 124731. <https://doi.org/10.1016/j.chemosphere.2019.124731>

Watkins A.M., Wood C.R., Lin M.T., and Abbott B.D. (2015): The effects of perfluorinated chemicals on adipocyte differentiation in vitro. *Molecular and Cellular Endocrinology* 400, 90-101. DOI: <https://doi.org/10.1016/j.mce.2014.10.020>

WEAVER, Y. M., EHRESMAN, D. J., BUTENHOFF, J. L. & HAGENBUCH, B. 2010. Roles of rat renal organic anion transporters in transporting perfluorinated carboxylates with different chain lengths. *Toxicological Sciences*, 113, 305-14.

Weaver, Y.M., Ehresman, D.J., Butenhoff, J.L., Hagenbuch, B., 2009. Roles of rat renal organic anion transporters in transporting perfluorinated carboxylates with different chain lengths. *Toxicological Sciences* 113, 305–314. <https://doi.org/10.1093/toxsci/kfp275>

Weaver, Y.M., Ehresman, D.J., Butenhoff, J.L., Hagenbuch, B., 2009. Roles of rat renal organic anion transporters in transporting perfluorinated carboxylates with different chain lengths. *Toxicological Sciences* 113, 305–314. <https://doi.org/10.1093/toxsci/kfp275>

Weber, A. K., Barber, L. B., Leblanc, D. R., Sunderland, E. M., & Vecitis, C. D. (2017). Geochemical and Hydrologic Factors Controlling Subsurface Transport of Poly- and Perfluoroalkyl Substances, Cape Cod, Massachusetts. *Environmental Science and Technology*, 51(8), 4269-4279. doi:10.1021/acs.est.6b05573

Wei, S., Chen, L.Q., Taniyasu, S., So, M.K., Murphy, M.B., Yamashita, N., Yeung, L.W.Y., Lam, P.K.S., 2007. Distribution of perfluorinated compounds in surface seawaters between Asia and Antarctica. *Mar. Pollut. Bull.* 54, 1813-1818.

Weiss J.M., Andersson P.L., Lamoree M.H., Leonards P.E., van Leeuwen S.P., and Hamers T. (2009): Competitive binding of poly- and perfluorinated compounds to the thyroid hormone transport protein transthyretin. *Toxicol Sci* 109 (2), 206-216. DOI: 10.1093/toxsci/kfp055

Wen B., Li L., Zhang H., Ma Y., Shan X.Q., and Zhang S. (2014): Field study on the uptake and translocation of perfluoroalkyl acids (PFAAs) by wheat (*Triticum aestivum* L.) grown in biosolids-amended soils. *Environ Pollut* 184, 547-554. DOI: 10.1016/j.envpol.2013.09.040

Wen L.L., Lin C.Y., Chou H.C., Chang C.C., Lo H.Y., and Juan S.H. (2016): Perfluorooctanesulfonate Mediates Renal Tubular Cell Apoptosis through PPARgamma Inactivation. *PLoS One* 11 (5), e0155190. DOI: 10.1371/journal.pone.0155190

WEN, B., LI, L., ZHANG, H., MA, Y., SHAN, X. Q. & ZHANG, S. 2014. Field study on the uptake and translocation of perfluoroalkyl acids (PFAAs) by wheat (*Triticum aestivum* L.) grown in biosolids-amended soils. *Environ Pollut*, 184, 547-54.

Wen, B., Li, L., Zhang, H., Ma, Y., Shan, X. Q., & Zhang, S. (2014). Field study on the uptake and translocation of perfluoroalkyl acids (PFAAs) by wheat (*Triticum aestivum* L.) grown in biosolids-amended soils. *Environ Pollut*, 184, 547-554. doi:10.1016/j.envpol.2013.09.040

Wen, B., Li, L., Zhang, H., Ma, Y., Shan, X.Q., Zhang, S., 2014. Field study on the uptake and translocation of perfluoroalkyl acids (PFAAs) by wheat (*Triticum aestivum* L.) grown in biosolids-amended soils. *Environmental Pollution* 184, 547-554.

WEN, L. L., LIN, C. Y., CHOU, H. C., CHANG, C. C., LO, H. Y. & JUAN, S. H. 2016. Perfluorooctanesulfonate Mediates Renal Tubular Cell Apoptosis through PPARgamma Inactivation. *PLoS One*, 11, e0155190.

Wen, W., Xia, X., Hu, D., Zhou, D., Wang, H., Zhai, Y., Lin, H., 2017. Long-Chain Perfluoroalkyl acids (PFAAs) Affect the Bioconcentration and Tissue Distribution of Short-Chain PFAAs in Zebrafish (*Danio rerio*). *Environmental Science and Technology* 51, 12358–12368. <https://doi.org/10.1021/acs.est.7b03647>

White S.S., Stanko J.P., Kato K., Calafat A.M., Hines E.P., and Fenton S.E. (2011): Gestational and chronic low-dose PFOA exposures and mammary gland growth and differentiation in three generations of CD-1 mice. *Environ Health Perspect* 119 (8), 1070-1076. DOI: 10.1289/ehp.1002741

WHITE, S. S., STANKO, J. P., KATO, K., CALAFAT, A. M., HINES, E. P. & FENTON, S. E. 2011. Gestational and chronic low-dose PFOA exposures and mammary gland growth and differentiation in three generations of CD-1 mice. *Environ Health Perspect*, 119, 1070-6.

WHO (2012): Guidance for immunotoxicity risk assessment for chemicals. World Health Organization Library Cataloguing-in-Publication Data. WHO/International Programme on Chemical Safety project on the Harmonization of Approaches to the Assessment of Risk from Exposure to Chemicals Harmonization Project Document No. 10. ISBN 978 92 4 150330 3 (NLM classification: QW 630.5.I3)

WHO 2012. Guidance for immunotoxicity risk assessment for chemicals. World Health Organization Library Cataloguing-in-Publication Data. WHO/International Programme on Chemical Safety project on the Harmonization of Approaches to the Assessment of Risk from Exposure to Chemicals, Harmonization Project Document No. 10. ISBN 978 92 4 150330 3 (NLM classification: QW 630.5.I3).

Wielogorska E., Elliott C.T., Danaher M., and Connolly L. (2015): Endocrine disruptor activity of multiple environmental food chain contaminants. *Toxicol In Vitro* 29 (1), 211-220. DOI: 10.1016/j.tiv.2014.10.014

Wielogórska E., Elliott C.T., Danaher M., and Connolly L. (2015): Endocrine disruptor activity of multiple environmental food chain contaminants. *Toxicology in Vitro* 29 (1), 211-220. DOI: <https://doi.org/10.1016/j.tiv.2014.10.014>

WIL (2005): A combined 28-day repeated dose oral toxicity study with the reproduction/developmental toxicity screening test of perfluorohexanoic acid and 1H, 1H, 2H, 2H tridecafluoro-1-octanol in rats, with recovery. Study number WIL-534001

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

WIL (2008a): A 28-day Oral (Gavage) Toxicity Study of H-28397 in Mice with a 28-day Recovery. WIL-189207. WIL Research Laboratories, LLC, Ashland, OH

WIL (2008b): A 28-day Oral (Gavage) Toxicity Study of H-28397 in Rats with a 28-day Recovery. DuPont-24447 / WIL-189205. WIL Research Laboratories, LLC, Ashland, OH

WIL (2009): A 90-Day Oral (Gavage) Toxicity Study of H-28548 in Rats with a 28-Day Recovery. DuPont-17751-1026 / WIL-189216. WIL Research Laboratories, LLC, Ashland, OH, 2008

WIL (2010a): An Oral (Gavage) Prenatal Developmental Toxicity Study of H-28548 in Rats. DuPont-18405-841 / WIL-189223. WIL Research Laboratories, LLC, Ashland, OH, 2008

WIL (2010b): An Oral (Gavage) Reproduction/Developmental Toxicity Screening Study of H-28548 in Mice DuPont-18405-1037 / WIL-189225. WIL Research Laboratories, LLC, Ashland, OH, 2008

WIL (2011): An Oral (Gavage) Reproduction/Developmental Toxicity Screening Study of EEA-NH4 in Rats. WIL-534016. WIL Research Laboratories, LLC, Ashland, OH, 2008

WIL (2014): A Whole-Body Inhalation Prenatal Developmental Toxicity Study of H-30380 in Rabbits. WIL-189264. WIL Research OH., U.S.A.

WIL (2016): Inhalation Toxicity Study of Trifluoro(trifluoromethoxy)ethylene (PMVE) in Sprague Dawley Rats. WIL-222501. WIL Research Laboratories, LLC, Ashland, OH, 2008

WIL 2005. A combined 28-day repeated dose oral toxicity study with the reproduction/developmental toxicity screening test of perfluorohexanoic acid and 1H, 1H, 2H, 2H tridecafluoro-1-octanol in rats, with recovery. In: WIL-534001, W. R. L. S. N. (ed.).

WIL 2008a. A 28-day Oral (Gavage) Toxicity Study of H-28397 in Mice with a 28-day Recovery. WIL Research Laboratories, LLC, Ashland, OH.

WIL 2008b. A 28-day Oral (Gavage) Toxicity Study of H-28397 in Rats with a 28-day Recovery. WIL Research Laboratories, LLC, Ashland, OH.

WIL 2009. A 90-Day Oral (Gavage) Toxicity Study of H-28548 in Rats with a 28-Day Recovery. WIL Research Laboratories, LLC, Ashland, OH, 2008.

WIL 2010a. An Oral (Gavage) Prenatal Developmental Toxicity Study of H-28548 in Rats. WIL Research Laboratories, LLC, Ashland, OH, 2008.

WIL 2010b. An Oral (Gavage) Reproduction/Developmental Toxicity Screening Study of H-28548 in Mice WIL Research Laboratories, LLC, Ashland, OH, 2008.

WIL 2011. An Oral (Gavage) Reproduction/Developmental Toxicity Screening Study of EEA-NH4 in Rats. WIL Research Laboratories, LLC, Ashland, OH, 2008.

WIL 2014. A Whole-Body Inhalation Prenatal Developmental Toxicity Study of H-30380 in Rabbits. WIL Research OH., U.S.A. .

WIL 2016. Inhalation Toxicity Study of Trifluoro(trifluoromethoxy)ethylene (PMVE) in Sprague Dawley Rats. WIL Research Laboratories, LLC, Ashland, OH, 2008.

Wilhelm, M., Kraft, M., Rauchfuss, K., & Holzer, J. (2008). Assessment and management of the first German case of a contamination with perfluorinated compounds (PFC) in the Region Sauerland, North Rhine-Westphalia. J.Toxicol.Environ.Health A, 71(11-12), 725-733.

ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS

Wilkenfeld RM (1981): The effects of 2,2,2-Trifluoroethanol on the testis of the Rat, Department of Radiation Biology and Biophysics, University of Rochester, school of Medicine and Dentistry, New-York, USA

WILKENFELD RM. 1981. The effects of 2,2,2-Trifluoroethanol on the testis of the Rat. Department of Radiation Biology and Biophysics, University of Rochester, school of Medicine and Dentistry, New-York, USA.

Wolf C.J., Schmid J.E., Lau C., and Abbott B.D. (2012): Activation of mouse and human peroxisome proliferator-activated receptor-alpha (PPAR alpha) by perfluoroalkyl acids (PFAAs): Further investigation of C4-C12 compounds. *Reproductive Toxicology* 33 (4), 546-551. DOI: 10.1016/j.reprotox.2011.09.009

Wolf C.J., Zehr R.D., Schmid J.E., Lau C., and Abbott B.D. (2010): Developmental effects of perfluorononanoic Acid in the mouse are dependent on peroxisome proliferator-activated receptor-alpha. *PPAR research* 2010, 282896. DOI: 10.1155/2010/282896

WOLF, C. J., SCHMID, J. E., LAU, C. & ABBOTT, B. D. 2012. Activation of mouse and human peroxisome proliferator-activated receptor-alpha (PPAR alpha) by perfluoroalkyl acids (PFAAs): Further investigation of C4-C12 compounds. *Reproductive Toxicology*, 33, 546-551.

WOLF, C. J., ZEHR, R. D., SCHMID, J. E., LAU, C. & ABBOTT, B. D. 2010. Developmental effects of perfluorononanoic Acid in the mouse are dependent on peroxisome proliferator-activated receptor-alpha. *PPAR research*, 2010, 282896.

Wong, F., Shoeib, M., Katsoyiannis, A., Eckhardt, S., Stohl, A., Bohlin-Nizzetto, P., Li, H., Fellin, P., Su, Y., Hung, H., 2018. Assessing temporal trends and source regions of per- and polyfluoroalkyl substances (PFASs) in air under the Arctic Monitoring and Assessment Programme (AMAP). *Atmospheric Environment* 172, 65-73.

Wood (2020): The use of PFAS and fluorine-free alternatives in textiles, upholstery, carpets, leather and apparel. Report on behalf of the European Commission under contract ENV.A.3/FRA/2015/0010. Wood Environment & Infrastructure Solutions UK Limited,, Wednesday 15th January 2020 at the European Commission, Brussels

Wood (2020): The use of PFAS and fluorine-free alternatives in textiles, upholstery, carpets, leather and apparel. Report on behalf of the European Commission under contract ENV.A.3/FRA/2015/0010. Wood Environment & Infrastructure Solutions UK Limited,, Wednesday 15th January 2020 at the European Commission, Brussels

Wood, C., Balazs, G.H., Rice, M., Work, T.M., Jones, T.T., Sterling, E., Summers, T.M., Brooker, J., Kurpita, L., King, C.S., Lynch, J.M., 2021. Sea turtles across the North Pacific are exposed to perfluoroalkyl substances. *Environ. Pollut.* 279. <https://doi.org/10.1016/j.envpol.2021.116875>

Wood, C., Balazs, G.H., Rice, M., Work, T.M., Jones, T.T., Sterling, E., Summers, T.M., Brooker, J., Kurpita, L., King, C.S., Lynch, J.M., 2021. Sea turtles across the North Pacific are exposed to perfluoroalkyl substances. *Environ. Pollut.* 279. <https://doi.org/10.1016/j.envpol.2021.116875>

Woodcroft, M.W., Ellis, D.A., Rafferty, S.P., Burns, D.C., March, R.E., Stock, N.L., Trumpour, K.S., Yee, J., Munro, K., 2010. Experimental characterization of the mechanism of perfluorocarboxylic acids' liver protein bioaccumulation: The key role of the neutral species. *Environmental Toxicology and Chemistry* 29, 1669–1677. <https://doi.org/10.1002/etc.199>

Woodcroft, M.W., Ellis, D.A., Rafferty, S.P., Burns, D.C., March, R.E., Stock, N.L., Trumpour, K.S., Yee, J., Munro, K., 2010. Experimental characterization of the mechanism of

perfluorocarboxylic acids' liver protein bioaccumulation: The key role of the neutral species. *Environmental Toxicology and Chemistry* 29, 1669–1677. <https://doi.org/10.1002/etc.199>

Woodlief T., Vance S., Hu Q., and DeWitt J. (2021): Immunotoxicity of Per- and Polyfluoroalkyl Substances: Insights into Short-Chain PFAS Exposure. *Toxics* 9 (5). DOI: 10.3390/toxics9050100

WOODLIEF, T., VANCE, S., HU, Q. & DEWITT, J. 2021. Immunotoxicity of Per- and Polyfluoroalkyl Substances: Insights into Short-Chain PFAS Exposure. *Toxics*, 9.

Wu, J., Martin, J.W., Zhai, Z., Lu, K., Li, L., Fang, X., Jin, H., Hu, J., Zhang, J., 2014. Airborne Trifluoroacetic Acid and Its Fraction from the Degradation of HFC-134a in Beijing, China. *Environmental Science & Technology* 48, 3675-3681.

Xiao F. Emerging poly- and perfluoroalkyl substances in the aquatic environment: A review of current literature. *Water Research* 2017; 124: 482-495: <https://doi.org/10.1016/j.watres.2017.07.024>.

Xiao, F. (2017). Emerging poly- and perfluoroalkyl substances in the aquatic environment: A review of current literature. *Water Research*, 124, 482-495. doi:<https://doi.org/10.1016/j.watres.2017.07.024>

Xiao, F., 2017. Emerging poly- and perfluoroalkyl substances in the aquatic environment: A review of current literature. *Water Research* 124, 482-495.

Xie W., Zhong W., Appenzeller B.M.R., Zhang J., Junaid M., and Xu N. (2020): Nexus between perfluoroalkyl compounds (PFCs) and human thyroid dysfunction: A systematic review evidenced from laboratory investigations and epidemiological studies. *Critical Reviews in Environmental Science and Technology*. DOI: 10.1080/10643389.2020.1795052

XIE, W., ZHONG, W., APPENZELLER, B. M. R., ZHANG, J., JUNAID, M. & XU, N. 2020. Nexus between perfluoroalkyl compounds (PFCs) and human thyroid dysfunction: A systematic review evidenced from laboratory investigations and epidemiological studies. *Critical Reviews in Environmental Science and Technology*.

Xie, Z., Wang, Z., Magand, O., Thollot, A., Ebinghaus, R., Mi, W., Dommergue, A., 2020. Occurrence of legacy and emerging organic contaminants in snow at Dome C in the Antarctic. *Sci. Total Environ.* 741.

Xu J, Guo C-S, Zhang Y, Meng W. Bioaccumulation and trophic transfer of perfluorinated compounds in a eutrophic freshwater food web. *Environmental Pollution* 2014; 184: 254-261: <https://doi.org/10.1016/j.envpol.2013.09.011>.

Xu J., Shimpi P., Armstrong L., Salter D., and Slitt A.L. (2016): PFOS induces adipogenesis and glucose uptake in association with activation of Nrf2 signaling pathway. *Toxicol Appl Pharmacol* 290, 21-30. DOI: 10.1016/j.taap.2015.11.002

Xu M., Liu G., Li M., Huo M., Zong W., and Liu R. (2020): Probing the Cell Apoptosis Pathway Induced by Perfluorooctanoic Acid and Perfluorooctane Sulfonate at the Subcellular and Molecular Levels. *Journal of Agricultural and Food Chemistry* 68 (2), 633-641. DOI: 10.1021/acs.jafc.9b07072

XU, J., SHIMPI, P., ARMSTRONG, L., SALTER, D. & SLITT, A. L. 2016. PFOS induces adipogenesis and glucose uptake in association with activation of Nrf2 signaling pathway. *Toxicol Appl Pharmacol*, 290, 21-30.

XU, M., LIU, G., LI, M., HUO, M., ZONG, W. & LIU, R. 2020. Probing the Cell Apoptosis Pathway Induced by Perfluorooctanoic Acid and Perfluorooctane Sulfonate at the Subcellular and Molecular Levels. *Journal of Agricultural and Food Chemistry*, 68, 633-641.

Yahia D., El-Nasser M.A., Abedel-Latif M., Tsukuba C., Yoshida M., Sato I., and Tsuda S. (2010): Effects of perfluorooctanoic acid (PFOA) exposure to pregnant mice on reproduction. *J Toxicol Sci* 35 (4), 527-533. DOI: 10.2131/jts.35.527

Yahia D., Tsukuba C., Yoshida M., Sato I., and Tsuda S. (2008): Neonatal death of mice treated with perfluorooctane sulfonate. *J Toxicol Sci* 33 (2), 219-226. DOI: 10.2131/jts.33.219

YAHIA, D., EL-NASSER, M. A., ABDEL-LATIF, M., TSUKUBA, C., YOSHIDA, M., SATO, I. & TSUDA, S. 2010. Effects of perfluorooctanoic acid (PFOA) exposure to pregnant mice on reproduction. *J Toxicol Sci*, 35, 527-33.

YAHIA, D., TSUKUBA, C., YOSHIDA, M., SATO, I. & TSUDA, S. 2008. Neonatal death of mice treated with perfluorooctane sulfonate. *J Toxicol Sci*, 33, 219-26.

Yamashita, N., Kannan, K., Taniyasu, S., Horii, Y., Okazawa, T., Petrick, G., Gamo, T., 2004. Analysis of Perfluorinated Acids at Parts-Per-Quadrillion Levels in Seawater Using Liquid Chromatography-Tandem Mass Spectrometry. *Environmental Science & Technology* 38, 5522-5528.

Yamashita, N., Taniyasu, S., Petrick, G., Wei, S., Gamo, T., Lam, P.K.S., Kannan, K., 2008. Perfluorinated acids as novel chemical tracers of global circulation of ocean waters. *Chemosphere* 70, 1247.

Yamashita, N., Yeung, L.W.Y., Taniyasu, S., Kwok, K.Y., Petrick, G., Gamo, T., Guruge, K.S., Lam, P.K.S., Loganathan, B.G., 2011. Global distribution of PFOS and related chemicals, *Global Contamination Trends of Persistent Organic Chemicals*, pp. 593-628.

Yamazaki, E., Taniyasu, S., Ruan, Y., Wang, Q., Petrick, G., Tanhua, T., Gamo, T., Wang, X., Lam, P.K.S., Yamashita, N., 2019. Vertical distribution of perfluoroalkyl substances in water columns around the Japan sea and the Mediterranean Sea. *Chemosphere* 231, 487-494.

Yamazaki, E., Taniyasu, S., Wang, X., Yamashita, N., 2021. Per- and polyfluoroalkyl substances in surface water, gas and particle in open ocean and coastal environment. *Chemosphere* 272.

Yamazaki, E., Yamashita, N., Taniyasu, S., Miyazawa, Y., Gamo, T., Ge, H., Kannan, K., 2015. Emission, Dynamics and Transport of Perfluoroalkyl Substances from Land to Ocean by the Great East Japan Earthquake in 2011. *Environmental Science & Technology* 49, 11421-11428.

YANG, C. H., GLOVER, K. P. & HAN, X. 2010. Characterization of cellular uptake of perfluorooctanoate via organic anion-transporting polypeptide 1A2, organic anion transporter 4, and urate transporter 1 for their potential roles in mediating human renal reabsorption of perfluorocarboxylates. *Toxicological Sciences*, 117, 294-302.

Yao X., Sha S., Wang Y., Sun X., Cao J., Kang J., Jiang L., Chen M., and Ma Y. (2016): Perfluorooctane Sulfonate Induces Autophagy-Dependent Apoptosis through Spinster 1-Mediated lysosomal-Mitochondrial Axis and Impaired Mitophagy. *Toxicol Sci* 153 (1), 198-211. DOI: 10.1093/toxsci/kfw118

YAO, X., SHA, S., WANG, Y., SUN, X., CAO, J., KANG, J., JIANG, L., CHEN, M. & MA, Y. 2016. Perfluorooctane Sulfonate Induces Autophagy-Dependent Apoptosis through Spinster 1-Mediated lysosomal-Mitochondrial Axis and Impaired Mitophagy. *Toxicol Sci*, 153, 198-211.

Yeung, L.W.Y., Dassuncao, C., Mabury, S., Sunderland, E.M., Zhang, X., Lohmann, R., 2017. Vertical profiles, sources, and transport of PFASs in the Arctic Ocean. *Environ. Sci. Technol.* 51, 6735.

Yi, L. B., Chai, L. Y., Xie, Y., Peng, Q. J. & Peng, Q. Z. (2016): Isolation, identification, and degradation performance of a PFOA-degrading strain. *Genetics and Molecular Research*, 15, 1-12.

Yi, L. B., Chai, L. Y., Xie, Y., Peng, Q. J. & Peng, Q. Z. (2016): Isolation, identification, and degradation performance of a PFOA-degrading strain. *Genetics and Molecular Research*, 15, 1-12.

YONG, Z. Y., KIM, K. Y. & OH, J. E. 2021. The occurrence and distributions of per- and polyfluoroalkyl substances (PFAS) in groundwater after a PFAS leakage incident in 2018. *Environmental Pollution*, 268.

YOO, H., WASHINGTON, J. W., JENKINS, T. M. & ELLINGTON, J. J. 2011. Quantitative determination of perfluorochemicals and fluorotelomer alcohols in plants from biosolid-amended fields using LC/MS/MS and GC/MS. *Environ Sci Technol*, 45, 7985-90.

Yoo, H., Washington, J. W., Jenkins, T. M., & Ellington, J. J. (2011). Quantitative determination of perfluorochemicals and fluorotelomer alcohols in plants from biosolid-amended fields using LC/MS/MS and GC/MS. *Environ Sci Technol*, 45(19), 7985-7990. doi:10.1021/es102972m

Young C.J. and Mabury S.A. (2010): Atmospheric perfluorinated acid precursors: chemistry, occurrence, and impacts. *Rev Environ Contam Toxicol*, 208, 1-109.

Young C.J., Hurley M.D., Wallington T.J., and Mabury S.A. (2008): Atmospheric chemistry of 4:2 fluorotelomer iodide (n-C₄F₉CH₂CH₂I): kinetics and products of photolysis and reaction with OH radicals and Cl atoms. *J Phys Chem A*, 112 (51), 13542-13548.

Young CJ, Hurley MD, Wallington TJ, Mabury SA (2009): Atmospheric chemistry of perfluorobutenes (CF₃CF=CF and CF₃CF₂CF=CF₂): kinetics and mechanisms of reactions with OH radicals and chlorine atoms, IR spectra, global warming potentials, and oxidation to perfluorocarboxylic acids. *Atmos Environ*, 43, 3717–3724.

Young, C.J., Furdui, V.I., Franklin, J., Koerner, R.M., Muir, D.C.G., Mabury, S.A., 2007. Perfluorinated acids in Arctic snow: New evidence for atmospheric formation. *Environ. Sci. Technol.* 41, 3455.

Yu N, Guo H, Yang J, Jin L, Wang X, Shi W, Zhang X, Yu H, Wei S. 2018. Non-Target and Suspect Screening of Per- and Polyfluoroalkyl Substances in Airborne Particulate Matter in China. *Environmental Science and Technology* 52:8205.

Yu, N., Wen, H., Wang, X., Yamazaki, E., Taniyasu, S., Yamashita, N., Yu, H., Wei, S., 2020. Nontarget Discovery of Per- and Polyfluoroalkyl Substances in Atmospheric Particulate Matter and Gaseous Phase Using Cryogenic Air Sampler. *Environmental Science & Technology* 54, 3103-3113.

Yuan Y., Ding X., Cheng Y., Kang H., Luo T., Zhang X., Kuang H., Chen Y., Zeng X., and Zhang D. (2020): PFOA evokes extracellular Ca²⁺ influx and compromises progesterone-induced response in human sperm. *Chemosphere* 241. DOI: 10.1016/j.chemosphere.2019.125074

YUAN, Y., DING, X., CHENG, Y., KANG, H., LUO, T., ZHANG, X., KUANG, H., CHEN, Y., ZENG, X. & ZHANG, D. 2020. PFOA evokes extracellular Ca²⁺ influx and compromises progesterone-induced response in human sperm. *Chemosphere*, 241.

Zeng Z.J., Ngai S., Wang Q.H., Liang W.T., and Huo X. (2021): Early-life exposure to widespread environmental toxicants and children's health risks: A focus on the post-vaccination antibody potency or immunoglobulin levels. *Science of the Total Environment* 781, 14. DOI: 10.1016/j.scitotenv.2021.146714

ZENG, Z. J., NGAI, S., WANG, Q. H., LIANG, W. T. & HUO, X. 2021. Early-life exposure to widespread environmental toxicants and children's health risks: A focus on the post-vaccination antibody potency or immunoglobulin levels. *Science of the Total Environment*, 781, 14.

Zhai Z, Wu J, Hu X, Li L, Guo J, Zhang B, et al. A 17-fold increase of trifluoroacetic acid in landscape waters of Beijing, China during the last decade. *Chemosphere* 2015; 129: 110-117: <https://doi.org/10.1016/j.chemosphere.2014.09.033>.

Zhai, Z., Wu, J., Hu, X., Li, L., Guo, J., Zhang, B., Hu, J. & Zhang, J. (2015): A 17-fold increase of trifluoroacetic acid in landscape waters of Beijing, China during the last decade. *Chemosphere*, 129, 110-117.

Zhang D.Y., Xu X.L., Ruan Q., Shen X.Y., and Lu Y. (2019): Subchronic effects of perfluorooctane sulphonate on the testicular morphology and spermatogenesis in mice. *Pakistan Journal of Zoology* 51 (6), 2217-2223. DOI: 10.17582/journal.pjz/2019.51.6.2217.2223

Zhang H., Lu H., Chen P., Chen X., Sun C., Ge R.S., Su Z., and Ye L. (2020): Effects of gestational Perfluorooctane Sulfonate exposure on the developments of fetal and adult Leydig cells in F1 males. *Environmental Pollution* 262, 114241. DOI: 10.1016/j.envpol.2020.114241

Zhang J., Begum A., Brännström K., Grundström C., Iakovleva I., Olofsson A., Sauer-Eriksson A.E., and Andersson P.L. (2016a): Structure-Based Virtual Screening Protocol for in Silico Identification of Potential Thyroid Disrupting Chemicals Targeting Transthyretin. *Environmental Science & Technology* 50 (21), 11984-11993. DOI: 10.1021/acs.est.6b02771

Zhang L., Krishnan P., Ehresman D.J., Smith P.B., Dutta M., Bagley B.D., Chang S.C., Butenhoff J.L., Patterson A.D., and Peters J.M. (2016b): Editor's Highlight: Perfluorooctane Sulfonate-Choline Ion Pair Formation: A Potential Mechanism Modulating Hepatic Steatosis and Oxidative Stress in Mice. *Toxicol Sci* 153 (1), 186-197. DOI: 10.1093/toxsci/kfw120

Zhang L., Ren X.-M., Wan B., and Guo L.-H. (2014): Structure-dependent binding and activation of perfluorinated compounds on human peroxisome proliferator-activated receptor γ . *Toxicology and Applied Pharmacology* 279 (3), 275-283. DOI: <https://doi.org/10.1016/j.taap.2014.06.020>

Zhang S., Lu X., Wang N., and Buck R.C. (2016): Biotransformation potential of 6:2 fluorotelomer sulfonate (6:2 FTSA) in aerobic and anaerobic sediment. *Chemosphere*, 154, 224-230.

Zhang S., Szostek B., McCausland P.K., Wolstenholme B.W., Lu X., Wang N., and Buck R.C. (2013): 6:2 and 8:2 fluorotelomer alcohol anaerobic biotransformation in digester sludge from a WWTP under methanogenic conditions. *Environ Sci Technol*, 47 (9), 4227-4235.

ZHANG, D. Q., WANG, M., HE, Q., NIU, X. & LIANG, Y. 2020a. Distribution of perfluoroalkyl substances (PFASs) in aquatic plant-based systems: From soil adsorption and plant uptake to effects on microbial community. *Environmental Pollution*, 257, 113575.

Zhang, D. Q., Wang, M., He, Q., Niu, X., & Liang, Y. (2020). Distribution of perfluoroalkyl substances (PFASs) in aquatic plant-based systems: From soil adsorption and plant uptake to effects on microbial community. *Environmental Pollution*, 257, 113575. doi:10.1016/j.envpol.2019.113575

ZHANG, D. Y., XU, X. L., RUAN, Q., SHEN, X. Y. & LU, Y. 2019a. Subchronic effects of perfluorooctane sulphonate on the testicular morphology and spermatogenesis in mice. *Pakistan Journal of Zoology*, 51, 2217-2223.

Zhang, D.Q., Wang, M., He, Q., Niu, X., Liang, Y., 2020a. Distribution of perfluoroalkyl substances (PFASs) in aquatic plant-based systems: From soil adsorption and plant uptake to effects on microbial community. *Environmental Pollution* 257.

ZHANG, H., LU, H., CHEN, P., CHEN, X., SUN, C., GE, R. S., SU, Z. & YE, L. 2020b. Effects of gestational Perfluorooctane Sulfonate exposure on the developments of fetal and adult Leydig cells in F1 males. *Environ Pollut*, 262, 114241.

ZHANG, J., BEGUM, A., BRÄNNSTRÖM, K., GRUNDSTRÖM, C., IAKOVLEVA, I., OLOFSSON, A., SAUER-ERIKSSON, A. E. & ANDERSSON, P. L. 2016a. Structure-Based Virtual Screening Protocol for in Silico Identification of Potential Thyroid Disrupting Chemicals Targeting Transthyretin. *Environmental Science & Technology*, 50, 11984-11993.

ZHANG, L., KRISHNAN, P., EHRESMAN, D. J., SMITH, P. B., DUTTA, M., BAGLEY, B. D., CHANG, S. C., BUTENHOFF, J. L., PATTERSON, A. D. & PETERS, J. M. 2016b. Editor's Highlight: Perfluorooctane Sulfonate-Choline Ion Pair Formation: A Potential Mechanism Modulating Hepatic Steatosis and Oxidative Stress in Mice. *Toxicol Sci*, 153, 186-97.

Zhang, L., Ren, X.-M., Guo, L.-H., 2013. Structure-based investigation on the interaction of perfluorinated compounds with human liver fatty acid binding protein. *Environmental Science and Technology* 47, 11293–11301. <https://doi.org/10.1021/es4026722>

Zhang, L., Ren, X.-M., Guo, L.-H., 2013. Structure-based investigation on the interaction of perfluorinated compounds with human liver fatty acid binding protein. *Environmental Science and Technology* 47, 11293–11301. <https://doi.org/10.1021/es4026722>

ZHANG, L., SUN, H., WANG, Q., CHEN, H., YAO, Y., ZHAO, Z. & ALDER, A. C. 2019b. Uptake mechanisms of perfluoroalkyl acids with different carbon chain lengths (C2-C8) by wheat (*Triticum aestivum* L.). *Science of The Total Environment*, 654, 19-27.

Zhang, L., Sun, H., Wang, Q., Chen, H., Yao, Y., Zhao, Z., & Alder, A. C. (2019). Uptake mechanisms of perfluoroalkyl acids with different carbon chain lengths (C2-C8) by wheat (*Triticum aestivum* L.). *Science of The Total Environment*, 654, 19-27. doi:10.1016/j.scitotenv.2018.10.443

Zhang, M., Wang, P., Lu, Y., Lu, X., Zhang, A., Liu, Z., Zhang, Y., Khan, K., Sarvajayakesavalu, S., 2020b. Bioaccumulation and human exposure of perfluoroalkyl acids (PFAAs) in vegetables from the largest vegetable production base of China. *Environment International* 135.

Zhang, T., Sun, H., Lin, Y., Qin, X., Zhang, Y., Geng, X., Kannan, K., 2013. Distribution of poly- and perfluoroalkyl substances in matched samples from pregnant women and carbon chain length related maternal transfer. *Environ. Sci. Technol.* 47, 7974.

ZHANG, W., CAO, H. & LIANG, Y. 2021. Plant uptake and soil fractionation of five ether-PFAS in plant-soil systems. *Science of The Total Environment*, 771, 144805.

Zhang, W., Cao, H., & Liang, Y. (2021). Plant uptake and soil fractionation of five ether-PFAS in plant-soil systems. *Science of The Total Environment*, 771, 144805. doi:10.1016/j.scitotenv.2020.144805

Zhang, W., Cao, H., & Liang, Y. (2021). Plant uptake and soil fractionation of five ether-PFAS in plant-soil systems. *Science of the Total Environment*, 771. doi:10.1016/j.scitotenv.2020.144805

Zhang, W., Cao, H., Liang, Y., 2021. Plant uptake and soil fractionation of five ether-PFAS in plant-soil systems. *Sci. Total Environ.* 771.

Zhang, W., Zhang, Y., Taniyasu, S., Yeung, L.W.Y., Lam, P.K.S., Wang, J., Li, X., Yamashita, N., Dai, J., 2013. Distribution and fate of perfluoroalkyl substances in municipal wastewater treatment plants in economically developed areas of China. *Environmental Pollution* 176, 10-17.

Zhang, X., Lohmann, R., Sunderland, E.M., 2019. Poly- And Perfluoroalkyl Substances in Seawater and Plankton from the Northwestern Atlantic Margin. *Environmental Science and Technology* 53, 12348–12356. <https://doi.org/10.1021/acs.est.9b03230>

Zhang, X., Lohmann, R., Sunderland, E.M., 2019. Poly- And Perfluoroalkyl Substances in Seawater and Plankton from the Northwestern Atlantic Margin. *Environmental Science and Technology* 53, 12348–12356. <https://doi.org/10.1021/acs.est.9b03230>

Zhang, Z., Song, N., Peng, Y., Fan, Z., Han, M., Zhao, M., . . . Liu, S. (2018). Environmental pollutant perfluorodecanoic acid upregulates cIAP2 to suppress gastric cell senescence. *Oncol Rep*, 41(2), 981-988. doi:10.3892/or.2018.6856

Zhao J., Hinton P., Chen J., and Jiang J. (2020): Causal inference for the effect of environmental chemicals on chronic kidney disease. *Computational and Structural Biotechnology Journal* 18, 93-99. DOI: 10.1016/j.csbj.2019.12.001

Zhao L., Folsom P.W., Wolstenholme B.W., Sun H., Wang N., and Buck R.C. (2013a): 6:2 fluorotelomer alcohol biotransformation in an aerobic river sediment system. *Chemosphere*, 90 (2), 203-209.

Zhao L., McCausland P.K., Folsom P.W., Wolstenholme B.W., Sun H., Wang N., and Buck R.C. (2013b): 6:2 Fluorotelomer alcohol aerobic biotransformation in activated sludge from two domestic wastewater treatment plants. *Chemosphere*, 92 (4), 464-470.

Zhao S, Zhu L, Liu L, Liu Z, Zhang Y. Bioaccumulation of perfluoroalkyl carboxylates (PFCAs) and perfluoroalkane sulfonates (PFASs) by earthworms (*Eisenia fetida*) in soil. *Environmental Pollution* 2013; 179: 45-52: <https://doi.org/10.1016/j.envpol.2013.04.002>.

Zhao S. and Zhu L. (2017): Uptake and metabolism of 10:2 fluorotelomer alcohol in soil-earthworm (*Eisenia fetida*) and soil-wheat (*Triticum aestivum* L.) systems. *Environmental Pollution*, 220 (Pt A), 124-131.

ZHAO, J., HINTON, P., CHEN, J. & JIANG, J. 2020. Causal inference for the effect of environmental chemicals on chronic kidney disease. *Computational and Structural Biotechnology Journal*, 18, 93-99.

ZHAO, L., BIAN, J., ZHANG, Y., ZHU, L. & LIU, Z. 2014. Comparison of the sorption behaviors and mechanisms of perfluorosulfonates and perfluorocarboxylic acids on three kinds of clay minerals. *Chemosphere*, 114, 51-58.

Zhao, L., Zhu, L., Yang, L., Liu, Z., Zhang, Y., 2012. Distribution and desorption of perfluorinated compounds in fractionated sediments. *Chemosphere* 88, 1390-1397.

ZHAO, S., LIANG, T., ZHOU, T., LI, D., WANG, B., ZHAN, J. & LIU, L. 2018. Biotransformation and responses of antioxidant enzymes in hydroponically cultured soybean and pumpkin exposed to perfluorooctane sulfonamide (FOSA). *Ecotoxicology and Environmental Safety*, 161, 669-675.

Zhao, S., Liang, T., Zhou, T., Li, D., Wang, B., Zhan, J., & Liu, L. (2018). Biotransformation and responses of antioxidant enzymes in hydroponically cultured soybean and pumpkin

exposed to perfluorooctane sulfonamide (FOSA). *Ecotoxicology and Environmental Safety*, 161, 669-675. doi:10.1016/j.ecoenv.2018.06.048

Zhao, S., Liang, T., Zhu, L., Yang, L., Liu, T., Fu, J., . . . Liu, L. (2019). Fate of 6:2 fluorotelomer sulfonic acid in pumpkin (*Cucurbita maxima* L.) based on hydroponic culture: Uptake, translocation and biotransformation. *Environmental Pollution*, 252, 804-812. doi:10.1016/j.envpol.2019.06.020

ZHAO, S., LIANG, T., ZHU, L., YANG, L., LIU, T., FU, J., WANG, B., ZHAN, J. & LIU, L. 2019. Fate of 6:2 fluorotelomer sulfonic acid in pumpkin (*Cucurbita maxima* L.) based on hydroponic culture: Uptake, translocation and biotransformation. *Environmental Pollution*, 252, 804-812.

Zhao, S., Wang, B. & Zhu, L. (2018): Uptake, elimination and biotransformation of N-ethyl perfluorooctanesulfonamide (N-EtFOSA) by the earthworms (*Eisenia fetida*) after in vivo and in vitro exposure. *Environmental Pollution*, 241, 19-25.

Zhao, W., Zitzow, J.D., Weaver, Y., Ehresman, D.J., Chang, S.-C., Butenhoff, J.L., Hagenbuch, B., 2017. Organic anion transporting polypeptides contribute to the disposition of perfluoroalkyl acids in humans and rats. *Toxicological Sciences* 156, 84-95. <https://doi.org/10.1093/toxsci/kfw236>

Zhao, W., Zitzow, J.D., Weaver, Y., Ehresman, D.J., Chang, S.-C., Butenhoff, J.L., Hagenbuch, B., 2017. Organic anion transporting polypeptides contribute to the disposition of perfluoroalkyl acids in humans and rats. *Toxicological Sciences* 156, 84-95. <https://doi.org/10.1093/toxsci/kfw236>

Zhao, Z., Xie, Z., Moller, A., Sturm, R., Tang, J., Zhang, G., Ebinghaus, R., 2012a. Distribution and long-range transport of polyfluoroalkyl substances in the Arctic, Atlantic Ocean and Antarctic coast. *Environ. Pollut.* 170, 71.

Zhao, Z., Xie, Z., Möller, A., Sturm, R., Tang, J., Zhang, G., Ebinghaus, R., 2012b. Distribution and long-range transport of polyfluoroalkyl substances in the Arctic, Atlantic Ocean and Antarctic coast. *Environmental Pollution* 170, 71-77.

Zheng L., Dong G.H., Jin Y.H., and He Q.C. (2009): Immunotoxic changes associated with a 7-day oral exposure to perfluorooctanesulfonate (PFOS) in adult male C57BL/6 mice. *Arch Toxicol* 83 (7), 679-689. DOI: 10.1007/s00204-008-0361-3

Zheng L., Dong G.H., Zhang Y.H., Liang Z.F., Jin Y.H., and He Q.C. (2011): Type 1 and Type 2 cytokines imbalance in adult male C57BL/6 mice following a 7-day oral exposure to perfluorooctanesulfonate (PFOS). *J Immunotoxicol* 8 (1), 30-38. DOI: 10.3109/1547691X.2010.537287

ZHENG, L., DONG, G. H., JIN, Y. H. & HE, Q. C. 2009. Immunotoxic changes associated with a 7-day oral exposure to perfluorooctanesulfonate (PFOS) in adult male C57BL/6 mice. *Arch Toxicol*, 83, 679-89.

ZHENG, L., DONG, G. H., ZHANG, Y. H., LIANG, Z. F., JIN, Y. H. & HE, Q. C. 2011. Type 1 and Type 2 cytokines imbalance in adult male C57BL/6 mice following a 7-day oral exposure to perfluorooctanesulfonate (PFOS). *J Immunotoxicol*, 8, 30-8.

Zhou X., Wang J., Sheng N., Cui R., Deng Y., and Dai J. (2018): Subchronic reproductive effects of 6:2 chlorinated polyfluorinated ether sulfonate (6:2 Cl-PFAES), an alternative to PFOS, on adult male mice. *Journal of Hazardous Materials* 358, 256-264. DOI: 10.1016/j.jhazmat.2018.07.004

Zhou X., Wang J., Sheng N., Cui R., Deng Y., and Dai J. (2018): Subchronic reproductive effects of 6:2 chlorinated polyfluorinated ether sulfonate (6:2 Cl-PFAES), an alternative to

PFOS, on adult male mice. *Journal of Hazardous Materials* 358, 256-264. DOI: <https://doi.org/10.1016/j.jhazmat.2018.07.004>

ZHOU, J., LI, M., LI, J., SHAO, Z., LIU, Y., WANG, T. & ZHU, L. 2020. Bioavailability and Bioaccumulation of 6:2 Fluorotelomer Sulfonate, 6:2 Chlorinated Polyfluoroalkyl Ether Sulfonates, and Perfluorophosphinates in a Soil-Plant System. *Journal of Agricultural and Food Chemistry*, 68, 4325-4334.

Zhou, J., Li, M., Li, J., Shao, Z., Liu, Y., Wang, T., & Zhu, L. (2020). Bioavailability and Bioaccumulation of 6:2 Fluorotelomer Sulfonate, 6:2 Chlorinated Polyfluoroalkyl Ether Sulfonates, and Perfluorophosphinates in a Soil-Plant System. *Journal of Agricultural and Food Chemistry*, 68(15), 4325-4334. doi:10.1021/acs.jafc.0c00542

Zhou, Q., Deng, S., Yu, Q., Zhang, Q., Yu, G., Huang, J., He, H., 2010. Sorption of perfluorooctane sulfonate on organo-montmorillonites. *Chemosphere* 78, 688-694.

ZHOU, X., WANG, J., SHENG, N., CUI, R., DENG, Y. & DAI, J. 2018. Subchronic reproductive effects of 6:2 chlorinated polyfluorinated ether sulfonate (6:2 Cl-PFAES), an alternative to PFOS, on adult male mice. *Journal of Hazardous Materials*, 358, 256-264.

Zhou, Y., Zhou, Z., Lian, Y., Sun, X., Wu, Y., Qiao, L., & Wang, M. (2021). Source, transportation, bioaccumulation, distribution and food risk assessment of perfluorinated alkyl substances in vegetables: A review. *Food Chemistry*, 349, 129137. doi:10.1016/j.foodchem.2021.129137

Zhou, Y., Zhou, Z., Lian, Y., Sun, X., Wu, Y., Qiao, L., Wang, M., 2021. Source, transportation, bioaccumulation, distribution and food risk assessment of perfluorinated alkyl substances in vegetables: A review. *Food Chemistry* 349, 129137.

Zhu, B., Jiang, W., Wang, W., Lin, Y., Ruan, T., Jiang, G. (2019): Occurrence and Degradation Potential of Fluoroalkylsilane Substances as Precursors of Perfluoroalkyl Carboxylic Acids. *Environ Sci Technol*, 53

Zhu, H., Kannan, K., 2019. Distribution and partitioning of perfluoroalkyl carboxylic acids in surface soil, plants, and earthworms at a contaminated site. *Sci. Total Environ.* 647, 954-961.