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ASSESSMENT OF POP CRITERIA FOR SPECIFIC SHORT-CHAIN PERFLUORINATED ALKYL SUBSTANCES

RAMBOLL ENVIRON

ASSESSMENT OF POP CRITERIA FOR SPECIFIC SHORT-CHAIN PERFLUORINATED ALKYL SUBSTANCES

Date	**December 6, 2016**
Description	**Companion Report to Ramboll Environ's January 2014 Assessment of POP Criteria for Specific Short-Chain Perfluorinated Alkyl Substances** **Review of Literature Published After December 2013**

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APPENDICES

1. EXECUTIVE SUMMARY

In January 2014, Environ International Corporation (now Ramboll Environ), prepared a whitepaper on the persistent organic pollutant (POP) characteristics of five short-chain fluorinated chemicals linked to 6:2 fluorotelomer product chemistry, including:

- Commercial Product
  - Short-chain polyfluoroalkyl acrylic polymer based on 6:2 fluorotelomer chemistry (Methacrylate Polymer; No CAS #)
- Manufacturing Intermediates
  - 6:2 fluorotelomer alcohol (6:2 FTOH; CAS # 647-42-7)
  - 6:2 fluorotelomer acrylate (6:2 FTAC; CAS # 17527-29-6)
  - 6:2 fluorotelomer methacrylate (6:2 FTMAC; CAS # 2144-53-8)
- Degradation Product
  - Perfluorohexanoic acid (PFHxA; CAS # 307-24-4) and its anion perfluorohexanoate (PFHx)

Ramboll Environ's January 2014 report considered data from published and unpublished scientific studies related to the POP criteria laid out in Annex D of the Stockholm Convention on Persistent Organic Pollutants, as published by the Stockholm United Nations Environment Programme (UNEP) in 2009, as listed below:

> *"**(b) Persistence:***
>
> *(i) Evidence that the half-life of the chemical in water is greater than two months, or that its half-life in soil is greater than six months, or that its half-life in sediment is greater than six months; or*
>
> *(ii) Evidence that the chemical is otherwise sufficiently persistent to justify its consideration within the scope of this Convention;*
>
> ***(c) Bioaccumulation:***
>
> *(i) Evidence that the bio-concentration factor or bioaccumulation factor in aquatic species for the chemical is greater than 5,000 or, in the absence of such data, that the log KOW is greater than 5;*
>
> *(ii) Evidence that a chemical presents other reasons for concern, such as high bioaccumulation in other species, high toxicity or ecotoxicity;*
>
> *or*
>
> *(iii) Monitoring data in biota indicating that the bioaccumulation potential of the chemical is sufficient to justify its consideration within the scope of this Convention;*
>
> ***(d) Potential for long-range environmental transport:***
>
> *(i) Measured levels of the chemical in locations distant from the sources of its release that are of potential concern;*
>
> *(ii) Monitoring data showing that long-range environmental transport of the chemical, with the potential for transfer to a receiving environment, may have occurred via air, water or migratory species; or*

> *(iii) Environmental fate properties and/or model results that demonstrate that the chemical has a potential for long-range environmental transport through air, water or migratory species, with the potential for transfer to a receiving environment in locations distant from the sources of its release. For a chemical that migrates significantly through the air, its half-life in air should be greater than two days;*
>
> *and*
>
> ***(e) Adverse effects:***
>
> *(i) Evidence of adverse effects to human health or to the environment that justifies consideration of the chemical within the scope of this Convention; or*
>
> *(ii) Toxicity or ecotoxicity data that indicate the potential for damage to human health or to the environment."*

Because Annex D of the Stockholm Convention does not provide numerical criteria for the "Adverse effects" criterion, Ramboll Environ's 2014 report also considered criteria laid out in Annex XIII of the REACH regulations, and guidance issued by the European Chemicals Agency in 2012[1] for identifying persistent, bioaccumulative, and toxic (PBT) substances.

Based on the information available in January 2014, Ramboll Environ concluded that none of the five substances met all of the criteria required to be classified as POPs and none of the substances met more than one criterion.

Earlier this year, the FluoroCouncil asked Ramboll Environ to identify and review relevant literature published since Ramboll Environ's initial assessment. Accordingly, Ramboll Environ searched the SCOPUS and PUBMED literature databases using key words related to the names of the five short-chain PFAS of interest.[2,3] Returned articles were screened based on publication date (published since December 2013) and relevancy to the Stockholm Criteria for persistence, bioaccumulation, potential for long-range environmental transport, and adverse effects to human health and the environment. This report summarizes the relevant literature published since December 2013 and evaluates whether these new studies change the conclusions outlined in Ramboll Environ's initial report. As a result, this report is intended to serve as a companion to Ramboll Environ's 2014 report.

Since 2013, several studies have been published on the environmental fate of the short chain PFAS of interest, including studies related to the degradation potential of the methacrylate polymer, fluorotelomer alcohol, fluorotelomer acrylate, and fluorotelomer methacrylate. Additionally, researchers have continued to measure 6:2 FTOH and PFHxA in remote environments, including the Arctic. Since 2013, additional information has also been published on the health hazards associated with 6:2 FTOH and PFHxA, particularly related to the substantiation of a NOAEL based on rat/mouse studies. Lastly, researchers have looked into the ecotoxicity and bioaccumulation potential of PFHxA. These new data are generally supportive of the primary conclusions reached in Ramboll Environ's initial report; none of the short chain PFAS evaluated in the study meet the Stockholm Convention POP criteria. In fact, as shown in Table 1.1, none of these substances meet more than one criterion.

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[1] Guidance on information requirements and chemical safety assessment: Part C: PBT and vPvB Assessment

[2] The literature search included the following search terms: {6:2 fluorotelomer alcohol} or {6:2 fluorotelomer acrylate} or {6:2 fluorotelomer methacrylate} or {Perfluorohexanoic acid} or {6:2 FTOH} or {6:2 FTAC} or {6:2 FTMAC} or {PFHxA}; Methacrylate and Polymer and Fluorinated; Fluorotelomer and Polymer; Perfluoroalkyl and polymer.

[3] SCOPUS is an ELSEVIER product, available at: https://www.scopus.com/; PUBMED is supported by the National Center for Biotechnology Information (NCBI) and is available at: https://www.ncbi.nlm.nih.gov/pubmed

Table 1.1: Summary of POP criteria for specific short-chain perfluorinated substances

Fluorochemical	Environmental Source	Stockholm Convention POP Criteria					Conclusion
		Persistence	Bioaccumulation	Long-range Environmental Transport	Toxicity		
					Ecotoxicity	Toxicity to Humans	
Methacrylate Polymer	Commercial product	Meets criteria	Does not meet criteria	Does not meet criteria	Does not meet criteria	Does not meet criteria	Does not meet POP criteria (meets 1 of 4)
6:2 FTOH	Manufacturing intermediate	Parent does not meet criteria*	Does not meet criteria	Meets criteria based on atmospheric transport**	Does not meet criteria	Does not meet criteria	Does not meet POP criteria (meets 1 of 4)
6:2 FTAC	Manufacturing intermediate	Parent unlikely to meet criteria*	Does not meet criteria	Unlikely to meet criteria	Does not meet criteria	Does not meet criteria	Does not meet POP criteria (meets 1 of 4)
6:2 FTMAC	Manufacturing intermediate	Parent unlikely to meet criteria*	Does not meet criteria	Does not meet criteria	Does not meet criteria	Does not meet criteria	Does not meet POP criteria (meets 1 of 4)
PFHxA/ PFHx	Degradation product	Meets criteria	Does not meet criteria	Indeterminate	Does not meet criteria	Does not meet criteria	Does not meet POP criteria (meets 1 of 4)

* Parent chemical forms PFHxA as a terminal degradation product

** Additional information is necessary to determine if concentrations in remote environments are of “potential concern” according to Annex D 1 (D) (i).

2. METHACRYLATE POLYMER

2.1 Physical and Chemical Properties

No additional data identified.

2.2 Environmental Fate

Several recent studies suggest that the degradation half-lives of fluorotelomer polymers may be shorter than previously reported, with degradation half-lives on the order of decades, rather than thousands of years. However, these polymers would still be considered persistent based on the Annex D criteria (i.e., degradation half-lives greater than six months).

a) Abiotic degradation

Washington and Jenkins (2015) conducted abiotic hydrolysis experiments on a commercial fluorotelomer polymer. Based on measurements of the hydrolysis products, 8:2 FTOH and 10:2 FTOH, the researchers estimated that the fluorotelomer polymer had a degradation half-life on the order of 55-89 years under neutral conditions and 0.7 years at pH ~12 (Washington and Jenkins 2015).

b) Hydrolysis

See abiotic degradation, above.

c) Phototransformation/photolysis

No additional data identified.

d) Biodegradation

Since 2013, several studies have investigated the degradation of fluorotelomer polymers in soil. Rankin et al. (2014) investigated the degradation of an 8:2 fluorotelomer-based acrylate polymer (FTACP) in a soil-plant microcosm over 5.5 months in the absence/presence of wastewater treatment plant biosolids. This study used a unique FTACP that is a homopolymer of 8:2 fluorotelomer acrylate and structurally different from commercial FTACPs. A FTACP biodegradation half-life of 8-111 years was inferred from measurements of degradation products, including 8:2 FTOH (Rankin et al. 2014). Additionally, Washington et al. (2015) investigated the degradability of two commercial acrylate-linked fluorotelomer polymers in four saturated soils. Estimated half-lives for these fluorotelomer polymers ranged from 33-112 years (Washington et al. 2015).

e) Potential for long-range environmental transport

No additional data identified.

f) Bioaccumulation

No additional data identified.

2.3 Human Health Hazard Assessment

a) Acute and repeat-dose toxicity

No additional data identified.

b) Mutagenicity and carcinogenicity

No additional data identified.

c) Reproductive and developmental toxicity

No additional data identified.

d) Neurotoxicity

No additional data identified.

e) Immunotoxicity

No additional data identified.

f) Acceptable exposure levels

No additional data identified.

2.4 Environmental Health Hazard Assessment

a) Aquatic compartment (including sediment)

No additional data identified.

b) Terrestrial compartment

No additional data identified.

2.5 References

Rankin K, Lee H, Tseng PJ and Mabury SA. 2014. Investigating the biodegradability of a fluorotelomer-based acrylate polymer in a soil-plant microcosm by indirect and direct analysis, 48(21): 12783–12790.

Washington JW and Jenkins TM. 2015. Abiotic Hydrolysis of Fluorotelomer-Based Polymers as a Source of Perfluorocarboxylates at the Global Scale. Environmental Science and Technology, 49(24): 14129–14135.

Washington JW, Jenkins TM, Rankin K and Naile JE. 2015. Decades-scale degradation of commercial, side-chain, fluorotelomer-based polymers in soils and water. Environmental Science and Technology, 49(2): 915–923.

3. 6:2 FLUOROTELOMER ALCOHOL

3.1 Physical and Chemical Properties

No additional data identified.

3.2 Environmental Fate

c) Abiotic degradation

No additional data identified.

d) Hydrolysis

No additional data identified.

e) Phototransformation/photolysis

No additional data identified.

f) Biodegradation

Since 2013, several additional studies have been published that address the biodegradation of 6:2 FTOH. The results of these studies are in keeping with previous studies, which suggest that 6:2 FTOH has an initial transformation half-life of less than two months.

He et al. (2013) measured the aerobic biotransformation of 6:2 FTOH in a closed bottle system with activated sludge. The results of this study confirm that 6:2 FTOH readily degrades in activated sludge with a half-life of 0.9 days. 5:3 polyfluorinated acid (5:3 FTCA) and 5:2 secondary fluorotelomer alcohol (5:2 sFTOH) were the primary metabolites measured at 28 days (He et al. 2013).[4] Similarly, Zhang et al. (2016) found that 6:2 FTOH has a biotransformation half-life of less than 3 days in an aerobic sediment mixture, regardless of initial dose. After 28 days, major degradation products included 5:2 sFTOH, 5:3 Acid, and PFHxA. As discussed in Ramboll Environ's initial report, these metabolites have not been shown to completely degrade in the environment with half-lives less than the six month criterion provided in Annex D.

Additionally, Kim et al. (2014) investigated the microbial aerobic biodegradation of 6:2 FTOH using three alkane-degrading bacteria (*Mycobacterium vaccae* JOB5, *Pseudomonas oleovorans*, and *Pseudomonas butanovora*) and one fluoroacetate-degrading bacterium (*Pseudomonas fluorescens* DSM8341) under aerobic conditions, with and without the external energy source, formate. 6:2 FTOH was degraded by all bacteria, with calculated half-lives of <1 day to >6 days. The researchers concluded that the extent and mechanisms of 6:2 FTOH biotransformation were affected by bacterial strain types, enzyme inducers, and levels of reducing energy (Kim et al. 2014).

Lastly, Tseng et al. (2014) studied the aerobic biotransformation of 6:2 FTOH by white-rot fungus, *Phanerochaete chrysosporium,* in closed bottle system. Results indicate that after 28 days of incubation most of the 6:2 FTOH in the culture medium was transformed to downstream perfluorinated compounds (Tseng et al. 2014).

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[4] Based on information provided in the abstract. Article text is not English.

g) Potential for long-range environmental transport

Since 2013, several additional studies have measured 6:2 FTOH in the air and snow in remote environments, including the Arctic. Air measurements are summarized in Table 3.1, and are within the range of concentrations measured during previous studies in remote areas, as summarized in Ramboll Environ's initial report. 6:2 FTOH concentrations in snow ranged from 1.5-6.6 picograms per liter (pg/L) in samples collected from Arctic glaciers around Ny-Ålesund in January and May of 2012 (Xie et al. 2015) and 5 – 115 pg/L in samples collected from the Antarctic Peninsula in 2010-2011 (Wang et al. 2015). As with the previous studies summarized in Ramboll Environ's initial report, these measurements indicate that 6:2 FTOH is subject to long-range atmospheric transport; however local and/or regional emissions sources are still a possible contributor in some remote areas.

Table 3.1: Identification in Remote Environments

Location	**Date**	**Concentration (pg/m3)**	**Phase**	**Reference**
Villum Research Station, Station Nord in North Greenland (81° 36′ N, 16° 40′ W)	2008-2013	<0.45 - 16.5	Gas and Particle	Bossi, Vorkamp, and Skov 2016
Ny- Ålesund, Arctic (78° 55′ N, 11° 56′ E)	2011-2012	0.6 – 5.1	Gas and Particle	Xie et al. 2015
Northern South China Sea	2013	0.7 – 8.6	Gas	Lai et al. 2016
Atlantic to Southern Ocean	2010-2011	0.14 – 7.82	Gas	Wang et al. 2015

h) Bioaccumulation

No additional data identified.

3.3 Human Health Hazard Assessment

a) Acute and repeat-dose toxicity

One newly identified study provides evidence in support of a no adverse effect level (NOAEL) following acute and repeated exposures to 6:2 FTOH.

In a subchronic study of male and female Crl:CD1(ICR) mice orally administered 6:2 FTOH at dosages of 1, 5, 25, or 100 mg/kg/day, the investigators reported NOAELs of 25 mg/kg/day in male mice (dosed for approximately 70 days prior to mating and two weeks thereafter) and 5 mg/kg/day in female mice (dosed for approximately 14 days prior to mating, two weeks thereafter, and during gestation and lactation until scheduled euthanasia) (Mukerji et al. 2015). In both male and female mice, dosages of 100 mg/kg/day yielded clinical abnormalities and death; signs of clinical toxicity noted prior to death included convulsions, ataxia, tremors, hyperreactivity, increased muscle tone, lethargy, pallor, labored breathing, and gasping. Additional findings in the 100 mg/kg/day dosing group included changes in red and white cell parameters, changes in liver-associated clinical chemistry parameters, changes in kidney and liver weights, changes in the incisor teeth consistent with fluoride exposure, decreases in urea nitrogen, creatinine, and cholesterol, and minimal increases in potassium. The lower NOAEL for female mice (5 mg/kg/day) is a result of more severe liver histopathological findings in this group, compared to male mice; these findings are described in more detail in subsection e), below. Additionally, results specific to the reproductive outcomes of this group are described in subsection c). 6:2 FTOH dosages of ≤25 mg/kg/day did not yield any deaths or clinical signs of toxicity (Mukerji et al. 2015).

The results of a second study, published by Serex and colleagues in 2014, were evaluated and described in the previous Ramboll Environ report (Serex et al. 2014, ENVIRON 2014). At the time of previous writing, this study's findings were unpublished and cited as a DuPont report (report number 23572); literature searches identified this study due to its recent publication in a peer-reviewed journal.

b) Mutagenicity and carcinogenicity

No additional data identified.

c) Reproductive and developmental toxicity

In the study conducted by Mukerji and colleagues, described in subsection a), no adverse reproductive effects were noted at any of the dosage levels tested (1, 5, 25, or 100 mg/kg/day) in either male or female Crl:CD1(ICR) mice. Investigators reported a NOAEL of 25 mg/kg/day for viability and growth of offspring born to the exposed male and female mice; pups of dams administered 100 mg/kg/day exhibited decreased survival, decreased body weight, and delayed maturation (Mukerji et al. 2015).

The results of a second newly identified study, published by O'Connor and colleagues in 2014, were evaluated and described in the previous Ramboll Environ report (O'Connor et al. 2014, ENVIRON 2014). At the time of previous writing, these data was unpublished and cited as a DuPont report (report number 25283); literature searches identified this study due to its recent publication in a peer-reviewed journal.

d) Neurotoxicity

No additional data identified.

e) Immunotoxicity

In the study conducted by Mukerji and colleagues, described in subsection a), male and female mice administered 100 mg/kg/day for approximately 90 days exhibited significant changes in mean liver parameters, with females experiencing greater changes compared to male mice and control female mice (Mukerji et al. 2015). Specifically, most measured liver parameters in highly-exposed female mice were increased by greater than 5-fold and up to 19-fold compared to control mice. Additionally, microscopic findings indicative of liver toxicity were identified in male and female mice in the 100 mg/kg/day dose group, and in low incidence within the group of female mice exposed to 25 mg/kg/day. The liver changes were more severe in female mice and included hepatocellular hypertrophy, oval cell hyperplasia, single cell necrosis of hepatocytes, and cystic degeneration. Minimal microscopic hepatocellular hypertrophy was also present in males administered 25 mg/kg/day, and females administered 5 mg/kg/day, though that is generally considered to be an adaptive rather than an adverse effect; no liver-related findings were identified in the 1 mg/kg/day groups.

f) Acceptable exposure levels

A new study of mice not previously evaluated by Ramboll Environ provides additional support of a NOAEL of 5 mg/kg/day in rodents (Mukerji et al. 2015). This does not change the conclusions of Ramboll Environ's previous report.

3.4 Environmental Health Hazard Assessment

a) Aquatic compartment (including sediment)

No additional data identified.

b) Terrestrial compartment

No additional data identified.

3.5 References

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

ENVIRON. 2014. Assessment of POP Criteria for Specific Short-Chain Perfluorinated Alkyl Substances. January.

Kim MH, Wang N and Chu KH. 2014. 6:2 Fluorotelomer alcohol (6:2 FTOH) biodegradation by multiple microbial species under different physiological conditions. Applied microbiology and biotechnology, 98(4): 1831–40.

Lai S, Song J, Song T, Huang Z, Zhang Y, Zhao Y, Liu G, Zheng J, Mi W, Tang J, Zou S, Ebinghaus R and Xie Z. 2016. Neutral polyfluoroalkyl substances in the atmosphere over the northern South China Sea. Environmental Pollution, 214: 449–455.

Mukerji P, Rae JC, Buck RC and O'Connor JC. 2015. Oral repeated-dose systemic and reproductive toxicity of 6:2 FLUOROTELOMER alcohol in mice. Toxicology Reports, 2: 130–143.

O'Connor JC, Munley SM, Serex TL and Buck RC. 2014. Evaluation of the reproductive and developmental toxicity of 6:2 fluorotelomer alcohol in rats. Toxicology, 317: 6–16.

Serex T, Anand S, Munley S, Donner EM, Frame SR, Buck RC and Loveless SE. 2014. Toxicological evaluation of 6:2 fluorotelomer alcohol. Toxicology, 319: 1–9.

Tseng N, Wang N, Szostek B and Mahendra S. 2014. Biotransformation of 6:2 fluorotelomer alcohol (6:2 FTOH) by a wood-rotting fungus. Environmental science & technology, 48(7): 4012–20.

Xie Z, Wang Z, Mi W, Möller A, Wolschke H and Ebinghaus R. 2015. Neutral Poly-/perfluoroalkyl Substances in Air and Snow from the Arctic. Scientific Reports, 5: 8912.

Wang Z, Xie Z, Mi W, Möller A, Wolschke H and Ebinghaus R. 2015. Neutral Poly/Per-Fluoroalkyl Substances in Air from the Atlantic to the Southern Ocean and in Antarctic Snow. Environmental Science and Technology, 49(13): 7770–7775.

Zhang S, Merino N, Wang N, Ruan T, Lu X. 2016. Impact of 6:2 fluorotelomer alcohol aerobic biotransformation on a sediment microbial community. Environmental science & technology, In Press.

4. 6:2 FLUOROTELOMER ACRYLATE

4.1 Physical and Chemical Properties

No additional data identified.

4.2 Environmental Fate

a) Abiotic degradation

No additional data identified.

b) Hydrolysis

No additional data identified.

c) Phototransformation/photolysis

No additional data identified.

d) Biodegradation

Although no additional biodegradation studies were identified for 6:2 FTAC, Royer et al. (2015) investigated the biodegradation of 8:2 FTAC and 8:2 FTMAC in aerobic soils over 105 days. Royer et al. calculated degradation half-lives for these longer chain compounds based on measurements of transient and terminal degradation products, including 8:2 FTOH. The researchers concluded that both compounds were hydrolyzed at the ester linkage, with a degradation half-life of ≤5 days for 8:2 FTAC (Royer et al. 2015). Although not directly relevant to 6:2 FTAC, this study supports the conclusion that Ramboll Environ reached in its initial report, that 6:2 FTAC biodegrades, but may result in low yields of persistent degradation products.

e) Potential for long-range environmental transport

No additional data identified.

f) Bioaccumulation

No additional data identified.

4.3 Human Health Hazard Assessment

a) Acute and repeat-dose toxicity

No additional data identified.

b) Mutagenicity and carcinogenicity

No additional data identified.

c) Reproductive and developmental toxicity

No additional data identified.

d) Neurotoxicity

No additional data identified.

e) Immunotoxicity

No additional data identified.

f) Acceptable exposure levels

No additional data identified.

4.4 Environmental Health Hazard Assessment

a) Aquatic compartment (including sediment)

No additional data identified.

b) Terrestrial compartment

No additional data identified.

4.5 References

Royer LA, Lee LS, Russell MH, Nies LF and Turco RF. 2015. Microbial transformation of 8:2 fluorotelomer acrylate and methacrylate in aerobic soils. Chemosphere, 129: 54–61.

5. 6:2 FLUOROTELOMER METHACRYLATE

5.1 Physical and Chemical Properties

No additional data identified.

5.2 Environmental Fate

a) Abiotic degradation

No additional data identified.

b) Hydrolysis

No additional data identified.

c) Phototransformation/photolysis

No additional data identified.

d) Biodegradation

No additional biodegradation studies were identified for 6:2 FMTAC; however, as discussed in Section 4.2, Royer et al. (2015) investigated the biodegradation of 8:2 FTAC and 8:2 FTMAC in aerobic soils. The researchers concluded that 8:2 FTMAC was hydrolyzed at the ester linkage, with a degradation half-life of 15 days, based on measurements of transient and terminal degradation products (Royer et al. 2015). This study supports the conclusion that Ramboll Environ reached in its initial report; although 6:2 FMTAC biodegrades, biodegradation may result in low yields of persistent degradation products.

e) Potential for long-range environmental transport

No additional data identified.

f) Bioaccumulation

No additional data identified.

5.3 Human Health Hazard Assessment

a) Acute and repeat-dose toxicity

No additional data identified.

b) Mutagenicity and carcinogenicity

No additional data identified.

c) Reproductive and developmental toxicity

No additional data identified.

d) Neurotoxicity

No additional data identified.

e) Immunotoxicity

No additional data identified.

f) Acceptable exposure levels

No additional data identified.

5.4 Environmental Health Hazard Assessment

a) Aquatic compartment (including sediment)

No additional data identified.

a) Terrestrial compartment

No additional data identified.

5.5 References

Royer LA, Lee LS, Russell MH, Nies LF and Turco RF. 2015. Microbial transformation of 8:2 fluorotelomer acrylate and methacrylate in aerobic soils. Chemosphere, 129: 54–61.

6. PERFLUOROHEXANOIC ACID

6.1 Physical and Chemical Properties

Schindler et al. (2013) used a modified vapor saturation method to measurement ambient temperature vapor pressure for several perfluorinated substances including, PFHxA. The vapor pressure of PFHxA was determined to be 44.00 Pascals (Pa) at 20° Celsius and 84.34 Pa at 27° Celsius (Schindler et al. 2013). These values are somewhat lower than the range of vapor pressures (114-121 Pa at 25° Celsius) provided in Ramboll Environ's initial report, which were estimated using software packages that may not accurately predict the physical and chemical properties of perfluorinated substances. As a result, the experimentally-derived vapor pressures reported in Schindler et al. (2013) are expected to be more accurate than the range provided in Ramboll Environ's initial report. Additionally, Schindler et al. (2013) calculated a freezing point for PFHxA of 291.15 – 293.15 Kelvin.

6.2 Environmental Fate

a) Abiotic degradation

No additional data identified.

b) Hydrolysis

No additional data identified.

c) Phototransformation/photolysis

No additional data identified.

d) Biodegradation

No additional data identified.

e) Potential for long-range environmental transport

Since 2013, several studies have measured PFHxA concentrations in remote environments and evaluated the mechanisms by which PFHxA may be transported in the environment. As shown in Table 6.1, Brumovský et al. (2016) and González-Gaya (2015) measured PFHxA in seawater at concentrations within the range of values listed in Table 6.4 of Ramboll Environ's initial report. Additionally, Rankin et al. (2016) evaluated the distribution of PFAS, including PFHxA, in background surface soils. PFHxA was detected in all samples, including samples collected in Antarctica (98.22±60.28 pg/g); Mapunguwe National Park, South Africa (85.75 ± 9.33 pg/g); Vehendi, Estonia (19.78 ± 6.35 pg/g to 52.86 ± 8.49 pg/g); and Inuvik, Canada (72.71 ± 13.23 pg/g).

Table 6.1: Identification in Remote Environments

Location	Date	Water Concentration (pg/L)	Reference
Western Mediterranean Ocean (surface water)	2014	80 – 189	Brumovský et al. 2016
Tropical and Subtropical Atlantic Ocean (surface water)	2010-2011	Nd – 296	González-Gaya 2015

Rankin et al. (2016) concluded that the remote location of most of the samples, combined with a statistical analysis of the sampling data (i.e., principal component analysis), is indicative of long-range environmental transport. Similar to several previous studies, Rankin et al. (2016) believe that PFHxA may be transported through volatile precursors, such as 6:2 FTOH, which are then subject to gas-phase oxidation and wet or dry deposition (Rankin et al. 2016).

In addition to long-range transport of neutral precursors, Styler et al. (2013) hypothesize that perfluorinated acids may be transported in the atmosphere on the surfaces of metal-rich particles. This is supported by laboratory experiments that show that gas-phase 6:2 FTOH sorbs to the surface of TiO_2, Fe_2O_3, Mauritanian sand, and Icelandic volcanic ash. The researchers also observed the heterogeneous photooxidation of 6:2 FTOH on the surfaces of these substances, resulting in the rapid production and subsequent slow degradation of surface-sorbed perfluorinated carboxylic acids (Styler et al. 2013). These results are merely suggestive and additional research is necessary to investigate whether particle-bound PFCAs, including PFHxA, could be subject to long range environmental transport.

f) Bioaccumulation

a. Empirical Bioaccumulation Evidence from Aquatic Species/Log Kow

Fang et al. (2014) measured PFHxA concentrations in fish from Taihu Lake in China. The detection frequency of PFHxA was only 19% despite relatively high water concentrations. This indicates that PFHxA has a low potential for bioaccumulation in aquatic species. Additionally, concentrations in biota and sediment samples taken from the Pearl River, Hong Kong, and the South China Sea were all below the limits of detection (Zhao et al. 2014).

b. Empirical Bioaccumulation Evidence from Other Species/High Ecotoxicity Concerns

Bizkarguenga et al. (2016) studied the uptake of 8:2 perfluoroalkyl phosphate diester and its degradation products, including PFHxA, by carrots and lettuce grown in compost-amended soils (Bizkarguenga et al. 2016). As shown in Table 6.2, the reported bioconcentration factors for PFHxA are much less than the Annex D criteria of >5,000, supporting the conclusion reached in Ramboll Environ’s initial report that PFHxA does not bioaccumulate to any significant degree. Additionally, Numata et al. (2014) investigated the transfer of a mixture of perfluoroalkyl acids from contaminated feed into the edible tissues of 24 fattening pigs. Biomagnification factors calculated in this study are also reported in Table 6.2.

c. Wildlife Monitoring Studies

Multiple studies were performed that measured the concentration of PFHxA (or PFHx) in wildlife biota, including aquatic and terrestrial species, at various locations, including in remote environments (Table 6.3). These studies generally show low concentrations in predators (polar bears, foxes, and seals), supporting Ramboll Environ’s initial conclusions that PFHxA does not biomagnify. As discussed in Ramboll Environ’s previous report, detection of chemicals in wildlife does not necessarily indicate a high bioaccumulation potential and could instead reflect sensitive analytical methods (Conder et al. 2008).

Table 6.2. Bioaccumulation Metrics for PFHxA

Species	Common Name	BCF	BMF	Units	Basis	Reference
D. carota ssp. sativus, Chantenay	carrot	2.1 - 11	--	dimensionless	Lab	Bizkarguenga et al. 2016
Sus spp.	Whole pig	--	0.13	dimensionless	Lab	Numata et al. 2014
Sus spp.	Pig meat	--	0.08	dimensionless	Lab	Numata et al. 2014
Sus spp.	Pig liver	--	0.42	dimensionless	Lab	Numata et al. 2014

BCF – bioconcentration factor

BMF – biomagnification factor

Table 6.3 – Wildlife Monitoring Data for PFHxA/PFHx

Species	Common Name	Tissue	Concentration	Units	Reference
Ursus maritimus	Polar bear	Brainstem	0.12	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Cerebellum	0.03	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Frontal Cortex	0.06	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Occipital lobe	0.03	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Temporal cortex	0.06	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Striatum	0.16	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Thalamus	0.16	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Hypothalamus	0.17	ng/g ww	Eggers Pedersen et al. 2015
Ursus maritimus	Polar bear	Hippocampus	0.39	ng/g ww	Eggers Pedersen et al. 2015

Species	Common Name	Tissue	Concentration	Units	Reference
Ursus maritimus	Polar bear	Brain avg.	0.13	ng/g ww	Eggers Pedersen et al. 2015
Exopalaemon spp.	White shrimp	Muscle	2.11	ng/g ww	Fang et al. 2014[a]
Reganisalanx brachyrostralis	White bait	Muscle	0.815	ng/g ww	Fang et al. 2014
Ctenogobius giurinus	Gobies	Muscle	3.29	ng/g ww	Fang et al. 2014
NS	Phytoplankton	Whole Body	ND	ng/g ww	Fang et al. 2014
NS	Zooplankton	Whole Body	ND	ng/g ww	Fang et al. 2014
NS	Freshwater mussel	Shell excluded	ND	ng/g ww	Fang et al. 2014
NS	Pearl mussel	Shell excluded	ND	ng/g ww	Fang et al. 2014
Hemiculter lcucisculus	Minnow	Muscle	ND	ng/g ww	Fang et al. 2014
Hypophtha lmichthys molitrix	Silver carp	Muscle	ND	ng/g ww	Fang et al. 2014
Carassius cuvieri	Crucian	Muscle	ND	ng/g ww	Fang et al. 2014
Coilia mystus	Lake Saury	Muscle	ND	ng/g ww	Fang et al. 2014
Cyprinus carpio	Carp	Muscle	ND	ng/g ww	Fang et al. 2014
Culter mongolicus	Mongolian culter	Muscle	ND	ng/g ww	Fang et al. 2014
Oriental weatherfish	Mudfish	Muscle	ND	ng/g ww	Fang et al. 2014
Rhodeus sinensis Gunther	Chinese bitterling	Muscle	ND	ng/g ww	Fang et al. 2014
NS	Tilapia	Muscle	ND-4.0	ng/g dw	Lin et al. 2014
NS	Tilapia	Liver	ND-7.0	ng/g dw	Lin et al. 2014
NS	Catfish	Muscle	ND	ng/g dw	Lin et al. 2014
NS	Catfish	Liver	ND	ng/g dw	Lin et al. 2014
Vulpes	Fox	Liver	<1-1.4	ug/kg ww	Riebe et al. 2016
Rupicapra rupicaptra	Chamois	Liver	<1	ug/kg ww	Riebe et al. 2016
Leptonychotes weddellii	Weddell seal	Plasma	<0.02-0.2	ng/mL	Routti et al. 2015
Phoca vitulina	Harbor seal	Plasma	<0.02-0.04	ng/g ww	Routti et al. 2014
Engraulis encrasicolus	Anchovy*	Muscle	0-0.05	ng/g ww	Yamada et al. 2014
Lophius piscatorius, Lophius budegassa	monkfish*	Muscle	0.4-0.43	ng/g ww	Yamada et al. 2014
Scyliorhinus canicula, Scyliorhinus stellaris	catshark*	Muscle	0.25-0.27	ng/g ww	Yamada et al. 2014
Gadus morhua	cod*	Muscle	0.43	ng/g ww	Yamada et al. 2014

Species	**Common Name**	**Tissue**	**Concentration**	**Units**	**Reference**
Limanda, Microstomus kitt	common dab*	Muscle	0.33-0.34	ng/g ww	Yamada et al. 2014
Hoplostethus atlanticus	orange roughy*	Muscle	1.2	ng/g ww	Yamada et al. 2014
Pleuronectes platessa, Glyptocephalus cynoglossus	plaice/witch*	Muscle	0.87	ng/g ww	Yamada et al. 2014
Mullus barbatus, Mullus surmelutus	goatfish*	Muscle	0.65-0.66	ng/g ww	Yamada et al. 2014
Coryphaenoides rupestris	grenadier*	Muscle	0.19	ng/g ww	Yamada et al. 2014
Trigla lucerna	gurnard*	Muscle	0-0.05	ng/g ww	Yamada et al. 2014
Melanogrammus aeglefinus	haddock*	Muscle	1.01	ng/g ww	Yamada et al. 2014
Merluccius	hake*	Muscle	0.33-0.34	ng/g ww	Yamada et al. 2014
Hippoglossus, Reinhardtius hippoglossoides	halibut*	Muscle	0.13-0.15	ng/g ww	Yamada et al. 2014
Zeus faber	john dory*	Muscle	0.53	ng/g ww	Yamada et al. 2014
Molva, Molva dypterygia	Ling*	Muscle	0.13	ng/g ww	Yamada et al. 2014
Scomber scombrus	mackerel*	Muscle	0.34-0.38	ng/g ww	Yamada et al. 2014
Pollachius	pollack*	Muscle	0.67	ng/g ww	Yamada et al. 2014
Trisopterus luscus	pout*	Muscle	1.06	ng/g ww	Yamada et al. 2014
Raja clavata, Raja naevus, Raja circularis	ray*	Muscle	0.36-0.37	ng/g ww	Yamada et al. 2014
Pollachius virens	saithe*	Muscle	0.16-0.17	ng/g ww	Yamada et al. 2014
Salmo salar	salmon*	Muscle	0.26-0.27	ng/g ww	Yamada et al. 2014
Sardina pilchardus	sardine*	Muscle	0.11-0.14	ng/g ww	Yamada et al. 2014
Scorpaena porcus, Scorpaena scrofa, Helicolenus dactylopterus	scorpionfish*	Muscle	1.6	ng/g ww	Yamada et al. 2014
Dicentrarchus labrax	seabass*	Muscle	0.42-0.44	ng/g ww	Yamada et al. 2014
Spondyliosoma Sparus aurata, Pagellus bogaraveo	sea bream*	Muscle	0.35-0.37	ng/g ww	Yamada et al. 2014

Species	**Common Name**	**Tissue**	**Concentration**	**Units**	**Reference**
Solea	sole*	Muscle	0.5	ng/g ww	Yamada et al. 2014
Xiphias gladius	swordfish*	Muscle	0-0.08	ng/g ww	Yamada et al. 2014
Thunnus	tuna*	Muscle	0.08-1	ng/g ww	Yamada et al. 2014
Merlangius merlangus	whiting*	Muscle	0.41-0.42	ng/g ww	Yamada et al. 2014
Barbus, barbus	Barbel~	Muscle	0-0.38	ng/g ww	Yamada et al. 2014
Alburmus	Bleak~	Muscle	0-0.32	ng/g ww	Yamada et al. 2014
Salmo trutta fario	Brown~	Muscle	0.07-0.21	ng/g ww	Yamada et al. 2014
Squalius cephalus	chub~	Muscle	2.2-2.47	ng/g ww	Yamada et al. 2014
Cyprinus carpio	common carp~	Muscle	0-0.14	ng/g ww	Yamada et al. 2014
Rutilus	common roach~	Muscle	0.11-0.24	ng/g ww	Yamada et al. 2014
Phoxinus	minnow~	Muscle	0-0.37	ng/g ww	Yamada et al. 2014
Anguilla	European eel~	Muscle	0.05-0.34	ng/g ww	Yamada et al. 2014
Perca fluviatilis	European perch~	Muscle	0.03-0.13	ng/g ww	Yamada et al. 2014
Abramis brama	freshwater bream~	Muscle	0.08-0.21	ng/g ww	Yamada et al. 2014
Gobio gobio	gudgeon~	Muscle	3.88-4.1	ng/g ww	Yamada et al. 2014
Esox Lucius	northern pike~	Muscle	0-0.13	ng/g ww	Yamada et al. 2014
Blicca bjoerkna	white bream~	Muscle	0-0.15	ng/g ww	Yamada et al. 2014
Chelon labrosus	thicklip grey mullet~	Muscle	0-0.21	ng/g ww	Yamada et al. 2014
Silurus glanis	wels catfish~	Muscle	0-0.13	ng/g ww	Yamada et al. 2014
Telestes souffia	western vairone~	Muscle	0-0.41	ng/g ww	Yamada et al. 2014
Sander lucioperca	pike-perch~	Muscle	0-0.14	ng/g ww	Yamada et al. 2014

NS – Not specified in report

ND – Not detected

*Data from fresh and frozen marine fish

~Data from fresh freshwater fish

[a] This source reports concentrations for PFHx

6.3 Human Health Hazard Assessment

Two new *in vivo* rodent studies provide additional evidence in support of a NOAEL in mice and rats (Klaunig et al. 2015, Iwai and Hoberman 2014), while three new epidemiological studies provide limited and/or weak evidence for a relationship between PFHxA exposure and specific adverse health effects (Zhou et al. 2016, Fan et al. 2014, Kim et al. 2016). Three *in vitro* studies identified in the updated literature search, which included studies in a human placental choriocarcinoma cell line (Gorrochategui et al. 2014), a fetal human liver cell line (Hu et al. 2014), and mouse melanoma B16 cells (Kasuya and Hatanaka, 2016) were reviewed in detail by Ramboll Environ, but not included in this report. This is because the results of *in vitro* studies are generally of questionable utility and subject to varying interpretation; the results of *in vivo* toxicology studies and epidemiological studies are preferable for health-based assessments whenever possible.

Two new reviews identified in the literature search provide somewhat differing perspectives on PFHxA. The first, by Rice (2015) concludes:

> "[PFHxA] compounds do not appear to possess the biopersistence and potent systemic and reproductive toxicity that are characteristic of C8-PFCs as a class. Instead, data from animal and epidemiological studies indicate that C6-PFCs are rapidly and completely excreted and do not appear to accumulate in biological fluids… PFHxA has a similar profile of toxicological effects to PFOA based on *in vivo* sub-chronic studies in rodents; however, the lack of bioaccumulation in the liver significantly decreases the potency of PFHxA, leading to NOAEL values that are at least an order of magnitude higher than the respective NOAEL values for long-chain PFCs. Moreover, PFHxA has been demonstrated to be non-carcinogenic in rodents, unlike PFOA, and appears to be a far less potent postnatal toxicant (Rice 2015)."

A second review, by Holmquist et al. (2016), includes a hazard-based characterization of PFHxA. According to the researchers, PFHxA presents a "low" hazard for carcinogenicity, mutagenicity/carcinogenicity, and acute toxicity; a "moderate" hazard for reproductive toxicity, developmental toxicity, and repeated dose toxicity; and is designated as having "potentially endocrine activity" and is lacking in neurotoxicity data.

a) Acute and repeat-dose toxicity

Klaunig and colleagues (2015) evaluated the chronic effects of Sprague-Dawley rats' oral consumption of 0, 2.5, 15, and 100 mg/kg/day of PFHxA in males, and 0, 5, 30, and 200 mg/kg/day of PFHxA in females. Rats were fed daily via oral gavage for 104 weeks. Male rats in the 100 mg/kg/day dose group experienced lower urinary pH values and decreases in serum triglycerides and free fatty acids compared to controls; the investigators also noted rales and yellow material on the ventral trunks, anogenital, and/or urogenital areas. Otherwise, the investigators report no statistically significant PFHxA-related changes in survival, body weight, food consumption, functional observational battery results, locomotor activity, hematology parameters, serum chemistry (exceptions noted above), hormone parameters, ophthalmic lesions, non-neoplastic findings, or neoplastic findings in male rats at any dose level. In female rats administered 200 mg/kg/day, the investigators noted pathological changes in the kidneys, specifically papillary necrosis and tubular degeneration. Similar to male rats, investigators noted rales and yellow material on the ventral trunks, anogenital, and/or urogenital areas of high-dose female rats at higher rates compared to male rats. Throughout the study period, high-dose female rats also experienced significantly lower mean red blood cell and hemoglobin values, and increases in reticulocyte counts, though these differences either returned to control levels or did not retain statistical significance by the termination of the study. This study supports a chronic PFHxA consumption NOAEL of 15 mg/kg/day in male rats, and a chronic PFHxA consumption NOAEL of 30 mg/kg/day in female rats (Klaunig et al. 2015).

b) Mutagenicity and carcinogenicity

Klaunig and colleagues, in a study described above (subsection a)), did not find evidence of carcinogenicity in male Sprague-Dawley rats fed PFHxA at 0, 2.5, 15, and 100 mg/kg/day or in female Sprague-Dawley rats fed 0, 5, 30, 200 mg/kg/day PFHxA for 104 weeks (Klaunig et al. 2015).

c) Reproductive and developmental toxicity

A cross-sectional study of 225 Taiwanese adolescents between 13 and 15 years old evaluated the correlation between serum PFHxA concentrations and reproductive hormone (testosterone and estradiol) concentrations (Zhou et al. 2016). The researchers reported a significant negative association between serum PFHxA concentrations and log-transformed testosterone concentrations in boys. However, since this was a cross-sectional study, it is not possible to evaluate causation (Zhou et al. 2016).

Iwai and Hoberman evaluated the reproductive toxicity potential of PFHxA ammonium salt in pregnant Crl:CD1(ICR) mice and their offspring (Iwai and Hoberman, 2014). Pregnant mice were administered 0, 100, 175, 350, and 500 mg/kg/day of the test substance between gestation days 6 and 18. The investigators report a NOAEL of 100 mg/kg/day in maternal mice, as dosages up to and at this level produced no signs of toxicity in mothers or offspring. Dosages at and above 175 mg/kg/day produced stillborn offspring, early offspring deaths (i.e., deaths between days 1 and 4 following birth), offspring with reduced weight, and some offspring with corneal opacity and delays in physical development. In particular, an increased number of offspring died between days 1 and 4 in the 350 mg/kg/day and 500 mg/kg/day dosage groups, compared to control offspring. Further, maternal mice in the 350 and 500 mg/kg/day groups experienced increased mortalities, excess salivation, and changes in body weight gains. While reduced offspring weights were noted across all dosage groups, the reduced weights persisted only in the 350 and 500 mg/kg/day groups (Iwai and Hoberman, 2014).

d) Neurotoxicity

Klaunig and colleagues, in a study described in subsection a), did not note changes in functional observational battery observations or locomotor activity in male Sprague-Dawley rats fed 0, 2.5, 15, and 100 mg/kg/day of PFHxA and female Sprague-Dawley rats fed 0, 5, 30, 200 mg/kg/day PFHxA for 104 weeks, compared to controls (Klaunig et al. 2015). Although some male rats in the 100 mg/kg/day dose group were reported to sleep or lie on their sides at an increased rate compared to control rats, and some female rats in the 5 mg/kg/day group demonstrated lower mean grip strength compared to control rats, these effects were not dose-response related and not correlated with other effects.

e) Immunotoxicity (e.g., spleen, thymus, lymph node weights/histopathology)

A cross-sectional study of 56,554 adults examined the correlation between the Gilbert's Syndrome phenotype and serum PFHxA concentrations; this study's population had a current or past history of living, working, or going to school in six perfluorooctanoic acid-contaminated water service districts in Ohio and West Virginia (Fan et al. 2014). Gilbert's Syndrome, also known as constitutional hepatic dysfunction or familial nonhemolytic jaundice, is an inherited gene mutation estimated to affect between 3 and 7 percent of Americans (Mayo Clinic 2016, NIH 2016). After adjusting for age, gender, race, smoking status, alcohol status, average household income, years of school completed, BMI, and the existence of a regular exercise program, individuals with Gilbert's Syndrome had higher PFHxA serum concentrations compared to healthy controls (mean concentration of 1.12 ng/ml PFHxA in Gilbert's Syndrome population, $p<0.0001$ when compared to controls) (Fan et al. 2014). However, given the cross-sectional nature of this study, it is not possible to determine the direction of association between serum PFHxA concentrations and presence of Gilbert's Syndrome phenotypes.

A case-control study led by Kim et al. (2016) compared the serum PFHxA concentrations of 27 South Korean infants with congenital hypothyroidism with 13 healthy control infants. The researchers were unable to identify a statistically significant correlation between congenital hypothyroidism and the presence of serum PFHxA; however, this study is limited by its small sample size and lack of maternal data (Kim et al. 2016).

f) Acceptable exposure levels

Two *in vivo* studies of rats provide evidence in support of a PFHxA-related NOAEL. Iwai and Hoberman (2014) report a NOAEL of 100 mg/kg/day during gestation for mice, while Klaunig and colleagues (2015) report chronic consumption NOAELs of 15 mg/kg/day and 30 mg/kg/day in male and female rats, respectively. These finding do not change the conclusions reached in the earlier Ramboll Environ report.

6.4 Environmental Health Hazard Assessment

a) Aquatic compartment (including sediment)

Since 2013, an additional study was performed to evaluate the aquatic toxicity of fluoroalkylated polymers and perfluoroalkyl carboxylic acids (PFHxA) in *Daphnia magna* (Barmentlo et al. 2015). An acute immobility test and a chronic reproductive test were performed. During the acute toxicity test an EC50 of 1048 mg/L was determined for PFHxA (Table 6.4). The chronic reproductive toxicity study in daphnia showed a significantly higher reproductive output for daphnids exposed to 3 and 83 mg/L PFHxA compared to controls, and at 770 and 1777 mg/L reproductive output significantly decreased. An EC50 of 776 mg/L was determined for the chronic toxicity test (Barmentlo et al. 2015).

Wang et al. (2014) studied the acute lethality of PFHxA in rotifer and calculated an LC50 of 140 mg/L. Wang et al. also performed a 3-day population growth study and a morphological effects study where they looked at the body size and egg size of rotifers. PFHxA significantly increased the rate of population growth and egg size compared to controls. No significant change was reported in body size after exposure to PFHxA (Wang et al. 2014). The results of these acute studies indicate PFHxA would still be regarded as "practically non-toxic" based on ECHA standards (EC50/LC50 > 100 mg/L).

b) Terrestrial compartment.

No additional data identified.

Table 6.4: Ecotoxicity Data

Species Name	Common Name	Effects Endpoint	Test Conditions	Duration	Acute or Chronic	Exposure Basis	EC50/ LC50	Units	Reference
Daphnia magna	Water flea	Immobility	NS	48-hour	Acute	Measured	1048	mg/L	Barmentlo et al. 2015
Daphnia magna	Water flea	Reproduction	Static-renewal	21-day	Chronic	Measured	776	mg/L	Barmentlo et al. 2015
Bracionus calyciflorus	Rotifer	Lethality	Static	24-hour	Acute	Measured	140	mg/L	Wang et al. 2014

NS – Not specified in report

6.5 References

Barmentlo SH, Stel JM, Van Doorn M, Eschauzier C, De Voogt P and Kraak MHS. 2015. Acute and chronic toxicity of short chained perfluoroalkyl substances to Daphnia magna. Environmental pollution (Barking, Essex : 1987), 198: 47–53.

Bizkarguenaga E, Zabaleta I, Prieto A, Fernandez LA 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.

Brumovský M, Karásková P, Borghini M, Nizzetto L, Brumovsky M, Karaskova P, Borghini M and Nizzetto L. 2016. Per- and polyfluoroalkyl substances in the Western Mediterranean Sea waters. Chemosphere, 159: 308–316.

Conder JM, Hoke RA, de WW, Russell MH, and Buck RC. 2008. Are PFCAs bioaccumulative? A critical review and comparison with regulatory criteria and persistent lipophilic compounds. Environ Sci Technol 42:995-1003.

Eggers Pedersen K, Basu N, Letcher R, Greaves AK, Sonne C, Dietz R and 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). Environmental research, 138: 22–31.

Fan H, Ducatman A and Zhang J. 2014. Perfluorocarbons and Gilbert syndrome (phenotype) in the C8 Health Study Population. Environmental research, 135: 70–5.

Fang S, Chen X, Zhao S, Zhang Y, Jiang W, Yang L and Zhu L. 2014. Trophic magnification and isomer fractionation of perfluoroalkyl substances in the food web of Taihu Lake, China. Environmental science & technology, 48(4): 2173–2182.

González-Gaya B, Dachs J, Roscales JL, Caballero G and Jiménez B. 2014. Perfluoroalkylated substances in the global tropical and subtropical surface oceans. Environmental Science and Technology, 48(22): 13076–13084.

Gorrochategui E, Perez-Albaladejo E, Casas J, Lacorte S and Porte C. 2014. Perfluorinated chemicals: differential toxicity, inhibition of aromatase activity and alteration of cellular lipids in human placental cells. Toxicology and applied pharmacology, 277(2): 124–130.

Holmquist H, Schellenberger S, van der Veen I, Peters GM, Leonards PEG and Cousins IT. 2016, May 1. Properties, performance and associated hazards of state-of-the-art durable water repellent (DWR) chemistry for textile finishing. Elsevier Ltd.

Hu J, Li J, Wang J, Zhang A and Dai J. 2014. Synergistic effects of perfluoroalkyl acids mixtures with J-shaped concentration-responses on viability of a human liver cell line. Chemosphere, 96: 81–88.

Iwai H and Hoberman AM. 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.

Kasuya MC and Hatanaka K. 2016. Cytotoxicity and cellular uptake of perfluorocarboxylic acids. Journal of Fluorine Chemistry, 188: 1–4.

Kim D-H, Kim U-J, Kim H-Y, Choi S-D and Oh J-E. 2016. Perfluoroalkyl substances in serum from South Korean infants with congenital hypothyroidism and healthy infants – Its relationship with thyroid hormones. Environmental Research, 147: 399–404.

Klaunig JE, Shinohara M, Iwai H, Chengelis CP, Kirkpatrick JB, Wang Z and Bruner RH. 2015. Evaluation of the chronic toxicity and carcinogenicity of perfluorohexanoic acid (PFHxA) in Sprague-Dawley rats. Toxicologic pathology, 43(2): 209–220.

Lin AY-C, Panchangam SC, Tsai Y-T and Yu T-H. 2014. Occurrence of perfluorinated compounds in the aquatic environment as found in science park effluent, river water, rainwater, sediments, and biotissues. Environmental Monitoring and Assessment, 186(5): 3265–3275.

Mayo Clinic. 2016. Diseases and Conditions: Liver Disease. http://www.mayoclinic.org/diseases-conditions/gilberts-syndrome/basics/definition/con-20024904

National Institutes of Health. 2016. Gilbert Syndrome. Genetics Home References. US National Library of Medicine. https://ghr.nlm.nih.gov/condition/gilbert-syndrome

Numata J, Kowalczyk J, Adolphs J, Ehlers S, Schafft H, Fuerst P, Müller-Graf C, Lahrssen-Wiederholt M and Greiner M. 2014. Toxicokinetics of Seven Perfluoroalkyl Sulfonic and Carboxylic Acids in Pigs Fed a Contaminated Diet. Journal of Agricultural and Food Chemistry, 62(28): 6861–6870.

Rankin K, Mabury SA, Jenkins TM and Washington JW. 2016. A North American and global survey of perfluoroalkyl substances in surface soils: Distribution patterns and mode of occurrence. Chemosphere, 161: 333–341.

Rice PA. 2015. C6-Perfluorinated Compounds: The New Greaseproofing Agents in Food Packaging. Current environmental health reports, 2(1): 33–40.

Riebe RA, Falk S, Georgii S, Brunn H, Failing K and Stahl T. 2016. Perfluoroalkyl Acid Concentrations in Livers of Fox (Vulpes vulpes) and Chamois (Rupicapra rupicapra) from Germany and Austria. Archives of environmental contamination and toxicology, 71(1): 7–15.

Routti H, Krafft BA, Herzke D, Eisert R and Oftedal O. 2015. Perfluoroalkyl substances detected in the world's southernmost marine mammal, the Weddell seal (Leptonychotes weddellii). Environmental pollution (Barking, Essex : 1987), 197: 62–67.

Schindler BJ, Buchanan JH, Mahle JJ, Peterson GW and Glover TG. 2013. Ambient temperature vapor pressure and adsorption capacity for (perfluorooctyl) ethylene, 3-(perfluorobutyl)propanol, perfluorohexanoic acid, ethyl perfluorooctanoate, and perfluoro-3,6-dioxaheptanoic acid. Journal of Chemical and Engineering Data, 58(6): 1806–1812.

Styler SA, Myers AL and Donaldson DJ. 2013. Heterogeneous photooxidation of fluorotelomer alcohols: A new source of aerosol-phase perfluorinated carboxylic acids. Environmental Science and Technology, 47(12): 6358–6367.

Wang Y, Niu J, Zhang L, Shi J. 204. Toxicity assessment of perfluorinated carboxylic acids (PFCAs) towards the rotifer *Brachionus calyciflioru*. Science of the Total Environment, 491-492: 266-70.

Zhou Y, Hu L-W, Qian ZM, Chang J-J, King C, Paul G, Lin S, Chen P-C, Lee YL and Dong G-H. 2016. Association of perfluoroalkyl substances exposure with reproductive hormone levels in adolescents: By sex status. Environment international, 94: 189–195.

APPENDIX 1
COMPLETE LIST OF LITERATURE CONSIDERED

Ahrens, L., Norström, K., Viktor, T., Cousins, A. P., & Josefsson, S. (2015). Stockholm Arlanda Airport as a source of per- and polyfluoroalkyl substances to water, sediment and fish, 129, 33–38. http://doi.org/10.1016/j.chemosphere.2014.03.136

Alves, A., Jacobs, G., Vanermen, G., Covaci, A., & Voorspoels, S. (2015). New approach for assessing human perfluoroalkyl exposure via hair. Talanta, 144, 574–83. http://doi.org/10.1016/j.talanta.2015.07.009

Anumol, T., Dagnino, S., Vandervort, D. R., & Snyder, S. A. (2016). Transformation of Polyfluorinated compounds in natural waters by advanced oxidation processes. Chemosphere, 144, 1780–7. http://doi.org/10.1016/j.chemosphere.2015.10.070

Appleman, T. D., Higgins, C. P., Quiñones, O., Vanderford, B. J., Kolstad, C., Zeigler-Holady, J. C., … ER, D. (2014). Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems. Water Research, 51, 246–55. http://doi.org/10.1016/j.watres.2013.10.067

Arvaniti, O. S., Asimakopoulos, A. G., Dasenaki, M. E., Ventouri, E. I., Stasinakis, A. S., & Thomaidis, N. S. (2014). Simultaneous determination of eighteen perfluorinated compounds in dissolved and particulate phases of wastewater, and in sewage sludge by liquid chromatography-tandem mass spectrometry. Analytical Methods, 6(5), 1341–1349. http://doi.org/10.1039/c3ay42015a

Bach, C., Boiteux, V., Hemard, J., Colin, A., Rosin, C., Munoz, J.-F., & Dauchy, X. (2016). Simultaneous determination of perfluoroalkyl iodides, perfluoroalkane sulfonamides, fluorotelomer alcohols, fluorotelomer iodides and fluorotelomer acrylates and methacrylates in water and sediments using solid-phase microextraction-gas chromatography/mas. Journal of Chromatography. A, 1448, 98–106. http://doi.org/10.1016/j.chroma.2016.04.025

Baduel, C., Paxman, C. J., & Mueller, J. F. (2015). Perfluoroalkyl substances in a firefighting training ground (FTG), distribution and potential future release. Journal of Hazardous Materials, 296, 46–53. http://doi.org/10.1016/j.jhazmat.2015.03.007

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 (Barking, Essex : 1987), 198, 47–53. http://doi.org/10.1016/j.envpol.2014.12.025

Bizkarguenaga, E., Zabaleta, I., Prieto, A., Fernandez, 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. http://doi.org/10.1016/j.chemosphere.2016.02.130

Bonefeld-Jørgensen, E. C., Long, M., Fredslund, S. O., Bossi, R., & Olsen, J. (2014). Breast cancer risk after exposure to perfluorinated compounds in Danish women: a case–control study nested in the Danish National Birth Cohort. Cancer Causes and Control, 25(11), 1439–1448. http://doi.org/10.1007/s10552-014-0446-7

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. http://doi.org/10.1016/j.envpol.2015.12.026

Brumovský, M., Karásková, P., Borghini, M., Nizzetto, L., Brumovsky, M., Karaskova, P., … Nizzetto, L. (2016). Per- and polyfluoroalkyl substances in the Western Mediterranean Sea waters. Chemosphere, 159, 308–316. http://doi.org/10.1016/j.chemosphere.2016.06.015

Butt, C. M., Muir, D. C. G., & Mabury, S. A. (2014). Biotransformation pathways of fluorotelomer-based polyfluoroalkyl substances: a review. Environmental Toxicology and Chemistry, 33(2), 243–267. http://doi.org/10.1002/etc.2407

Campo, J., Masiá, A., Picó, Y., Farré, M., & Barceló, D. (2014). Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants. The Science of the Total Environment, 472, 912–22. http://doi.org/10.1016/j.scitotenv.2013.11.056

Capriotti, A. L., Cavaliere, C., Cavazzini, A., Foglia, P., Laganà, A., Piovesana, S., & Samperi, R. (2013). High performance liquid chromatography tandem mass spectrometry determination of perfluorinated acids in cow milk. Journal of Chromatography. A, 1319, 72–9. http://doi.org/10.1016/j.chroma.2013.10.029

Cavaliere, C., Capriotti, A. L., Ferraris, F., Foglia, P., Samperi, R., Ventura, S., & Laganà, A. (2016). Multiresidue analysis of endocrine-disrupting compounds and perfluorinated sulfates and carboxylic acids in sediments by ultra-high-performance liquid chromatography-tandem mass spectrometry. Journal of Chromatography A, 1438, 133–142. http://doi.org/10.1016/j.chroma.2016.02.022

Chen, H., Reinhard, M., Nguyen, V. T., & Gin, K. Y.-H. (2016). Reversible and irreversible sorption of perfluorinated compounds (PFCs) by sediments of an urban reservoir. Chemosphere, 144, 1747–1753. http://doi.org/10.1016/j.chemosphere.2015.10.055

Chen, X., Zhu, L., Pan, X., Fang, S., Zhang, Y., & Yang, L. (2015). Isomeric specific partitioning behaviors of perfluoroalkyl substances in water dissolved phase, suspended particulate matters and sediments in Liao River Basin and Taihu Lake, China. Water Research, 80, 235–244. http://doi.org/10.1016/j.watres.2015.04.032

Dellatte, E., Brambilla, G., De Filippis, S. P., di Domenico, A., Pulkrabova, J., Eschauzier, C., … de Voogt, P. (2013). Occurrence of selected perfluorinated alkyl acids in lunch meals served at school canteens in Italy and their relevance for children's intake. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment, 30(9), 1590–1597. http://doi.org/10.1080/19440049.2013.813648

Du, Z., Deng, S., Chen, Y., Wang, B., Huang, J., Wang, Y., & Yu, G. (2015). Removal of perfluorinated carboxylates from washing wastewater of perfluorooctanesulfonyl fluoride using activated carbons and resins. Journal of Hazardous Materials, 286, 136–43. http://doi.org/10.1016/j.jhazmat.2014.12.037

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). Environmental Research, 138, 22–31. http://doi.org/10.1016/j.envres.2015.01.015

Fan, H., Ducatman, A., & Zhang, J. (2014). Perfluorocarbons and Gilbert syndrome (phenotype) in the C8 Health Study Population. Environmental Research, 135, 70–5. http://doi.org/10.1016/j.envres.2014.08.011

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 & Technology, 48(4), 2173–2182. http://doi.org/10.1021/es405018b

Filipovic, M., & Berger, U. (2015). Are perfluoroalkyl acids in waste water treatment plant effluents the result of primary emissions from the technosphere or of environmental recirculation? Chemosphere, 129, 74–80. http://doi.org/10.1016/j.chemosphere.2014.07.082

Filipovic, M., Woldegiorgis, A., Norstrom, K., Bibi, M., Lindberg, M., & Osteras, 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. http://doi.org/10.1016/j.chemosphere.2014.09.005

Fu, Y., Wang, T., Fu, Q., Wang, P., & Lu, Y. (2014). Associations between serum concentrations of perfluoroalkyl acids and serum lipid levels in a Chinese population. Ecotoxicology and Environmental Safety, 106, 246–52. http://doi.org/10.1016/j.ecoenv.2014.04.039

Gallen, C., Drage, D., Kaserzon, S., Baduel, C., Gallen, M., Banks, A., … Mueller, J. F. (2016). Occurrence and distribution of brominated flame retardants and perfluoroalkyl substances in Australian landfill leachate and biosolids. Journal of Hazardous Materials, 312, 55–64. http://doi.org/10.1016/j.jhazmat.2016.03.031

Gebbink, W. A., Berger, U., & Cousins, I. T. (2015). Estimating human exposure to PFOS isomers and PFCA homologues: the relative importance of direct and indirect (precursor) exposure. Environment International, 74, 160–169. http://doi.org/10.1016/j.envint.2014.10.013

Gebbink, W. A., Glynn, A., Darnerud, P. O., & Berger, U. (2015). Perfluoroalkyl acids and their precursors in Swedish food: The relative importance of direct and indirect dietary exposure. Environmental Pollution (Barking, Essex : 1987), 198, 108–115. http://doi.org/10.1016/j.envpol.2014.12.022

Gellrich, V., Brunn, H., & Stahl, T. (2013). Perfluoroalkyl and polyfluoroalkyl substances (PFASs) in mineral water and tap water. Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering, 48(2), 129–135. http://doi.org/10.1080/10934529.2013.719431

Gong, X., Li, B., Liu, Y., Liu, R., & Song, Y. (2015). Pollution levels and ecological risk assessment of typical perfluorinated compounds in riverine water and sediments of Hun River and Daliao River Watershed. Huanjing Kexue Xuebao/Acta Scientiae Circumstantiae, 35(7), 2177–2184. http://doi.org/10.13671/j.hjkxxb.2014.1016

Gong, X., Liu, R., Li, B., Song, Y., & Liu, Y. (2016). Perfluoroalkyl acids in Daliao River system of northeast China: determination, distribution and ecological risk. Environmental Earth Sciences, 75(6). http://doi.org/10.1007/s12665-016-5345-7

González-Gaya, B., Dachs, J., Roscales, J. L., Caballero, G., & Jiménez, B. (2014). Perfluoroalkylated substances in the global tropical and subtropical surface oceans. Environmental Science and Technology, 48(22), 13076–13084. http://doi.org/10.1021/es503490z

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. Toxicology and Applied Pharmacology, 277(2), 124–130. http://doi.org/10.1016/j.taap.2014.03.012

Guerra, P., Kim, M., Kinsman, L., Ng, T., Alaee, M., & Smyth, S. A. (2014). Parameters affecting the formation of perfluoroalkyl acids during wastewater treatment. Journal of Hazardous Materials, 272, 148–54. http://doi.org/10.1016/j.jhazmat.2014.03.016

Guo, C., Zhang, Y., Zhao, X., Du, P., Liu, S., Lv, J., … Xu, J. (2015). Distribution, source characterization and inventory of perfluoroalkyl substances in Taihu Lake, China. Chemosphere, 127, 201–207. http://doi.org/10.1016/j.chemosphere.2015.01.053

He, N., Zhou, M., Wang, L., & Sun, H. (2013). Biodegradation of 6-2 fluorotelomer alcohol in activated sludge. Huanjing Kexue Xuebao/Acta Scientiae Circumstantiae, 33(2), 383–388.

Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84874687241&partnerID=40&md5=54fe3407fc37a8bfd8827b48beb74ab8

He, P., Zhang, H., Li, J., He, L., Luo, J., Liu, G., … Cui, X. (2016). [Residue Characteristics of Perfluorinated Compounds in the Atmosphere of Shenzhen]. Huan jing ke xue= Huanjing kexue, 37(4), 1240–1247.

Hellsing, M. S., Josefsson, S., Hughes, A. V, & Ahrens, L. (2016). Sorption of perfluoroalkyl substances to two types of minerals. Chemosphere, 159, 385–391. http://doi.org/10.1016/j.chemosphere.2016.06.016

Holmquist, H., Schellenberger, S., van der Veen, I., Peters, G. M., Leonards, P. E. G., & Cousins, I. T. (2016, May 1). Properties, performance and associated hazards of state-of-the-art durable water repellent (DWR) chemistry for textile finishing. Elsevier Ltd. http://doi.org/10.1016/j.envint.2016.02.035

Houtz, E. F., Sutton, R., Park, J.-S., & Sedlak, M. (2016). Poly- and perfluoroalkyl substances in wastewater: Significance of unknown precursors, manufacturing shifts, and likely AFFF impacts. Water Research, 95, 142–149. http://doi.org/10.1016/j.watres.2016.02.055

Hu, J., Li, J., Wang, J., Zhang, A., & Dai, J. (2014). Synergistic effects of perfluoroalkyl acids mixtures with J-shaped concentration-responses on viability of a human liver cell line. Chemosphere, 96, 81–88. http://doi.org/10.1016/j.chemosphere.2013.07.033

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. International Journal of Toxicology, 33(3), 219–237. http://doi.org/10.1177/1091581814529449

Jiang, W., Zhang, Y., Yang, L., Chu, X., & Zhu, L. (2015). Perfluoroalkyl acids (PFAAs) with isomer analysis in the commercial PFOS and PFOA products in China. Chemosphere, 127, 180–187. http://doi.org/10.1016/j.chemosphere.2015.01.049

Kang, H., Choi, K., Lee, H.-S., Kim, D.-H., Park, N.-Y., Kim, S., & Kho, Y. (2016). Elevated levels of short carbon-chain PFCAs in breast milk among Korean women: Current status and potential challenges. Environmental Research, 148, 351–359. http://doi.org/10.1016/j.envres.2016.04.017

Karaskova, P., Venier, M., Melymuk, L., Becanova, J., Vojta, S., Prokes, R., … Klánová, J. (2016). Perfluorinated alkyl substances (PFASs) in household dust in Central Europe and North America. Environment International, 94, 315–324. http://doi.org/10.1016/j.envint.2016.05.031

Kasuya, M. C., & Hatanaka, K. (2016). Cytotoxicity and cellular uptake of perfluorocarboxylic acids. Journal of Fluorine Chemistry, 188, 1–4. http://doi.org/10.1016/j.jfluchem.2016.05.006

Kim, D.-H., Kim, U.-J., Kim, H.-Y., Choi, S.-D., & Oh, J.-E. (2016). Perfluoroalkyl substances in serum from South Korean infants with congenital hypothyroidism and healthy infants – Its relationship with thyroid hormones. Environmental Research, 147, 399–404. http://doi.org/10.1016/j.envres.2016.02.037

Kim, D.-H., Lee, M.-Y., Oh, J.-E., DH, K., MY, L., & JE, O. (2014). Perfluorinated compounds in serum and urine samples from children aged 5-13 years in South Korea. Environmental Pollution (Barking, Essex : 1987), 192, 171–8. http://doi.org/10.1016/j.envpol.2014.05.024

Kim, H.-Y., Kim, S.-K., Kang, D.-M., Hwang, Y.-S., & Oh, J.-E. (2014). The relationships between sixteen perfluorinated compound concentrations in blood serum and food, and other parameters, in the general population of South Korea with proportionate stratified sampling method. The Science of the Total Environment, 470–471, 1390–400. http://doi.org/10.1016/j.scitotenv.2013.06.039

Kim, M. H., Wang, N., & Chu, K. H. (2014). 6:2 Fluorotelomer alcohol (6:2 FTOH) biodegradation by multiple microbial species under different physiological conditions. Applied Microbiology and Biotechnology, 98(4), 1831–40. http://doi.org/10.1007/s00253-013-5131-3

Kim, M., Park, M. S., Son, J., Park, I., Lee, H.-S. H.-K. H.-K. H.-S., Kim, C., … Lee, H.-S. H.-K. H.-K. H.-S. (2015). Perfluoroheptanoic acid affects amphibian embryogenesisby inducing the phosphorylation of ERK and JNK. International Journal of Molecular Medicine, 36(6), 1693–700. http://doi.org/10.3892/ijmm.2015.2370

Klaunig, J. E., Shinohara, M., Iwai, H., Chengelis, C. P., Kirkpatrick, J. B., Wang, Z., & 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. http://doi.org/10.1177/0192623314530532

Klenow, S., Heinemeyer, G., Brambilla, G., Dellatte, E., Herzke, D., & de Voogt, P. (2013). Dietary exposure to selected perfluoroalkyl acids (PFAAs) in four European regions. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment, 30(12), 2141–2151. http://doi.org/10.1080/19440049.2013.849006

Kowalczyk, J., Riede, S., Schafft, H., Breves, G., & Lahrssen-Wiederholt, M. (2015). Can perfluoroalkyl acids biodegrade in the rumen simulation technique (RUSITEC)? Environ Sci Eur Environmental Sciences Europe : Bridging Science and Regulation at the Regional and European Level, 27(1), 1–11.

Krafft, M. P., & Riess, J. G. (2015). Selected physicochemical aspects of poly- and perfluoroalkylated substances relevant to performance, environment and sustainability-Part one, 129, 4–19. http://doi.org/10.1016/j.chemosphere.2014.08.039

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. http://doi.org/10.1016/j.chemosphere.2013.09.018

Lai, S., Song, J., Song, T., Huang, Z., Zhang, Y., Zhao, Y., … Xie, Z. (2016). Neutral polyfluoroalkyl substances in the atmosphere over the northern South China Sea. Environmental Pollution, 214, 449–455. http://doi.org/10.1016/j.envpol.2016.04.047

Lang, J. R., Allred, B. M., Peaslee, G. F., Field, J. A., & Barlaz, M. A. (2016). Release of Per- and Polyfluoroalkyl Substances (PFASs) from Carpet and Clothing in Model Anaerobic Landfill Reactors. Environmental Science & Technology, 50(10), 5024–5032. http://doi.org/10.1021/acs.est.5b06237

Lashgari, M., & Lee, H. K. (2014). Determination of perfluorinated carboxylic acids in fish fillet by micro-solid phase extraction, followed by liquid chromatography-triple quadrupole mass spectrometry. Journal of Chromatography. A, 1369, 26–32. http://doi.org/10.1016/j.chroma.2014.09.082

Lin, A. Y.-C., Panchangam, S. C., Tsai, Y.-T., & Yu, T.-H. (2014). Occurrence of perfluorinated compounds in the aquatic environment as found in science park effluent, river water, rainwater, sediments, and biotissues. Environmental Monitoring and Assessment, 186(5), 3265–3275. http://doi.org/10.1007/s10661-014-3617-9

Liu, B., Zhang, H., Xie, L., Li, J., Wang, X., Zhao, L., … Yang, B. (2015). Spatial distribution and partition of perfluoroalkyl acids (PFAAs) in rivers of the Pearl River Delta, southern China. The Science of the Total Environment, 524–525, 1–7. http://doi.org/10.1016/j.scitotenv.2015.04.004

Liu, C., & Liu, J. (2016). Aerobic biotransformation of polyfluoroalkyl phosphate esters (PAPs) in soil. Environmental Pollution (Barking, Essex : 1987), 212, 230–237. http://doi.org/10.1016/j.envpol.2016.01.069

Liu, W.-X., He, W., Qin, N., Kong, X.-Z., He, Q.-S., Yang, B., … Xu, F.-L. (2015). Temporal-spatial distributions and ecological risks of perfluoroalkyl acids (PFAAs) in the surface water from the fifth-largest freshwater lake in China (Lake Chaohu). Environmental Pollution (Barking, Essex : 1987), 200, 24–34. http://doi.org/10.1016/j.envpol.2015.01.028

Liu, W., Takahashi, S., Sakuramachi, Y., Harada, K. H., & Koizumi, A. (2013). Polyfluorinated telomers in indoor air of Japanese houses. Chemosphere, 90(5), 1672–1677. http://doi.org/10.1016/j.chemosphere.2012.09.062

Liu, X., Guo, Z., Folk, E. E., & Roache, N. F. (2015). Determination of fluorotelomer alcohols in selected consumer products and preliminary investigation of their fate in the indoor environment. Chemosphere, 129, 81–86. http://doi.org/10.1016/j.chemosphere.2014.06.012

Liu, X., Yu, Y., Li, Y., Zhang, H., Ling, J., Sun, X., … Duan, G. (2014). Fluorocarbon-bonded magnetic mesoporous microspheres for the analysis of perfluorinated compounds in human serum by high-performance liquid chromatography coupled to tandem mass spectrometry. Analytica Chimica Acta, 844, 35–43. http://doi.org/10.1016/j.aca.2014.07.032

Liu, Y., Jiang, Q., Han, M., Zhao, X., & Guo, R. (2015). Contamination profiles of perfluorinated substances in surface sediments of Hongfeng Lake Basin. Research of Environmental Sciences, 28(4), 517–523. http://doi.org/10.13198/j.issn.1001-6929.2015.04.05

Llorca, M., Farré, M., Karapanagioti, H. K., & Barceló, D. (2014). Levels and fate of perfluoroalkyl substances in beached plastic pellets and sediments collected from Greece. Marine Pollution Bulletin, 87(1–2), 286–91. http://doi.org/10.1016/j.marpolbul.2014.07.036

Lorenzo, M., Campo, J., Farré, M., Pérez, F., Picó, Y., & Barceló, D. (2016). Perfluoroalkyl substances in the Ebro and Guadalquivir river basins (Spain). The Science of the Total Environment, 540, 191–9. http://doi.org/10.1016/j.scitotenv.2015.07.045

Lu, Z., Song, L., Zhao, Z., Ma, Y., Wang, J., Yang, H., … Giesy, J. P. (2015). Occurrence and trends in concentrations of perfluoroalkyl substances (PFASs) in surface waters of eastern China. Chemosphere, 119, 820–827. http://doi.org/10.1016/j.chemosphere.2014.08.045

MacInnis, J. J., VandenBoer, T. C., & Young, C. J. (2016). Development of a gas phase source for perfluoroalkyl acids to examine atmospheric sampling methods. The Analyst, 141(12), 3765–3775. http://doi.org/10.1039/c6an00313c

Martín, J., Rodríguez-Gómez, R., Zafra-Gómez, A., Alonso, E., Vílchez, J. L., & Navalón, A. (2016). Polar stir bars for isolation and preconcentration of perfluoroalkyl substances from human milk samples prior to UHPLC-MS/MS analysis. Bioanalysis, 8(7), 633–647. http://doi.org/10.4155/bio-2015-0009

McKenzie, E. R., Siegrist, R. L., McCray, J. E., & Higgins, C. P. (2016). The influence of a non-aqueous phase liquid (NAPL) and chemical oxidant application on perfluoroalkyl acid (PFAA) fate and transport. Water Research, 92, 199–207. http://doi.org/10.1016/j.watres.2016.01.025

Meng, J., Wang, T., Wang, P., Zhang, Y., Li, Q., Lu, Y., & Giesy, J. P. (2015). Are levels of perfluoroalkyl substances in soil related to urbanization in rapidly developing coastal areas in North China? Environmental Pollution (Barking, Essex : 1987), 199, 102–9. http://doi.org/10.1016/j.envpol.2015.01.022

Moreta, C., & Tena, M. T. (2014). Determination of perfluorinated alkyl acids in corn, popcorn and popcorn bags before and after cooking by focused ultrasound solid-liquid extraction, liquid chromatography and quadrupole-time of flight mass spectrometry. Journal of Chromatography. A, 1355, 211–8. http://doi.org/10.1016/j.chroma.2014.06.018

Mukerji, P., Rae, J. C., Buck, R. C., & O’Connor, J. C. (2015). Oral repeated-dose systemic and reproductive toxicity of 6:2 FLUOROTELOMER alcohol in mice. Toxicology Reports, 2, 130–143. http://doi.org/10.1016/j.toxrep.2014.12.002

Ng, C. A., & Hungerbuehler, K. (2015). Exploring the Use of Molecular Docking to Identify Bioaccumulative Perfluorinated Alkyl Acids (PFAAs). Environmental Science & Technology, 49(20), 12306–12314. http://doi.org/10.1021/acs.est.5b03000

Numata, J., Kowalczyk, J., Adolphs, J., Ehlers, S., Schafft, H., Fuerst, P., … Greiner, M. (2014). Toxicokinetics of Seven Perfluoroalkyl Sulfonic and Carboxylic Acids in Pigs Fed a Contaminated Diet. Journal of Agricultural and Food Chemistry, 62(28), 6861–6870. http://doi.org/10.1021/jf405827u

O’Connor, J. C., Munley, S. M., Serex, T. L., & Buck, R. C. (2014). Evaluation of the reproductive and developmental toxicity of 6:2 fluorotelomer alcohol in rats. Toxicology, 317, 6–16. http://doi.org/10.1016/j.tox.2014.01.002

Pan, C.-G., Ying, G.-G., Zhao, J.-L., Liu, Y.-S., Jiang, Y.-X., & Zhang, Q.-Q. (2014). Spatiotemporal distribution and mass loadings of perfluoroalkyl substances in the Yangtze River of China. The Science of the Total Environment, 493, 580–7. http://doi.org/10.1016/j.scitotenv.2014.06.033

Park, S., Lee, L. S., Medina, V. F., Zull, A., & Waisner, S. (2016). Heat-activated persulfate oxidation of PFOA, 6:2 fluorotelomer sulfonate, and PFOS under conditions suitable for in-situ groundwater remediation. Chemosphere, 145, 376–83. http://doi.org/10.1016/j.chemosphere.2015.11.097

Pisarenko, A. N., Marti, E. J., Gerrity, D., Peller, J. R., & Dickenson, E. R. V. (2015). Effects of molecular ozone and hydroxyl radical on formation of N-nitrosamines and perfluoroalkyl acids during ozonation of treated wastewaters. Environmental Science: Water Research and Technology, 1(5), 668–678. http://doi.org/10.1039/c5ew00046g

Portolés, T., Rosales, L. E., Sancho, J. V, Santos, F. J., & Moyano, E. (2015). Gas chromatography-tandem mass spectrometry with atmospheric pressure chemical ionization for fluorotelomer alcohols and perfluorinated sulfonamides determination. Journal of Chromatography A, 1413, 107–116. http://doi.org/10.1016/j.chroma.2015.08.016

Rand, A. A., & Mabury, S. A. (2014). Protein binding associated with exposure to fluorotelomer alcohols (FTOHs) and polyfluoroalkyl phosphate esters (PAPs) in rats. Environmental Science & Technology, 48(4), 2421–2429. http://doi.org/10.1021/es404390x

Rankin, K., Lee, H., Tseng, P. J., & Mabury, S. A. (2014). Investigating the biodegradability of a fluorotelomer-based acrylate polymer in a soil-plant microcosm by indirect and direct analysis, 48(21), 12783–12790. http://doi.org/10.1021/es502986w

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. http://doi.org/10.1016/j.chemosphere.2016.06.109

Rantakokko, P., Männistö, V., Airaksinen, R., Koponen, J., Viluksela, M., Kiviranta, H., & Pihlajamäki, J. (2015). Persistent organic pollutants and non-alcoholic fatty liver disease in morbidly obese patients: A cohort study. Environmental Health: A Global Access Science Source, 14(1). http://doi.org/10.1186/s12940-015-0066-z

Rice, P. A. (2015). C6-Perfluorinated Compounds: The New Greaseproofing Agents in Food Packaging. Current Environmental Health Reports, 2(1), 33–40. http://doi.org/10.1007/s40572-014-0039-3

Riebe, R. A., Falk, S., Georgii, S., Brunn, H., Failing, K., & Stahl, T. (2016). Perfluoroalkyl Acid Concentrations in Livers of Fox (Vulpes vulpes) and Chamois (Rupicapra rupicapra) from Germany and Austria. Archives of Environmental Contamination and Toxicology, 71(1), 7–15. http://doi.org/10.1007/s00244-015-0250-8

Rodriguez-Jorquera, I. A., Silva-Sanchez, C., Strynar, M., Denslow, N. D., & Toor, G. S. (2016). Footprints of Urban Micro-Pollution in Protected Areas: Investigating the Longitudinal Distribution of Perfluoroalkyl Acids in Wildlife Preserves. PloS One, 11(2), e0148654. http://doi.org/10.1371/journal.pone.0148654

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). Environmental Pollution (Barking, Essex : 1987), 197, 62–67. http://doi.org/10.1016/j.envpol.2014.11.026

Routti, H., Lydersen, C., Hanssen, L., & Kovacs, K. M. (2014). Contaminant levels in the world’s northernmost harbor seals (Phoca vitulina). Marine Pollution Bulletin, 87(1–2), 140–6. http://doi.org/10.1016/j.marpolbul.2014.08.001

Royer, L. A., Lee, L. S., Russell, M. H., Nies, L. F., & Turco, R. F. (2015). Microbial transformation of 8:2 fluorotelomer acrylate and methacrylate in aerobic soils. Chemosphere, 129, 54–61. http://doi.org/10.1016/j.chemosphere.2014.09.077

Ruan, T., Sulecki, L. M., Wolstenholme, B. W., Jiang, G., Wang, N., & Buck, R. C. (2014). 6:2 Fluorotelomer iodide in vitro metabolism by rat liver microsomes: comparison with [1,2-(14)C] 6:2 fluorotelomer alcohol. Chemosphere, 112, 34–41. http://doi.org/10.1016/j.chemosphere.2014.02.068

Russell, M. H., Himmelstein, M. W., & Buck, R. C. (2015). Inhalation and oral toxicokinetics of 6:2 FTOH and its metabolites in mammals. Chemosphere, 120, 328–35. http://doi.org/10.1016/j.chemosphere.2014.07.092

Sanchez-Vidal, A., Llorca, M., Farré, M., Canals, M., Barceló, D., Puig, P., & Calafat, A. (2015). Delivery of unprecedented amounts of perfluoroalkyl substances towards the deep-sea. The Science of the Total Environment, 526, 41–8. http://doi.org/10.1016/j.scitotenv.2015.04.080

Santos, A., Rodriguez, S., Pardo, F., & Romero, A. (2016). Use of Fenton reagent combined with humic acids for the removal of PFOA from contaminated water. The Science of the Total Environment, 563–564, 657–663. http://doi.org/10.1016/j.scitotenv.2015.09.044

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), 114, 337–339. http://doi.org/10.1016/j.chemosphere.2014.05.044

Schindler, B. J., Buchanan, J. H., Mahle, J. J., Peterson, G. W., & Glover, T. G. (2013). Ambient temperature vapor pressure and adsorption capacity for (perfluorooctyl) ethylene, 3-(perfluorobutyl)propanol, perfluorohexanoic acid, ethyl perfluorooctanoate, and perfluoro-3,6-dioxaheptanoic acid. Journal of Chemical and Engineering Data, 58(6), 1806–1812. http://doi.org/10.1021/je400205g

Schwanz, T. G., Llorca, M., Farré, M., & Barceló, D. (2016). Perfluoroalkyl substances assessment in drinking waters from Brazil, France and Spain. The Science of the Total Environment, 539, 143–52. http://doi.org/10.1016/j.scitotenv.2015.08.034

Serex, T., Anand, S., Munley, S., Donner, E. M., Frame, S. R., Buck, R. C., & Loveless, S. E. (2014). Toxicological evaluation of 6:2 fluorotelomer alcohol. Toxicology, 319, 1–9. http://doi.org/10.1016/j.tox.2014.01.009

Shan, G., Chen, X., & Zhu, L. (2015). Occurrence, fluxes and sources of perfluoroalkyl substances with isomer analysis in the snow of northern China. Journal of Hazardous Materials, 299, 639–646. http://doi.org/10.1016/j.jhazmat.2015.07.074

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. The Science of the Total Environment, 490, 351–9. http://doi.org/10.1016/j.scitotenv.2014.05.005

Shao, M., Ding, G., Zhang, J., Wei, L., Xue, H., Zhang, N., … Sun, Y. (2016). Occurrence and distribution of perfluoroalkyl substances (PFASs) in surface water and bottom water of the Shuangtaizi Estuary, China. Environmental Pollution (Barking, Essex : 1987), 216, 675–681. http://doi.org/10.1016/j.envpol.2016.06.031

Sharma, B. M., Bharat, G. K., Tayal, S., Larssen, T., Bečanová, J., Karásková, P., … Nizzetto, L. (2015). Perfluoroalkyl substances (PFAS) in river and ground/drinking water of the Ganges River basin: Emissions and implications for human exposure. Environmental Pollution (Barking, Essex : 1987), 208(Pt B), 704–13. http://doi.org/10.1016/j.envpol.2015.10.050

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(1), 217–227. http://doi.org/10.1007/s00204-014-1391-7

Shiwaku, Y., Lee, P., Thepaksorn, P., Zheng, B., Koizumi, A., & Harada, K. H. (2016). Spatial and temporal trends in perfluorooctanoic and perfluorohexanoic acid in well, surface, and tap water around a fluoropolymer plant in Osaka, Japan. Chemosphere, 164, 603–610. http://doi.org/10.1016/j.chemosphere.2016.09.006

Styler, S. A., Myers, A. L., & Donaldson, D. J. (2013). Heterogeneous photooxidation of fluorotelomer alcohols: A new source of aerosol-phase perfluorinated carboxylic acids. Environmental Science and Technology, 47(12), 6358–6367. http://doi.org/10.1021/es4011509

Surma, M., Giżejewski, Z., & Zieliński, H. (2015). Determination of perfluorinated sulfonate and perfluorinated acids in tissues of free-living European beaver (castor fiber L.) by d-SPE/ micro-UHPLC-MS/MS. Ecotoxicology and Environmental Safety, 120, 436–44. http://doi.org/10.1016/j.ecoenv.2015.06.029

Takemine, S., Matsumura, C., Yamamoto, K., Suzuki, M., Tsurukawa, M., Imaishi, H., … Kondo, A. (2014). Discharge of perfluorinated compounds from rivers and their influence on the coastal seas of Hyogo prefecture, Japan. Environmental Pollution (Barking, Essex : 1987), 184, 397–404. http://doi.org/10.1016/j.envpol.2013.09.016

Tseng, N., Wang, N., Szostek, B., & Mahendra, S. (2014). Biotransformation of 6:2 fluorotelomer alcohol (6:2 FTOH) by a wood-rotting fungus. Environmental Science & Technology, 48(7), 4012–20. http://doi.org/10.1021/es4057483

Valsecchi, S., Conti, D., Crebelli, R., Polesello, S., Rusconi, M., Mazzoni, M., … Aste, F. (2016). Deriving environmental quality standards for perfluorooctanoic acid (PFOA) and related short chain perfluorinated alkyl acids. Journal of Hazardous Materials. http://doi.org/10.1016/j.jhazmat.2016.04.055

Vestergren, R., Herzke, D., Wang, T., & Cousins, I. T. (2015). Are imported consumer products an important diffuse source of PFASs to the Norwegian environment? Environmental Pollution, 198, 223–230. http://doi.org/10.1016/j.envpol.2014.12.034

Wang, Y. H., Hu, L. F., Jiang, W., Nie, Y., Hong, C., & Lu, G. H. (2016). Chitosan coated magnetic nanoparticles for extraction and analysis trace-level perfluorinated compounds in water solution coupled with UPLC-MS/MS. In Material Science and Environmental Engineering - Proceedings of the 3rd annual 2015 International Conference on Material Science and Environmental Engineering, ICMSEE 2015 (pp. 315–320). Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes of Ministry of Education, College of Environment, Hohai University, Nanjing, China. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-84960383184&partnerID=40&md5=087aad5eeb32c5d44a3385921f2da25d

Wang, Y., Niu, J., Zhang, L., & Shi, J. (2014). Toxicity assessment of perfluorinated carboxylic acids (PFCAs) towards the rotifer Brachionus calyciflorus. The Science of the Total Environment, 491–492, 266–70. http://doi.org/10.1016/j.scitotenv.2014.02.028

Wang, Z., Cousins, I. T., Scheringer, M., Buck, R. C., & Hungerbuhler, K. (2014). Global emission inventories for C4-C14 perfluoroalkyl carboxylic acid (PFCA) homologues from 1951 to 2030, part II: the remaining pieces of the puzzle. Environment International, 69, 166–176. http://doi.org/10.1016/j.envint.2014.04.006

Wang, Z., Xie, Z., Mi, W., Möller, A., Wolschke, H., & Ebinghaus, R. (2015). Neutral Poly/Per-Fluoroalkyl Substances in Air from the Atlantic to the Southern Ocean and in Antarctic Snow. Environmental Science and Technology, 49(13), 7770–7775. http://doi.org/10.1021/acs.est.5b00920

Wang, Z., Xie, Z., Möller, A., Mi, W., Wolschke, H., & Ebinghaus, R. (2014). Atmospheric concentrations and gas/particle partitioning of neutral poly- and perfluoroalkyl substances in northern German coast. Atmospheric Environment, 95, 207–213. http://doi.org/10.1016/j.atmosenv.2014.06.036

Washington, J. W., & Jenkins, T. M. (2015). Abiotic Hydrolysis of Fluorotelomer-Based Polymers as a Source of Perfluorocarboxylates at the Global Scale. Environmental Science and Technology, 49(24), 14129–14135. http://doi.org/10.1021/acs.est.5b03686

Washington, J. W., Jenkins, T. M., Rankin, K., & Naile, J. E. (2015). Decades-scale degradation of commercial, side-chain, fluorotelomer-based polymers in soils and water. Environmental Science and Technology, 49(2), 915–923. http://doi.org/10.1021/es504347u

Watanabe, N., Takata, M., Takemine, S., & Yamamoto, K. (2015). Thermal mineralization behavior of PFOA, PFHxA, and PFOS during reactivation of granular activated carbon (GAC) in nitrogen atmosphere. Environmental Science and Pollution Research International. http://doi.org/10.1007/s11356-015-5353-2

Watanabe, N., Takemine, S., Yamamoto, K., Haga, Y., & Takata, M. (2016). Residual organic fluorinated compounds from thermal treatment of PFOA, PFHxA and PFOS adsorbed onto granular activated carbon (GAC). Journal of Material Cycles and Waste Management, 18(4), 625–630. http://doi.org/10.1007/s10163-016-0532-x

Wolf, C. J., Rider, C. V, Lau, C., & Abbott, B. D. (2014). Evaluating the additivity of perfluoroalkyl acids in binary combinations on peroxisome proliferator-activated receptor-alpha activation. Toxicology, 316, 43–54. http://doi.org/10.1016/j.tox.2013.12.002

Xie, Z., Wang, Z., Mi, W., Möller, A., Wolschke, H., & Ebinghaus, R. (2015). Neutral Poly-/perfluoroalkyl Substances in Air and Snow from the Arctic. Scientific Reports, 5, 8912. http://doi.org/10.1038/srep08912

Xu, C., Zhu, J., Li, Y., Yu, Y., & Duan, G. (2015). Fluorous solid-phase extraction (F-SPE) as a pilot tool for quantitative determination of perfluorochemicals in water samples coupled with liquid chromatography-tandem mass spectrometry. RSC Advances, 5(17), 13192–13199. http://doi.org/10.1039/c4ra16040a

Yamada, A., Bemrah, N., Veyrand, B., Pollono, C., Merlo, M., Desvignes, V., … Leblanc, J.-C. (2014). Perfluoroalkyl acid contamination and polyunsaturated fatty acid composition of French freshwater and marine fishes. Journal of Agricultural and Food Chemistry, 62(30), 7593–603. http://doi.org/10.1021/jf501113j

Yamada, A., Bemrah, N., Veyrand, B., Pollono, C., Merlo, M., Desvignes, V., … Leblanc, J. C. (2014). Dietary exposure to perfluoroalkyl acids of specific French adult sub-populations: high seafood consumers, high freshwater fish consumers and pregnant women. The Science of the Total Environment, 491–492, 170–5. http://doi.org/10.1016/j.scitotenv.2014.01.089

Yan, H., Cousins, I. T., Zhang, C., & Zhou, Q. (2015). Perfluoroalkyl acids in municipal landfill leachates from China: Occurrence, fate during leachate treatment and potential impact on groundwater. The Science of the Total Environment, 524–525, 23–31. http://doi.org/10.1016/j.scitotenv.2015.03.111

Yuan, G., Peng, H., Huang, C., & Hu, J. (2016). Ubiquitous Occurrence of Fluorotelomer Alcohols in Eco-Friendly Paper-Made Food-Contact Materials and Their Implication for Human Exposure. Environmental Science and Technology, 50(2), 942–950. http://doi.org/10.1021/acs.est.5b03806

Zafeiraki, E., Costopoulou, D., Vassiliadou, I., Bakeas, E., & Leondiadis, L. (2014). Determination of perfluorinated compounds (PFCs) in various foodstuff packaging materials used in the Greek market. Chemosphere, 94, 169–176. http://doi.org/10.1016/j.chemosphere.2013.09.092

Zafeiraki, E., Costopoulou, D., Vassiliadou, I., Leondiadis, L., Dassenakis, E., Hoogenboom, R. L. A. P., & van Leeuwen, S. P. J. (2016). Perfluoroalkylated substances (PFASs) in home and commercially produced chicken eggs from the Netherlands and Greece. Chemosphere, 144, 2106–12. http://doi.org/10.1016/j.chemosphere.2015.10.105

Zafeiraki, E., Costopoulou, D., Vassiliadou, I., Leondiadis, L., Dassenakis, E., Traag, W., … van Leeuwen, S. P. J. (2015). Determination of perfluoroalkylated substances (PFASs) in drinking water from the Netherlands and Greece. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment, 32(12), 2048–57. http://doi.org/10.1080/19440049.2015.1086823

Zhang, C.-J., Qu, Y., Zhao, X., & Zhou, Q. (2015). Photoinduced Reductive Decomposition of Perflurooctanoic Acid in Water: Effect of Temperature and Ionic Strength. Clean - Soil, Air, Water, 43(2), 223–228. http://doi.org/10.1002/clen.201300869

Zhang, C., Peng, Y., Ning, K., Niu, X., Tan, S., & Su, P. (n.d.). Remediation of Perfluoroalkyl Substances in Landfill Leachates by Electrocoagulation. Clean - Soil, Air, Water, 42(12), 1740–1743. http://doi.org/10.1002/clen.201300563

Zhang, C., Peng, Y., Niu, X., & Ning, K. (2014). Determination of perfluoroalkyl substances in municipal landfill leachates from Beijing, China. Asian Journal of Chemistry, 26(13), 3833–3836. http://doi.org/10.14233/ajchem.2014.15963

Zhang, C., Wang, L., Li, J., Su, P., & Peng, C. (2015). Removal of perfluorinated compounds in wastewater treatment plant effluents by electrochemical oxidation. Water Science and Technology, 71(12), 1783–1789. http://doi.org/10.2166/wst.2015.160

Zhang, H., Chen, Q., Yao, D., Chai, Z., & Shen, J. (2013). Feasibility to monitor environmental organofluorine pollutants using typical plants. Shenzhen Daxue Xuebao (Ligong Ban)/Journal of Shenzhen University Science and Engineering, 30(1), 35–41. http://doi.org/10.3724/SP.J.1249.2013.01035

Zhang, S., Lu, X., Wang, N., & Buck, R. C. (2016). Biotransformation potential of 6:2 fluorotelomer sulfonate (6:2 FTSA) in aerobic and anaerobic sediment. Chemosphere, 154, 224–230. http://doi.org/10.1016/j.chemosphere.2016.03.062

Zhang, S., Merino, N., Wang, N., Ruan, T., & Lu, X. (2016). Impact of 6:2 fluorotelomer alcohol aerobic biotransformation on a sediment microbial community. The Science of the Total Environment. http://doi.org/10.1016/j.scitotenv.2016.09.214

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. http://doi.org/10.1016/j.chemosphere.2014.03.098

Zhao, S., Fang, S., Zhu, L., Liu, L., Liu, Z., & Zhang, Y. (2014). Mutual impacts of wheat (Triticum aestivum L.) and earthworms (Eisenia fetida) on the bioavailability of perfluoroalkyl substances (PFASs) in soil. Environmental Pollution (Barking, Essex : 1987), 184, 495–501. http://doi.org/10.1016/j.envpol.2013.09.032

Zhao, S., & Zhu, L. (2016). Uptake and metabolism of 10:2 fluorotelomer alcohol in soil-earthworm (Eisenia fetida) and soil-wheat (Triticum aestivum L.) systems. Environmental Pollution (Barking, Essex : 1987). http://doi.org/10.1016/j.envpol.2016.09.030

Zhao, Y. G., Wan, H. T., Wong, M. H., & Wong, C. K. C. (2014). Partitioning behavior of perfluorinated compounds between sediment and biota in the Pearl River Delta of South China. Marine Pollution Bulletin, 83(1), 148–154. http://doi.org/10.1016/j.marpolbul.2014.03.060

Zhao, Z., Xie, Z., Tang, J., Sturm, R., Chen, Y., Zhang, G., & Ebinghaus, R. (2015). Seasonal variations and spatial distributions of perfluoroalkyl substances in the rivers Elbe and lower Weser and the North Sea. Chemosphere, 129, 118–25. http://doi.org/10.1016/j.chemosphere.2014.03.050

Zhou, Y., Hu, L.-W., Qian, Z. M., Chang, J.-J., King, C., Paul, G., … Dong, G.-H. (2016). Association of perfluoroalkyl substances exposure with reproductive hormone levels in adolescents: By sex status. Environment International, 94, 189–195. http://doi.org/10.1016/j.envint.2016.05.018

Zhou, Z., Shi, Y., Vestergren, R., Wang, T., Liang, Y., & Cai, Y. (2014). Highly elevated serum concentrations of perfluoroalkyl substances in fishery employees from Tangxun lake, china. Environmental Science & Technology, 48(7), 3864–74. http://doi.org/10.1021/es4057467

Zhu, P., Ling, X., Liu, W., Kong, L., & Yao, Y. (2016). Simple and fast determination of perfluorinated compounds in Taihu Lake by SPE-UHPLC-MS/MS. Journal of Chromatography. B, Analytical Technologies in the Biomedical and Life Sciences, 1031, 61–67. http://doi.org/10.1016/j.jchromb.2016.07.031

Zhu, Y., Qin, X.-D., Zeng, X.-W., Paul, G., Morawska, L., Su, M.-W., … Dong, G.-H. (2016). Associations of serum perfluoroalkyl acid levels with T-helper cell-specific cytokines in children: By gender and asthma status. Science of the Total Environment, 559, 166–173. http://doi.org/10.1016/j.scitotenv.2016.03.187

Zhu, Z., Wang, T., Wang, P., Lu, Y., & Giesy, J. P. (2014). Perfluoroalkyl and polyfluoroalkyl substances in sediments from South Bohai coastal watersheds, China. Marine Pollution Bulletin, 85(2), 619–27. http://doi.org/10.1016/j.marpolbul.2013.12.042

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CONSIDERATION OF PBT INFORMATION IN THE REACH DOSSIERS

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Ms. Bowman,

In December 2016, Ramboll Environ prepared an update to its 2014 whitepaper on the persistent organic pollutant (POP) characteristics of five short-chain fluorinated chemicals linked to 6:2 fluorotelomer product chemistry. The companion report considered scientific literature published after Ramboll Environ issued its original report. Both reports relied upon the criteria outlined in Annex D of the Stockholm Convention on Persistent Organic Pollutants to determine whether specific short-chained fluorinated chemicals meet the criteria for persistence, bioaccumulation, potential for long-range environmental transport, and toxicity (or adverse effects).

Since the companion report was issued in December, the FlouroCouncil has informed Ramboll Environ that the REACH dossiers for 6:2 FTOH, 6:2 FTAC, and 6:2 FTMAC have been updated. These dossiers rely upon unpublished studies submitted to ECHA by various companies, and would not have appeared in our search of the publicly-available literature. The updated REACH dossiers for 6:2 FTAC and 6:2 FTMAC contain PBT assessments for these chemicals.

Based on our review of the PBT assessments in the 6:2 FTAC and 6:2 FTMAC dossiers, 6:2 FTAC has recently been classified as toxic. (6:2 FTMAC is currently classified as not toxic.) The 6:2 FTAC dossier indicates that the chemical's toxic (or T) classification is based on a study of 6:2 FTOH. This study showed effects on liver and teeth of parental mice at doses of 25 mg/kg in females and 100 mg/kg in males after 70 days of exposure. The PBT assessment concluded that 6:2 FTAC should be classified as T because this study indicates 6:2 FTOH meets the STOT-RE Category 2 criteria (i.e., has an effect level >10 - ≤100 mg/kg/day). We were unable to review this study in full, since it is not public and has not been made available to us. However, the reclassification of 6:2 FTAC (or even 6:2 FTOH) as T would not change Ramboll Environ's general conclusion that none of the short-chain PFAS evaluated in our January 2014 and December 2016 whitepapers meet all of the Stockholm Convention criteria for persistence, bioaccumulation, potential for long-range transport, and toxicity.

Yours sincerely

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