



20 June 2018

## **EEB and IPEN Comments to the ANNEX XV RESTRICTION REPORT on C9-C14 PFCAs -including their salts and precursors**

EEB and IPEN welcomes the opportunity to comment on this Restriction Report and thank the German and Swedish authorities for preparing this proposal. We strongly support its recommendation to restrict the manufacturing, use, placing on the market and import of C9-C14 PFCAs, their salts and related substances. We would also like to commend the Dossier Submitters for recommending that the restriction includes recycled material and articles made from recycled materials.

We are, however, extremely concerned that the restriction is not proposed to include “the manufacture of a substance where this occurs as an unintended by-product of the manufacture of fluorochemicals with a carbon chain equal to or shorter than 8 atoms”, as well as the proposed thresholds of PFCAs for mixtures and articles placed on the market. In relation to these concerns and some additional issues, we would like to submit the following information, comments and suggestions.

### **Compelling evidence of need for strong restriction decision**

The dossier provides clear evidence of the long-term, costly and detrimental consequences of continued released of C9-C14 PFCAs. It acknowledges that they are released into the environment during every life cycle step and via various exposure pathways, do not undergo any further abiotic or biotic degradation under environmentally relevant conditions and that they are very likely to cause severe and irreversible adverse effects on the environment and human health if their releases are not minimized. It further described that they are already ubiquitously present in the environment and that remediation of soil and water is difficult and very costly.

While no user of the C9-C14 PFCAs has been identified in the EU, the dossier also states that the availability of fluorine free alternatives for many sectors is growing. It is therefore clear that all evidence and incentives for a strong restriction proposal are there, and that all other considerations must be made with this in mind.

### **PFCAs as by-products**

It is described in the dossier that C9-C14 PFCAs occur as a byproduct in production of PFOA as well as the so-called “C6-based chemistries”, and that these unintended by-products are proposed to not be covered by the restriction.

While PFOA production will decrease once the EU restriction comes into force in 2020 and the substance is listed in the Stockholm Convention, it will not fully cease due to the derogations included in the restriction decision. In addition, the restriction dossier further describes that industry is shifting towards C6 substances, namely perfluorohexanoic acid

(PFHxA) based substances. It is therefore clear that C9-C14 PFCAs will continue to be produced if this exemption is allowed in the restriction decision.

This conclusion is even clearly stated in the dossier itself on page 18:

*“Thus, releases will continue because the substances are unintentional by products during the manufacturing of short-chain alternatives, such as the C6-based chemistries and some remaining uses of C8-based chemistries (derogated uses, such as firefighting foams).”*

In addition, mounting evidence shows that the C6 fluorinated substances are regrettable substitutions that are persistent, bioaccumulate and are toxic. Serious concerns about C6 and C4 fluorinated substances include:

- Many are found in the Arctic, including in wildlife and humans.
- Many are found in remote areas of the Earth including remote mountain areas, in the ocean, and in deep sea locations.
- There is some data indicating that short-chain perfluorinated compounds are more efficiently taken up in food crops.
- Many are found in wildlife and in humans.
- There are many pathways of exposure to these substances including consumer products, household dust, drinking water, and others.
- Those with publicly data indicate transfer from mother to the developing fetus during pregnancy and excretion during breast feeding.
- Those with publicly available data show a variety of serious adverse effects, including in vitro data indicating endocrine disruption, DNA damage, altered differentiation, effects on behavior and cognition, and impaired development, among others. In humans, effects include altering blood lipids, reduced fertility, immunosuppression, thyroid hormone function, and attention deficit disorder among others.
- Claims of confidential business information have obstructed efforts by regulators and scientists to adequately assess the characteristics of the proposed fluorinated alternatives.

Please see Annex 1 for references to peer reviewed scientific studies on these regrettable substitutes.

It is therefore surprising that the restriction proposal instead of discouraging the increased use of C6 fluorinated substances, specifically states that it is not intended to prevent the manufacturing of C6 and other short-chained fluorinated substances. This creates a large gap in the regulation that will cause further harm and costly clean-up measures.

EEB and IPEN therefore propose to remove this suggested exemption.

### **Thresholds for PFCAs should be lowered**

The restriction proposal suggests restricting the use, placing on the market and import of C9-C14 PFCAs, their salts and related substances as substances on their own or in a mixture or in an article or parts therein in a concentration equal to or above 25 ppb for the sum of C9-C14 PFCAs and their salts or 260 ppb for the sum of C9-C14 PFCA related substances. These thresholds are based on the content of PFCAs in mixtures sold to

industry that contain C9-C14 PFCA's and related substances in trace levels up to 25 ppb and 260 ppb, respectively.

Since the primary goal of the proposal is to reduce and eliminate releases of C9-C14 PFCA's and related substances to the environment, these limits should be as low as possible. More importantly, there is no justification for these proposed limits based on environmental and health implications. The limits should be based on emerging scientific evidence, not convenience for industry. For these substances, 25 ppb (25,000 ppt) and 260 ppb (260,000 ppt) are not "trace" amounts and these levels would ensure subsequent soil and water pollution and possibly contamination in people.

Recent advisories and limits for PFAS in drinking water provide useful guidelines on limits. US EPA has a health advisory level of 70 ppt for PFOS and PFOA.<sup>1</sup> The US State of Minnesota has a health advisory limit in drinking water of 35 ppt for PFOA and 27 ppt for PFOS.<sup>2</sup> The US State of Vermont has a drinking water health advisory combined limit for PFOS and PFOA of 20 ppt.<sup>3</sup> In drinking water, the US State of New Jersey has established an enforceable maximum contaminant level for PFOA of 14 ppt and for PFNA, 13 ppt.<sup>4</sup> An analysis including impacts on immune suppression in children has yielded a proposed drinking water limit of 1 ppt.<sup>5</sup>

EEB and IPEN therefore propose to lower PFCA thresholds significantly, to less than 70 parts-per-trillion to fully achieve the intent of this restriction.

### **Semiconductor derogation should be rejected**

Only one, non-EU company has come forward to request a derogation at a very late stage for import of (their) semiconductors. Since sufficient evidence was not provided and no companies in the EU is still using C9-C14 PFCA's intentionally for this or any other purpose, this derogation should not be approved. Furthermore, it is clear that the semiconductor industry is moving away from fluorinated substances. In 2017, the World Semiconductor Council, which includes all major manufacturers in Europe, announced a global phase-out of PFOS and recommended that, "*Governments/Authorities inform their appropriate environmental regulatory ministries and the UN Stockholm Convention of this successful action by the global semiconductor industry.*"<sup>6</sup>

---

<sup>1</sup> <https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos>

<sup>2</sup>

<http://www.health.state.mn.us/divs/eh/hazardous/topics/pfcs/current.html#Example1>

<sup>3</sup> [https://anrweb.vt.gov/PubDocs/DEC/PFOA/PFOA%20-%20PFOS%20Health%20Advisories/Vermont/PFOA PFOS HealthAdvisory June 22 2016 .pdf](https://anrweb.vt.gov/PubDocs/DEC/PFOA/PFOA%20-%20PFOS%20Health%20Advisories/Vermont/PFOA%20PFOS%20HealthAdvisory%20June%2022%202016.pdf)

<sup>4</sup> [http://www.nj.gov/health/ceohs/documents/pfas\\_drinking%20water.pdf](http://www.nj.gov/health/ceohs/documents/pfas_drinking%20water.pdf)

<sup>5</sup> Grandjean P, Budtz-Jorgensen (2013) Immunotoxicity of perfluorinated alkylates: calculation of benchmark doses based on serum concentration in children, Environmental Health 12:35

<sup>6</sup>

[https://www.semiconductors.org/clientuploads/directory/DocumentSIA/International%20Trade%20and%20IP/21st%20WSC%20Joint%20Statement%20May%202017%20Kyo to%20\(Final\).pdf](https://www.semiconductors.org/clientuploads/directory/DocumentSIA/International%20Trade%20and%20IP/21st%20WSC%20Joint%20Statement%20May%202017%20Kyo%20to%20(Final).pdf)

### **Costs for remediation are extremely high**

Finally, we would like to provide some further information in relation to the costs of remediation, which are mentioned in relation to the economic impacts but not quantified. These costs should be clearly stated to make sure that the burden on country budgets is taken into account when considering any exemptions to this restriction. As expected, pollution prevention is far more economical than clean-up. Calculations of the total costs for cleaning up groundwater polluted by PFAS around firefighting areas in Norway show that 3.5-5.5 million euros is required per training site.<sup>7</sup> Industrial sludge disposal on agricultural fields in Germany polluted both surface water and a drinking water reservoir resulting in PFAS contamination in humans. Approximately 2.5 million euros have been spent on clean-up annually since 2006 and operating costs of the water purification plant are approximately 100,000 euros/year.<sup>8</sup> In Sweden, addressing PFAS contamination of drinking water costs Uppsala 1 million euros/year and developing a new water supply in Ronne cost 3 million euros.<sup>9</sup> In the US, the Air Force is expected to spend more than USD\$2 billion for PFAS clean-up around military bases.<sup>10</sup> A single US state spends USD\$2 million per month responding to PFAS contamination.<sup>11</sup>

RAC and SEAC opinions should clearly describe the human and environmental impacts of the suggested derogations, both in terms of harms and of economic cost, in order to allow policy decision makers (REACH Committee and Commission) to fully understand the risks of their decisions.

---

<sup>7</sup> UNEP (2017) Risk management evaluation on pentadecafluorooctanoic acid (CAS No: 335-67-1, PFOA, perfluorooctanoic acid), its salts and PFOA-related compounds, Stockholm Convention POPs Review Committee, UNEP/POPS/POPRC.13/7/Add.2

<sup>8</sup> UNEP (2017) Risk management evaluation on pentadecafluorooctanoic acid (CAS No: 335-67-1, PFOA, perfluorooctanoic acid), its salts and PFOA-related compounds, Stockholm Convention POPs Review Committee, UNEP/POPS/POPRC.13/7/Add.2

<sup>9</sup> UNEP (2017) Risk management evaluation on pentadecafluorooctanoic acid (CAS No: 335-67-1, PFOA, perfluorooctanoic acid), its salts and PFOA-related compounds, Stockholm Convention POPs Review Committee, UNEP/POPS/POPRC.13/7/Add.2

<sup>10</sup> Finley B (2016) Air Force plans to spend \$2 billion to clean up PFC-contaminated water, Denver Post, 2 November 2016 <https://www.denverpost.com/2016/11/02/air-force-plans-to-spend-2-billion-to-clean-up-pfc-contaminated-water/>

<sup>11</sup> Fromson N (2018) State PFAS costs growing officials say Wolverine must pay, WZZM, 17 January 2018 <https://www.wzzm13.com/article/news/local/water-worries/state-pfas-costs-growing-officials-say-wolverine-must-pay/69-508967100>

## Annex 1. Characteristics of C6 and C4 fluorinated substances

### Perfluorohexanoic acid (PFHxA) CAS 307-24-4 is associated with the following adverse characteristics:

Found in the Arctic: “In the Greenland Sea, the ΣPFASs concentrations ranged from 45 to 280 pg/L, and five most frequently detected compounds were perfluorooctanoic acid (PFOA), perfluorohexanesulfonate (PFHxS), perfluorohexanoic acid (PFHxA), perfluorooctane sulfonate (PFOS) and perfluorobutane sulfonate (PFBS)”<sup>12</sup>

Found in remote mountain snow: PFHxA was found in Haba Snow Mountains, China, High Tatras, Slovakia, Alps/Lake Macun, Switzerland, and Kackar Mountains, Turkey.<sup>13</sup>

Alters amphibian embryogenesis: “An initial frog embryo teratogenicity assay-Xenopus (FETAX) assay was performed that identified perfluorohexanoic (PFHxA) and perfluoroheptanoic (PFHpA) acids as potential teratogens and developmental toxicants... immunoblotting revealed that PFHpA significantly increased the phosphorylation of extracellular signal-regulated kinase (ERK) and c-Jun N-terminal kinase (JNK), while PFHxA slightly increased these, as compared with the control. These results suggest that PFHxA and PFHpA are developmental toxicants and teratogens, with PFHpA producing more severe effects on liver and heart development through the induction of ERK and JNK phosphorylation.”<sup>14</sup>

Industry study finds decreased survival in female Sprague Dawley rats: “While no difference in survival rates in males was seen, a dose-dependent decrease in survival in PFHxA-treated female rats was observed.”<sup>15</sup>

Exposes the human fetus via presence in amniotic fluid: “The number of AF samples with detectable concentrations differed by PFAS (PFOA n = 27; PFHxA n = 13; PFNA n = 11; PFOS n = 6; PFHpA n = 5; PFPeA n = 2; other PFASs n = 0) (Table 1). The median concentrations of PFASs in AF were less than corresponding LOQ, except for PFOA, which was the most frequently detected PFAS in AF (median: 0.043 ng/mL) (Table 1). However, the highest mean concentration in AF was found for PFHxA (0.191 ng/mL), followed by PFOA (0.044 ng/mL), PFPeA (0.032 ng/mL), PFNA (0.025 ng/mL), PFOS (0.020 ng/mL), and PFHpA (0.013 ng/mL). The median and mean (range) concentrations of ΣPFASs in AF

---

<sup>12</sup> Zhao Z, Xie Z, Möller A, Sturm R, Tang J, Zhang G, Ebinghaus R (2012) Distribution and long-range transport of polyfluoroalkyl substances in the Arctic, Atlantic Ocean and Antarctic coast, *Environ Pollut* 170:71-77

<sup>13</sup> Cobbing M, Jacobson T, Santen M (2015) Footprints in the snow: Hazardous PFC in remote locations around the globe, Greenpeace

<sup>14</sup> Kim M, Park MS, Son J, Park I, Lee HK, Kim C, Min BH, Ryoo J, Choi KS, Lee DS, Lee HS (2015) Perfluoroheptanoic acid affects amphibian embryogenesis by inducing the phosphorylation of ERK and JNK, *In J Mol Med* 36:1693-1700

<sup>15</sup> Klaunig JE, Shinohara M, Iwai H, Chengelis CP, Kirkpatrick JB, Wang Z, Bruner RH (2015) Evaluation of the chronic toxicity and carcinogenicity of perfluorohexanoic acid (PFHxA) in Sprague-Dawley rats, *Toxicol Pathol* 43:209-220

were 0.262 and 0.289 (0.129–1.234) ng/mL. The detection of PFASs in AF suggests that in addition to maternal transfer via CB, the fetus is also exposed to PFASs through AF.”<sup>16</sup>

Altered testosterone levels in male adolescents: “Among males, PFASs were negatively associated with ln(testosterone) level for PFOS ( $\beta=-0.0029$ , 95%CI: -0.0055, -0.0003), PFDA ( $\beta=-0.2565$ , 95%CI: -0.4135, -0.0994), PFHxA ( $\beta=-0.3095$ , 95%CI: -0.5942, -0.0248), and PFNA ( $\beta=-0.4233$ , 95%CI: -0.6998, -0.1467). Furthermore, male participant ln(estradiol) levels were positively associated with PFOA ( $\beta=0.0921$ , 95%CI: 0.0186, 0.1656), and PFHxS ( $\beta=0.0462$ , 95%CI: 0.0020, 0.0905).”<sup>17</sup>

Found in higher concentrations in people with Gilbert Syndrome: “Gilbert syndrome (GS) is an inherited defect of bilirubin conjugation, most commonly caused by a gene mutation for the enzyme UGT1A. GS is known to affect the metabolism and excretion of drugs and xenobiotics...Among 10 PFC compounds considered, only perfluorohexanoic acid (PFHxA) was seen at a significantly higher concentration in GS men and women. PFHxA exposure may be associated with GS.”<sup>18</sup>

Found in world’s southernmost marine mammal: “Perfluoroundecanoic acid (PFUnDA) was detected in all samples at concentrations ranging from 0.08 to 0.23 ng/ml. Perfluorooctane sulfonate (PFOS), perfluorohexanoate (PFHxA) and perfluorotridecanoate (PFTriDA) were sporadically detected, while the remaining compounds were below the limit of detection. This is the first report of detectible concentrations of PFASs in an endemic Antarctic marine mammal species. We suggest that the pollutants have been subjected to long range atmospheric transportation and/or derive from a local source. A review of these and published data indicate that perfluoroalkyl carboxylates (PFCAs) dominate in biotic PFAS patterns in species feeding south of the Antarctic Circumpolar Current (ACC), whereas PFOS was the major PFAS detected in species feeding predominantly north of the current.”<sup>19</sup>

Marine fish contamination in France: “Freshwater fish contamination is mostly driven by perfluorooctane sulfonate (PFOS) (75%), whereas marine fish contamination is split between perfluorooctanoic acid (PFOA) (24%), PFOS (20%), perfluorohexanoic acid (PFHxA) (15%), perfluoropentanoic acid (PFHpA) (11%), and perfluorobutanoic acid (PFBA) (11%). Common carp, pike-perch, European perch, thicklip grey mullet, and common roach presented the most unfavorable balance profile due to their high level of PFAAs and low level of n-3 long-chain polyunsaturated fatty acids (LC-PUFAs).”<sup>20</sup>

---

<sup>16</sup> Zhang Tao, Sun H, Lin Y, Qin X, Zhang Y, Gen X, Kannan K (2013) Distribution of poly- and perfluoroalkyl substances in matched samples from pregnant women and carbon chain length related maternal transfer, *Environ Sci Technol* 47:7974-7981

<sup>17</sup> Zhou Y, Hu LW, Qian ZM, Chang JJ, King C, Paul G, Lin S, Chen PC, Lee YL, Dong GH (2016) *Environ Int* 94:189-195

<sup>18</sup> Fan H, Ducatman A, Zhang J (2014) Perfluorocarbons and Gilbert syndrome (phenotype) in the C8 Health Study Population, *Environ Res* 135:70-75

<sup>19</sup> Routti H, Krafft BA, Herzke D, Eisert R, Oftedal O (2015) Perfluoroalkyl substances detected in the world's southernmost marine mammal, the Weddell seal (*Leptonychotes weddellii*), *Environ Pollut* 197:62-67

<sup>20</sup> Yamada A, Bemrah N, Veyrand B, Pollono C, Merlo M, Desvignes V, Sirot V, Oseredczuk M, Marchand P, Cariou R, Antignac JP, Le Bizec B, Leblanc JS (2014)

Found in Korean breast milk: “Perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), and perfluoroheptanoic acid (PFHpA) were detected in higher frequencies, ranging between 67.4% and 81.8%. The concentrations of short carbon-chain PFCAs in breast milk such as PFPeA and PFHxA were the highest ever reported to date, and were comparable to that of PFOS... Fish consumption and the use of consumer products, e.g., skin care products, cosmetics and non-stick coated cooking utensils, were identified as significant predictors of PFAS concentrations in breast milk.”<sup>21</sup>

Human exposure: “The estimated daily exposures (resulting from both direct and precursor intake) for the general adult population are highest for PFOS and perfluorooctanoic acid (PFOA), followed by perfluorohexanoic acid (PFHxA) and perfluorodecanoic acid (PFDA), while lower daily exposures are estimated for perfluorobutanoic acid (PFBA) and perfluorododecanoic acid (PFDoDA).”<sup>22</sup>

Found in blood in Hong Kong residents: “Perfluorooctane sulfonate (PFOS) was the dominant PFC, followed by perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS)... The levels of PFOS, PFOA, PFHxS and perfluorohexanoic acid (PFHxA) were significantly higher in the male plasma samples ( $p < 0.05$ ), while the mean plasma levels of DEHP and n-butyl benzyl phthalate (BBP) were significantly higher in the young age group ( $p < 0.02$ ).”<sup>23</sup>

Found in house dust: “Concentrations of 20 perfluorinated alkyl substances (PFASs) were measured in dust samples from 41 homes in Canada, the Czech Republic, and United States in the spring-summer of 2013. The most frequently detected compounds were perfluorohexanoic acid (PFHxA) and perfluorooctane sulfonate (PFOS).”<sup>24</sup>

Found in well water in Japan: “The PFOA concentrations in well water ranged from 45.2 to 7440 ng/L (median = 240 ng/L), while PFHxA concentrations ranged from 9.68 to 970 (median = 45.4 ng/L) in 2015-2016.”<sup>25</sup>

---

Perfluoroalkyl acid contamination and polyunsaturated fatty acid composition of French freshwater and marine fishes, *J Agric Food Chem* 62:7593-7603

<sup>21</sup> Kang H, Choi K, Lee HS, Kim DH, Park NY, Kim S, Kho Y (2016) Elevated levels of short carbon-chain PFCAs in breast milk among Korean women: Current status and potential challenges, *Environ Res* 148:351-359

<sup>22</sup> Gebbink WA, Berger U, Cousins IT (2015) Estimating human exposure to PFOS isomers and PFCA homologues: the relative importance of direct and indirect (precursor) exposure, *Environ Int* 74:160-169

<sup>23</sup> Wan HT, Leung PY, Zhao YG, Wei X, Wong MH, Wong CK (2013) Blood plasma concentrations of endocrine disrupting chemicals in Hong Kong populations, *J Hazard Mater* 261:763-769

<sup>24</sup> Karaskova P, Venier M, Melymuk L, Becanova J, Voja S, Prokes R, Diamond ML, Klanova J (2016) Perfluorinated alkyl substances (PFASs) in household dust in Central Europe and North America, *Environ Int* 94:315-324

<sup>25</sup> Shiwaku Y, Lee P, Thepaksorn P, Zheng B, Koizumi A, Harada KH (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

Found in drinking water in Netherlands: “PFASs were detected in the drinking water from the western part of the Netherlands. This seems attributable to the source, which is purified surface water in this area. Short-chain PFASs and especially perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), perfluorobutane sulfonate (PFBS), and perfluorohexane sulfonate (PFHxS) were detected most frequently, whereas long-chain PFASs (C > 8) were only rarely detected.”<sup>26</sup>

Found in landfill leachates in Spain: “PFCAs accounted for the majority of the detected PFASs and perfluorooctanoic acid (PFOA) was the dominant compound in raw leachates (42.6%), followed by shorter chain PFHxA (30.1%), PFPeA and PFBA.”<sup>27</sup>

Found in landfill leachates in Australia: “Leachate was collected from 13 landfill sites and biosolids were collected from 16 wastewater treatment plants (WWTPs), across Australia. Perfluorohexanoate (PFHxA) (12-5700ng/L) was the most abundant investigated persistent, bioaccumulative and toxic (PBT) chemical in leachate.”<sup>28</sup>

Found in wastewater effluent in the US: “Effluent from six municipal treatment plants contained similar amounts of total PFASs, with highest median concentrations of PFHxA (24 ng/L), followed by PFOA (23 ng/L), PFBA (19 ng/L), and PFOS (15 ng/L). Compared to SF Bay municipal wastewater samples collected in 2009, the short chain perfluorinated carboxylates PFBA and PFHxA rose significantly in concentration.”<sup>29</sup>

Found in storm water and other effluents in Finland: “In storm water the highest concentration was found for PFHxA (17 ng/l). The highest concentration of PFOS and PFOA were 9.9 and 5.1 ng/l, respectively. PFOS, PFOA and PFHxA were detected in every effluent, storm water and landfill leachate sample, whereas PFDA was detected in most of the samples (77%). In the target industry, PFOS concentrations varied between 1,400 and 18,000 µg/l. In addition, on one sampling occasion PFOA and PFHxA were found (0.027 and 0.009 µg/l, respectively). For effluents, PFAA mass flows into the Baltic Sea were calculated. For municipal wastewater treatment plants average mass flows per day varied for PFOS between 1,073 and 38,880 mg/day, for PFOA 960 and 2,700 mg/day, for PFHxA

---

<sup>26</sup> Zafeiraki E, Costopoulou D, Vassiliadou I, Leondiadis L, Dassenakis E, Traag W, Hoogenboom RL, van Leeuwen SP (2015) Determination of perfluoroalkylated substances (PFASs) in drinking water from the Netherlands and Greece, *Food Addit Contam Part A Chem Anal Control Expo Risk Asses* 32:2048-2057

<sup>27</sup> Fuertes I, Gomez-Lavin S, Elizalde MP, Urtiaga A (2016) Perfluorinated alkyl substances (PFASs) in northern Spain municipal solid waste landfill leachates, *Chemosphere* 168:399-407

<sup>28</sup> Gallen C, Drage D, Kaserzon S, Baduel C, Gallen M, Banks A, Broomhall S, Mueller JF (2016) Occurrence and distribution of brominated flame retardants and perfluoroalkyl substances in Australian landfill leachate and biosolids, *J Hazard Mater* 312:55-64

<sup>29</sup> Houtz EF, Sutton R, Park JS, Sedlak M (2016) Poly- and perfluoroalkyl substances in wastewater: Significance of unknown precursors, manufacturing shifts, and likely AFFF impacts, *Water Res* 95:142-149



408 and 1,269 mg/day and for PFDA 84 and 270 mg/day. In IWWTP mass flows for PFOS, PFOA, PFHxA and PFDA were 495 mg/d, 28 mg/d, 23 mg/d and 0.6 mg/g, respectively.”<sup>30</sup>

Found in US wildlife preserves: “The most detected PFAAs was PFOS, followed by perfluorooctanoic acid (PFOA), and perfluorohexanoic acid (PFHxA).”<sup>31</sup>

Found in the Mediterranean Sea: “Perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), perfluorohexanesulfonate (PFHxS) and perfluorooctanesulfonate (PFOS) were detected in all samples and were the dominant PFASs found.”<sup>32</sup>

Found in the Ganges River basin: “15 PFAS were frequently detected in the river with the highest concentrations observed for PFHxA (0.4-4.7 ng L<sup>-1</sup>) and PFBS (<MQL - 10.2 ng L<sup>-1</sup>) among PFCAs and PFSAs, respectively. Prevalence of short-chain PFAS indicates that the effects of PFOA and PFOS substitution are visible in environmental samples from India.”<sup>33</sup>

Found in surface waters of eastern China: “Perfluorooctanoic acid (PFOA) was the prevalent PFAS in Shanghai. In contrast, PFOA and perfluorohexanoic acid (PFHxA) were the prevalent PFASs in Zhejiang Province... correlation analyses between concentrations of individual PFASs showed the correlation between PFHxA and PFOA was positive, while the correlation between PFHxA and perfluorooctane sulfonamide (FOSA) was negative in Shanghai, which indicated that PFHxA and PFOA have common sources.”<sup>34</sup>

Found in Taihu Lake in China: “...in samples from Taihu Lake, PFOA, perfluorohexanoic acid (PFHxA), and PFOS were the predominant compounds (mean 56 ng/L, 19 ng/L, and 15 ng/L, respectively).”<sup>35</sup>

Found in snow in northern China: “The levels of total PFASs in the snow samples were 33.5-229 ng/L, suggesting heavy atmospheric pollution of PFASs in northern China. PFOA

---

<sup>30</sup> Perkola N, Sainio P (2013) Survey of perfluorinated alkyl acids in Finnish effluents, storm water, landfill leachate and sludge, *Environ Sci Pollut Res Int* (2013) 20:7979-7987

<sup>31</sup> Rodriguez-Jorquera IA, Silva-Sanchez C, Strynar M, Denslow ND, Toor GS (2016) Footprints of Urban Micro-Pollution in Protected Areas: Investigating the Longitudinal Distribution of Perfluoroalkyl Acids in Wildlife Preserves, *Water Res* 11(2):e0148654. doi: 10.1371/journal.pone.0148654

<sup>32</sup> Brumovsky M, Karaskova P, Borghini M, Nizzetto L (2016) Per- and polyfluoroalkyl substances in the Western Mediterranean Sea waters, 159:308-316

<sup>33</sup> Sharma BM, Bharat GK, Tayal S, Larssen T, Becanova J, Karaskova P, Whitehead PG, Futter MN, Butterfield D, Nizzetto L (2016) Perfluoroalkyl substances (PFAS) in river and ground/drinking water of the Ganges River basin: Emissions and implications for human exposure, *Environ Pollut* 208(PtB):704-713

<sup>34</sup> Lu Z, Song L, Zhao Z, Ma Y, Wang J, Yang H, Ma H, Cai M, Codling G, Ebinghaus R, Xie Z, Giesy JP (2015) Occurrence and trends in concentrations of perfluoroalkyl substances (PFASs) in surface waters of eastern China, *Chemosphere* 119:820-827

<sup>35</sup> Yu N, Shi W, Zhang B, Su G, Feng J, Zhang X, Wei S, Yu H (2013) Occurrence of perfluoroalkyl acids including perfluorooctane sulfonate isomers in Huai River Basin and Taihu Lake in Jiangsu Province, China, *Environ Sci Technol* 47:710-717

(9.08-107 ng/L), PFOS (3.52-54.3 ng/L), perfluoroheptanoate (PFHpA) (3.66-44.8 ng/L), and perfluorohexanoate (PFHxA) (3.21-23.6 ng/L) were predominant with a summed contribution of 82% to the total PFASs.”<sup>36</sup>

Found in the Ebro and Guadalquivir river basins in Spain: “In water samples, of 21 analytes screened, 11 were found in Ebro and 9 in Guadalquivir. In both basins, the most frequent were PFBA, PFPeA and PFOA. Maximum concentration was detected for PFBA, up to 251.3 ng L(-1) in Ebro and 742.9 ng L(-1) in Guadalquivir. Regarding the sediments, 8 PFASs were detected in the samples from Ebro and 9 in those from Guadalquivir. The PFASs most frequently detected were PFBA, PFPeA, PFOA and PFOS. Maximum concentration in Ebro samples was, in dry weight, for PFOA (32.3 ng g(-1)) and in Guadalquivir samples for PFBA (63.8 ng g(-1)). For biota, 12 PFASs were detected in fish from the Ebro River and only one (PFOS) in that from Guadalquivir. In the Ebro basin, the most frequent were PFBA, PFHxA, PFOA, PFBS, PFOS and PFOSA. Maximum concentration in Ebro samples was, in wet weight, for PFHxA with 1280.2 ng g(-1), and in Guadalquivir samples for PFOS with 79.8 ng g(-1). These compounds were detected in the whole course of the rivers including the upper parts. In some points contamination was due to point sources mostly related to human activities (e.g. ski resorts, military camps, urban areas.). However, there are also some areas clearly affected by diffuse sources as atmospheric deposition.”<sup>37</sup>

Found in sewage treatment plant and nearby rivers in Spain: “All samples, except two sludges from Guadalquivir River STPs, were contaminated with at least one PFAS. Perfluorobutanoate (PFBA), perfluoropentanoate (PFPeA) and perfluorooctane sulfonate (L-PFOS) were the most frequently detected. The highest concentration in water was determined in 2010 in a Guadalquivir River STP (perfluorohexanoate, PFHxA: 5.60µg L(-1)) and, in 2011, in an Ebro River STP (perfluorobutane sulfonate, L-PFBS: 0.31µg L(-1)). In sludge samples, the maximum concentration in 2010 was 1.79µg g(-1) dry weight (dw) (L-PFOS, in a Llobregat River STP), and in 2011, 1.88µg g(-1) dw (PFBA, in one Guadalquivir River STP).”<sup>38</sup>

Found in watersheds: “The total concentrations of the PFASs in the dissolved phase were 44.4-781 ng/L in Liao River with high contribution of perfluorobutane sulfonate (PFBS) (75.7%) and PFOA (9.86%). The ΣPFASs in the dissolved phase in Taihu Lake was 17.2-94.4 ng/L with PFOA (39.8%), perfluorohexanoate (PFHxA) (30.1%) and PFOS (16.8%) as the dominant PFASs.”<sup>39</sup>

---

<sup>36</sup> Shan G, Chen X, Zhu L (2015) Occurrence, fluxes and sources of perfluoroalkyl substances with isomer analysis in the snow of northern China, *J Hazard Mater* 299:639-646

<sup>37</sup> Lorenzo M, Campo J, Farre M, Perez F, Pico Y, Barcelo D (2016) Perfluoroalkyl substances in the Ebro and Guadalquivir river basins (Spain), *Sci Total Environ* 540:191-199

<sup>38</sup> Campo J, Masia A, Pico Y, Farre M, Barcelo D (2014) Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants, *Sci Total Environ* 472:912-922

<sup>39</sup> 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 Res* 80:235-244

Found in the deep sea: “The finding of perfluoroalkyl substances (PFASs) in particles sinking to the deep northwestern Mediterranean Sea confirms the role of the latter as ballast for the transfer of pollutants to the deep sea... The finding of quantifiable concentrations of long-chain PFOA, PFOS and PFNA substances and significantly high concentrations of the short-chain substances PFHxA and PFBA indicates that these compounds, sorbed onto particulate matter, are quickly and directly transferred to the ocean's interior, thus highlighting the role of DSWC in removing those pollutants from the coastal ocean.”<sup>40</sup>

Found in global tropical and subtropical oceans: “Perfluorooctanesulfonic acid (PFOS) was the most abundant compound, accounting for 33% of the total PFASs globally, followed by perfluorodecanoic acid (PFDA, 22%) and perfluorohexanoic acid (PFHxA, 12%), being the rest of the individual congeners under 10% of total PFASs, even for perfluorooctane carboxylic acid (PFOA, 6%).”<sup>41</sup>

Found in the coastal sea of Japan: “Widespread contamination of coastal waters was confirmed with PFHxA as the dominant compound. Perfluorooctanoic acid was also prevalent in coastal waters. The concentration of PFHxA in coastal seawater and the distance from the mouth of the Samondogawa River were inversely related. This discharge of high concentrations of PFHxA from the Samondogawa River may have affected concentrations of PFCs in Osaka Bay.”<sup>42</sup>

Found in rivers of Pearl River Delta in China: “Perfluorobutane sulfonic acid (PFBS), perfluorooctanoic acid (PFOA), and perfluorooctane sulfonic acid (PFOS) were the three most abundant PFAAs and on average accounted for 28%, 16% and 10% of  $\sum$  PFAAs, respectively. Higher concentrations of  $\sum$  PFAAs were found in the samples collected from Jiangmen section of Xijiang River, Dongguan section of Dongjiang River and the Pearl River flowing the cities which had very well-developed manufacturing industries. PCA model was employed to quantitatively calculate the contributions of extracted sources. Factor 1 (72.48% of the total variance) had high loading for perfluorohexanoic acid (PFHxA), perfluoropentanoic acid (PFPeA), PFBS and PFOS.”<sup>43</sup>

Found in the Yangtze River: “Among the selected 18 PFASs, perfluorooctanoic acid (PFOA) was the dominant PFAS compound found both in water and sediment for the two seasons with its maximum concentration of 18.03 ng/L in water and 0.72 ng/g in sediment, followed by perfluorobutane sulfonic acid (PFBS) with its maximum concentration of 41.9

---

<sup>40</sup> Sanchez-Vidal A, Llorca M, Farre M, Canals M, Barcelo D, Puig P, Calafat A (2015) Delivery of unprecedented amounts of perfluoroalkyl substances towards the deep-sea, *Sci Total Environ* 526:41-48

<sup>41</sup> Gonzalez-Gaya B, Dachs J, Roscales JL, Caballero G, Jimenez B (2014) Perfluoroalkylated substances in the global tropical and subtropical surface oceans, *Environ Sci Technol* 48:13076-13084

<sup>42</sup> Takemine S, Matsumura C, Yamamoto K, Suzuki M, Tsurukawa M, Imaishi H, Nakano T, Kondo A (2014) Discharge of perfluorinated compounds from rivers and their influence on the coastal seas of Hyogo prefecture, Japan, *Environ Pollut* 184:397-404

<sup>43</sup> Lui B, Zhang H, Xie L, Li J, Wang X, Zhao L, Wang Y, Yang B (2015) Spatial distribution and partition of perfluoroalkyl acids (PFAAs) in rivers of the Pearl River Delta, southern China, *Sci Total Environ* 524-525:1-7

ng/L in water in Wuhan, whereas the lowest concentrations of PFASs were observed at Poyang lake. The annual loadings of PFOA, perfluorohexanoic acid (PFHxA), PFBS, perfluorooctane sulfonic acid (PFOS) and the total PFASs in the Yangtze River were 6.8 tons, 2.2 tons, 8.2 tons, 0.88 tons, and 20.7 tons, respectively. Wuhan and Er'zhou of Hubei contributed the most amounts of PFASs into the Yangtze River. A correlation was found between some PFASs, for example PFBS and PFOS, which suggests that both of these PFASs originate from common sources in the region."<sup>44</sup>

Found in the 5<sup>th</sup> largest freshwater lake in China: "PFOA was the predominant contaminant ( $8.62 \pm 4.40$  ng/L), followed by PFBA ( $2.04 \pm 1.16$  ng/L) and PFHxA ( $1.23 \pm 1.50$  ng/L)."<sup>45</sup>

Efficiently translocated into plants: "Regarding to the degradation products, the higher their water solubility, the higher the plant translocation. In this sense, the lower the carbon chain length of PFCAs, the higher the BCFs determined (PFBA > PFHxA > PFHpA > PFOA > PFNA)."<sup>46</sup>

Fluoropolymer manufacturing plant contaminates drinking water: "In the present study, 10 PFCs were quantitatively determined in water samples collected in the vicinity of a fluoropolymer manufacturing plant and in drinking water resources located downstream. The release of PFHxA and PFNA to the receiving river was estimated at 10 and 4.5 tons/year, respectively. PFHxA (0.058-0.156  $\mu\text{g/L}$ ), PFNA (0.013-0.035  $\mu\text{g/L}$ ) and PFOA (0.007-0.025  $\mu\text{g/L}$ ) were predominant and prevalent in all the studied drinking water resources, confirming with the composition profile the impact of the industrial park release."<sup>47</sup>

Found in outdoor consumer products such as jackets, trousers, boots, etc. PFHxA was found in Arc'teryx Alpha SL jacket (Sweden), Blackyak U-Jade jacket (Republic of Korea), Haglofs L.I.M III jacket (Finland), Mammut Nordwand Pro HS Hooded jacket (Switzerland), Norrona Lofoten Gore-tex pro jacket (Norway), Patagonia Men's Super Alpine jacket (Taiwan), Salewa Ultar GTX ACT M jacket (Italy), The North Face Women Stratos jacket (Sweden), Arc'teryx Beta AR Pant Men's trousers (Taiwan), Columbia Jump Off Cargo Pants Men pants (Russia), Jack Wolfskin Cloudburst Pants Women trousers (Russia), Mammut Nordwand Pro Pants Man trousers (Slovenia), Patagonia M's Torrentshell Pants trousers (Hong Kong), The North Face Ravina Pants trousers (UK), Columbia Women's Redmond

---

<sup>44</sup> Pan CG, Ying GG, Zhao JL, Liu YS, Jiang YX, Jiang YX, Zhang QQ (2014) Spatiotemporal distribution and mass loadings of perfluoroalkyl substances in the Yangtze River of China, *Sci Total Environ* 493:580-587

<sup>45</sup> Liu WX, He W, Qin N, Kong XZ, He Qs, Yang B, Yang C, Jorgensen SE, Xu FL (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), *Environ Pollut* 200:24-34

<sup>46</sup> Bizkarguenaga E, Zabaleta I, Prieto A, Fernandez LA, Zuloaga O (2016) Uptake of 8:2 perfluoroalkyl phosphate diester and its degradation products by carrot and lettuce from compost-amended soil, *Chemosphere* 152:309-317

<sup>47</sup> Dauchy X, Boiteux V, Rosin C, Munoz JF (2012) Relationship between industrial discharges and contamination of raw water resources by perfluorinated compounds. Part I: Case study of a fluoropolymer manufacturing plant, *Bull Environ Contam Toxicol* 89:525-530

Low Waterproof shoes (Turkey), Haglofs Grym HI GT men shoes (Norway), Jack Wolfskin LL All Terrain Texapore Men shoes (Turkey), Mammut Redburn Mid GTX Men shoes (Slovakia), The North Face (Men's Hedghog Hike Mid GTX, shoes (Hong Kong), Columbia Silver Ridge 25L backpack (Columbia online store), Patagonia Ascensionist pack 45L backpack (Republic of Korea), The North Face Shadow 40+10 backpack (Hungary), The North Face Snow Leopard sleeping bag (Chile), Jack Wolfskin Gossamer tent (Austria), and Mammut 9.8 Eternity Dry rope (Switzerland).<sup>48</sup>

**Perfluorohexane sulfonate (PFHxS or C6), CAS: 355-4, is associated with the following adverse characteristics:**

Found in the Arctic: "five most frequently detected compounds were perfluorooctanoic acid (PFOA), perfluorohexanesulfonate (PFHxS), perfluorohexanoic acid (PFHxA), perfluorooctane sulfonate (PFOS) and perfluorobutane sulfonate (PFBS)"<sup>49</sup>

Found in Arctic wildlife: "Perfluorohexane sulfonate was measured at concentrations up to 2.71 ng/g ww."<sup>50</sup>

Thyroid disruption (along with PFOS): "PFHxS and PFOS were negatively associated ( $p < 0.05$ ) with fT4, and all 4 PFASs were positively associated ( $p < 0.05$ ) with fT3, fT3/fT4, TSH, and TT3 in the group with joint exposure to high TPOAb and low iodine (T1I1)." <sup>51</sup>

Induces programmed cell death in brain cells in rats: "This is a first report that PFHxS induces apoptosis of CGC (Cerebellar granule cells) isolated from the developing brain and its possible mode of action is associated with ERK1/2 pathway."<sup>52</sup>

Endocrine disruption in vitro: "PFHxS, PFOS and PFOA significantly induced the ER transactivity, whereas PFHxS, PFOS, PFOA, PFNA and PFDA significantly antagonized the AR activity in a concentration-dependent manner."<sup>53</sup>

Alters function of thyroid hormone receptor in vitro: "A dose-dependent impact on GH3 cells was observed in the range  $1 \times 10^{-9}$ - $1 \times 10^{-4}$  M: seven PFAAs (perfluorooctane sulfonate (PFOS), perfluorohexane sulfonate (PFHxS), perfluorooctanoic acid, perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), and perfluorododecanoic acid (PFDoA)) inhibited the GH3 cell growth, and four

---

<sup>48</sup> Santen M, Brigden K, Cobbing M (2016) Leaving Traces: The hidden hazardous chemicals in outdoor gear, Greenpeace

<sup>49</sup> Zhao Z, Xie Z, Möller A, Sturm R, Tang J, Zhang G, Ebinghaus R (2012) Distribution and long-range transport of polyfluoroalkyl substances in the Arctic, Atlantic Ocean and Antarctic coast, *Environ Pollut* 170:71-77

<sup>50</sup> Verreault J, Houde M, Gabrielsen GW, Berger U, Haukås M, Letcher RJ, Muir DC (2005) Perfluorinated alkyl substances in plasma, liver, brain, and eggs of glaucous gulls (*Larus hyperboreus*) from the Norwegian arctic, *Environ Sci Technol* 39:7439-45.

<sup>51</sup> Webster GM, Rauch SA, Ste Marie N, Mattman A, Lanphear BP, Venners SA (2016) Cross-Sectional Associations of Serum Perfluoroalkyl Acids and Thyroid Hormones in U.S. Adults: Variation According to TPOAb and Iodine Status (NHANES 2007-2008). *Environ Health Perspect.* 124:935-942

<sup>52</sup> Lee YJ1, Choi SY, Yang JH (2014) PFHxS induces apoptosis of neuronal cells via ERK1/2-mediated pathway, *Chemosphere* 94:121-127

<sup>53</sup> Kjeldsen LS1, Bonfeld-Jørgensen EC (2013) Perfluorinated compounds affect the function of sex hormone receptors, *Environ Sci Pollut Res Int.* 20:8031-8044

PFAAs (PFOS, PFHxS, PFNA, and PFUnA) antagonized the T3-induced GH3 cell proliferation. At the highest test concentration, PFHxS showed a further increase of the T3-induced GH3 growth.”<sup>54</sup>

DNA damage in vitro: “PFHxS, PFOA, PFOS and PFNA showed a dose dependent increase in DNA damage in the concentration range from  $2 \times 10^{-7}$  to  $2 \times 10^{-5}$  M determined by the comet assay.”<sup>55</sup>

Alters adipocyte differentiation in vitro: “There was a significant concentration-related increase in cell number and decreased cell size after exposure to PFOA, PFHxS, PFOS, and PFNA... The strongest overall effect was a nearly 10-fold induction of Scd1 by PFHxS.”<sup>56</sup>

Alters brain proteins essential for brain development in mice: “neonatal exposure to PFHxS, during the peak of the brain growth spurt, can alter neuroprotein levels, e.g. CaMKII, GAP-43, synaptophysin and tau, which are essential for normal brain development in mice.”<sup>57</sup>

Induces apoptosis of neuronal cells in vitro: “PFHxS increased the apoptotic death of CGC [Cerebellar granule cells] in concentration-dependent manner. It also increased the activation of ERK1/2, JNK and p38 MAPK with different temporal activation... This is a first report that PFHxS induces apoptosis of CGC isolated from the developing brain and its possible mode of action is associated with ERK1/2 pathway.”<sup>58</sup>

Altered behavior and cognition in mice: “The present study indicates that a single exposure to PFHxS on postnatal day 10, during a vulnerable period of brain development can alter adult spontaneous behavior and cognitive function in both male and female mice, effects that are both dose-response related and long-lasting/irreversible.”<sup>59</sup>

Impairs lipoprotein production in rats: “Whereas PFBS modestly reduced only plasma triglycerides (TG), PFHxS and PFOS markedly reduced TG, non-HDL-C, and HDL-C... the potency of PFAS to affect lipoprotein metabolism increased with increasing alkyl chain

---

<sup>54</sup> Long M, Ghisari M, Bonefeld-Jorgensen EC (2013) Effects of perfluoroalkyl acids on the function of the thyroid hormone and the aryl hydrocarbon receptor, *Environ Sci Pollut* 20:8045-8056

<sup>55</sup> Wielsoe M, Long M, Ghisari M, Bonefeld-Jorgensen EC (2015) Perfluoroalkylated substances (PFAS) affect oxidative stress biomarkers in vitro, *Chemosphere* 129:239-245

<sup>56</sup> Watkins AM, Wood CR, Lin MT, Abbott BD (2015) The effects of perfluorinated chemicals on adipocyte differentiation in vitro, *Mol Cell Endocrinol* 400:90-101

<sup>57</sup> Lee I, Viberg H (2013) A single neonatal exposure to perfluorohexane sulfonate (PFHxS) affects the levels of important neuroproteins in the developing mouse brain, *Neurotoxicology* 37:190-196

<sup>58</sup> Lee YJ, Choi SY, Yang JH (2014) PFHxS induces apoptosis of neuronal cells via ERK1/2-mediated pathway, *Chemosphere* 94:121-127

<sup>59</sup> Viberg H1, Lee I, Eriksson P (2013) Adult dose-dependent behavioral and cognitive disturbances after a single neonatal PFHxS dose, *Toxicology* 304:185-191

length. PFHxS and PFOS reduce plasma TG and total cholesterol mainly by impairing lipoprotein production..."<sup>60</sup>

Affects genes involved in brain development in chickens: "PFHxS affects genes involved in tissue development and morphology, cellular assembly and organization, and cell-to-cell signaling."<sup>61</sup>

Negatively affects gene expression important for development in chickens: "PFHxS significantly alters the expression ( $\geq 1.5$ -fold,  $p \leq 0.001$ ) of 11 transcripts at the low dose (890 ng/g) and 101 transcripts at the high dose (38,000 ng/g). Functional enrichment analysis shows that PFHxS affects genes involved in tissue development and morphology, cellular assembly and organization, and cell-to-cell signaling."<sup>62</sup>

Found in pregnant women and cord blood: "In maternal plasma, there was >90 % detection for the perfluoroalkyl substances (PFASs) perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), perfluorohexane sulfonate (PFHxS), and dichlorodiphenyldichloroethylene (DDE), oxychlorodane and PCB 138 and 153...The PFASs were the most frequently detected (23-64 %) chemical class in cord plasma. In a subset of 1st and 3rd trimester paired samples, PFAS concentrations were found to be strongly correlated and had ICCs ranging from 0.64 (PFOA) to 0.83 (PFHxS)."<sup>63</sup>

Efficiently transferred across the placenta and decreases birth weight in humans: "Ranking of transplacental transfer efficiency was PFOA>PFHxS>PFOS...Umbilical cord PFHxS concentration showed a significant inverse association with birth weight (OR=0.26; 95% CI, 0.08-0.85) or a marginally significant inverse association with birth length (OR=0.33; 95% CI, 0.09-1.17)."<sup>64</sup>

Transferred from the mother to the fetus in humans. "Median concentrations of PFAS (ng/mL) of PFHxS, PFOS, PFOA, and PFNA in maternal plasma (0.79, 6.18, 2.85 and 0.84,

---

<sup>60</sup> Bijland S, Rensen PC, Pieterman EJ, Maas AC, van der Hoorn JW, van Erk MJ, Havekes LM, Willems van Dijk K, Chang SC, Ehresman DJ, Butenhoff JL, Princen HM (2011) Perfluoroalkyl sulfonates cause alkyl chain length-dependent hepatic steatosis and hypolipidemia mainly by impairing lipoprotein production in APOE\*3-Leiden CETP mice, *Toxicol Sci* 123:290-303

<sup>61</sup> Cassone CG, Taylor JJ, O'Brien JM, Williams A, Yauk CL, Crump D, Kennedy SW (2012) Transcriptional profiles in the cerebral hemisphere of chicken embryos following in ovo perfluorohexane sulfonate exposure, *Toxicol Sci* 129:380-391

<sup>62</sup> Cassone C, Taylor J, O'Brien J, Williams A, Yauk C, Crump D, Kennedy S (2012) Transcriptional profiles in the cerebral cortex of chicken embryos following in ovo perfluorohexane sulfonate exposure, *Toxicol Sci* 129:380-391

<sup>63</sup> Fisher M, Arbuckle TE, Liang CL, LBlanc A, Gaudreau E, Foster WG, Haines D, Davis K, Fraser WD (2016) Concentrations of persistent organic pollutants in maternal and cord blood from the maternal-infant research on environmental chemicals (MIREC) cohort study, *Environ Health* 15:59 doi: 10.1186/s12940-016-0143-y

<sup>64</sup> Lee YJ, Kim MK, Bae J, Yang JH (2013) Concentrations of perfluoroalkyl compounds in maternal and umbilical cord sera and birth outcomes in Korea, *Chemosphere* 90:1603-1609

respectively) and serum (0.84, 6.99, 2.97 and 0.85) were higher than in cord serum (0.40, 1.86, 1.90 and 0.32)."<sup>65</sup>

Excreted during breast feeding: "Women reporting full breastfeeding for  $\geq 12$  months had 32-44% lower levels of perfluorooctane sulfonate, perfluorooctanoic acid, and perfluorohexane sulfonate than women who never nursed their infants full-time... Breastfeeding appears to be a major source of elimination of certain PFAA among women, and consequently PFAA exposure of nursed infants could be significant."<sup>66</sup>

Affects blood lipids in humans during pregnancy: "Five of the seven PFASs studied were positively associated with HDL cholesterol, and all seven had elevated HDL associated with the highest quartile of exposure."<sup>67</sup>

Altered sperm morphology in humans: "The proportion of morphologically normal cells was 35% lower [95% confidence interval (CI): 4-66%] for the third tertile of PFOS exposure as compared with the first. A similar reduction was found in relation to increasing PFHxS levels."<sup>68</sup>

Reduced fertility in humans: "exposure to PFOA and PFHxS, even at lower levels than previously reported, may reduce fecundability."<sup>69</sup>

Immunosuppression in childhood: "As a measure of pre-natal exposure to PFAS, the concentrations of perfluorooctanoate (PFOA), perfluorononanoate (PFNA), perfluorohexane sulfonate (PFHxS), and perfluorooctane sulfonate (PFOS) were determined in maternal blood from 99 BraMat participants. Main outcome measures were anti-vaccine antibody levels, common infectious diseases and allergy- and asthma-related health outcomes in the children up to the age of 3 years. There was an inverse association between the level of anti-rubella antibodies in the children's serum at age 3 years and the concentrations of the four PFAS. Furthermore, there was a positive association between the maternal concentrations of PFOA and PFNA and the number of episodes of common cold for the children, and between PFOA and PFHxS and the number of episodes of gastroenteritis. No associations were found between maternal PFAS concentrations and

---

<sup>65</sup> Manzano-Salgado CB1, Casas M2, Lopez-Espinosa MJ3, Ballester F3, Basterrechea M4, Grimalt J05, Jiménez AM6, Kraus T7, Schettgen T7, Sunyer J2, Vrijheid M2 (2015) Transfer of perfluoroalkyl substances from mother to fetus in a Spanish birth cohort, *Environ Res.* 142:471-478

<sup>66</sup> Bjeremo H, Darnerud PO, Pearson M, Barbieri HE, Lindroos AK, Nalsen C, Lindh CH, Jonsson BA, Glynn A (2013) Serum concentrations of perfluorinated alkyl acids and their associations with diet and personal characteristics among Swedish adults, *Mol Nutr Res* 57:2206-2215

<sup>67</sup> Haug LS, Eggesbø M, Becher G, Sabaredzovic A, Thomsen C, Wilson RE, Travlos GS, Hoppin JA, Baird DD, Longnecker MP. (2014) Perfluoroalkyl substances and lipid concentrations in plasma during pregnancy among women in the Norwegian Mother and Child Cohort Study, *Environ Int.* 62:104-112

<sup>68</sup> Toft G, Jönsson BA, Lindh CH, Giwercman A, Spano M, Heederik D, Lenters V, Vermeulen R, Rylander L, Pedersen HS, Ludwicki JK, Zvezdai V, Bonde JP (2012) Exposure to perfluorinated compounds and human semen quality in Arctic and European populations, *Hum Reprod* 27:2532-2540

<sup>69</sup> Vélez MP, Arbuckle TE, Fraser WD. (2015) Maternal exposure to perfluorinated chemicals and reduced fecundity: the MIREC study, *Hum Reprod.* 30:701-709



the allergy- and asthma-related health outcomes investigated. The results indicate that pre-natal exposure to PFAS may be associated with immunosuppression in early childhood.”<sup>70</sup>

Reduced birth weight: “PFOS (median, 19.6 ng/mL), PFOA (median, 3.7 ng/mL), and PFHxS (median, 1.6 ng/mL) were detected in 100% of samples...On average, girls born to mothers with prenatal concentrations of PFOS in the upper tertile weighed 140 g less [95% confidence interval (CI): -238, -42] at birth than girls born to mothers with concentrations in the lower tertile in adjusted models. Similar patterns were seen for PFOA (-133 g; 95% CI: -237, -30) and PFHxS (-108 g; 95% CI: -206, -10)... Girls with higher prenatal exposure to each of the PFCs examined were smaller at birth than those with lower exposure.”

Glucose tolerance problems in humans: “Significantly elevated odds of gestational IGT (impaired glucose tolerance) was observed in the second quartile of perfluorohexane sulfonate (PFHxS) (OR=3.5, 95% CI=1.4-8.9).”<sup>71</sup>

Affects blood lipids and cholesterol in humans: “We found some evidence of a significant association between perfluoroalkyl substances, notably PFHxS, with total cholesterol (TC), low-density lipoprotein cholesterol (LDL), total cholesterol/high density lipoprotein cholesterol ratio (TC/HDL) and non-HDL cholesterol as well as an elevated odds of high cholesterol.”<sup>72</sup>

Impacts thyroid hormone levels in humans: “Higher serum concentrations of PFOA and PFHxS are associated with total T3, total T4, and free T4 in the U.S. general population.”<sup>73</sup>

Alters thyroid hormones: “PFHxS and PFOS were negatively associated ( $p < 0.05$ ) with fT4, and all four PFASs were positively associated ( $p < 0.05$ ) with fT3, fT3/fT4, TSH, and TT3 in the group with joint exposure to high TPOAb and low iodine (T1I1)... We found evidence of PFAS-associated thyroid disruption in a subset of U.S. adults with high TPOAb (a marker of autoimmune hypothyroidism) and low iodine status, who may represent a vulnerable subgroup. However, the small sample size, cross-sectional design, and possibility of reverse causation are limitations of this work.”<sup>74</sup>

---

<sup>70</sup> Granum B, Haug LS, Namork E, Stolevik SB, Thomsen C, Aaberge IS, van Loveren H, Lovik M, Nygaard UC (2013) Pre-natal exposure to perfluoroalkyl substances may be associated with altered vaccine antibody levels and immune-related health outcomes in early childhood, *J Immunotoxicol* 10:373-379

<sup>71</sup> Shapiro GD, Dodds L, Arbuckle TE, Ashley-Martin J, Ettinger AS, Fisher M, Taback S, Bouchard MF, Monnier P, Dallaire R, Morisset P, Dallaire R, Morisset AS, Fraser W (2016) Exposure to organophosphorus and organochlorine pesticides, perfluoroalkyl substances, and polychlorinated biphenyls in pregnancy and the association with impaired glucose tolerance and gestational diabetes mellitus: The MIREC Study, *Environ Res* 147:71-81

<sup>72</sup> Fisher M, Arbuckle TE, Wade M, Haines DA (2012) Do perfluoroalkyl substances affect metabolic function and plasma lipids?—Analysis of the 2007-2009, Canadian Health Measures Survey (CHMS) Cycle 1, *Environ Res* 121:95-103

<sup>73</sup> Wen LL, Lin LY, Su TC, Chen PC, Lin CY (2013) Association between serum perfluorinated chemicals and thyroid function in U.S. adults: the National Health and Nutrition Examination Survey 2007-2010, *J Clin Endocrinol Metab* 98:E1456-1464

<sup>74</sup> Webster GM, Rauch SA, Ste Marie N, Mattman A, Lanphear BP, Venners SA. 2016. Cross-sectional associations of serum perfluoroalkyl acids and thyroid hormones in U.S.

Reduced effectiveness of vaccine in humans: “There was an inverse association between the level of anti-rubella antibodies in the children's serum at age 3 years and the concentrations of the four PFAS”<sup>75</sup>

Altered impulsivity in children: “Higher levels of blood PFOS, PFNA, PFDA, PFHxS, and PFOSA were associated with significantly shorter IRTs (impaired response inhibition) during the DRL (differential reinforcement of low rates of responding) task. The magnitude of these associations was such that IRTs during the task decreased by 29-34% for every 1 SD increase in the corresponding blood PFC. This study suggests an association between PFC exposure and children's impulsivity.”<sup>76</sup>

Attention deficit disorder in children: “The prevalence of ADHD plus medication increased with perfluorohexane sulfonate (PFHxS) levels, with an adjusted odds ratio of 1.59 (95% confidence interval, 1.21-2.08) comparing the highest quartile of exposure to the lowest.”<sup>77</sup>

Attention deficit disorder in children: “The adjusted odds ratio (OR) for parentally reported ADHD in association with a 1- $\mu$ g/L increase in serum PFOS (modeled as a continuous predictor) was 1.03 [95% confidence interval (CI), 1.01-1.05]. Adjusted ORs for 1- $\mu$ g/L increases in PFOA and PFHxS were also statistically significant (PFOA: OR = 1.12; 95% CI, 1.01-1.23; PFHxS: OR = 1.06; 95% CI, 1.02-1.11)”<sup>78</sup>

Increase in adiposity in girls: “Median (25-75th percentiles) prenatal plasma perfluorooctanoate (PFOA), perfluorooctane sulfonate (PFOS), perfluorohexane sulfonate (PFHxS), and perfluorononanoate (PFNA) concentrations in children assessed in early childhood were 5.6 (4.1-7.7), 24.8 (18.4-33.9), 2.4 (1.6-3.8), and 0.6 (0.5-0.9) ng/mL, respectively. Among girls, each interquartile increment of prenatal PFOA concentrations was associated with 0.21 kg/m<sup>2</sup> (95% CI: -0.05, 0.48) higher body mass index, 0.76 mm (95% CI: -0.17, 1.70) higher sum of subscapular and triceps skinfold thickness, and 0.17 kg/m<sup>2</sup> (95% CI: -0.02, 0.36) higher DXA total fat mass index in mid-childhood. Similar associations were observed for PFOS, PFHxS, and PFNA.”<sup>79</sup>

---

adults: variation according to TPOAb and iodine status (NHANES 2007-2008). *Environ Health Perspect* 124:935-942; <http://dx.doi.org/10.1289/ehp.1409589>

<sup>75</sup> Granum B, Haug LS, Namork E, Stølevik SB, Thomsen C, Aaberge IS, van Loveren H, Løvik M, Nygaard UC (2013) Pre-natal exposure to perfluoroalkyl substances may be associated with altered vaccine antibody levels and immune-related health outcomes in early childhood, *J Immunotoxicol* 10:373-379

<sup>76</sup> Gump BB, Wu Q, Dumas AK, Kannan K (2011) Perfluorochemical (PFC) exposure in children: associations with impaired response inhibition, *Environ Sci Technol* 45:8151-8159

<sup>77</sup> Stein CR, Savitz DA (2011) Serum perfluorinated compound concentration and attention deficit/hyperactivity disorder in children 5-18 years of age, *Environ Health Perspect* 119:1466-1471

<sup>78</sup> Hoffman K, Webster TF, Weisskopf MG, Weinberg J, Vieira VM (2010) Exposure to polyfluoroalkyl chemicals and attention deficit/hyperactivity disorder in U.S. children 12-15 years of age, *Environ Health Perspect* 118:1762-1767

<sup>79</sup> Mora AM, Oken E, Rifas-Shiman SL, Webster TF, Gillman MW, Calafat AM, Ye X, Sagiv SK (2016) Prenatal Exposure to Perfluoroalkyl Substances and Adiposity in Early and Mid-Childhood, *Environ Health Perspect* DOI: 10.1289/EHP24

Earlier menopause in humans: “women with higher levels of PFCs had earlier menopause than did women with the lowest PFC levels. We observed a monotonic association with PFHxS: The HR was 1.42 (95% CI: 1.08, 1.87) for serum concentrations in tertile 2 versus tertile 1, and 1.70 (95% CI: 1.36, 2.12) for tertile 3 versus tertile 1.”<sup>80</sup>

Found in the Arctic Indigenous Peoples: “levels of PFAS congeners perfluorohexane sulfonate and perfluorononanoic acid were sustained. The detection of POPs and heavy metals in maternal blood indicates fetal exposure to these compounds possibly influencing fetal development.”<sup>81</sup>

Found in humans in European and Arctic regions: “Measurements of PFASs in serum from 262 partners of pregnant women from Greenland, Poland and Ukraine, were also carried out by liquid chromatography tandem mass spectrometry. Perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS), and perfluorononanoic acid (PFNA) were detected in 97% of the blood samples.”<sup>82</sup>

Found in Korean residents: “The concentrations of other PFASs were in the decreasing order of; PFOA (median=1.30 ng/mL)>PFNA (median=0.85 ng/mL)>PFHxS (median=0.47 ng/mL)>PFOSA (median=0.12 ng/mL).”<sup>83</sup>

Found in blood in Europe: “PFOS was the main compound detected at 0.09-3.35 ng mL(-1), followed by PFOA and PFHxS.”<sup>84</sup>

Found in fluorochemical industry workers: “We detected PFOS, PFOA, perfluorohexane sulfonate (PFHxS), perfluorononanoic acid (PFNA), and perfluorodecanoic acid (PFDA) in all samples.”<sup>85</sup>

Found in blood in Norway and associated with higher HDL cholesterol: “The highest median concentration was observed for PFOS (13.03 ng/mL), followed by PFOA (2.25

---

<sup>80</sup> Taylor KW, Hoffman K, Thayer KA, Daniels JL (2014) Polyfluoroalkyl chemicals and menopause among women 20-65 years of age (NHANES), *Environ Health Perspect* 122:145-150

<sup>81</sup> Long M, Knudsen AK, Pedersen HS, Bonefeld-Jørgensen EC (2015) Food intake and serum persistent organic pollutants in the Greenlandic pregnant women: The ACCEPT sub-study, *Sci Total Environ* 529:198-212

<sup>82</sup> Leter G, Consales C, Eleuteri P, Uccelli R, Specht IO, Toft G, Moccia T, Budillon A, Jönsson BA, Lindh CH, Giwercman A, Pedersen HS, Ludwicki JK, Zvezdai V, Heederik D, Bonde JP, Spanò M. (2014) Exposure to perfluoroalkyl substances and sperm DNA global methylation in Arctic and European populations, *Environ Mol Mutagen* 55:591-600

<sup>83</sup> Cho CR, Lam NH, Cho BM, Kannan K, Cho HS (2015) *Sci Total Environ* 512-513:397-405

<sup>84</sup> Gomez-Canela C, Fernandez-Sanjuan M, Farres M, Lacorte S (2015) Factors affecting the accumulation of perfluoroalkyl substances in human blood, *Environ Sci Pollut Res* 22:1480-1486

<sup>85</sup> Wang J, Zhang Y, Zhang W, Jin Y, Dai J (2012) Association of perfluorooctanoic acid with HDL cholesterol and circulating miR-26b and miR-199-3p in workers of a fluorochemical plant and nearby residents, *Environ Sci Technol* 46:9274-9281

ng/mL), then PFHxS (0.60 ng/mL), PFNA (0.39 ng/mL), PFUnDA (0.22 ng/mL), PFHpS (0.13 ng/mL), and finally PFDA (0.09 ng/mL)... In adjusted quartile analyses, all seven PFASs had higher HDL cholesterol associated with the highest quartile of exposure, relative to the lowest quartile of exposure (or, in the case of PFDA, associated with concentration at or above the median versus below the median) (Table 5). Additionally, PFOS, PFNA, PFDA, PFUnDA, and PFHxS showed positive linear associations with HDL cholesterol in adjusted models.”<sup>86</sup>

Found in blood in Hong Kong residents: “Perfluorooctane sulfonate (PFOS) was the dominant PFC, followed by perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS)... The levels of PFOS, PFOA, PFHxS and perfluorohexanoic acid (PFHxA) were significantly higher in the male plasma samples ( $p < 0.05$ ), while the mean plasma levels of DEHP and n-butyl benzyl phthalate (BBP) were significantly higher in the young age group ( $p < 0.02$ ).”<sup>87</sup>

Placental transfer in humans: “Median concentrations of PFAS (ng/mL) of PFHxS, PFOS, PFOA, and PFNA in maternal plasma (0.79, 6.18, 2.85 and 0.84, respectively) and serum (0.84, 6.99, 2.97 and 0.85) were higher than in cord serum (0.40, 1.86, 1.90 and 0.32).”<sup>88</sup>

Excreted in human milk: “Each month of breastfeeding was associated with lower maternal serum concentrations of PFOA (-3%; 95% CI: -5, -2%), PFOS (-3%; 95% CI: -3, -2%), PFNA (-2%; 95% CI: -2, -1%), and PFHxS (-1%; 95% CI: -2, 0%).”<sup>89</sup>

Found in house cats: “The highest PFAS serum concentrations detected were in indoor cats due to disproportionately elevated PFHxS levels... Domestic cats appear to be useful sentinels for assessing primary PFAS exposure routes, especially indoor sources of relevance to children.”<sup>90</sup>

Bioaccumulation in the food web: “Biomagnification factors displayed values  $> 1$  for perfluorohexane sulfonate (PFHxS), perfluorononanoic acid (PFNA), PFOS and

---

<sup>86</sup> Starling AP, Engel SM, Whitworth KW, Richardson DB, Stuebe AM, Daniels JL, Haug LS, Eggesbo M, Becher G, Sabaredzovic A, Thomsen C, Wilson RE, Travlos GS, Hoppin JA, Baird DB, Longnecker (2014) Perfluoroalkyl substances and lipid concentrations in plasma during pregnancy among women in the Norwegian Mother and Child Cohort Study *Environ Int* 62:104-112

<sup>87</sup> Wan HT, Leung PY, Zhao YG, Wei X, Wong MH, Wong CK (2013) Blood plasma concentrations of endocrine disrupting chemicals in Hong Kong populations, *J Hazard Mater* 261:763-769

<sup>88</sup> Manzano-Salgado CB, Casas M, Lopez-Espinosa MJ, Ballester F, Basterrechea M, Grimalt JO, Jimenez AM, Kraus T, Schettgen T, Sunyer J, Vrijheid M (2015) Transfer of perfluoroalkyl substances from mother to fetus in a Spanish birth cohort, *Environ Res* 142:471-478

<sup>89</sup> Mondal D, Weldon RH, Armstrong BG, Gibson LJ, Lopez-Espinosa MJ, Shin HM, Fletcher T. (2014) Breastfeeding: a potential excretion route for mothers and implications for infant exposure to perfluoroalkyl acids, *Environ Health Perspect* 122:187-92

<sup>90</sup> Bost PC, Strynar MJ, Reiner JL, Zweigenbaum JA, Secoura PL, Lindstrom AB, Dye JA (2016) U.S. domestic cats as sentinels for perfluoroalkyl substances: Possible linkages with housing, obesity, and disease, *Environ Res* 151:145-153

SigmaPFAS(7). Multivariate analyses showed that the degree of trophic transfer of PFAS is similar to that of PCB, DDT and PBDE, despite their accumulation through different pathways.”<sup>91</sup>

Found in Great Lakes gulls: “C6, C8 and C10 PFASs, PFEtCH<sub>x</sub>S, and C7-14 and C16 PFCAs were quantifiable at >97% of the 114 egg samples... This study showed the increasing complexity of PFAS-CECs, and emphasized the importance of continuing monitoring of bioaccumulative PFAS in Great Lakes herring gulls.”<sup>92</sup>

Found in gulls in the Ebro Delta: “In egg yolks, perfluorooctane sulfonate (PFOS) was the main compound detected followed by perfluorononanoic acid (PFNA), perfluorohexane sulfonate (PFHS) and perfluorooctanoic acid (PFOA).”<sup>93</sup>

Bioaccumulation in wheat and earthworms: “Translocation factors (TF) of perfluorinated carboxylates (PFCAs) in wheat peaked at perfluorohexanoic acid and decreased significantly as the number of carbons increased or decreased. Perfluorohexane sulfonate produced the greatest TF of the three perfluorinated sulfonates (PFSAs) examined. Wheat increased the bioaccumulation of all 11 PFASs in earthworms and earthworms increased the bioaccumulation in wheat of PFCAs containing seven or less perfluorinated carbons, decreased bioaccumulation of PFCAs with more than seven carbons, and decreased bioaccumulation of PFSAs. In general, the co-presence of wheat and earthworms enhanced the bioavailability of PFASs in soil.”<sup>94</sup>

Risk of human exposure in fires: “Serum concentration of PFH<sub>x</sub>S was statistically higher in firefighters both before and after adjustment.”<sup>95</sup>

Found in drinking water in Netherlands: “PFASs were detected in the drinking water from the western part of the Netherlands. This seems attributable to the source, which is purified surface water in this area. Short-chain PFASs and especially perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), perfluorobutane sulfonate (PFBS), and perfluorohexane

---

<sup>91</sup> Haukås M, Berger U, Hop H, Gulliksen B, Gabrielsen GW (2007) Bioaccumulation of per- and polyfluorinated alkyl substances (PFAS) in selected species from the Barents Sea food web, *Environ Pollut* 148:360-371

<sup>92</sup> Letcher RJ, Su G, Moore JN, Williams LL, Martin PA, de Solla SR, Bowerman WW (2015) Perfluorinated sulfonate and carboxylate compounds and precursors in herring gull eggs from across the Laurentian Great Lakes of North America: Temporal and recent spatial comparisons and exposure implications, *Sci Total Environ* 538:468-477

<sup>93</sup> Vicente J, Sanpera C, Garcia-Tarrason M, Perez A, Lacorte S (2015) Perfluoroalkyl and polyfluoroalkyl substances in entire clutches of Audouin's gulls from the Ebro Delta, *Chemosphere* 119 Suppl:S62-8. doi: 10.1016/j.chemosphere.2014.04.041.

<sup>94</sup> 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, *Environ Pollut* 184:495-501

<sup>95</sup> Jin C, Sun Y, Islam A, Qian Y, Ducatman A (2011) Perfluoroalkyl acids including perfluorooctane sulfonate and perfluorohexane sulfonate in firefighters, *J Occup Environ Med* 53:324-328

sulfonate (PFHxS) were detected most frequently, whereas long-chain PFASs (C > 8) were only rarely detected.”<sup>96</sup>

Contaminated drinking water linked to human body burden: “PFAA levels in blood serum from 297 young women from Uppsala County, Sweden, sampled during 1996-1999 and 2008-2011 were analyzed. Significantly higher concentrations of perfluorobutane sulfonic acid (PFBS) and perfluorohexane sulfonic acid (PFHxS) were found among women who lived in districts modeled to have received contaminated drinking water compared to unaffected districts both in 1996-1999 and 2008-2011, indicating that the contamination was already present in the late 1990s.”<sup>97</sup>

Found in river estuary: “Perfluorobutanesulfonate (PFBS) and perfluorohexanesulfonate (PFHxS) were the two dominant compounds among the target PFASs, which may be due to their production and use as PFOS substitutes in the Pearl River Delta (PRD) areas.”<sup>98</sup>

Found in US wastewater treatment plants: “Despite the differences in reporting levels, the PFASs that were detected in >70% of the source water samples (n = 39) included PFSAs, perfluorobutane sulfonic acid (74%), perfluorohexane sulfonic acid (79%), and perfluorooctane sulfonic acid (84%), and PFCAs, perfluoropentanoic acid (74%), perfluorohexanoic acid (79%), perfluoroheptanoic acid (74%), and perfluorooctanoic acid (74%). More importantly, water treatment techniques such as ferric or alum coagulation, granular/micro-/ultra- filtration, aeration, oxidation (i.e., permanganate, ultraviolet/hydrogen peroxide), and disinfection (i.e., ozonation, chlorine dioxide, chlorination, and chloramination) were mostly ineffective in removing PFASs. However, anion exchange and granular activated carbon treatment preferably removed longer-chain PFASs and the PFSAs compared to the PFCAs, and reverse osmosis demonstrated significant removal for all the PFASs, including the smallest PFAS, perfluorobutanoic acid.”<sup>99</sup>

Found in Thai wastewater treatment plants: “Total 10 PFCs including perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluoropropanoic acid (PFPA), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorohexane sulfonate (PFHxS), perfluoronanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), and perfluorododecanoic acid (PFDoA) were measured

---

<sup>96</sup> Zafeiraki E, Costopoulou D, Vassiliadou I, Leondiadis L, Dassenakis E, Traag W, Hoogenboom RL, van Leeuwen SP (2015) Determination of perfluoroalkylated substances (PFASs) in drinking water from the Netherlands and Greece, *Food Addit Contam Part A Chem Anal Control Expo Risk Asses* 32:2048-2057

<sup>97</sup> Gyllenhammar I, Berger U, Sundstrom M, McCleaf P, Euren K, Eriksson S, Ahlgren S, Lignell S, Aune M, Kotova N, Glynn A (2015) Influence of contaminated drinking water on perfluoroalkyl acid levels in human serum--A case study from Uppsala, Sweden, *Environ Res* 140:673-683

<sup>98</sup> Gao Y, Fu J, Meng M, Wang Y, Chen B, Jiang G (2015) Spatial distribution and fate of perfluoroalkyl substances in sediments from the Pearl River Estuary, South China, *Mar Pollut Bull* 96:226-234

<sup>99</sup> Appleman TD, Higgins CP, Quinones O, Vanderford BJ, Kolstad C, Zeigler-Holady JC, Dickenson ER (2014) Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems, *Water Res* 51:246-255

to identify their occurrences. PFCs were detected in both liquid and solid phase in most samples...Due to PFCs non-biodegradable property, both WWTPs were found ineffective in removing PFCs using activated sludge processes.”<sup>100</sup>

Found in watersheds: “The  $\Sigma$ PFASs in the dissolved phase in Taihu Lake was 17.2-94.4 ng/L with PFOA (39.8%), perfluorohexanoate (PFHxA) (30.1%) and PFOS (16.8%) as the dominant PFASs.”<sup>101</sup>

Contaminates French drinking water: “In raw-water samples, the highest individual PFC concentration was 139 ng/L for perfluorohexanoic acid (PFHxA). The sum of all of the determined components was >100 ng/L at three sampling points (199, 117, and 115 ng/L). Of the investigated PFCs, perfluorooctane sulfonate (PFOS), perfluorohexane sulfonate (PFHxS), perfluorooctanoic acid (PFOA), and PFHxA predominated (detected in 27%, 13%, 11%, and 7% of samples, respectively).”<sup>102</sup>

Found in Lake Ontario sediments and cores: “Perfluorooctanesulfonate (PFOS), perfluorooctanoate (PFOA), perfluorononanoate (PFNA), perfluorodecanoate (PFDA), and perfluoroundecanoate (PFUnDA) were detected in all 26 surface sediment samples, whereas perfluorohexane sulfonate (PFHxS), perfluorooctane sulfonamide (FOSA), perfluorododecanoate (PFDoDA) and perfluorobutanoate (PFBA) were detected in over 70% of the surface sediment samples... Sediment core samples collected from Niagara basin showed an increase in unidentified organic fluorine in recent years (1995-2006). These results suggest that the use and manufacture of fluorinated organic compounds other than known PFCAs and PFSAs has diversified and increased.”<sup>103</sup>

Found in South African maternal serum and infant cord blood: “In maternal serum perfluorooctane sulfonate (PFOS) was found to be the most abundant PFC (1.6 ng mL<sup>-1</sup>), followed by perfluorooctanoate (PFOA: 1.3 ng mL<sup>-1</sup>) and perfluorohexane sulfonate (PFHxS: 0.5 ng mL<sup>-1</sup>); however, in cord blood PFOA was the most abundant compound (1.3 ng mL<sup>-1</sup>) followed by PFOS (0.7 ng mL<sup>-1</sup>) and PFHxS (0.3 ng mL<sup>-1</sup>).”<sup>104</sup>

Found in human blood in China and at higher levels that PFOA in some cities: “In Fuxin and Jinzhou, the percentage proportion of PFOA was significantly higher than that of

---

<sup>100</sup> Kunacheva C, Tanaka S, Fuji S, Boontanon SK, Musirat C, Wongwattana T, Shivakoti BR (2011) Mass flows of perfluorinated compounds (PFCs) in central wastewater treatment plants of industrial zones in Thailand, *Chemosphere* 83:737-744

<sup>101</sup> 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 Res* 80:235-244

<sup>102</sup> Boiteux V, Dauchy X, Rosin C, Munoz JF (2012) National screening study on 10 perfluorinated compounds in raw and treated tap water in France, *Arch Environ Contam Toxicol* 63:1-12

<sup>103</sup> Yeung LW, De Silva AO, Loi El, Marvin CH, Taniyasu S, Yamashita N, Mabury SA, Muir DC, Lam PK (2013) Perfluoroalkyl substances and extractable organic fluorine in surface sediments and cores from Lake Ontario, *Environ Int* 59:389-397

<sup>104</sup> Hanssen L, Röllin H, Odland JØ, Moe MK, Sandanger TM (2010) Perfluorinated compounds in maternal serum and cord blood from selected areas of South Africa: results of a pilot study, *J Environ Monit* 12:1355-1361

perfluorohexanesulfonate (PFHxS) by about two times. By contrast, in Shenyang, Anshan, and Yingkou, the percentage proportion of PFHxS was about three times higher than that of PFOA.”<sup>105</sup>

Found in human hair: “Some PFAS were not present in any hair sample (e.g. PFHpA, PFTeDA, PFNA, PFPeS, PFHpS, PFOS and PFNS), while other PFAS were frequently detected (PFBA, PFPeA, PFHxA, PFOA, PFBS, PFHxS, PFOS, PFDS and PFDoS) in human hair.”<sup>106</sup>

Found in humans in community with known drinking water contamination: “Serum samples from 196 residents of two communities were analyzed for seven PFCs. Perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), and perfluorohexanesulfonate (PFHxS) were detected in all serum samples collected. Perfluorobutanoic acid (PFBA) and perfluorobutane sulfonate (PFBS) were found in 28% and 3% of the samples, respectively.”<sup>107</sup>

Found in children: “Statistically, serum concentrations of perfluorobutane sulfonate (PFBS), perfluorohexane sulfonate (PFHxS), and perfluorooctanoic acid (PFOA) had significantly positive correlations with ages of children ( $p < 0.05$ ). Furthermore, serum PFBS, PFHxS, and PFOA concentrations in the male children were considerably higher than those in the female children ( $p = 0.049$ ,  $p = 0.000$ ,  $p = 0.000$ ).”<sup>108</sup>

Found in dust in homes and daycare centers: “PFOS and PFOA were the most prominent compounds detected, occurring in over 95% of the samples at median concentrations of 201 and 142 ng/g of dust, respectively. Maximal concentrations of PFOS were 12 100 ng/g (95th percentile, 2240 ng/g), PFOA 1960 ng/g (95th percentile, 1200 ng/g), and perfluorohexanesulfonate (PFHS) 35 700 ng/g (95th percentile, 2300 ng/g) ...These results indicate that perfluorinated compounds are present in house dust at levels that may represent an important pathway for human exposure.”<sup>109</sup>

Increasing levels in primiparous women: “We investigated temporal trends of blood serum levels of 13 perfluorinated alkyl acids (PFAAs) and perfluorooctane sulfonamide (FOSA) in primiparous women (N = 413) from Uppsala County, Sweden, sampled 3 weeks after delivery 1996-2010. Levels of the short-chain perfluorobutane sulfonate (PFBS) and perfluorohexane sulfonate (PFHxS) increased 11%/y and 8.3%/y, respectively, and levels

---

<sup>105</sup> Liu J, Li J, Luan Y, Zhao Y, Wu Y (2009) Geographical distribution of perfluorinated compounds in human blood from Liaoning province, China, *Environ Sci Technol* 43:4044-4048

<sup>106</sup> Alves A, Jacobs G, Vanermen G, Covaci A, Voorspoels S (2015) New approach for assessing human perfluoroalkyl exposure via hair, *Talanta* 144:575-583

<sup>107</sup> Landsteiner A, Huset C, Johnson J, Williams A (2014) Biomonitoring for perfluorochemicals in a Minnesota community with known drinking water contamination, *J Environ Health* 77:14-19

<sup>108</sup> Bao J, Lee YL, Chen PC, Jin YH, Dong GH (2014) Perfluoroalkyl acids in blood serum samples from children in Taiwan, *Environ Sci Pollut Res Int* 21:7650-7655

<sup>109</sup> Strynar MJ, Lindstrom AB (2008) Perfluorinated compounds in house dust from Ohio and North Carolina, USA, *Environ Sci Technol* 42:3751-3756



of the long-chain perfluorononanoate (PFNA) and perfluorodecanoate (PFDA) increased 4.3%/y and 3.8%/y, respectively.”<sup>110</sup>

Use in airport firefighting foams pollutes groundwater, lakes, soils, and fish: “...a former airfield, abandoned since 1994, may still be a point source of PFAAs to nearby recipients... PFHxA, PFOA, PFHxS and PFOS were observed in 9%, 49%, 71% and 58% in all soil samples respectively... PFHxA, PFOA, PFHxS and PFOS were observed in 56%, 75%, 69% and 94% respectively in all of the ground water samples... European Perch contained generally the highest PFOS and PFHxS concentrations in all Lakes...Our results provide evidence that the historical use of AFFF at the site have contaminated an aquifer (7500 m(3)d(-1)), that will require constant PFAA purification before being used for drinking water production.”<sup>111</sup>

Found in outdoor consumer products such as jackets. For example, PFHxS was found in a Columbia Alpine Action jacket (Chile).<sup>112</sup>

**Perfluorobutane sulfonate (C4 or PFBS), CAS 375-73-5 is associated with the following adverse characteristics:**

Found in the Arctic: “In the Greenland Sea, the  $\Sigma$ PFASs concentrations ranged from 45 to 280 pg/L, and five most frequently detected compounds were perfluorooctanoic acid (PFOA), perfluorohexanesulfonate (PFHxS), perfluorohexanoic acid (PFHxA), perfluorooctane sulfonate (PFOS) and perfluorobutane sulfonate (PFBS)”<sup>113</sup>

Alters zebrafish behavior: “The locomotor activity of zebrafish larvae has become widely used for evaluation of chemicals with neurotoxic properties. In the present study the behavioral effects of seven structurally different PFAAs (i.e. TFAA, PFBA, PFOA, PFNA, PFDA, PFBS and PFOS) were evaluated in zebrafish larvae. Exposure to high concentrations of TFAA, PFNA, PFBS and PFOS resulted in distinct changes in behavioral patterns.”<sup>114</sup>

---

<sup>110</sup> Glynn A, Berger U, Bignert A, Ullah S, Aune M, Lignell S, Sarnerud PO (2012) Perfluorinated alkyl acids in blood serum from primiparous women in Sweden: serial sampling during pregnancy and nursing, and temporal trends 1996-2010, *Environ Sci Technol* 46:90719079

<sup>111</sup> Filipovic M, Woldegiorgis A, Norstrom K, Bibi M, Lindberg M, Osteras AH (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

<sup>112</sup> Santen M, Brigden K, Cobbing M (2016) Leaving Traces: The hidden hazardous chemicals in outdoor gear, Greenpeace

<sup>113</sup> Zhao Z, Xie Z, Möller A, Sturm R, Tang J, Zhang G, Ebinghaus R (2012) Distribution and long-range transport of polyfluoroalkyl substances in the Arctic, Atlantic Ocean and Antarctic coast, *Environ Pollut* 170:71-77

<sup>114</sup> Ulhaq M, Orn S, Carlsson G, Morrison DA, Norrgren L (2013) Locomotor behavior in zebrafish (*Danio rerio*) larvae exposed to perfluoroalkyl acids, *Aquat Toxicol* 144-145:332-340

Alters heart rates in zebrafish: “Effects on hatching rate and success were found in PFOA exposed embryos and heart rates were affected after exposure to PFOS, PFOA and PFBS.”<sup>115</sup>

Disrupts various lipid assemblies: “PFBS decreased the transition temperature and transition width of PC bilayers... PFBS disrupted different model lipid assemblies, indicating potential for PFBS to be a human toxicant.”<sup>116</sup>

Modulates immune response in vitro: “PFBS, PFOSA, PFOS, PFDA and fluorotelomer inhibited PHA-induced IL-10 release... PFBS and PFDA prevented LPS-induced I- $\kappa$ B degradation. Overall, these studies suggest that PFCs affect NF- $\kappa$ B activation, which directly suppresses cytokine secretion by immune cells.”<sup>117</sup>

Inhibition of aromatase in human placental cells in vitro: “Moreover, this work evidences a high potential of PFOS, PFOA and PFBS to act as aromatase inhibitors in placental cells with IC50s in the range of 57-80  $\mu$ M, the inhibitory effect of PFBS being particularly important despite the rather low uptake of the compound by cells...Overall, this work highlights the ability of the PFC mixture to alter cellular lipid pattern at concentrations well below those that generate toxicity, and the potential of the short chain PFBS, often considered a safe substitute of PFOS, to significantly inhibit aromatase activity in placental cells.”<sup>118</sup>

Affects mRNA synthesis in vitro: “Significant changes in mRNA abundance were observed. The effects caused by the shorter chain replacement chemicals differed significantly from those caused by PFOS or PFOA. Furthermore, not all of the PFCs caused the same effects, and changes could not simply be attributed to chain-length or functional group.”<sup>119</sup>

Found in infiltrated Rhine River Water: “The compound perfluorobutanesulfonate (PFBS) was found at the highest concentrations of all PFCs investigated, up to 37 ng/L in infiltrated river water ( $71 \pm 13\%$  of  $\Sigma$ PFCs)”<sup>120</sup>

---

<sup>115</sup> Hagenaaers A, Vergauwen L, De Coen W, Knapen D (2011) Structure-activity relationship assessment of four perfluorinated chemicals using a prolonged zebrafish early life stage test, *Chemosphere* 82:764-772

<sup>116</sup> Oldham ED, Xie W, Farnoud AM, Fiegel J, Lehmler HJ (2012) Disruption of phosphatidylcholine monolayers and bilayers by perfluorobutane sulfonate, *J Phys Chem B* 116:9999-10007

<sup>117</sup> Corsini E, Sangiovanni E, Avogadro A, Galbiati V, Viviani B, Marinovich M, Galli CL, Dell'Agli M, Germolec DR (2012) In vitro characterization of the immunotoxic potential of several perfluorinated compounds (PFCs), *Toxicol Appl Pharmacol* 258:248-255

<sup>118</sup> Gorrochategui E, Perez-Albaladejo E, Casas J, Lacorte S, Porte C (2014) Perfluorinated chemicals: differential toxicity, inhibition of aromatase activity and alteration of cellular lipids in human placental cells, *Toxicol Appl Pharmacol* 277:124-130

<sup>119</sup> Naile JE, Wiseman S, Bachtold K, Jones PD, Giesy JP (2012) Transcriptional effects of perfluorinated compounds in rat hepatoma cells, *Chemosphere* 86:270-277

<sup>120</sup> Eschauzier C, Haftka J, Stuyfzand PJ, de Voogt P (2010) Perfluorinated compounds in infiltrated river rhine water and infiltrated rainwater in coastal dunes, *Environ Sci Technol* 44:7450-7455

Persistent to sewage treatment: “in German sludge,  $\Sigma$ PFC ranged from 20.7 to 38.6 ng/g dw and PFBS was the dominant compound... This study demonstrates that PFCs are persistent to sludge treatment and the loads in sludge may pose a future environmental risk, if not controlled.”<sup>121</sup>

Found in wastewater treatment plants and drinking water treatment plants: “The results showed that both perfluorobutane sulfonic acid (PFBS) and perfluorooctane sulfonic acid (PFOS) were the predominant compounds in the water phase of WWTPs and DWTPs, while PFOS was dominant in dewatered sludge of WWTPs.”<sup>122</sup>

Found in US wastewater treatment plants: “Despite the differences in reporting levels, the PFASs that were detected in >70% of the source water samples (n = 39) included PFSAs, perfluorobutane sulfonic acid (74%), perfluorohexane sulfonic acid (79%), and perfluorooctane sulfonic acid (84%), and PFCAs, perfluoropentanoic acid (74%), perfluorohexanoic acid (79%), perfluoroheptanoic acid (74%), and perfluorooctanoic acid (74%). More importantly, water treatment techniques such as ferric or alum coagulation, granular/micro-/ultra- filtration, aeration, oxidation (i.e., permanganate, ultraviolet/hydrogen peroxide), and disinfection (i.e., ozonation, chlorine dioxide, chlorination, and chloramination) were mostly ineffective in removing PFASs. However, anion exchange and granular activated carbon treatment preferably removed longer-chain PFASs and the PFSAs compared to the PFCAs, and reverse osmosis demonstrated significant removal for all the PFASs, including the smallest PFAS, perfluorobutanoic acid.”<sup>123</sup>

Found in sewage treatment plant and nearby rivers in Spain: “All samples, except two sludges from Guadalquivir River STPs, were contaminated with at least one PFAS. Perfluorobutanoate (PFBA), perfluoropentanoate (PFPeA) and perfluorooctane sulfonate (L-PFOS) were the most frequently detected. The highest concentration in water was determined in 2010 in a Guadalquivir River STP (perfluorohexanoate, PFHxA: 5.60 $\mu$ g/L(-1)) and, in 2011, in an Ebro River STP (perfluorobutane sulfonate, L-PFBS: 0.31 $\mu$ g/L(-1)). In sludge samples, the maximum concentration in 2010 was 1.79 $\mu$ gg(-1) dry weight (dw) (L-PFOS, in a Llobregat River STP), and in 2011, 1.88 $\mu$ gg(-1)dw (PFBA, in one Guadalquivir River STP).”<sup>124</sup>

Resistant to microbial degradation: “the tested short chain perfluoroalkyl substances (i.e., PFBS and trifluoroacetic acid) and a polyfluoroalkyl PFOS analogue, 6 : 2 fluorotelomer

---

<sup>121</sup> Gómez-Canela C, Barth JA, Lacorte S (2012) Occurrence and fate of perfluorinated compounds in sewage sludge from Spain and Germany, *Environ Sci Pollut Res Int* 19:4109-4119

<sup>122</sup> Pan CG, Liu YS, Ying GG (2016) Perfluoroalkyl substances (PFASs) in wastewater treatment plants and drinking water treatment plants: Removal efficiency and exposure risk, *Water Res* 106: 562-570

<sup>123</sup> Appleman TD, Higgins CP, Quinones O, Vanderford BJ, Kolstad C, Zeigler-Holady JC, Dickenson ER (2014) Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems, *Water Res* 51:246-255

<sup>124</sup> Campo J, Masia A, Pico Y, Farre M, Barcelo D (2014) Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants, *Sci Total Environ* 472:912-922

sulfonic acid (FTSA) were also resistant to anaerobic biodegradation. Likewise, no conclusive evidence of microbial degradation was observed under aerobic conditions for any of the short-chain perfluoroalkyl and polyfluoroalkyl carboxylic acids tested after 32 weeks of incubation. Collectively, these results indicate that PFOS and its alternatives such as short chain perfluoroalkyl sulfonates and carboxylates and their polyfluorinated homologues are highly resistant to microbial degradation.”<sup>125</sup>

Found in river water and sediment near manufacturing plants in China: “Eighteen different perfluoroalkyl substances (PFASs) were investigated in 35 river water samples and 34 sediment samples collected from rivers in the Liaodong Bay basin containing two fluorine industry parks. Perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS) were the predominant PFASs in freshwater, with median concentrations of 26.5 ng/L and 1.87 ng/L, respectively. However, perfluorobutane sulfonate (PFBS) had the highest maximum concentration (up to 124.1 ng/L, approximately two orders of magnitude higher) in water at a site which is the nearest to the industrial source of PFASs.”<sup>126</sup>

Found in the Daling River in China near fluorine industry parks: “Xihe tributary, which is adjacent to two local fluorine industrial parks, contained the highest level of PFASs. Short-chain PFASs, including perfluorobutanoic acid and perfluorobutane sulfonate, were of higher levels due to their emerging as alternative products for perfluorooctane sulfonate. High level of perfluorooctanoic acid was also found in Daling River. Based on these results, it can be concluded that the relatively severe pollutions of Xihe tributary were caused by long-term development of the two local fluorine industry parks.”<sup>127</sup>

Transport from factories into Daling River: “The C4 perfluorobutane sulfonic acid (PFBS) and perfluorobutanoic acid (PFBA) were the predominant short-chain PFAAs in river water, with maximum concentrations of 2.90 and 1.35 µg/L, respectively. Park 1 equipped with a telomerization process was identified to be the source of linear and branched mixtures of PFBS, PFBA, and perfluorooctanoic acid (PFOA), while park 2 with an electrochemical fluorination process (ECF) was identified to be the source of linear and branched mixtures of PFBS and PFOA.”<sup>128</sup>

Fluorine industry pollution into Daling River: “The highest concentration of ΣPFASs (9540 ng L<sup>-1</sup>) and dominant homologues were found in surface water collected in summer. Perfluorobutanoic acid (PFBA), perfluorobutane sulfonate (PFBS), and perfluorooctanoic

---

<sup>125</sup> Ochoa-Herrera V, Field JA, Luna-Velasco A, Sierra-Alvarez R (2016) Microbial toxicity and biodegradability of perfluorooctane sulfonate (PFOS) and shorter chain perfluoroalkyl and polyfluoroalkyl substances (PFASs), *Environ Sci Process Impacts* 18:1236-1246

<sup>126</sup> Chen H, Zhang C, Han J, Sun R, Kong X, Wang X, He X (2015) Levels and spatial distribution of perfluoroalkyl substances in China Liaodong Bay basin with concentrated fluorine industry parks, *Mar Pollut Bull* 101:965-971

<sup>127</sup> Meng J, Wang T, Wang P, Zhu Z, Li Q, Lu Y (2015) Perfluoroalkyl substances in Daling River adjacent to fluorine industrial parks: implication from industrial emission, *Bull Environ Contam Toxicol* 94:34-40

<sup>128</sup> Wang P, Lu Y, Wang T, Zhu Z, Li Q, Zhang Y, Fu Y, Xiao Y, Giesy JP (2015) Transport of short-chain perfluoroalkyl acids from concentrated fluoropolymer facilities to the Daling River estuary, China, *Environ Sci Pollut Res Int* 22:9626-9636

acid (PFOA) were the dominant PFASs in four seasons with a total contribution of over 90%. The discharge of two fluorine chemical industry parks was predicted to be the main contamination source of PFASs in the study area. The daily and annual mass flows were calculated according to data of detected PFAS concentrations and water discharge, and the annual mass loading of PFASs into the Bohai Sea from the Daling River reached to 461 kg year<sup>-1</sup>.<sup>129</sup>

Found in the Ganges River basin: "15 PFAS were frequently detected in the river with the highest concentrations observed for PFHxA (0.4-4.7 ng L<sup>-1</sup>) and PFBS (<MQL - 10.2 ng L<sup>-1</sup>) among PFCAs and PFSAs, respectively. Prevalence of short-chain PFAS indicates that the effects of PFOA and PFOS substitution are visible in environmental samples from India."<sup>130</sup>

Found in river estuary: "Perfluorobutanesulfonate (PFBS) and perfluorohexanesulfonate (PFHxS) were the two dominant compounds among the target PFASs, which may be due to their production and use as PFOS substitutes in the Pearl River Delta (PRD) areas."<sup>131</sup>

Found in Pearl River in China: "Perfluorooctanoate (PFOA), perfluorobutane sulfonate (PFBS), and perfluorooctane sulfonate (PFOS) were the three most abundant PFAAs and on average accounted for 20%, 24%, and 19% of  $\Sigma$ PFAAs, respectively. PFBS was the most abundant PFAA in the Dong Jiang tributary, and PFOA was the highest PFAA in the samples from the main stream of the Pearl River."<sup>132</sup>

Found in rivers of Pearl River Delta in China: "Perfluorobutane sulfonic acid (PFBS), perfluorooctanoic acid (PFOA), and perfluorooctane sulfonic acid (PFOS) were the three most abundant PFAAs and on average accounted for 28%, 16% and 10% of  $\Sigma$  PFAAs, respectively. Higher concentrations of  $\Sigma$  PFAAs were found in the samples collected from Jiangmen section of Xijiang River, Dongguan section of Dongjiang River and the Pearl River flowing the cities which had very well-developed manufacturing industries. PCA model was employed to quantitatively calculate the contributions of extracted sources. Factor 1 (72.48% of the total variance) had high loading for perfluorohexanoic acid (PFHxA), perfluoropentanoic acid (PFPeA), PFBS and PFOS."<sup>133</sup>

---

<sup>129</sup> Zhu Z, Wang T, Meng J, Wang P, Li Q, Lu Y (2015) Perfluoroalkyl substances in the Daling River with concentrated fluorine industries in China: seasonal variation, mass flow, and risk assessment, *Environ Sci Pollut Int* 22:100009-100018

<sup>130</sup> Sharma BM, Bharat GK, Tayal S, Larssen T, Becanova J, Karaskova P, Whitehead PG, Futter MN, Butterfield D, Nizzetto L (2016) Perfluoroalkyl substances (PFAS) in river and ground/drinking water of the Ganges River basin: Emissions and implications for human exposure, *Environ Pollut* 208(PtB):704-713

<sup>131</sup> Gao Y, Fu J, Meng M, Wang Y, Chen B, Jiang G (2015) Spatial distribution and fate of perfluoroalkyl substances in sediments from the Pearl River Estuary, South China, *Mar Pollut Bull* 96:226-234

<sup>132</sup> Zhang Y, Lai S, Zhao Z, Liu F, Chen H, Zou S, Xie Z, Ebinghaus R (2013) Spatial distribution of perfluoroalkyl acids in the Pearl River of southern China, *Chemosphere* 93:1519-1525

<sup>133</sup> Lui B, Zhang H, Xie L, Li J, Wang X, Zhao L, Wang Y, Yang B (2015) Spatial distribution and partition of perfluoroalkyl acids (PFAAs) in rivers of the Pearl River Delta, southern China, *Sci Total Environ* 524-525:1-7

Found in Indo-Pacific humpback dolphins and finless porpoises: “Significant increasing trends of several individual PFCAs and perfluorobutane sulfonate (PFBS) were found in cetacean samples from 2002 to 2014...This pattern may be attributed to the increasing usage of PFCAs and C4-based PFASs following the restriction/voluntary withdrawal of the production and use of perfluorooctane sulfonate (PFOS) related products. In addition, significantly increasing temporal shifting trends of PFOS to PFBS were observed in the dolphin liver samples. This pattern may be attributed to the substitution of PFOS by its alternative, PFBS...”<sup>134</sup>

Found in watersheds: “The total concentrations of the PFASs in the dissolved phase were 44.4-781 ng/L in Liao River with high contribution of perfluorobutane sulfonate (PFBS) (75.7%) and PFOA (9.86%). The  $\Sigma$ PFASs in the dissolved phase in Taihu Lake was 17.2-94.4 ng/L with PFOA (39.8%), perfluorohexanoate (PFHxA) (30.1%) and PFOS (16.8%) as the dominant PFASs.”<sup>135</sup>

Found in river estuary: “The predominant PFASs were perfluorobutanoic acid (PFBA), perfluoropentanoic acid, perfluorooctanoic acid, perfluorohexanoic acid and perfluorobutane sulfonate (PFBS)... As short-chain PFASs, such as PFBS and PFBA, have been the prevalent compounds in some places and are continuously produced and used, long-term monitoring and effective pollution controls are suggested.”<sup>136</sup>

Found in the Ebro and Guadalquivir river basins in Spain: “In water samples, of 21 analytes screened, 11 were found in Ebro and 9 in Guadalquivir. In both basins, the most frequent were PFBA, PFPeA and PFOA. Maximum concentration was detected for PFBA, up to 251.3 ng L(-1) in Ebro and 742.9 ng L(-1) in Guadalquivir. Regarding the sediments, 8 PFASs were detected in the samples from Ebro and 9 in those from Guadalquivir. The PFASs most frequently detected were PFBA, PFPeA, PFOA and PFOS. Maximum concentration in Ebro samples was, in dry weight, for PFOA (32.3 ng g(-1)) and in Guadalquivir samples for PFBA (63.8 ng g(-1)). For biota, 12 PFASs were detected in fish from the Ebro River and only one (PFOS) in that from Guadalquivir. In the Ebro basin, the most frequent were PFBA, PFHxA, PFOA, PFBS, PFOS and PFOSA. Maximum concentration in Ebro samples was, in wet weight, for PFHxA with 1280.2 ng g(-1), and in Guadalquivir samples for PFOS with 79.8 ng g(-1). These compounds were detected in the whole course of the rivers including the upper parts. In some points contamination was due to point sources mostly related to

---

<sup>134</sup> Lam JC, Lyu J, Kwok KY, Lam PK (2016) Perfluoroalkyl Substances (PFASs) in Marine Mammals from the South China Sea and Their Temporal Changes 2002-2014: Concern for Alternatives of PFOS? *Environ Sci Technol* 50:6728-6736

<sup>135</sup> 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 Res* 80:235-244

<sup>136</sup> Shao M, Ding G, Zhang J, Wei L, Xue H, Zhang N, Li Y, Chen G, Sun Y (2016) Occurrence and distribution of perfluoroalkyl substances (PFASs) in surface water and bottom water of the Shuangtaizi Estuary, China, *Environ Pollut* 216:675681

human activities (e.g. ski resorts, military camps, urban areas.). However, there are also some areas clearly affected by diffuse sources as atmospheric deposition.”<sup>137</sup>

Found in the Yangtze River: “Among the selected 18 PFASs, perfluorooctanoic acid (PFOA) was the dominant PFAS compound found both in water and sediment for the two seasons with its maximum concentration of 18.03 ng/L in water and 0.72 ng/g in sediment, followed by perfluorobutane sulfonic acid (PFBS) with its maximum concentration of 41.9 ng/L in water in Wuhan, whereas the lowest concentrations of PFASs were observed at Poyang lake. The annual loadings of PFOA, perfluorohexanoic acid (PFHxA), PFBS, perfluorooctane sulfonic acid (PFOS) and the total PFASs in the Yangtze River were 6.8 tons, 2.2 tons, 8.2 tons, 0.88 tons, and 20.7 tons, respectively. Wuhan and Er'zhou of Hubei contributed the most amounts of PFASs into the Yangtze River. A correlation was found between some PFASs, for example PFBS and PFOS, which suggests that both of these PFASs originate from common sources in the region.”<sup>138</sup>

Found in drinking water in Netherlands: “PFASs were detected in the drinking water from the western part of the Netherlands. This seems attributable to the source, which is purified surface water in this area. Short-chain PFASs and especially perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorooctanoic acid (PFOA), perfluorobutane sulfonate (PFBS), and perfluorohexane sulfonate (PFHxS) were detected most frequently, whereas long-chain PFASs (C > 8) were only rarely detected.”<sup>139</sup>

Contaminated drinking water linked to human body burden: “PFAA levels in blood serum from 297 young women from Uppsala County, Sweden, sampled during 1996-1999 and 2008-2011 were analyzed. Significantly higher concentrations of perfluorobutane sulfonic acid (PFBS) and perfluorohexane sulfonic acid (PFHxS) were found among women who lived in districts modeled to have received contaminated drinking water compared to unaffected districts both in 1996-1999 and 2008-2011, indicating that the contamination was already present in the late 1990s.”<sup>140</sup>

Found in humans in community with known drinking water contamination: “Serum samples from 196 residents of two communities were analyzed for seven PFCs. Perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), and

---

<sup>137</sup> Lorenzo M, Campo J, Farre M, Perez F, Pico Y, Barcelo D (2016) Perfluoroalkyl substances in the Ebro and Guadalquivir river basins (Spain), *Sci Total Environ* 540:191-199

<sup>138</sup> Pan CG, Ying GG, Zhao JL, Liu YS, Jiang YX, Jiang YX, Zhang QQ (2014) Spatiotemporal distribution and mass loadings of perfluoroalkyl substances in the Yangtze River of China, *Sci Total Environ* 493:580-587

<sup>139</sup> Zafeiraki E, Costopoulou D, Vassiliadou I, Leondiadis L, Dassenakis E, Traag W, Hoogenboom RL, van Leeuwen SP (2015) Determination of perfluoroalkylated substances (PFASs) in drinking water from the Netherlands and Greece, *Food Addit Contam Part A Chem Anal Control Expo Risk Asses* 32:2048-2057

<sup>140</sup> Gyllenhammar I, Berger U, Sundstrom M, McCleaf P, Euren K, Eriksson S, Ahlgren S, Lignell S, Aune M, Kotova N, Glynn A (2015) Influence of contaminated drinking water on perfluoroalkyl acid levels in human serum--A case study from Uppsala, Sweden, *Environ Res* 140-673-683

perfluorohexanesulfonate (PFHxS) were detected in all serum samples collected. Perfluorobutanoic acid (PFBA) and perfluorobutane sulfonate (PFBS) were found in 28% and 3% of the samples, respectively.”<sup>141</sup>

Increasing levels in primiparous women: “We investigated temporal trends of blood serum levels of 13 perfluorinated alkyl acids (PFAAs) and perfluorooctane sulfonamide (FOSA) in primiparous women (N = 413) from Uppsala County, Sweden, sampled 3 weeks after delivery 1996-2010. Levels of the short-chain perfluorobutane sulfonate (PFBS) and perfluorohexane sulfonate (PFHxS) increased 11%/y and 8.3%/y, respectively, and levels of the long-chain perfluorononanoate (PFNA) and perfluorodecanoate (PFDA) increased 4.3%/y and 3.8%/y, respectively.”<sup>142</sup>

Found in human hair: “Some PFAS were not present in any hair sample (e.g. PFHpA, PFTeDA, PFNA, PFPeS, PFHpS, PFOS and PFNS), while other PFAS were frequently detected (PFBA, PFPeA, PFHxA, PFOA, PFBS, PFHxS, PFOS, PFDS and PFDoS) in human hair.”<sup>143</sup>

Found in children: “Statistically, serum concentrations of perfluorobutane sulfonate (PFBS), perfluorohexane sulfonate (PFHxS), and perfluorooctanoic acid (PFOA) had significantly positive correlations with ages of children ( $p < 0.05$ ). Furthermore, serum PFBS, PFHxS, and PFOA concentrations in the male children were considerably higher than those in the female children ( $p = 0.049$ ,  $p = 0.000$ ,  $p = 0.000$ ).”<sup>144</sup>

Found in consumer products: “On the other hand, high PFAS levels were identified in ski waxes (up to about 2000  $\mu\text{g}/\text{kg}$  PFOA), leather samples (up to about 200  $\mu\text{g}/\text{kg}$  PFBA and 120  $\mu\text{g}/\text{kg}$  PFBS), outdoor textiles (up to 19  $\mu\text{g}/\text{m}^2$  PFOA) and some other baking papers (up to 15  $\mu\text{g}/\text{m}^2$  PFOA).”<sup>145</sup>

Taken up in maize: “Perfluorobutanoic acid (PFBA) had the highest uptake rate within the group of PFCAs with an average of 2.46  $\mu\text{g g}^{-1}$  root DWd(-1) and perfluorooctane sulfonic acid (PFOS) had the highest uptake rate (3.63  $\mu\text{g g}^{-1}$  root DWd(-1)) within the group of PFSAs. The shoot:root ratio for shorter-chain PFCAs ( $\leq C7$ ) and PFBS (C4) was

---

<sup>141</sup> Landsteiner A, Huset C, Johnson J, Williams A (2014) Biomonitoring for perfluorochemicals in a Minnesota community with known drinking water contamination, *J Environ Health* 77:14-19

<sup>142</sup> Glynn A, Berger U, Bignert A, Ullah S, Aune M, Lignell S, Sarnerud PO (2012) Perfluorinated alkyl acids in blood serum from primiparous women in Sweden: serial sampling during pregnancy and nursing, and temporal trends 1996-2010, *Environ Sci Technol* 46:90719079

<sup>143</sup> Alves A, Jacobs G, Vanermen G, Covaci A, Voorspoels S (2015) New approach for assessing human perfluoroalkyl exposure via hair, *Talanta* 144:575-583

<sup>144</sup> Bao J, Lee YL, Chen PC, Jin YH, Dong GH (2014) Perfluoroalkyl acids in blood serum samples from children in Taiwan, *Environ Sci Pollut Res Int* 21:7650-7655

<sup>145</sup> Kotthoff M, Muller J, Jurling H, Schlummer M, Fiedler D (2015) Perfluoroalkyl and polyfluoroalkyl substances in consumer products, *Environ Sci Pollut Res Int* 22:14546-14549



>2.0, which indicates that shorter-chain PFASs are transferred predominantly and at higher concentrations to the shoot.”<sup>146</sup>

Found in outdoor consumer products such as jackets, trousers, boots, etc. PFBS was found in Arc'teryx Alpha SL jacket (Sweden), Haglofs L.I.M III jacket (Finland), Mammut Nordwand Pro HS Hooded jacket (Switzerland), Norrona Lofoten Gore-tex pro jacket (Norway), Patagonia Men's Super Alpine jacket (Taiwan), Salewa Ultrar GTX ACT M jacket (Italy), Arc'teryx Beta AR Pant Men's trousers (Taiwan), Jack Wolfskin Cloudburst Pants Women trousers (Russia), Mammut Nordwand Pro Pants Man trousers (Slovenia), Columbia Women's Redmond Low Waterproof shoes (Turkey), Jack Wolfskin LL All Terrain Texapore Men shoes (Turkey), Mammut Redburn Mid GTX Men shoes (Slovakia), The North Face Men's Hedghog Hik Mid GTX shoes (Hong Kong), and Patagonia Ascensionist pack 45L backpack (Republic of Korea).<sup>147</sup>

### **Perfluorobutanoic acid (PFBA) CAS 375-22-4 5 is associated with the following adverse characteristics:**

Found in the Arctic: “Perfluoroalkyl substances (PFAS) have been globally detected in various environmental matrices, yet their fate and transport to the Arctic is still unclear, especially for the European Arctic. In this study, concentrations of 17 PFAS were quantified in two ice cores (n=26), surface snow (n=9) and surface water samples (n=14) collected along a spatial gradient in Svalbard, Norway. Concentrations of selected ions (Na(+), SO<sub>4</sub>(2-), etc.) were also determined for tracing the origins and sources of PFAS. Perfluorobutanoate (PFBA), perfluorooctanoate (PFOA) and perfluorononanoate (PFNA) were the dominant compounds found in ice core samples.”<sup>148</sup>

Found on a high-altitude glacier in the Eastern Alps: “The seasonal accumulations of perfluorinated substances (PFAS), polybrominated diphenyl ethers (PBDE) and polycyclic aromatic hydrocarbons (PAH) were measured in a 10 m shallow firn core from a high altitude glacier at Mt. Ortles (Italy, 3830 m above sea level) in South Tyrol in the Italian Eastern Alps. The most abundant persistent organic pollutants of each group were perfluorobutanoic acid (PFBA), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA) (for PFASs); BDE 47, BDE 99, BDE 209 (for PBDEs) and phenanthrene (PHE), fluoranthene (FLA) and pyrene (PYR) (for PAHs).”<sup>149</sup>

---

<sup>146</sup> 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

<sup>147</sup> Santen M, Brigden K, Cobbing M (2016) Leaving Traces: The hidden hazardous chemicals in outdoor gear, Greenpeace

<sup>148</sup> Kwok KY, Yamazaki E, Yamashita N, Taniyasu S, Murphy MB, Horii Y, Petrick G, Kallerborn R, Kannan K, Murano K, Lam PK (2013) Transport of perfluoroalkyl substances (PFAS) from an arctic glacier to downstream locations: implications for sources, *Sci Total Environ* 447:46-55

<sup>149</sup> Kirchgeorg T, Dreyer A, Gabrielli P, Gabrieli J, Thompson LG, Barbante C, Ebinghaus R (2016) Seasonal accumulation of persistent organic pollutants on a high altitude glacier in the Eastern Alps, *Environ Pollut* 218:804-812

Found in remote mountain snow: PFBS was found in Kiruna/Övre, Sweden, Troms fylke, Norway, Kilpisjärvi, Finland, High Tatras, Slovakia, and Patagonia /Torres del Paine, Chile.<sup>150</sup>

Found in Tibetan mountain snow: “Perfluorobutanoic acid (PFBA) dominated the recent surface snowpack of Lake Namco which is mainly associated with India sources where the shorter chain volatile PFASs precursors predominate.”<sup>151</sup>

Found in Baiyangdian Lake in norther China: “The concentrations of 16 perfluorinated compounds (PFCs) were measured in surface water and organisms from Baiyangdian Lake. Perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid, and perfluorobutanoic acid (PFBA) were the major PFC species in the water at 6.8-56.8, 0.1-17.5 and 3.0-14.6 ng/L, respectively.”<sup>152</sup>

Efficiently translocated into plants: “Regarding to the degradation products, the higher their water solubility, the higher the plant translocation. In this sense, the lower the carbon chain length of PFCAs, the higher the BCFs determined (PFBA > PFHxA > PFHpA > PFOA > PFNA).”<sup>153</sup>

Marine fish contamination in France: “Freshwater fish contamination is mostly driven by perfluorooctane sulfonate (PFOS) (75%), whereas marine fish contamination is split between perfluorooctanoic acid (PFOA) (24%), PFOS (20%), perfluorohexanoic acid (PFHxA) (15%), perfluoropentanoic acid (PFHpA) (11%), and perfluorobutanoic acid (PFBA) (11%). Common carp, pike-perch, European perch, thicklip grey mullet, and common roach presented the most unfavorable balance profile due to their high level of PFAAs and low level of n-3 long-chain polyunsaturated fatty acids (LC-PUFAs).”<sup>154</sup>

Human exposure: “The estimated daily exposures (resulting from both direct and precursor intake) for the general adult population are highest for PFOS and perfluorooctanoic acid (PFOA), followed by perfluorohexanoic acid (PFHxA) and

---

<sup>150</sup> Cobbing M, Jacobson T, Santen M (2015) Footprints in the snow: Hazardous PFC in remote locations around the globe, Greenpeace

<sup>151</sup> Wang X, Halsall C, Codling G, Xie Z, Xu B, Zhao Z, Xue Y, Ebinghaus R, Jones KC (2014) Accumulation of perfluoroalkyl compounds in tibetan mountain snow: temporal patterns from 1980 to 2010, *Environ Sci Technol* 48:173-181

<sup>152</sup> Zhou Z, Shi Y, Li W, Xu L, Cai Y (2012) Perfluorinated compounds in surface water and organisms from Baiyangdian Lake in North China: source profiles, bioaccumulation and potential risk, *Bull Environ Contam Toxicol* 89:519-524

<sup>153</sup> Bizkarguenaga E, Zabaleta I, Prieto A, Fernandez LA, Zuloaga O (2016) Uptake of 8:2 perfluoroalkyl phosphate diester and its degradation products by carrot and lettuce from compost-amended soil, *Chemosphere* 152:309-317

<sup>154</sup> Yamada A, Bemrah N, Veyrand B, Pollono C, Merlo M, Desvignes V, Sirot V, Oseredczuk M, Marchand P, Cariou R, Antignac JP, Le Bizec B, Leblanc JS (2014) Perfluoroalkyl acid contamination and polyunsaturated fatty acid composition of French freshwater and marine fishes, *J Agric Food Chem* 62:7593-7603

perfluorodecanoic acid (PFDA), while lower daily exposures are estimated for perfluorobutanoic acid (PFBA) and perfluorododecanoic acid (PFDoDA).<sup>155</sup>

Found in humans in community with known drinking water contamination: “Serum samples from 196 residents of two communities were analyzed for seven PFCs. Perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), and perfluorohexanesulfonate (PFHxS) were detected in all serum samples collected. Perfluorobutanoic acid (PFBA) and perfluorobutane sulfonate (PFBS) were found in 28% and 3% of the samples, respectively.”<sup>156</sup>

Transferred to crops grown in sewage treatment plant solid-amended soil: “Uptake of PFAAs by greenhouse lettuce (*Lactuca sativa*) and tomato (*Lycopersicon lycopersicum*) grown in an industrially impacted biosolids-amended soil, a municipal biosolids-amended soil, and a control soil was measured. Bioaccumulation factors (BAFs) were calculated for the edible portions of both lettuce and tomato. Dry weight concentrations observed in lettuce grown in a soil amended (biosolids:soil dry weight ratio of 1:10) with PFAA industrially contaminated biosolids were up to 266 and 236 ng/g for perfluorobutanoic acid (PFBA) and perfluoropentanoic acid (PFPeA), respectively, and reached 56 and 211 ng/g for PFBA and PFPeA in tomato, respectively. BAFs for many PFAAs were well above unity, with PFBA having the highest BAF in lettuce (56.8) and PFPeA the highest in tomato (17.1)... The greatest accumulation was seen for PFBA and PFPeA in both field-grown lettuce and tomato; BAFs for PFBA were highest in both crops.”<sup>157</sup>

Taken up in maize: “Perfluorobutanoic acid (PFBA) had the highest uptake rate within the group of PFCAs with an average of 2.46  $\mu\text{g g}^{-1}$  root DWd<sup>-1</sup> and perfluorooctane sulfonic acid (PFOS) had the highest uptake rate (3.63  $\mu\text{g g}^{-1}$  root DWd<sup>-1</sup>) within the group of PFSAs. The shoot:root ratio for shorter-chain PFCAs ( $\leq C7$ ) and PFBS (C4) was  $>2.0$ , which indicates that shorter-chain PFASs are transferred predominantly and at higher concentrations to the shoot.”<sup>158</sup>

Found in pine needles along ski tracks: “Pine trees (*Pinus mugo* in Slovakia and *Pinus sylvestris* in Norway) were chosen for sampling in ski resorts. Relative distributions, overall concentrations, trend estimates, elevation patterns, and distance from primary sources were assessed. PFOA was the predominant PFAS constituent in pine needles from Slovakia (8-93%). In Norway, the most-abundant PFAS was perfluorobutanoic acid (PFBA: 3-66%). A difference in product composition (particularly in ski waxes) and differences in

---

<sup>155</sup> Gebbink WA, Berger U, Cousins IT (2015) Estimating human exposure to PFOS isomers and PFCA homologues: the relative importance of direct and indirect (precursor) exposure, *Environ Int* 74:160-169

<sup>156</sup> Landsteiner A, Huset C, Johnson J, Williams A (2014) Biomonitoring for perfluorochemicals in a Minnesota community with known drinking water contamination, *J Environ Health* 77:14-19

<sup>157</sup> Blaine AC, Rich CD, Hundal LS, Lau C, Mills MA, Harris KM, Higgins CP (2013) Uptake of perfluoroalkyl acids into edible crops via land applied biosolids: field and greenhouse studies, *Environ Sci Technol* 47:14062-14069

<sup>158</sup> 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

Norwegian and Slovakian regulations are considered to be the primary reason for these differences. Open application of PFOA in industry and products has been banned in Norway since 2011. The replacement of PFOA with short-chain substitutes is thus considered the reason for the observed pattern differences in the analyzed pine needles. Regular monitoring and screening programs are recommended.”<sup>159</sup>

Found in wastewater effluent in the US: “Effluent from six municipal treatment plants contained similar amounts of total PFASs, with highest median concentrations of PFHxA (24 ng/L), followed by PFOA (23 ng/L), PFBA (19 ng/L), and PFOS (15 ng/L). Compared to SF Bay municipal wastewater samples collected in 2009, the short chain perfluorinated carboxylates PFBA and PFHxA rose significantly in concentration.”<sup>160</sup>

Found in sewage treatment plant and nearby rivers in Spain: “All samples, except two sludges from Guadalquivir River STPs, were contaminated with at least one PFAS. Perfluorobutanoate (PFBA), perfluoropentanoate (PFPeA) and perfluorooctane sulfonate (L-PFOS) were the most frequently detected. The highest concentration in water was determined in 2010 in a Guadalquivir River STP (perfluorohexanoate, PFHxA: 5.60µg/L(-1)) and, in 2011, in an Ebro River STP (perfluorobutane sulfonate, L-PFBS: 0.31µg/L(-1)). In sludge samples, the maximum concentration in 2010 was 1.79µgg(-1)dry weight (dw) (L-PFOS, in a Llobregat River STP), and in 2011, 1.88µgg(-1)dw (PFBA, in one Guadalquivir River STP).”<sup>161</sup>

Found in the Ebro and Guadalquivir river basins in Spain: “In water samples, of 21 analytes screened, 11 were found in Ebro and 9 in Guadalquivir. In both basins, the most frequent were PFBA, PFPeA and PFOA. Maximum concentration was detected for PFBA, up to 251.3 ng L(-1) in Ebro and 742.9 ng L(-1) in Guadalquivir. Regarding the sediments, 8 PFASs were detected in the samples from Ebro and 9 in those from Guadalquivir. The PFASs most frequently detected were PFBA, PFPeA, PFOA and PFOS. Maximum concentration in Ebro samples was, in dry weight, for PFOA (32.3 ng g(-1)) and in Guadalquivir samples for PFBA (63.8 ng g(-1)). For biota, 12 PFASs were detected in fish from the Ebro River and only one (PFOS) in that from Guadalquivir. In the Ebro basin, the most frequent were PFBA, PFHxA, PFOA, PFBS, PFOS and PFOSA. Maximum concentration in Ebro samples was, in wet weight, for PFHxA with 1280.2 ng g(-1), and in Guadalquivir samples for PFOS with 79.8 ng g(-1). These compounds were detected in the whole course of the rivers including the upper parts. In some points contamination was due to point sources mostly related to

---

<sup>159</sup> Chropenova M, Karaskova P, Kallenborn R, Greguskova EK, Cupr P (2016) Pine Needles for the Screening of Perfluorinated Alkylated Substances (PFASs) along Ski Tracks, *Environ Sci Technol* 50:9487-9496

<sup>160</sup> Houtz EF, Sutton R, Park JS, Sedlak M (2016) Poly- and perfluoroalkyl substances in wastewater: Significance of unknown precursors, manufacturing shifts, and likely AFFF impacts, *Water Res* 95:142-149

<sup>161</sup> Campo J, Masia A, Pico Y, Farre M, Barcelo D (2014) Distribution and fate of perfluoroalkyl substances in Mediterranean Spanish sewage treatment plants, *Sci Total Environ* 472:912-922

human activities (e.g. ski resorts, military camps, urban areas.). However, there are also some areas clearly affected by diffuse sources as atmospheric deposition.”<sup>162</sup>

Found in the 5<sup>th</sup> largest freshwater lake in China: “PFOA was the predominant contaminant (8.62 ± 4.40 ng/L), followed by PFBA (2.04 ± 1.16 ng/L) and PFHxA (1.23 ± 1.50 ng/L).<sup>163</sup>

Found in the deep sea: “The finding of perfluoroalkyl substances (PFASs) in particles sinking to the deep northwestern Mediterranean Sea confirms the role of the latter as ballast for the transfer of pollutants to the deep sea... The finding of quantifiable concentrations of long-chain PFOA, PFOS and PFNA substances and significantly high concentrations of the short-chain substances PFHxA and PFBA indicates that these compounds, sorbed onto particulate matter, are quickly and directly transferred to the ocean's interior, thus highlighting the role of DSWC in removing those pollutants from the coastal ocean.”<sup>164</sup>

Found in consumer products: “On the other hand, high PFAS levels were identified in ski waxes (up to about 2000 µg/kg PFOA), leather samples (up to about 200 µg/kg PFBA and 120 µg/kg PFBS), outdoor textiles (up to 19 µg/m<sup>2</sup> PFOA) and some other baking papers (up to 15 µg/m<sup>2</sup> PFOA).”<sup>165</sup>

Found in outdoor consumer products such as jackets, trousers, boots, etc. PFBA was found in Arc'teryx Alpha SL jacket (Sweden), Blackyak U-Jade jacket #1 (Republic of Korea), Haglofs L.I.M III jacket (Finland), Mammut Nordwand Pro HS Hooded jacket (Switzerland), Norrona Lofoten Gore-tex pro jacket (Norway), Patagonia Men's Super Alpine jacket (Taiwan), Salewa Ultrar GTX ACT M jacket (Italy), Arc'teryx Beta AR Pant Men's trousers (Taiwan), Jack Wolfskin Cloudburst Pants Women trousers (Russia), Mammut Nordwand Pro Pants Man trousers (Slovenia), Patagonia M's Torrentshell Pants trousers (Hong Kong), Salewa Kali GTX M PNT trousers (Italy), Columbia Women's Redmond Low Waterproof shoes (Turkey), Haglofs Grym HI GT men shoes (Norway), Mammut Redburn Mid GTX Men shoes (Slovakia), The North Face Men's Hedghog Hik Mid GTX shoes (Hong Kong), Patagonia Ascensionist pack 45L backpack (Republic of Korea), The North Face Snow Leopard sleeping bag (Chile), Jack Wolfskin Gossamer Tent (Austria), and Mammut 9.8 Eternity Dry rope (Switzerland).<sup>166</sup>

---

<sup>162</sup> Lorenzo M, Campo J, Farre M, Perez F, Pico Y, Barcelo D (2016) Perfluoroalkyl substances in the Ebro and Guadalquivir river basins (Spain), *Sci Total Environ* 540:191-199

<sup>163</sup> Liu WX, He W, Qin N, Kong XZ, He Qs, Yang B, Yang C, Jorgensen SE, Xu FL (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), *Environ Pollut* 200:24-34

<sup>164</sup> Sanchez-Vidal A, Llorca M, Farre M, Canals M, Barcelo D, Puig P, Calafat A (2015) Delivery of unprecedented amounts of perfluoroalkyl substances towards the deep-sea, *Sci Total Environ* 526:41-48

<sup>165</sup> Kotthoff M, Muller J, Jurling H, Schlummer M, Fiedler D (2015) Perfluoroalkyl and polyfluoroalkyl substances in consumer products, *Environ Sci Pollut Res Int* 22:14546-14549

<sup>166</sup> Santen M, Brigden K, Cobbing M (2016) Leaving Traces: The hidden hazardous chemicals in outdoor gear, Greenpeace

#### **4:2 fluorotelomer alcohol (4:2 FTOH) is associated with the following adverse characteristics:**

Source of PFCAs to Arctic regions via oxidation: “Gas-phase 3,3,3-trifluoropropanol, 4:2 FTOH, and 6:2 FTOH exhibited significant uptake to each of the surfaces under study. The sand- and ash-catalyzed heterogeneous photooxidation of 6:2 FTOH resulted in the rapid production and subsequent slow degradation of surface-sorbed perfluorinated carboxylic acids (PFCAs)... These results provide the first evidence that the heterogeneous oxidation of FTOHs at metal-rich atmospheric surfaces may provide a significant loss mechanism for these chemicals and also act as a source of aerosol-phase PFCAs close to source regions. Subsequent long-range transport of these aerosol-sorbed PFCAs has the potential to join oceanic transport and local gas-phase FTOH oxidation as a source of PFCAs to Arctic regions.”<sup>167</sup>

Can travel beyond national borders: “There is interest in the production, use, and environmental occurrence of perfluorinated compounds (PFCs) across Asia and the Asian contributions to the burden of these compounds reaching the Arctic and other remote regions via long-range transport. A spatial survey of perfluorinated compounds was therefore undertaken across China, India, and Japan in 2009 using passive air samplers... A site in the west Pacific Ocean exhibited a Japanese profile in which 8:2 FTO and 8:2 FTOH were predominant. In contrast, a southern Indian profile with high 4:2 FTOH concentrations was observed at a background site in southern China.”<sup>168</sup>

Impairs population growth of *Tetrahymena thermophila*: “For 8:2 FTOH and 10:2 FTOH, no growth inhibition was found in either of the systems. In contrast, 4:2 FTOH interfered with population growth in the closed system (EC(50) = 276.1 mg/L), whereas, 6:2 FTOH had an influence on population growth both in the closed system (EC(50) = 64.3 mg/L) and in the open system. Macronucleus destruction was observed with 6:2 FTOH. No direct membrane damage was detectable.. Some evidence, such as the absence of direct membrane or macronucleus damage, indicate that certain FTOH could likely cause apoptosis.”<sup>169</sup>

Toxic to rat hepatocytes in vitro: “The LC(50) depended on perfluorinated chain length, with the shortest (4:2 FTOH; x=4) and longest (8:2 FTOH; x=8) FTOHs tested being more toxic than the medium chain length FTOH (6:2 FTOH; x=6); a structure-toxicity relationship that is consistent with that for 2-alkenals.”<sup>170</sup>

#### **6:2 fluorotelomer alcohol (6:2 FTOH) is associated with the following adverse characteristics:**

---

<sup>167</sup> Styler SA, Myers AL, Donaldson DJ (2013) Heterogeneous photooxidation of fluorotelomer alcohols; a new source of aerosol-phase perfluorinated carboxylic acids. *Environ Sci Technol* 47:6358-6367

<sup>168</sup> Li J, Del Vento S, Schuster J, Zhang G, Chakraborty P, Kobara Y, Jones KC (2011) *Environ Sci Technol* 45:7241-7248

<sup>169</sup> Wang Z, Ud-Daula A, Fiedler S, Schramm KW (2010) Impact of fluorotelomer alcohols (FTOH) on the molecular and macroscopic phenotype of *Tetrahymena thermophila*, *Environ Sci Pollut Res Int* 17:154-164

<sup>170</sup> Martin JW, Chan K, Mabury SA, O'Brien PJ (2009) Bioactivation of fluorotelomer alcohols in isolated rat hepatocytes, *Chem Bio Interact* 177:196-203

Found in the Arctic: "Atmospheric concentrations of organochlorine pesticides (OCPs), polybrominated diphenyl ethers (PBDEs) and neutral per- and polyfluoroalkyl substances (PFAS) have been measured at Villum Research Station, Station Nord (North Greenland) in the period 2008-2013...The average sum of the seven measured neutral PFAS ( $\Sigma$ 7PFAS) ranged from 1.82 to 32.1 pg m<sup>-3</sup>. The most abundant compound was 8:2 FTOH (44% of  $\Sigma$ 7PFAS), followed by 6:2 FTOH and 10:2 FTOH."<sup>171</sup>

Found in the Arctic: "Twenty high-volume air samples were collected during a crossing of the North Atlantic and Canadian Archipelago in July 2005 to investigate air concentrations of fluorotelomer alcohols (FTOHs) and perfluoroalkyl sulfonamido ethanols (PFASs). These commercial chemicals are widely used as surface treatments and are believed to be precursors for perfluorocarboxylic acids (PFCAs) and perfluorooctane sulfonate (PFOS) that accumulate in humans and biota, including those from remote arctic regions. The highest concentrations (sum of gas- and particle-phase) of FTOHs were for 8:2 FTOH (perfluorooctyl ethanol) (5.8-26 pg/m<sup>3</sup>), followed by 10:2 FTOH (perfluorodecyl ethanol) (1.9-17 pg/ m<sup>3</sup>) and 6:2 FTOH (perfluorohexyl ethanol) [BDL (below detection limit) to 6.0 pg/m<sup>3</sup>]."<sup>172</sup>

Source of PFCAs to Arctic regions via oxidation: "Gas-phase 3,3,3-trifluoropropanol, 4:2 FTOH, and 6:2 FTOH exhibited significant uptake to each of the surfaces under study. The sand- and ash-catalyzed heterogeneous photooxidation of 6:2 FTOH resulted in the rapid production and subsequent slow degradation of surface-sorbed perfluorinated carboxylic acids (PFCAs)... These results provide the first evidence that the heterogeneous oxidation of FTOHs at metal-rich atmospheric surfaces may provide a significant loss mechanism for these chemicals and also act as a source of aerosol-phase PFCAs close to source regions. Subsequent long-range transport of these aerosol-sorbed PFCAs has the potential to join oceanic transport and local gas-phase FTOH oxidation as a source of PFCAs to Arctic regions."<sup>173</sup>

Found in the Antarctic Peninsula: "Higher ratios of 8:2 to 10:2 to 6:2 FTOH were observed in the southern hemisphere, especially around the Antarctic Peninsula, suggesting that PFASs in the region were mainly from the long-range atmospheric transport. No obvious decrease of PFASs was observed in the background marine atmosphere after 2005."<sup>174</sup>

Long-range transport over South China Sea: "FTOHs was the predominant PFAS group, accounting for 95.2-99.3% of total PFASs ( $\Sigma$ PFASs), while the other PFASs accounted for a small fraction of  $\Sigma$ PFASs. The concentrations of  $\Sigma$ PFASs ranged from 18.0 to 109.9 pg m<sup>-3</sup> with an average of 54.5 pg m<sup>-3</sup>...Long-range transport is suggested to be a major

---

<sup>171</sup> Bossi R, Vorkamp K, Skov H (2016) Concentrations of organochlorine pesticides, polybrominated diphenyl ethers and perfluorinated compounds in the atmosphere of North Greenland, *Environ Pollut* 217:4-10

<sup>172</sup> Shoeib M, Harner T, Vlahos P (2006) Perfluorinated Chemicals in the Arctic Atmosphere *Environ Sci Technol* 40:7577-7583

<sup>173</sup> Styler SA, Myers AL, Donaldson DJ (2013) Perfluorinated chemicals in the arctic atmosphere, *Environ Sci Technol* 47:6358-6367

<sup>174</sup> Wang Z, Xie Z, Mi W, Moller A, Wolschke H, Ebinghaus R (2015) Neutral Poly/Per-Fluoroalkyl Substances in Air from the Atlantic to the Southern Ocean and in Antarctic Snow, *Environ Sci Technol* 49:7770-7775

pathway for introducing gaseous PFASs into the atmosphere over the northern SCS. In order to further understand the fate of gaseous PFASs during transport, the atmospheric decay of neutral PFASs under the influence of reaction with OH radicals and atmospheric physical processes were estimated. Concentrations of 8:2 FTOH, 6:2 FTOH and MeFBSE from selected source region to the atmosphere over the SCS after long-range transport were predicted and compared with the observed concentrations.”<sup>175</sup>

Atmosphere and deposition over Tianjin, China: “Fluorotelomer alcohols (FTOHs) were the dominant neutral PFASs in the atmosphere with total concentrations of 93.6-131 pg/m<sup>3</sup> and 8:2 FTOH contributing the most, whereas perfluorooctane sulfonamide derivatives (PFOSAs) were two magnitudes lower or undetected.”<sup>176</sup>

Impairs population growth of *Tetrahymena thermophila*: “For 8:2 FTOH and 10:2 FTOH, no growth inhibition was found in either of the systems. In contrast, 4:2 FTOH interfered with population growth in the closed system (EC(50) = 276.1 mg/L), whereas, 6:2 FTOH had an influence on population growth both in the closed system (EC(50) = 64.3 mg/L) and in the open system. Macronucleus destruction was observed with 6:2 FTOH. No direct membrane damage was detectable.. Some evidence, such as the absence of direct membrane or macronucleus damage, indicate that certain FTOH could likely cause apoptosis.”<sup>177</sup>

Endocrine disruption in zebra fish: “In this study, 18-week-old zebrafish (*Danio rerio*) were exposed to 0, 0.03, 0.3 and 3.0mg/l 1H,1H,2H,2H-perfluorooctan-1-ol (6:2 FTOH) for 7 days, and the effects on plasma sex hormone levels were measured followed by use of real-time PCR to examine selected gene expression in hypothalamic-pituitary-gonadal (HPG) axis and liver. Exposure to 6:2 FTOH significantly increased plasma estradiol (E2) and testosterone (T) levels in both males and females. Furthermore, the ratio of T/E2 was reduced in females while increased in males. In females, the increase of E2 was accompanied by up-regulated hepatic estrogenic receptor alpha (ERalpha) and vitellogenin (VTG1 and VTG3) expression. In males, the elevation of the T level is consistent with the up-regulation of cytochrome P450 c17alpha-hydroxylase, 17, 20-lase (CYP17) and the down-regulation of cytochrome P450 aromatase A (CYP19A). The present study demonstrated that waterborne exposure to 6:2 FTOH alter plasma sex hormone levels and the ratio of T/E2, as well as the transcriptional profiles of some genes in the HPG axis and liver. The results suggested that FTOHs may disturb fish reproduction through endocrine disrupted activity.”<sup>178</sup>

---

<sup>175</sup> Lai S, Song J, Song T, Huang Z, Zhang Y, Zhao Y, Liu G, Zheng J, Mi W, Tang J, Zou S, Ebinghaus R, Xie Z (2016) Neutral polyfluoroalkyl substances in the atmosphere over the northern South China Sea, *Environ Pollut* 214:449-455

<sup>176</sup> Yao Y, Chang S, Sun H, Gan Z, Hu H, Zhao Y, Zhang Y (2016) Neutral and ionic per- and polyfluoroalkyl substances (PFASs) in atmospheric and dry deposition samples over a source region (Tianjin, China), *Environ Pollut* 212:449-456

<sup>177</sup> Wang Z, Ud-Daulla A, Fiedler S, Schramm KW (2010) Impact of fluorotelomer alcohols (FTOH) on the molecular and macroscopic phenotype of *Tetrahymena thermophila*, *Environ Sci Pollut Res Int* 17:154-164

<sup>178</sup> Liu C, Yu L, Deng J, Lam PK, Wu RS, Zhou B (2009) Waterborne exposure to fluorotelomer alcohol 6:2 FTOH alters plasma sex hormone and gene transcription in the hypothalamic-pituitary-gonadal (HPG) axis of zebrafish, *Aquat Toxicol* 93:131-137



Effects on estrogen receptor in male medaka (*Oryzias latipes*): “An in vitro yeast two-hybrid assay indicated a significant, dose-dependent interaction between medaka estrogen receptor alpha (ERalpha) and coactivator TIF2 upon treatment with 6:2 FTOH, 8:2 FTOH or 2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-nonadecafluoro-1-decanol (NFDH). The relative ranks of tested chemicals on the estrogenic effects for medaka ERalpha descended in the order of estradiol-17beta (100)>>6:2 FTOH (0.16)>NFDH (0.016)>8:2 FTOH (0.0044)... Expression analysis of hepatic vitellogenin (VTG) protein showed estrogenic potentials with, 6:2 FTOH and 8:2 FTOH, indicative of the induction of VTG synthesis in the livers of male medaka. We also investigated mRNA expression levels of two ER subtypes (ERalpha and beta) and two VTGs (VTG I and VTG II) in the livers of male medaka following exposure to FTOHs. Quantitative real-time polymerase chain reaction analyses revealed that hepatic ERalpha, VTG I, and VTG II mRNA responded rapidly to FTOHs such as 6:2 FTOH and 8:2 FTOH after 8-h exposure, whereas no effects of these compounds on ERbeta mRNA transcription were observed. These results from both in vitro and in vivo assays strongly suggest that certain FTOHs, such as 6:2 FTOH and 8:2 FTOH, induce hepatic VTG through activation of ERalpha in male medaka.”<sup>179</sup>

Estrogenic activity in cultured tilapia hepatocytes: “A dose-dependent induction of VTG was observed in E2-, 4-NP-, PFOS-, PFOA- and 6:2 FTOH-treated cells, whereas VTG levels remained unchanged in the 4:2 FTOH and 8:2 FTOH exposure groups at the concentrations tested... The overall results demonstrated that PFOS, PFOA and FTOHs have estrogenic activities and that exposure to a combination of E2 and PFCs produced anti-estrogenic effects. The results of the estrogen receptor inhibition assay further suggested that the estrogenic effect of PFCs may be mediated by the estrogen receptor pathway in primary cultured tilapia hepatocytes.”<sup>180</sup>

Estrogenic effects on human estrogen receptor: “The present study demonstrates the estrogenic effects of fluorotelomer alcohols (FTOHs). In a yeast two-hybrid assay, treatment with 1H,1H,2H,2H-perfluorooctan-1-ol (6:2 FTOH), 1H,1H,2H,2H-perfluorodecan-1-ol (8:2 FTOH) and 2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-nonadecafluoro-1-decanol (NFDH) showed a dose-dependent interaction between the human estrogen receptor (hER) isoforms hERalpha or hERbeta ligand-binding domain and coactivator TIF2, whereas there were no estrogenic effects of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) for these hERs... These results suggest that certain FTOHs including 6:2 FTOH, 8:2 FTOH and NFDH interact with hER isoforms alpha and beta in vitro.”<sup>181</sup>

---

<sup>179</sup> Ishibashi H, Yamauchi R, Matsuoka M, Kim JW, Hirano M, Yamaguchi A, Tominaga N, Arizono K (2008) Fluorotelomer alcohols induce hepatic vitellogenin through activation of the estrogen receptor in male medaka (*Oryzias latipes*), *Chemosphere* 71:1853-1859

<sup>180</sup> Liu C, Du Y, Zhou B (2007) Evaluation of estrogenic activities and mechanism of action of perfluorinated chemicals determined by vitellogenin induction in primary cultured tilapia hepatocytes, *Aquat Toxicol* 85:267-277

<sup>181</sup> Ishibashi H, Ishida H, Matsuoka M, Tominaga N, Arizono K (2007) Estrogenic effects of fluorotelomer alcohols for human estrogen receptor isoforms alpha and beta in vitro, *Bio Pharm Bull* 30:1358-1359

Estrogen activity revealed in mcf-y breast cancer cell proliferation: “By means of an E-screen assay, we detected the proliferation-promoting capacity of the fluorotelomer alcohols 1H,1H,2H,2H-perfluorooctan-1-ol (6:2 FTOH) and 1H,1H,2H,2H-perfluoro-decan-1-ol (8:2 FTOH)... We observed small but relevant up-regulation of the estrogen receptor as a consequence of exposures to 6:2 FTOH or 8:2 FTOH. The latter finding suggests an alternative mode of action of the fluorotelomer alcohols compared with that of E2.”<sup>182</sup>

Significant data gaps remain in the toxicological profile of C6-FTOH: “The pharmacological profile of this compound in humans and rodents in vivo is not well characterised, and data from biomonitoring studies determining levels of this compound or its metabolites in human biological fluids are lacking. Data on the chronic, reproductive, and developmental toxicity of this compound are also scanty, as there are no available studies examining the toxicological profile of the C6-FTOH in mice, which have been shown to be more sensitive to the toxicological effects of PFCs than rats. Given the fact that toxicity data for the FTOHs are highly pertinent to the safety evaluation of dietary exposure to perfluorinated PFCs, confirmation that the C6-PFC compounds are a safer alternative to the long-chain PFCs awaits data from appropriately designed studies conducted with the C6-FTOH that address these data gaps.”<sup>183</sup>

Biotransformation to other perfluorinated substances in the environment: “6:2 FTI [F(CF<sub>2</sub>)<sub>6</sub>CH<sub>2</sub>CH<sub>2</sub>I] is a principal industrial raw material used to manufacture 6:2 FTOH [F(CF<sub>2</sub>)<sub>6</sub>CH<sub>2</sub>CH<sub>2</sub>OH] and 6:2 FTOH-based products and could enter aerobic environments from possible industrial emissions where it is manufactured. This is the first study to assess 6:2 FTI aerobic soil biotransformation, quantify transformation products, and elucidate its biotransformation pathways. 6:2 FTI biotransformation led to 6:2 FTOH as a key intermediate, which was subsequently biotransformed to other significant transformation products, including PFPeA [F(CF<sub>2</sub>)<sub>4</sub>COOH, 20 mol % at day 91], 5:3 acid [F(CF<sub>2</sub>)<sub>5</sub>CH<sub>2</sub>CH<sub>2</sub>COOH, 16 mol %], PFHxA [F(CF<sub>2</sub>)<sub>5</sub>COOH, 3.8 mol %], and 4:3 acid [F(CF<sub>2</sub>)<sub>4</sub>CH<sub>2</sub>CH<sub>2</sub>COOH, 3.0 mol %]. 6:2 FTI biotransformation also led to a significant level of PFHpA [F(CF<sub>2</sub>)<sub>6</sub>COOH, 16 mol % at day 91]...”<sup>184</sup>

Released from textiles and found in indoor air: “Concentrations of FTOHs measured in air ranged from 0.15 to 46.8, 0.25 to 286, and 0.11 to 57.5ng/m<sup>3</sup> for 6:2, 8:2 and 10:2 FTOHs, respectively. The highest concentrations in air were identified in shops selling outdoor clothing, indicating outdoor textiles to be a relevant source of FTOH in indoor workplace environments. Total amounts of FTOH in materials of outdoor textiles accounted for <0.8-7.6, 12.1-180.9 and 4.65-105.7µg/dm<sup>2</sup> for 6:2, 8:2 and 10:2 FTOHs, respectively. Emission from selected textiles revealed emission rates of up to 494ng/h. The measured data show that a) FTOHs are present in indoor textiles (e.g. carpets), b) they are

---

<sup>182</sup> Maras M, Vanparys C, Muylle F, Robbens J, Berger U, Barber JL, Blust R, De Coen W (2006) Estrogen-like properties of fluorotelomer alcohols as revealed by mcf-7 breast cancer cell proliferation, *Enviro Health Perspect* 114:100-105

<sup>183</sup> Penelope A. Rice, C6-Perfluorinated Compounds: The New Greaseproofing Agents in Food Packaging, *Curr Envir Health Rpt* (2015) 2:33-40

<sup>184</sup> Ruan T, Szostek B, Folsom PW, Wolstenholme BW, Liu R, Liu J, Jiang G, Wang N, Buck RC (2013) Aerobic soil biotransformation of 6:2 fluorotelomer iodide, *Environ Sci Technol*

released at ambient temperatures and c) indoor air of shops selling outdoor textiles contains the highest levels of FTOH.”<sup>185</sup>

Found indoor air in office environments: “In air, FTOHs were present in the highest concentrations, particularly 8:2-FTOH (GM = 9920 pg/m<sup>3</sup>). FTOHs varied significantly by building with the highest levels observed in a newly constructed building. PFOA in serum was significantly correlated with air levels of 6:2-FTOH (r = 0.43), 8:2-FTOH (r = 0.60), and 10:2-FTOH (r = 0.62). Collectively, FTOHs in air significantly predicted PFOA in serum (p < 0.001) and explained approximately 36% of the variation in serum PFOA concentrations... In conclusion, FTOH concentrations in office air significantly predict serum PFOA concentrations in office workers. Variation in PFC air concentrations by building is likely due to differences in the number, type, and age of potential sources such as carpeting, furniture, and/or paint.”<sup>186</sup>

Found in factory air manufacturing fabric in China: “The PUF disks were dominated by 8:2 FTOH and 10:2 FTOH which accounted for 55 ± 7% and 32 ± 10% of total neutral PFASs, respectively. In general 6:2 FTOH had a smaller contribution with 12 ± 10%, but had a higher contribution at the drying process in workshop 1 with a concentration of 898 ng/(sample·d).”<sup>187</sup>

Found in food contact materials and their migration: “The occurrence of fluorotelomer alcohols (FTOHs) was investigated in 94 food-contact materials (FCMs). We detected 6:2 FTOH (<0.60-1110 ng/g), 8:2 FTOH (<0.40-8490 ng/g), and 10:2 FTOH (<0.02-9350 ng/g) in most FCM samples, and four longer-chain C14-20 FTOHs were, for the first time, identified in FCMs with relatively high concentrations (<0.02-8450 ng/g for 12:2 FTOH, <0.02-1640 ng/g for 14:2 FTOH, <0.02-372 ng/g for 16:2 FTOH, and <0.02-130 ng/g for 18:2 FTOH)...All nine detectable FCMs produced in the United States were dominated by 6:2 FTOH, which was significantly different from those produced in China. The median concentration of total FTOHs in eco-friendly paper tableware was 2990 ng/g, which was lower than in popcorn bags (18 200 ng/g) but much higher than other FCMs (<0.55-38.7 ng/g). FTOHs could migrate from paper bowls, with migration efficiencies of 0.004-0.24% into water, 0.004-0.24% into 10% ethanol, 0.009-2.79% into 30% ethanol, 0.06-13.0% into 50% ethanol (v/v) simulants, and 0.04-2.28% into oil. Migration efficiencies decreased with increasing carbon chain lengths of FTOHs.”<sup>188</sup>

---

<sup>185</sup> Schlummer M, Gruber L, Fiedler D, Kizlauskas M, Muller J (2013) Detection of fluorotelomer alcohols in indoor environments and their relevance for human exposure, *Environ Int* 57-58:42-49

<sup>186</sup> Fraser AJ, Webster TF, Watkins DJ, Nelson JW, Stapleton HM, Calafat AM, Kato K, Shoeib M, Vieira VM, McClean MD (2012) Polyfluorinated compounds in serum linked to indoor air in office environments, *Environ Sci Technol* 46:1209-1215

<sup>187</sup> Heydebreck F, Tang J, Xie Z, Ebinghaus R (2016) Emissions of Per- and Polyfluoroalkyl Substances in a Textile Manufacturing Plant in China and Their Relevance for Workers' Exposure, *Environ Sci Technol* 50:10386-10396

<sup>188</sup> 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, *Environ Sci Technol* 50:942-950

Found consumer products: “Concentrations of FTOHs were approximately 2-3 orders of magnitude higher than those of perfluoroalkyl carboxylic acids (PFCA)s.... Population normalized emission rates of perfluorooctanoic acid, 6:2 FTOH and 8:2 FTOH from imported consumer products were estimated to be 6.6, 2130 and 197  $\mu\text{g year}^{-1}$  capita<sup>-1</sup>) respectively for the “intermediate” emission scenario.”<sup>189</sup>

Found in consumer products in the US: “The content of 6:2 FTOH ranged from non-detectable to 331  $\mu\text{g g}^{-1}$ , 8:2 FTOH from non-detectable to 92  $\mu\text{g g}^{-1}$ , and 10:2 FTOH from non-detectable to 24  $\mu\text{g g}^{-1}$ . In addition, two consumer products from the home textile category were tested in the washing-drying process. One product from the treated apparel category and one from the home textile category were tested in the micro-scale chamber under elevated temperatures. The experimental data show that the washing-drying process with one cycle did not significantly reduce the FTOH concentrations in the tested consumer products. FTOH off-gassing was observed under accelerated aging conditions.”<sup>190</sup>

Found in consumer products in Germany: The most abundantly detected FTOH was FTOH 4:2, with maxima of 547.1  $\mu\text{g/kg}$  in cleaners and highest FTOH levels were found in impregnating sprays (up to 719,000  $\mu\text{g/kg}$  8:2 FTOH. In outdoor textiles, FTOH 8:2 reach maximum levels of 379.9  $\mu\text{g/m}^2$ . “Notably, none of the textile samples was free of FTOH 6:2, 8:2 or 10:2, and only one and two carpet and paper-based FCM samples each were below LOQ of FTOH 8:2 and 10:2, respectively... Their presence and comparable ratios of 10:2 and 6:2 FTOH, however, indicate that FTOH moieties in PAPS or polymeric surfactants may be the initial source of PFHxA, PFDA and probably PFOA.”<sup>191</sup>

Found in indoor air in Japanese homes: “The indoor air sampling was conducted in 49 households of the Keihan area, during winter and summer 2008. Most samples contained 6:2 FTOH, 8:2 FTOH, 10:2 FTOH and 8:2 FTOAc. The median concentration of 8:2 FTOH (5.84  $\text{ng m}^{-3}$ ) was highest among fluorotelomers, followed by those of 10:2 FTOH (1.12  $\text{ng m}^{-3}$ ), 6:2 FTOH (0.29  $\text{ng m}^{-3}$ ), and others.”<sup>192</sup>

Found in residential and non-residential house dust in South Korea: 6:2 FTOH was found ranging from <LOD – 12.7  $\text{ng/g}$  in house dust and 65.5  $\text{ng/g}$  in a library.<sup>193</sup>

---

<sup>189</sup> Vestergren R, Herzke D, Wang T, Cousins IT (2015) Are imported consumer products an important diffuse source of PFASs to the Norwegian environment? *Environ Pollut* 198:223-230

<sup>190</sup> Liu X, Guo Z, Folk EE 4<sup>th</sup>, Roache NF (2015) Determination of fluorotelomer alcohols in selected consumer products and preliminary investigation of their fate in the indoor environment, *Chemosphere* 120:81-86

<sup>191</sup> Kotthoff M, Muller J, Jurling H, Schlummer M, Fiedler D (2015) Perfluoroalkyl and polyfluoroalkyl substances in consumer products, *Environ Sci Pollut Res Int* 22:14546-14559

<sup>192</sup> Liu W, Takahashi S, Sakuramachi Y, Harada KH, Koizumi A (2013) Polyfluorinated telomers in indoor air of Japanese houses, *Chemosphere* 90:1672-1677

<sup>193</sup> Tian Z, Kim SK, Shoeib M, Oh JE, Park JE (2016) Human exposure to per- and polyfluoroalkyl substances (PFASs) via house dust in Korea: Implication to exposure pathway, *Sci Total Environ* 553:266-275

Found in indoor dust and packaging materials in Egypt: “The concentrations of PFASs precursors obtained in dust samples from 17 homes, 5 workplaces and 9 cars are presented in Fig. 1 and Table S6 in the supporting information. In homes, total neutral PFASs concentrations ranged from 1.09 to 55.2 ng g<sup>-1</sup>, and followed the order FTOHs > FOSEs > FOSAs > FTAs. Among FTOHs, the 8:2 FTOH was the dominant compound followed by 6:2 and 10:2 FTOHs with concentrations ranging from 0.71 to 10.1 ng g<sup>-1</sup>. The detection frequency ranged from 78% for 6:2 FTOH to 100% for 8:2 and 10:2 FTOHs... A significant positive correlation exists for 6:2 FTOH, 8:2 FTOH, and 10:2 FTOH dust concentrations ( $r^2 \geq 0.64$ ,  $p < 0.001$ ,  $n = 17$ ) in homes suggesting a common source for these compounds. This correlation holds for car samples ( $r^2 = 0.60$ ,  $p < 0.01$ ,  $n = 9$ ) but not for workplace samples ( $r^2 = 0.04$ ,  $p > 0.05$ ,  $n = 5$ ) perhaps due to the small number of samples analyzed.”<sup>194</sup>

Can be converted to PFHxA in sewage sludge: “After the end of use, 6:2 FTOH-based products may be released to domestic wastewater treatment plants (WWTPs) as a first major environmental entry point. Activated sludge collected from two WWTPs was dosed with 6:2 FTOH to investigate its biotransformation rate and to identify major transformation products. The volatile 5:2 sFTOH [F(CF<sub>2</sub>)<sub>5</sub>CH(OH)CH<sub>3</sub>] is the most abundant transformation product and accounted for an average of 40 mol% of initially dosed 6:2 FTOH after two months of incubation with activated sludge, with 30 mol% detected in the headspace. PFPeA [F(CF<sub>2</sub>)<sub>4</sub>COOH] averaged 4.4 mol% after two months, 2.4-7 times lower than that in sediment and soils. The much lower level of PFPeA formed in activated sludge compared with soil indicates that microbial populations in activated sludge may lack enzymes or suitable environment conditions to promote rapid 5:2 sFTOH decarboxylation to form PFPeA, resulting in more 5:2 sFTOH partitioned to the headspace. PFHxA [F(CF<sub>2</sub>)<sub>5</sub>COOH] and 5:3 [F(CF<sub>2</sub>)<sub>5</sub>CH<sub>2</sub>CH<sub>2</sub>COOH] acid are major non-volatile transformation products in activated sludge. For example, PFHxA averaged 11 mol% after two months, which is about 30% higher compared with sediment and soils, suggesting that microbes in WWTPs may utilize similar pathways as that in sediment and soils to convert 5:2 sFTOH to PFHxA.”<sup>195</sup>

Found in outdoor consumer products such as jackets, trousers, boots, etc. 6:2 FTOH was found in Arc'teryx Alpha SL jacket (Sweden), Columbia Alpine Action jacket (Chile), Haglofs L.I.M III jacket (Finland), Mammut Nordwand Pro HS Hooded jacket (Switzerland), Norrona Lofoten Gore-tex pro jacket (Norway), Patagonia Men's Super Alpine jacket (Taiwan), The North Face Women Stratos jacket (Sweden), Arc'teryx Beta AR Pant Men's trousers (Taiwan), Columbia Jump Off Cargo Pants Men (Russia), Haglofs Rugged II Mountain Pant trousers (Denmark), Jack Wolfskin Cloudburst Pants Women trousers (Russia), Mammut Nordwand Pro Pants Man trousers (Slovenia), Salewa Kali GTX M PNT trousers (Italy), The North Face Ravina Pants trousers (UK), Columbia Women's Redmond Low Waterproof shoes (Turkey), Jack Wolfskin LL All Terrain Texapore Men shoes (Turkey), Mammut Redburn Mid GTX Men shoes (Slovakia), Salewa Condor Evo GTX shoes

---

<sup>194</sup> Shoeib T, Hassan Y, Rauert C, Harner T (2016) Poly- and perfluoroalkyl substances (PFASs) in indoor dust and food packaging materials in Egypt: Trends in developed and developing countries, *Chemosphere* 144:1573-1581

<sup>195</sup> Zhao L, McCausland PK, Folsom PW, Wolstenholme BW, Sun H, Wang N, Buck RC (2013) 6:2 Fluorotelomer alcohol aerobic biotransformation in activated sludge from two domestic wastewater treatment plants, *Chemosphere* 92:464-470

(Slovenia), Mammut Alpine UL Winter sleeping bag (Germany), Mammut 9.8 Eternity Dry rope (Switzerland).<sup>196</sup>

### **6:2 fluorotelomer acid (6:2 FTA) is associated with the following adverse characteristics:**

Found in residential indoor air: “Individual PFC concentrations were between 42 pg m<sup>(-3)</sup> (6:2 FTA) and 209 ng m<sup>(-3)</sup> (8:2 FTOH). Concentrations of total FTOHs, FTAs, and FASAs + FASEs ranged from 0.2 to 152 ng m<sup>(-3)</sup> (FTAs), from 3.3 to 307 ng m<sup>(-3)</sup> (FTOHs), and from 4.4 to 148 ng m<sup>(-3)</sup> (FASAs + FASEs). Most elevated individual, group, and total PFC concentrations were detected in two stores selling outdoor equipment, one furniture shop, and one carpet shop. Indoor air concentrations were several orders of magnitude higher than published outdoor air concentrations indicating indoor air environments as sources for PFCs to the atmosphere.”<sup>197</sup>

Found in outdoor consumer products. 6:2 FTA was found in Haglofs Grym HI GT men shoes (Norway).<sup>198</sup>

### **6:2 fluorotelomer sulfonate (6:2 FTS) is associated with the following adverse characteristics:**

Persistent: “The 6:2 FTS biotransformation was relatively slow, with 63.7% remaining at day 90 and all observed transformation products together accounting for 6.3% of the initial 6:2 FTS applied...The relatively slow 6:2 FTS degradation in activated sludge may be due to microbial aerobic de-sulfonation of 6:2 FTS, required for 6:2 FTS further biotransformation, being a rate-limiting step in microorganisms of activated sludge in WWTPs.”<sup>199</sup>

Found in maternal and cord serum: “In this study, 50 paired maternal and cord serum samples collected in Jiangsu province of China were analyzed for fifteen PFAA precursors. Among the detected PFAAs, 6:2 fluorotelomer sulfonate (6:2 FTS), N-methyl- and N-ethyl-perfluorooctanesulfonamidoacetates had comparable detection rate in both maternal and cord sera, while the mean concentrations and detection rates of 8:2 FTS and perfluorooctane sulfonamide (PFOSA) were higher in maternal sera compared to cord sera (Mann-Whitney U test, P < 0.05). Analysis of variance and least significant difference tests

---

<sup>196</sup> Santen M, Brigden K, Cobbing M (2016) Leaving Traces: The hidden hazardous chemicals in outdoor gear, Greenpeace

<sup>197</sup> Langer V, Dreyer A, Ebinghaus R (2010) Polyfluorinated compounds in residential and nonresidential indoor air, *Environ Sci Technol* 44:8075-8081

<sup>198</sup> Santen M, Brigden K, Cobbing M (2016) Leaving Traces: The hidden hazardous chemicals in outdoor gear, Greenpeace

<sup>199</sup> Wang N, Liu J, Buck RC, Korzeniowski SH, Wolstenholm BW, Folsom PW, Sulecki LM (2011) 6:2 fluorotelomer sulfonate aerobic biotransformation in activated sludge of waste water treatment plants, *Chemosphere* 82:853-858

showed that the youngest maternal age group (21-24 years old) had the highest concentration of 6:2 FTS in cord sera.”<sup>200</sup>

Found in the effluent from an airport industrial treatment plant: “Effluent samples from two treatment plants contained much higher levels of PFASs: over two samplings, wastewater from one municipal plant contained an average of 420 ng/L PFOS and wastewater from an airport industrial treatment plant contained 560 ng/L PFOS, 390 ng/L 6:2 FtS, 570 ng/L PFPeA, and 500 ng/L PFHxA. The elevated levels observed in effluent samples from these two plants are likely related to aqueous film forming foam (AFFF) sources impacting their influent; PFASs attributable to both current use and discontinued AFFF formulations were observed.”<sup>201</sup>

Found in outdoor consumer products. 6:2 FTS was found in Haglofs LIM III jacket (Finland), Salewa Ultar GTX ACT M jacket (Italy), and The North Face Men’s Hedghog Hike Mid GTX shoes (Hong Kong).<sup>202</sup>

---

<sup>200</sup> Yang L, Wang Z, Shi Y, Li J, Wang Y, Zhao Y, Wu Y, Cai Z (2016) Human placental transfer of perfluoroalkyl acid precursors: Levels and profiles in paired maternal and cord serum, *Chemosphere* 144:1631-1638

<sup>201</sup> Houtz EF, Sutton R, Park JS, Sedlak M (2016) Poly- and perfluoroalkyl substances in wastewater: Significance of unknown precursors, manufacturing shifts, and likely AFFF impacts, *Water Res* 95:142-149

<sup>202</sup> Santen M, Brigden K, Cobbing M (2016) Leaving Traces: The hidden hazardous chemicals in outdoor gear, Greenpeace