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Socio-Economic Assessment of PFHxS and PFHxS-related Substances

Final Report

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1 Introduction

This report provides background information of relevance to the Risk Management Evaluation (RME) of PFHxS, its salts and related substances under Annex F of the Stockholm Convention. This background report builds on the Risk Profile report on PFHxS (UNEP/POPS/POPRC.14/6/Add.1). It provides information and analysis drawing from a number of different published works as well as from work specifically performed to generate more information for the RME. The report sets out and is structured according to the following four subjects:

- Available information on the number of producers and users of PFHxS and PFHxS related substances globally and related tonnages;
- Reduction potential of global regulation of PFHxS;
- Available information on socioeconomic costs and benefits of global regulation; and
- Available information on cost and technical feasibilities for waste handling and clean-up of contaminated sites.

2 Information on the number of producers and users of PFHxS and PFHxS related substances globally and related tonnages

2.1 Production volumes

A report (Report M-961/2018) on the sources of PFHxS in the environment was commissioned by the Norwegian Environment Agency in 2018 and prepared by the Brancheninstitut für Prozessoptimierung (BiPRO) GmbH with assistance from ETH Zürich (BiPRO, 2018). This report was mainly intended to provide background information for regulatory work under the Stockholm Convention and has a global scope.

Using market research reports for PFHxS (CAS No: 355-46-4) and PHxSF (CAS No: 423-50-7), review of peer-reviewed literature and other information sources in the public domain, and stakeholder consultations, the study sought to shed light on the sources to PFHxS in the environment. Information on the global production and use of PFHxS, its salts and related compounds and content in consumer products were collected. Across all evaluated sources of information as well as from consultation of stakeholders, such as possible manufacturers and producers of consumer products, it was found that there is a lack of publicly available information on the quantitative production levels and descriptions of product-specific uses of PFHxS and PFHxS-related compounds. There was also some question over the quality of the market research reports.

The available data suggests that production capacity of PFHxS remained constant at about 1,000 – 1,500 kg from 2011 - 2016. It identified actual production of PFHxS at about 700 - 750 kg in 2012 and evidence that it decreased to less than 700 kg in 2016 and a further slight decrease in production of PFHxS was expected for 2017 (BiPRO, 2018).

Only two key global PFHxS manufacturers (both from China) were identified in the market research reports. These are referred to as Company X and Company Y as the names of the companies are confidential. For the year 2016 the market research reports identified production market shares of almost 96 % and 5% respectively. The market research reports did not identify the Italian manufacturer Miteni which, while declaring that it ceased manufacture in 2013, still offered PFHxS as a product on its website shortly before its bankruptcy at the end of 2018. This suggests, then, that data in the market research reports (and probably also more generally across the literature as a whole) are incomplete.

Based in China, Company X had a constant production capacity for PFHxS in a range between 900 - 1100 kg per year during the time period from 2012 to 2016. The actual annual production of PFHxS in this period was estimated to average around 650 - 690 kg. The report identifies that, in 2017, a decrease in production was expected.

Also based in China, Company Y also had a constant PFHxS production capacity of about 100 - 300 kg per year during the time-period from 2012 to 2016. The actual annual production of PFHxS was estimated to be in the range of 30 - 50 kg.

This leads to the conclusion in the report that, based on information available from market research reports for PFHxS, there are two main global producers based in China with an accumulated annual production capacity between 1,000 – 1,500 kg and an actual global annual production of about 700 - 750 kg. The report identifies that the indicated global capacity / production values are lower than expected owing to the identification of only two producers. It was expected that the number of manufacturers would be higher globally.

Consultation was also carried out in the BiPRO study (BiPRO, 2018) to identify global users and producers. Responses were received from 30 companies. Four companies directly replied that they do not want to participate. Most of the contacted stakeholders, however, indicated that they are either not producing or using any of the substances investigated. Only one respondent (who wished to remain anonymous) indicated a past use of PFHxS of 25-30 t/a (in paper food packaging). Several potential Chinese producers were contacted during the consultation period but no relevant quantitative information could be obtained.

The EU REACH Annex XV report for the Identification of a Substance of Very High Concern for PFHxS (ECHA, 2017b) notes that one European company (in Italy) was known to be marketing the PFHxS potassium salt. During the extensive consultation carried out for the preparation of the REACH Restriction Dossier the Italian company (Miteni, which was the major manufacturer of fluorinated substances in the EU) identified that it stopped manufacturing PFHxS in 2013. Miteni's management have also now declared bankruptcy and to suspend production activities by the end of the year (2018). This was announced on 31 October 2018 (EMCC, 2018).

There are no REACH registrations for PFHxS, its salts or related substances suggesting that there is no production or use of PFHxS, its salts or related substances in the EU in quantities above 1 tonne per year per manufacturer or importer. However, classification and labelling notifications have been submitted to ECHA for PFHxS as recently as 19 January 2018 which suggests that PFHxS and related substances may be available on the EU market albeit at the lower volumes of <1 tonne per year per manufacturer or importer. Further, while REACH requires registration of monomers it does not require the registration of polymers such as the methacrylate polymers identified by The Republic of Korea in its Annex F submission (as discussed in later sections).

Accordingly, the evidence (or lack of) gathered from repeated efforts at consultation might tend to suggest that the number of producers and levels of production are as low as those identified in the market research reports reviewed in the BiPRO report (BiPRO, 2018). However, as noted earlier, the absence of at least one known manufacturer (Miteni) from those reports suggests that data on production and use in the market research reports (and probably also more generally across the literature as a whole) are incomplete. Thus, it is difficult to draw firm conclusions on numbers and scale of production.

Boucher et al (2018) recently presented a global emission inventory of C4–C10 perfluoroalkanesulfonic acids (PFSAs) including PFHxS released during the life cycle of perfluorohexanesulfonyl fluoride (PHxSF)- and perfluorodecanesulfonyl fluoride (PDSF)-based products. The authors note that "*past and ongoing intentional production of PHxSF and its derivatives cannot be quantified and is not included because no public information about their production volumes could be found*" and use alternative methods for estimation. Table 2-1 summarises the paper's estimate of global sum emissions of PFHxS from individual source categories for three time periods considered in that study. The paper notes that a majority of the emissions are estimated to have occurred from production within CG1 countries (comprising initial producing countries such as Japan, Western Europe and the United States) during the period before 3M's phase-out of POSF-based products, with emissions of PFHxS predicted to continue from product use and disposal (1–21 t) and degradation of xFHxSA/Es (1–66 t) between 2016 and 2030. The unintentional production of PHxSF related substances as impurities in Chinese manufacturing of POSF-based products is estimated to be far less significant in comparison. The authors identify that results highlight the potential ongoing environmental exposure to these substances and the need for more detailed data about their production levels and uses (where this again tends to highlight the fact that publicly available data on PFHxS are incomplete).

Table 2-1: Ranges of Global Estimated Sum Emissions of PFHxS from the Life Cycle of PHxSF-Based Products (rounded to the nearest metric ton) (Boucher et al, 2018)

PFHxS	1958–2002	2003–2015	2016–2030	Total
Emissions from production[a]	86–86	2–2	0–1	88–89
Emissions from use and disposal	6–307	3–30	1–21	10–358
Emissions from degradation of xFHxSA/Es [b]	1–410	1–124	1–66	3–600
Emissions from degradation of PHxSF[b]	20–61	1–2	0–1	21–64
Total	**113–864**	**7–158**	**2–89**	**122–1111**
PHxSF emissions from production[a]	78–78	2–2	0–1	80–81

a Ranges of calculated emissions from production are often small because of the use of single emission factors and production volumes as well as the small uncertainty range of the homologue composition of products.

b These values were estimated by the degradation processes implemented in the CliMoChem model.

The values given as ranges by Boucher et al (2018) in Table 2-1 have been converted into annual emissions of PFHxS by dividing the lower, upper and a mid-point values in Table 2-1 by the number of years covered by the time periods. These are provided as Table 2-2.

Table 2-2: Ranges and average of annual global estimated emissions of PFHxS derived from (Boucher et al, 2018) data in Table 2-1

PFHxS	1958–2002			2003–2015			2016–2030		
	Low	High	Mid	Low	High	Mid	Low	High	Mid
Emissions from production (kg)	1,955			167			0	71	36
Emissions from use and disposal (kg)	136	6,977	3,557	250	2,500	1,375	71	1,500	786
Emissions from degradation of xFHxSA/Es (kg)	23	9,318	4,670	83	10,333	5,208	71	4,714	2,393
Emissions from degradation of PHxSF (kg)	455	1,386	920	83	167	125	0	71	36
total (kg)	2,568	19,636	11,102	583	13,167	6,875	143	6,357	3,250
PHxSF emissions from production (kg)	1,773	1,773	1,773	167	167	167	0	71	36

Since the annual data extrapolated from the Boucher et al (2018) study in Table 2-2 relate to emissions and the BiPRO data (BiPRO, 2018) relate to production, it is difficult to make a direct comparison between the two sets of data. However, the Boucher et al (2018) data would tend to confirm that more recent and current global production and use is unlikely to be measured in the 10s or 100s of tonnes or higher as was the case when action on PFOS was under consideration in the early 2000s. At the same time, the extent to which both sets of data are drawn from the same sources of production and use data is not known.

Whilst far from being ideal, in the absence of any other information from any other source, the RME analysis must rely on the available (but likely incomplete) data on recent/current global production provided in the BiPRO report (BiPRO, 2018), namely that global annual production of the order of the following for the time periods indicated:

Pre 2000	227,000kg
2012	700-750kg
2017	<700kg

It should be stressed, however, that these data are unlikely to capture the full range of uses and production of PFHxS with information from, for example, The Republic of Korea’s Annex F submission identifying uses that were previously unknown. In many ways this only adds weight to the case for global regulation. This RME can only consider the case for global regulation considering known uses. It cannot account for those which are, as yet, unknown but ongoing. Any global regulation would, however, apply to both known and currently unknown uses.

2.2 Identified uses

In terms of the different identified uses the Risk Profile report (UNEP/POPS/POPRC.14/6/Add.1) identifies that PFHxS, its salts and PFHxS-related compounds have been intentionally used at least in the following applications:

- **Aqueous Film Forming Foams (AFFFs) for firefighting:** Historically, 3M used PFHxS in the production of its AFFF formulations (Olsen et al., 2005). According to Olsen et al., 3M produced PFHxS (or PFHS) as a building block for compounds incorporated in firefighting foams and this information is in accordance with patents from 3M (3M, 1972, 1973, 1992) and from another potential historical producer (reviewed in Norwegian Environment Agency M-961/2018). In particular, 3M (1992) indicates that PFHxS-related compounds and PFOS were likely used in the same AFFF formulations, i.e. previously known as "PFOS-based AFFFs" (e.g. FC-600). It is possible that such "PFOS-based AFFFs" containing PFHxS-related compounds have been discontinued after 3M ceased its global production in 2000–2002 (3M, 2000a), however, production by companies other than 3M cannot be excluded. Furthermore, there may still be substantial stockpiles of such legacy AFFF formulations around the world (UN Environment, 2011; Zushi et al., 2017). Furthermore, Shanghai Vatten has recently developed and commercialized at least one new PFHxS-related amphoteric surfactant for foam fire-extinguishers (Vatten, 2018; Huang et al., 2015).

- **Metal plating:** A number of patents (Dainippon, 1979, 1988; 3M, 1981; Hengxin, 2015) were identified for the use of PFHxS, its salts and various PFHxS-related compounds in metal plating as mist suppressants, suggesting that such use may have occurred. It is likely that at least Hubei Hengxin from China has marketed the potassium salt of PFHxS for metal plating (Hengxin, 2018). Furthermore, it should be noted that the manufacturing (including importing) or processing of one salt of PFHxS (tridecafluorohexanesulfonic acid, compound with 2,2'-iminodiethanol (1:1); CAS No: 70225-16-0) for use as a component of an etchant, including a surfactant or fume suppressant, used in the plating process to produce electronic devices shall not be considered a significant new use subject to reporting under the US EPA Significant New Use Rule on perfluoroalkyl sulfonates and long-chain perfluoroalkyl carboxylate chemical substances (US EPA, 2013).

- **Textiles, leather and upholstery:** Historically, 3M used PFHxS-related compounds in some of its aftermarket (post-production) carpet protection products (Olsen et al., 2005). It is possible that such aftermarket carpet and upholstery protector products produced by 3M have been discontinued after the company ceased its global production in 2000–2002 (3M, 2000a). However, it is reported that water-proofing textile finishes based on PFHxS-related compounds have recently been developed by at least Hubei Hengxin Chemical Co., Ltd. (CAS No: 68259-15-4, (tridecafluoro-N-methylhexanesulfonamide); CAS No: 68555-75-9 (tridecafluoro-N-(2-hydroxyethyl)-N-methylhexanesulfonamide); and CAS No: 67584-57-0, (2-[methyl[(tridecafluorohexyl) sulfonyl]amino]ethyl acrylate)) and Wuhan Fengfan Surface Engineering Co., Ltd. from China (Huang et al., 2015; Hengxin, 2018), as alternatives to PFOS-based compounds (Huang et al., 2015). The industrial activities with C-6 waterproofing agent for textiles in the Taihu Lake region in China might be a potential source of PFHxS where recent production and use of PFHxS as an alternative to PFOS and PFOA has been reported (Ma et al., 2017).

- **Polishing agents and cleaning/washing agents:** One PFHxS-related compound (CAS No: 67584-53-6, [N-Ethyl-N-(tridecafluorohexyl) sulfonyl]glycine, potassium salt) was reportedly used in polishing agents and cleaning/washing agents at least between 2000 and 2015 in Denmark, Norway and Sweden with the use volumes claimed as confidential business information (SPIN, 2018). For example, the FCP102 Floor Sealer and FCP300 Duro Gloss Floor Sealer & Finish from Fritztile contain this compound (Fritztile, 2018a,b).

- **Coating and impregnation/proofing:** One PFHxS-related compound (CAS No: 67584-61-6, 2-[Methyl[(Tridecafluorohexyl) Sulfonyl]Amino]Ethyl Methacrylate) was reportedly used in impregnation/proofing for protection from damp, fungus, etc. at least in four products between 2003 and 2009 in Denmark (SPIN, 2018).

- **Manufacturing of semiconductors:** During the POPRC-13 meeting in 2017, an industry representative noted that PFHxS, its salts and PFHxS-related compounds are currently being used as replacements to PFOS, PFOA and their related compounds in the semiconductor industry. This information is further strengthened by published information that indicates that PFHxS is used in the semiconductor industry in Taiwan province of China (Lin et al., 2010). PFHxS (133,330 ng/L), together with PFOS (128,670 ng/L), was one of the primary contaminants at a semiconductor fabrication plant waste water effluent site. Both PFSAs are present in the effluent in similar amounts showing that PFHxS is a primary substance in this process and are not unintentionally present at this site.

- **Other potential uses:** Hubei Hengxin has marketed the potassium salt of PFHxS and PFHxS-related compounds (CAS No: 68259-15-4, tridecafluoro-N-methylhexanesulfonamide) for potential uses as a flame retardant and in pesticides, respectively (Hengxin, 2018). PFHxS has been detected in food packaging materials (Schaider et al., 2017). Information regarding use of PFHxS in a company that develops, manufactures, and distributes analogue and digital imaging products has been reported (The Netherlands submission to PFOA intersessional work, 2018).

Additional information on previously unknown uses has been received through requests for information under Annex F of the convention. Here the Republic of Korea identifies in its updated Annex F submission that there are indications that PFHxS are used in an additive of solar cell texturing solution and a car coating spray. The Annex F submission identifies that there has been no production of PFHxS and PFHxS-related compounds in the Republic of Korea and all PFHxS-containing products were imports to the country.

The Republic of Korea has monitored PFAS at 70 water treatment and purification plants nationwide since 2012. PFHxS concentrations ranged from 0.002 µg/L to 0.013 µg/L in 2016, but PFHxS suddenly increased up to 0.454 µg/L at a plant in streams of the Nakdong River in 2017 (The Republic of Korea, Annex F information). This is in line with detection of PFHxS in tap water samples originating from the same river in a study in which PFHxS were in the highest concentrations ranging from not detected (n.d.) to 190 ng/L (Park et al 2018). The detection of PFHxS was caused by the use of solar cell texturing solutions containing PFHxS-related compound that were imported into the Republic of Korea. After corrective actions, the PFHxS concentrations dropped to the levels of previous years.

2.3 Quantities of use

In spite of information received under the Annex F procedure, information on actual quantities of use remains scarce and incomplete.

In relation to the uses reported by the Republic of Korea in its Annex F submission, the 2016 Statistical Survey of Chemicals system under the Chemicals Control Act indicates that 20 tonnes of product containing methacrylate polymers with side chains of PFHxS-related substances were imported into the Republic of Korea from the EU in the period 2013 to 2015 for use as a 'car coating spray'[1]. There are no data on quantities of use in an 'additive solar texturing solution'.

Regarding the 20 tonnes of car spray product containing the methacrylate polymer, further investigation suggests that the PFHxS-related compounds in the polymer side chains are PFOS with PFHxS unintentionally present as an impurity. No specific information is available on the levels of methacrylate polymer or PFHxS in the product. The Material Safety Data Sheet (MSDS) for the product[2] does not list the CAS number of interest. However, totalling the ranges given for the constituents listed in the MSDS suggests that between 28% and 54% of the content is unaccounted for on the MSDS. Assuming that there are two chemical constituents that are not accounted for on the MSDS (and that one of these is the methacrylate polymer) suggests that the product may be between 14% and 27% methacrylate polymer w/w. Assuming the actual content is in the middle of this range (i.e. 20%) suggests around 4,075kg methacylate polymer in the 20 tonnes of product. Reviewing the potential chemical structures of the methacrylate polymer and PFHxS-related side chains (PFOS), analysis of the molecular weights suggests that around 50% of the methacrylate polymer is likely to be made up of PFOS with PFHxS being unintentionally present. Thus the intended weight of the PFOS component in the 20 tonnes of methacrylate polymer-containing product is 2,038kg. Based on unintentional presence of PFHxS in other 'PFOS based' applications around 10% of the PFOS can be expected to be PFHxS present as an impurity. Thus, using the assumptions above, the 20t methacrylate polymer-containing car sprays used in the three-year period (2013-2015) contained 1,834kg PFOS and 204kg PFHxS – making an annual use of 611kg of PFOS and 68kg of PFHxS.

Clearly, the intentional use of PFOS in "car coating sprays" (or solar panels) is not consistent with the permitted or essential uses set out in the Stockholm Convention. As such, these uses should be the subject of future enforcement action.

The only other source of quantitative information on key countries' consumption is the BiPRO report (BiPRO, 2018). This identifies that around 620 - 640 kg of PFHxS was consumed in China, about 40 - 60 kg in Southeast Asia and about 10 - 30 kg in the rest of the world, leading to a total consumption in the range of 670 - 730 kg in 2016. Note that this will not include the 68kg PFHxS identified above by the Republic of Korea (nor the 611kg of PFOS) because this use was not identified in the BiPRO report.

While it is the only available estimate, the 670 – 730 kg provided in the BiPRO report (BiPRO, 2018) is unlikely to represent a complete and accurate assessment of the total quantity of use. The report estimates that 66% of total use is in AFFF firefighting foams and 22% in textile finishing which, applied to the approximately 700kg of total annual use from 2016 onwards, represents 462kg and 154 kg respectively for each of these uses. The remaining 12% (84kg) of annual use in the report is attributed to 'other' applications which, according to the descriptions of uses provided in the Risk Profile report (UNEP/POPS/POPRC.14/6/Add.1), would cover combined uses in:

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[1] The product brand name is confidential but contains CAS No. 127133-66-8 - Butylmethacrylate polymers with methylacrylic acid, lauryl methacrylate and 2-[methyl[(perfluoroalkyl (C=4-8)) sulfonyl]amino]ethyl methacrylate.

[2] Confidential

- Metal plating;
- Polishing agents and cleaning/washing agents;
- Coating and impregnation/proofing;
- Manufacturing of semiconductors; and
- Potential uses as a flame retardant, in pesticides and in imaging products.

A combined use of 84kg across all of these applications seems likely to be an underestimate of potential levels of use, especially when it is considered that a further 68kg per year of PFHxS (and 611kg per year of PFOS) has been identified as being used in the previously unidentified use of 'car sprays' by the Republic of Korea in its Annex F submission. There is also evidence that PFHxS has been (and is being) used as a substitute for PFOS and PFOA in the semiconductor industry (UNEP/POPS/POPRC.14/6/Add.1). PFHxS (and related substances) are known to be technically feasible substitutes for PFOS and PFOA in a number of applications (Kemi, 2017), including several where current use of PFHxS appears minimal.

There is also the potential for increased use of PFHxS. This is confirmed by a Chinese manufacturer that currently advertises PHxSF as "*one of the most essential raw materials for preparing fluorine containing surfactants. The fluorine containing surfactant can be widely used in textile, leather, papermaking, pesticide, electroplating, oilfield, fire control, photosensitive material, synthetic material and other fields*" (Made in China.com).

To summarise, the available evidence that has been accumulated through successive studies is likely only to provide a partial assessment of the total quantities of PFHxS used globally. The only quantitative data on specific applications relates to uses in firefighting foam and in textiles from BiPRO report (BiPRO, 2018) suggesting a total current consumption of around 700kg of which 66% (462 kg) is used in firefighting foams and 22% (154 kg) in textiles with the remainder (84kg) used in 'other applications' which would seem to include metal plating, polishing agents and cleaning/washing agents, coating and impregnation/proofing, manufacturing of semiconductors, and potential uses as a flame retardant, in pesticides and in imaging products. As noted above, for these combined 'other uses' in particular, 84kg per year seems likely to be an underestimate. In addition to the data from the BiPRO report, information from the Republic of Korea's Annex F submission suggests that some 68kg per year of PFHxS (and 611kg of PFOS) are used in 'car sprays' in Korea. An additional (but unknown) amount is used as an 'additive solar texturing solution' in the Republic of Korea.

The following sections provide more detailed information on what is known about the individual uses identified as background to the consideration of the costs and benefits of global regulation of PFHxS.

2.4 Further analysis of uses in Fire Fighting Foams

2.4.1 Overview

In terms of use in fire-fighting foams, information from the stakeholder consultation and literature review suggests whilst, in the past, there were foams for which PFHxS was the (main) active fluoro ingredient these foams are no longer generally manufactured, although at least one manufacturer of such foams was identified and is discussed below. PFHxS has been found to present as an impurity in some older foams manufactured using the electrochemical fluorination (ECF) process that was used in the past. Here, the AFFF industry has indicated that PFHxS and PFHxS-related substances are not present as impurities in modern AFFF because the synthesis route is now by telomerisation rather than the electrochemical fluorination methods which may give rise to PFHxS and other substance impurities during the manufacturing process.

Whilst the AFFFs currently on the market may not contain PFHxS as an impurity, the lifespan of fire-fighting foams has been variously reported as 10-20 years (British Fire Protection Association in the PFOS RRS (RPA, 2004)) and 10-25 years[3]. As such, some of the older ECF produced foams that do contain PFHxS as an impurity are possibly still in the AFFF stockpiles maintained in readiness at key sites such as refineries, petrochemical sites or fuel storage plants (tank farms), oil and gas facilities offshore to deal with the unlikely (but potentially catastrophic) possibility of a fire.

In relation to global regulation of PFHxS, its salts and related substances in fire-fighting foams, then, two issues are relevant:

- Presence of PFHxS in current stockpiles of AFFF kept at various types of installation (such as refineries, tank farms, chemical works, etc.) for the fighting of major fires; and
- Manufacture of foams for which PFHxS is a major constituent as opposed to being present as an impurity.

2.4.2 PFHxS present as an unintentional impurity in AFFF stockpiles

As noted above, large stockpiles must be maintained. The analysis in the EU REACH Restriction Dossier estimates that the EU's total stockpile of Class B fire-fighting foam (AFFF) is around 35,500t based on an aggregation of 2004 UK data to the EU. The EU REACH Restriction Dossier also estimates that this stockpile comprises around 88% PFAS based and 12% Fluorine free (F3) foam such that PFAS based foams make up some 31,240t of the total EU stockpile of AFFF foam concentrates.

The Dossier identifies that fluorinated compounds make up 1-6% of the AFFF concentrate but that 3% is often reported (for example (FFFC, 2011), (RPA, 2004) and others). Applying this 3% content to the total amount of PFAS based foam concentrate (31,240t), the Dossier estimates a total of 937.2t of PFAS in the EU stockpile of foams. Based on 8% of the stock being use/replenished per year, the Dossier estimates annual use/replenishment of 2,499t of PFAS based foam containing 75t of PFAS itself.

The German Mineralölwirtschaftsverband provided data to the stakeholder consultation on the measured content of substances including PFHxS in a selection of older fire-fighting foams that are part of the stockpiles of fire-fighting foams maintained at refineries and tank farms in Germany. These data suggest a range of between 31 and 98µg/kg (ppb) of PFHxS and an average of 59µg/kg (ppb) PFHxS in foam concentrates. Applying these measured values to the estimates of PFAS foam that may contain PFHxS impurities provides estimates of both the total quantity of PFHxS in the EU stockpile and the amount used/disposed and replenished per year.

However, some of the PFAS based foams may contain PFHxS present as an impurity owing to production via ECF and some will have been produced using synthesis by telomerisation and will not (because synthesis via this route does not give rise to PFHxS or PFHxS related substances). There are no data on the percentage split between PFAS based foams that contain PFHxS as an impurity and those that do not. In order to derive estimates of the quantities involved, the EU Dossier applies the following three scenarios to provide a spread of possibilities:

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[3] Comment no. 1225 to the PFOA restriction proposal says "By far the largest part of the fire-fighting foams are stored for 10-25 years"

- Scenario 1: 50% of the PFAS based foams stockpiled contain PFHxS impurities;
- Scenario 2: 70% of the PFAS based foams stockpiled contain PFHxS impurities; and
- Scenario 3: 100% of the PFAS based foams stockpiled contain PFHxS impurities.

Applying these percentages to the total estimated 31,240t of PFAS based foams in the EU stockpile suggests the following amounts of AFFF containing PFHxS:

- Scenario 1: 15,620t of foam containing PFHxS in the EU stockpile;
- Scenario 2: 21,868 of foam containing PFHxS in the EU stockpile;
- Scenario 3: 31,240 of foam containing PFHxS in the EU stockpile.

These are provided in Table 2-3 and suggest that, owing to the very low levels of PFHxS present as an impurity the estimated quantity of PFHxS in the stockpile is low ‘used’ is low, with estimates ranging between 484g and 1,843g (grammes) across the whole of the EU in some 15,620t to 31,240t of AFFF concentrate.

Table 2-3: Estimated total quantity of PFHxS in the EU stockpile of foams

		Scenario 1: 50% of PFAS foams contain PFHxS as an impurity	Scenario 2: 70% of PFAS foams contain PFHxS as an impurity	Scenario 3: 100% of PFAS foams contain PFHxS as an impurity
% of PFAS foams containing PFHxS		50%	70%	100%
Total EU Stockpile of foams				
Total stock quantity of PFAS foam containing PFHxS (t)		15 620	21 868	31 240
Total PFHxS (g)	PFHxS content min	484	678	968
	PFHxS content max	1 531	2 143	3 062
	PFHxS content average	922	1 290	1 843
Annual stock ‘use’/disposal/replenishment (at 8% used/disposed/replenished per year)				
Annual use/consumption/depletion of foam containing PFHxS		1 250	1 749	2 499
PFHxS in foam used per year (g)	PFHxS content min	39	54	77
	PFHxS content max	122	171	245
	PFHxS content average	74	103	147

In terms of other signatories to the Stockholm Convention, the US is the only signatory to have undertaken a thorough inventory of all Class B foams in 2004 as part of work on PFOS and provided updated estimates. The US submission (compiled by the US Fire-fighting Foam Coalition - FFFC by surveys and representative sampling of all types of installation stockpiling foams in the US including the Military (FFFC, 2011)) provides the estimates of total fire-fighting foam concentrates which, when converted from US gallons, provide suggests a total of 37,661t foam concentrate at all facilities and for all uses in the US.

Applying the average PFHxS content data from the EU calculations to the US estimates of AFFF stockpiles provides an estimate of the quantity of PFHxS that may be present as an impurity in the US AFFF stockpiles. This is provided as Table 2-4. This suggests around 978g to 1,956g of PFHxS in some 16,575t to 33,150t of AFFF foam. The table also provides some estimates of how these small quantities of PFHxS might be distributed between the various locations of stockpiles.

Table 2-4: Estimated total quantity of PFHxS in the US stockpile of foams

Country/Region (estimated total AFFF stock)		Scenario 1: 50% of PFAS foams contain PFHxS as an impurity	Scenario 2: 70% of PFAS foams contain PFHxS as an impurity	Scenario 3: 100% of PFAS foams contain PFHxS as an impurity
EU = 35,491t	Estimated stock quantity of PFAS foam containing PFHxS (t)	15,620	21,868	31,240
	PFHxS - Based on average content values (g)	922	1,290	1,843
US = 37,661t	Implied total stock quantity of PFAS foam containing PFHxS (t)	16,575	23,205	33,150
	PFHxS - Based on average content values (g)	978	1,369	1,956
US Breakdown of PFHxS presence (g) by location type				
	AFFF stock quantity (t)			
US military	10,737	279	390	558
Other Federal	164	4	6	9
Aviation (AREF)	2,760	72	100	143
Aviation (hangars)	3,218	84	117	167
Fire depts (non-aviation)	5,148	134	187	267
Oil refineries	7,192	187	261	374
Other petrochemical	7,571	197	275	393
Merchant ships/offshore rigs	303	8	11	16
Misc applications	568	15	21	29

Conclusion in relation to PFHxS present as an unintentional impurity in stockpiles

All of the data above tend to suggest that, although PFHxS, its salts and related substances may be present as an impurity in some older ECF produced foams, the switch to manufacture by telomerisation means that PFHxS is not present as an impurity in modern AFFF. Even if it is subsequently identified that some manufacturers still use the ECF route (which is not known), these are likely to be in the minority. Alternative manufacturing via telomerisation appears to be the mainstream method employed and, as such, there is no technical obstacle to switching to manufacture by this route.

In terms of the older ECF produced foams containing PFHxS, its salts or related substances, the evidence suggests that at, 31 to 98µg/kg (ppb) and an average of 59µg/kg (ppb), the PFHxS content is very low – equivalent to around 0.059g PFHxS per tonne of concentrate. When combined with information on the total quantities stockpiled, this suggests that very large quantities of older ECF produced foam concentrate globally may contain PFHxS at these very low levels.

Removal of this PFHxS would imply the identification of batches of AFFF containing impurities via, for example, testing and their early safe disposal via high temperature incineration destruction. With an estimated 16,949t of foam needing to be identified and destroyed to eliminate just 1Kg of PFHxS or related substance from the stockpile, the cost of this approach is likely to be prohibitive and disproportionate to the benefits. Here, stockpiles of AFFF are not consumed but, rather, are maintained to deal with the possibility of a fire. In the unlikely event of a fire there may be some emissions but the vast majority of the foams will never be used to fight fire before the end of their service life. In this respect, the case for PFHxS is similar to that of PFOS and also PFOA and a similar approach should be taken, namely actions to reduce the potential for emissions from the existing stockpile and to ensure safe disposal at the end of service life.

To illustrate and cross-check the conclusions on disproportionate costs, estimates have been made on the likely costs of identifying and disposing of AFFF containing PFHxS impurities. These and the associated logic are as follows.

Assuming 100,000t of AFFF stockpiled as an example and 50% of this stock containing PFHxS as an impurity, this equates to 50,000t of PFHxS-containing AFFF and a total quantity of 2.95kg PFHxS. Assuming, also, that 30% of this stock (30,000t) can be eliminated from suspicion of containing PFHxS, this leaves 70,000t of AFFF stockpile for which testing or other investigation would have to be carried out to identify presence of PFHxS. If it is assumed that the costs of these investigations equate to €50 per tonne, with 70,000t under investigation, the total testing and investigation costs are €3.5million.

Regarding the costs of removing and disposing of the 50,000t of PFHxS-containing foam, if it assumed that AFFF would be safely disposed of at the end of the service life in any event, the removal and disposal of the PFHxS containing foam simply represents a shortening of the service life of the foam. Thus, assuming a service life of, say, 14 years for AFFF, there is a loss of ‘service life years’ of 1 year for a foam in the stockpile that is 13 years old, 2 years for a 12 year old foam, etc.

As it is the older ECF produced foams that contain PFHxS and 50% of the 100,000t stockpile of foam is assumed to contain PFHxS in the calculations, the age profile of the foam is likely to be all in the older (8-14) year time period (meaning that remaining service life is 0-6 years). Assuming an even distribution in the age profile suggests 7,143t (50,000t/7) of AFFF of each age. Typical costs of AFFF are of the order €3000 per tonne. Assuming the 14 year service life, this equates to €214 per year of service life. Combining the estimated tonnages, the service life lost and the cost of lost service life provides an estimate of the costs of early disposal of the PFHxS containing AFFF in Table 2-5. As can be seen from this, these assumptions suggest a total cost of around €32million for early disposal of PFHxS containing foam in a total example stockpile of 100,000t of all foams (PFHxS containing at PFHxS free).

When added to the testing and investigation costs of €3.5million, the total cost of the action in relation to a 100,000t stockpile are of the order of €35.6million and result in the removal of 2.95kg PFHxS from the stockpile. That equates to a cost of around €12million per kg PFHxS removed from the stockpile. That said, it is noteworthy that all of the data on measured quantities of PFHxS in older foams provided by the German Mineralölwirtschaftsverband also reveal the presence of other substances including PFOA in the foams. As such, the action described would also lead to the elimination of PFOA as well as other fluorinated chemicals for which there is increased concern. This is out of the scope of the current report and has not been assessed in detail but is, nonetheless a factor that increases the benefits side of the equation.

Table 2-5: Age, service life years lost and cost of lost service life years

Age profile	Tonnes of VF-9126/PFHxS based AFFF	Service life left Years lost	Cost of lost service life years
14	7,143	0	€ 0
13	7,143	1	€ 1,530,612
12	7,143	2	€ 3,061,224
11	7,143	3	€ 4,591,837
10	7,143	4	€ 6,122,449
9	7,143	5	€ 7,653,061
8	7,143	6	€ 9,183,673
Total	**50,000**		**€ 32,142,857**

The European Chemicals Agency (ECHA) Socio-Economic Analysis Committee has produced a guide on the *Evaluation of restriction reports and applications for authorisation for PBT and vPvB substances in SEAC.* This describes efforts to define benchmarks for the proportionality /disproportionality of actions to reduce uses/emissions of PBTs/vPvBs. After the VU (Vrije Universiteit Amsterdam) project for the development of a benchmark for regulatory decision making under REACH for PBTs/vPvBs reported a very wide 'grey zone' (with margins the order of magnitude somewhere between €1000 and €50,000 per kg PBT substituted, remediated or reduced emission) within which measures may be either proportionate or disproportionate, SEAC concluded that it was not (yet) able to set (what would be a formal) benchmark. However, comparing the 'grey zone' values of €1000 - €50,000 per kg removed with the costs of €12million per kg PFHxS calculated using the above analysis would suggests that action to identify and dispose of AFFF containing PFHxS as an impurity are likely to be disproportionate.

2.4.3 Foams for which PFHxS is the main active ingredient

As noted earlier, however incomplete, the only available information on quantities of use in fire-fighting foams is from the BiPRO study (BiPRO, 2018). This suggests a total current production of PFHxS of around 700kg, all of which is in China. Around 66% of this (462 kg) is estimated to be used in to manufacture fire-fighting foams.

Information from literature review has also identified one manufacturer of a fire-fighting foams for which PFHxS is the main active fluoro ingredient. The Huang et al (2013) presentation on PFOS and alternatives to the Basel Convention identifies one foam known as VF-9126 with PFHxS present at a concentration of 1050 mg/L, far above other ingredients (PFBA = 27 mg/L, PFHxA = 2.24 mg/L). PFHxS was also found in two other foams but only at a concentration of 13.1 mg/L and 9.39 mg/L with no PFHxS being found in the fourth tested foam. A later paper by Huang et al (2015) updates the above identifying VF-9126 as having 1771 mg/L PFHxS and adding two others: VF-230 at 5,082 mg/L PFHxS and VF-9128 at 583 mg/L PFHxS. The average across these three products is 2464 mg/L where this value is used in the subsequent calculations.

All of these foams are still produced in China by Shanghai Vatten Chemical Hi-tec Co, Ltd[4], tending to confirm the findings of the Bipro (2018) study or at least adding weight to them. There are no data on production quantities of foams produced. However, based on the BiPRO study (BiPRO, 2018) estimate of 462 kg of PFHxS and the average concentration of 2464 mg/L of PFHxS in foam concentrate calculated above one can deduce production of some 187,500 Litres (or 188) per year of PFHxS fire-fighting foam in China.

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[4] http://vatten.com.cn/en/product/Amphoteric-Fluorinated-Surfactant-VF-9126.html

Once again, there are no data on levels of production of fire-fighting foam as a whole in China. However, import and export data have been examined to provide some context to this figure of 188t PFHxS containing foam.

Data from UN COMTRADE data suggests that, in 2017, China exported a total of 38,360t of HS code “3813: Fire-extinguishers; preparations and charges and charged fire-extinguishing grenades”. This is the closest HS code available in the database and may not reflect all FFF. As such it may under (rather than over) estimate China’s total export (and production). Comparison of this 38,340t total exported with the 188t of PFHxS based foam suggests that, if all of the PFHxS foam were exported it would be equivalent to a very small proportion (0.5%) of China's total annual export of fire-fighting foams. This, at least, would suggest that PFHxS based foams such as those produced by Vatten are not critical or even important from an economic and trade perspective. By the same token, with such a tiny market share (and none in the EU), it is difficult to argue that use of PFHxS in products such as those produced by Vatten in China is critical - the data suggest that at 99.5% of all firefighting foam exported from China does not contain PFHxS as the main active ingredient.

Using the UN COMTRADE data it is also possible to predict where PFHxS foams such as VF-9126 might be exported to. Analysis of these data suggest that 63% of China’s exported fire-fighting foam is exported to only 5 countries: Malaysia, Indonesia, Rep. of Korea, India and the Philippines. In these countries imports from China make up between 79% and 93% of the total imports of fire-fighting foams.

Table 2-6 provides these summary data on imports to the five countries. In the table, the data have also been extrapolated to predict the quantity of Vatten type (PFHxS) based foam imported into these countries (and the Rest of the World –RoW) conservatively assuming that all Vatten type form is exported from China (and none is for the home market) because there are no data to determine the proportions exported versus being used domestically. This also provides information on the implied total PFHxS imported into each in kg (again assuming that all Chinese production is exported). Just as the Vatten PFHxS-type foams are likely to make up only a small percentage of Chinese exports of AFFF, so they make up an even smaller proportion of the imports to these countries (0.9%-1.1%). As such one can conclude that VF-9126 type foams containing PFHxS as the main active fluoro ingredient do not make up a significant or essential component of countries’ stockpiles of FFF foams. Here they may make up a maximum of 0.4%-0.5% of stockpiles in these countries (and far less in other countries).

Table 2-6: Imports of FFF of Chinese origin and implied quantities of PFHxS

Reporter	% of China's total exports of FFF	Chinese imports as % of total FFF imported	Kg Vatten PFHxS type FFF	Vatten PFHxS type FFF as % of imports	Kg PFHxS
Malaysia	21%	93%	39,479	0.5%	97
Indonesia	12%	82%	22,734	0.4%	56
Rep. of Korea	12%	79%	21,635	0.4%	53
India	10%	85%	18,242	0.4%	45
Philippines	9%	90%	16,848	0.4%	42
Total top 5	**63%**		**118,937**		**293**
RoW	**37%**		**68,563**		**169**

In its Annex F submission India identifies uses of PFHxS in fire-fighting foams (the only use identified) noting that "There is no equivalent product currently available in the market place which can help replace or be used to extinguish such kind of large fires without the fluorinated surfactant use". The data would suggest that, even if it is the case that fluorinated surfactant is an essential use in India, this is unlikely to be the case for PFHxS based foams (such as those produced by Vatten).

Applying a similar approach and logic as applied earlier to the costs of early disposal, Table 2-7 provides estimates of the costs of early safe disposal of existing global stocks of PFHxS based AFFF such as those produced by Vatten. Assuming 188t of annual production and a 14 year service life suggests a stockpile of around 2,632t. With an evenly distributed age profile and, as with the cost estimates provided earlier, a cost of €214 per year of service life per tonne, the total costs of early disposal of these foams is of the order of €3.6million. The total quantity of PFHxS that would be eliminated from the global stockpile is 6,468kg. Accordingly the measure would cost of the order of €567/kg PFHxS destroyed.

As identified above, work for ECHA's SEAC identified a 'grey zone' of €1000 - €50,000 per kg where costs may be proportionate/disproportionate. Comparing this with the costs of €567/kg PFHxS eliminated suggests that action to dispose of AFFF containing PFHxS as the main active ingredient more likely to be proportionate than disproportionate. Certainly when compared with the costs of €12million per kg calculated for the action to identify and dispose of AFFF containing PFHxS as an impurity, the action in relation to foams containing PFHxS as the main fluoro active ingredient appear relatively inexpensive.

Table 2-7: Age, service life years lost and cost of lost service life years for the destruction of PFHxS based foams

Age profile	Tonnes of VF-9126/PFHxS based AFFF	Service life left Years lost	Cost of lost service life years
14	188	0	€ 0
13	188	1	€ 40,286
12	188	2	€ 80,571
11	188	3	€ 120,857
10	188	4	€ 161,143
9	188	5	€ 201,429
8	188	6	€ 241,714
7	188	7	€ 282,000
6	188	8	€ 322,286
5	188	9	€ 362,571
4	188	10	€ 402,857
3	188	11	€ 443,143
2	188	12	€ 483,429
1	188	13	€ 523,714
Total	**2,632**		**€ 3,666,000**

2.5 Further analysis of uses of PFHxS in Textiles

There is evidence that PFHxS has, in the past, been used as waterproofing and dirt/stain proofing treatments for carpets, upholstery, textile and leather applications. 3M produced a number of products for the purpose in the years before 2000 but ceased production of PFHxS and related compounds by the end of 2002 (3M, 2000). Since that time the evidence set out below suggests slowly diminishing use of PFHxS in textiles but the potential for future expansion in use, particularly if global regulation on the use of PFOA (in addition to those already in place on PFOS) trigger a shift towards PFHxS, its salts and related substances.

2006: In a report from SFT (Norwegian Pollution Control Authority, 2006) analysis of results from different textiles are presented. PFHxS was found in close to 30% of the tested items.

2007: Norin and Schulze (2007) investigated the PFAS content in impregnation products for textiles (weather clothing and shoes). There was limited information about content of fluorinated substances on the products or in the safety data sheets received from the distributers but 46% (6 of 13 tested products) contained PFHxS as well as PFOS.

2009: In 2009 SFT and NILU (Norway) screened possible PFAS sources in Norway[5] in 30 products with household uses and industrial manufacturing uses (Herzke et al, 2012). None of the tested waterproofing agents contained PFHxS. PFHxS was detected in two of the analysed wet room selling paints, four non-stick products, one carpet (probably due to Teflon treatment), a pair of leather shoes and an electronic toy.

2013: In 2013 the presence of PFASs were analysed in ten samples taken from seven articles of outdoor clothing articles for children (as well as shoes and swimwear articles) (Greenpeace, 2013). PFASs were detected in nine of the ten waterproof clothing samples. In five of the samples PFHxS was detected at levels of 20-2260µg/kg (an average 520.7 µg/kg across all samples containing

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[5] Products from both Norway and Sweden were included in the study.

PFHxS). Where country of manufacture was known (8 out of 10), all of the products containing PFHxS were manufactured in China. The data also show that PFOA was present in three of the waterproof clothing samples, notably samples for which PFHxS was not present[6].

2014: A study from NORAP (Nordic Risk Assessment Group, 2014) analysed 29 different consumer products including impregnated textiles (and also articles such as kitchenware and dental floss), but did not detect any PFHxS.

2016: Greenpeace Laboratories undertook a further study on Per- and poly-fluorinated chemicals in outdoor gear (including waterproof clothing) in 2016 (Greenpeace, 2016). The results showed that across the multiple articles and samples tested found PFHxS in only one item (a jacket manufactured in Vietnam) at very low levels (0.9 µg/kg). PFOA, however, was detected in most of the items (most of which were manufactured in China but also Vietnam and Bangladesh).

Repeated stakeholder consultations as part of the preparation of the EU REACH Restriction (and also the previous BiPRO - 2018 study) identified no current uses of PFHxS (including its salts and precursors) in the manufacture of textiles and textile articles in the EU. The Draft EU REACH Restriction dossier identifies that quantities of PFHxS may be imported on finished textile articles and, potentially, other articles for which PFOS was previously used as a waterproofing/stain resistant textile treatment (which might include leather and carpets) and for which PFOA is also, at present used. Accordingly, the Draft EU Restriction Dossier proposes a threshold for PFHxS of 25ppb (i.e. 25µg/kg) in articles. This is, in part, justified because, without action to prevent it, the quantities and ranges of uses of PFHxS may expand once action on PFOA comes into force (in 2020 in the EU) with evidence for this presented in the Dossier including that:

- water-proofing textile finishes based on PFHxS-based compounds have recently been developed by at least Hubei Hengxin Chemical Co., Ltd. (CAS numbers. 68259-15-4 (tridecafluoro-N-methylhexanesulphonamide), 68555-75-9 (tridecafluoro-N-(2-hydroxyethyl)-N-methylhexanesulphonamide), and 67584-57-0 (2-[methyl[(tridecafluorohexyl)sulphonyl]amino]ethyl acrylate)) and Wuhan Fengfan Surface Engineering Co., Ltd. from China (Huang et al., 2015; Hengxin, 2018), as alternatives to PFOS-based compounds (Huang et al., 2015).
- The industrial activities with C-6 waterproofing agent for textiles in the Taihu Lake region in China might be a potential source of PFHxS where recent production and use of PFHxS as an alternative to PFOS and PFOA has been reported (Ma et al., 2017). In 2010, it was estimated that the production of surface treatment products containing PFHxS- or perfluorobutane sulfonic acid (PFBS)-related compounds in China would reach 1000 tonnes per year in the next 5–10 years (Huang et al., 2010); no recent update of this estimate is currently available.

As noted earlier, the data on production and uses of PFHxS, its salts and related substances is extremely scarce. Information from the BiPRO study (BiPRO, 2018), although likely to be incomplete, tends to suggest a total current production of around 700kg of which 22% (154 kg) is used in textiles.

Data from the most comprehensive study of presence and concentration in articles suggest that, in articles where PFHxS was identified (such as in durable water repellent (DWR) outdoor gear) the

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[6] PFOA was, however, also present in three of the six swimwear article samples.

average concentration was 520.7 µg/kg (Greenpeace, 2013). At this concentration use of 154kg of PFHxS is equivalent 295,730t of outdoor gear treated with PFHxS (at 520.7 µg/kg).

Data on global production and consumption of DWR outdoor gear is not available to provide context. However, UN COMTRADE data are available for the commodity of 'overcoats, car coats, capes, cloaks, anoraks, incl. ski jackets, windcheaters' (Commodity numbers 6201 and 6202) (UN COMTRADE). These data suggest that, in 2017 some 660,133t of these articles were exported from China (no data are available for Vietnam and Bangladesh, other places of origin for products testing positively in Greenpeace, 2013).

Comparison of the 295,730t of outdoor gear treated with PFHxS elaborated above with the export data for of 'overcoats, car coats, capes, cloaks, anoraks, incl. ski jackets, windcheaters' (Commodity numbers 6201 and 6202) would suggest that 45% of the exports contain PFHxS. This seems an excessively high proportion given more recent (2016) tests on outdoor gear in Greenpeace (2016). This, in turn, suggest that the category of 'overcoats, car coats, capes, cloaks, anoraks, incl. ski jackets, windcheaters' (Commodity numbers 6201 and 6202) in the UN COMTRADE data does not cover the full scope of use of PFHxS in durable water repellent (DWR) outdoor gear. This is obvious when it is considered that PFHxS was also found in articles such as shoes, sleeping bags, tents and swimwear in 2013 (Greenpeace, 2013). Never-the-less, the estimate of 295,730t of outdoor gear treated with 154kg PFHxS seems a reasonable estimate.

Assuming that the same threshold of 25ppb (i.e. 25µg/kg) of PFHxS in articles proposed in the EU Draft Restriction Dossier was adopted at global level this could be expected to reduce PFHxS content in articles from 520.7 g/kg to 25µg/kg, reduction of 95%. Similarly this could be expected to produce a reduction from 154kg PFHxS to 7kg PFHxS globally in some 295,730t of outdoor gear manufactured annually.

As noted above, the EU REACH Restriction dossier also considers the potential expansion of PFHxS once action on PFOA is implemented. As noted above data from the most comprehensive study of presence and concentration in articles suggest that, in articles where PFHxS was identified (such as in DWR outdoor gear) the average concentration was 520.7 µg/kg (Greenpeace, 2013). Averaged over all articles (i.e. including those not containing PFHxS) the concentration was 260.4 µg/kg. Thus, assuming that PFHxS expands in use on articles where it is not currently used there is a doubling in use (520.7/260.4). This implies an increase from 154kg/year to 308kg/year although the actual increase might be greater.

2.6 Other uses

As is set out in the Risk Profile (UNEP/POPS/POPRC.14/6/Add.1, 2018) (as well as other documents), PFHxS, its salts and related substances have a number of other uses and potential uses including:

- Mist suppressants in metal plating
- Polishing agents and cleaning/washing agents
- Coating and impregnation/proofing
- Manufacturing of semiconductors

Other potential uses identified in the Risk profile include in flame retardant and in pesticides, food packaging materials and analogue and digital imaging products.

In spite of the lack of use data on semiconductors, recent evidence suggests use and the potential for expanding use in this application. The Risk Profile report (UNEP/POPS/POPRC.14/6/Add.1) identifies that during the POPRC-13 meeting on the Stockholm Convention in 2017, an industry representative noted that PFHxS, its salts and PFHxS-related compounds are currently being used as replacements to PFOS, PFOA and their related compounds in the semiconductor industry. This information is further strengthened by published information that indicates that PFHxS is used in the semiconductor industry in Taiwan province of China (Lin et al., 2010). PFHxS (133,330 ng/L), together with PFOS (128,670 ng/L), was one of the primary contaminants at a semiconductor fabrication plant waste water effluent site. Both PFSAs are present in the effluent in similar amounts showing that PFHxS is a primary substance in this process and are not unintentionally present at this site. There are, however, no data on which to base any detailed assessment of use and costs/benefits of regulating that use.

In common with uses in semiconductor manufacture, there are no data on the quantities of use of PFHxS, its salts and related substances used in the other applications described in the Risk Profile. The only information that is available (from the BiPRO study (BiPRO, 2018)) tends to suggest a total current production of around 700kg of which 12% (84kg) is used in 'other uses'. In the absence of detailed information it is assumed that the changes in levels of use suggested for the textiles would also apply to these other uses. As such it is concluded that:

- current use in these other applications is 84kg;
- under a scenario of global regulation of PFHxS, its salts and related substances this would reduce to 4kg; and
- if action on PFOA triggers an expansion use would increase to (at least) 168kg.

In addition to the uses identified in the Risk Profile, as described in Section 2.3 earlier, an Annex F submission suggests annual use of 68 kg of PFHxS in car coating sprays as well as unquantified amounts used in solar cell texturing solution.

3 Reduction potential of global regulation of PFHxS

Based on the discussion on uses and quantities set out above, Table 3-1 summarises use under the conditions of global regulation, in the case of a Business as Usual case (BAU) based on continuation of continued use at current levels and a further BAU case reflecting expanded use of PFHxS in response to action on PFOA (assumed to apply from 2020 for the purposes of the analysis).

Table 3-1: Levels of use (emissions) of PFHxS under the scenarios

	Past use	Current use and BAU (kg/year)	Global regulation scenario (kg/year)	BAU - Expands with PFOA action (kg/year)
Fire-fighting foam	Before 2012 = 1,500 2012-2015 = 750 2016 onwards = 700 +68 = 768 to account for 'car sprays'	462	0	462
Textiles		154	7	308
Other – risk profile		84	4	168
Other – 'car sprays'		68	0	68
Total		**768**	**11**	**1,006**

The Annex XV report identifying PFHxS as a SVHC (ECHA, 2017a)) concludes that PFHxS is stable under environmental conditions and abiotic degradation is expected to be as low as for the chemically similar substance PFOS, which has a half-life of >42 years. Applying a half-life of 42 years to the annual emissions under the baseline (BAU), the global regulation scenario and the expanded BAU provided in Table 3-1 allows projection of global environmental stocks of PFHxS under each scenario and, for reference purposes, under a zero emissions from 2020 scenario. This is provided in Figure 3-1.

Owing to the persistence of PFHxS (half-life >42 years) even a relatively small annual emission can quickly produce a large stock in the environment. It is this attribute (together with the bioaccumulation and toxicity) that sets such substances apart from other, less persistent, substances for which half-lives are short enough for there to be no (or negligible) residue from one year to the next. Thus, for a non-persistent substance (i.e. the 'normal' case) the environmental stock is taken as broadly equalling the annual emissions (because no or negligible emissions from one year persist into the next).

For an extremely persistent substance such as PFHxS around 98% of an emission in year n persists into year n+1. Thus, an annual emission of 1t produces an environmental stock of 1t in year 1 and 1.98t in year 2 (because the emission from the first year persists into the second). As such, where in the 'normal case' of a non-persistent substance the environmental stock is taken as equalling the annual emissions (and the same for emissions reductions) the same does not apply to extremely persistent substances such as PFHxS, its salts and related substances.

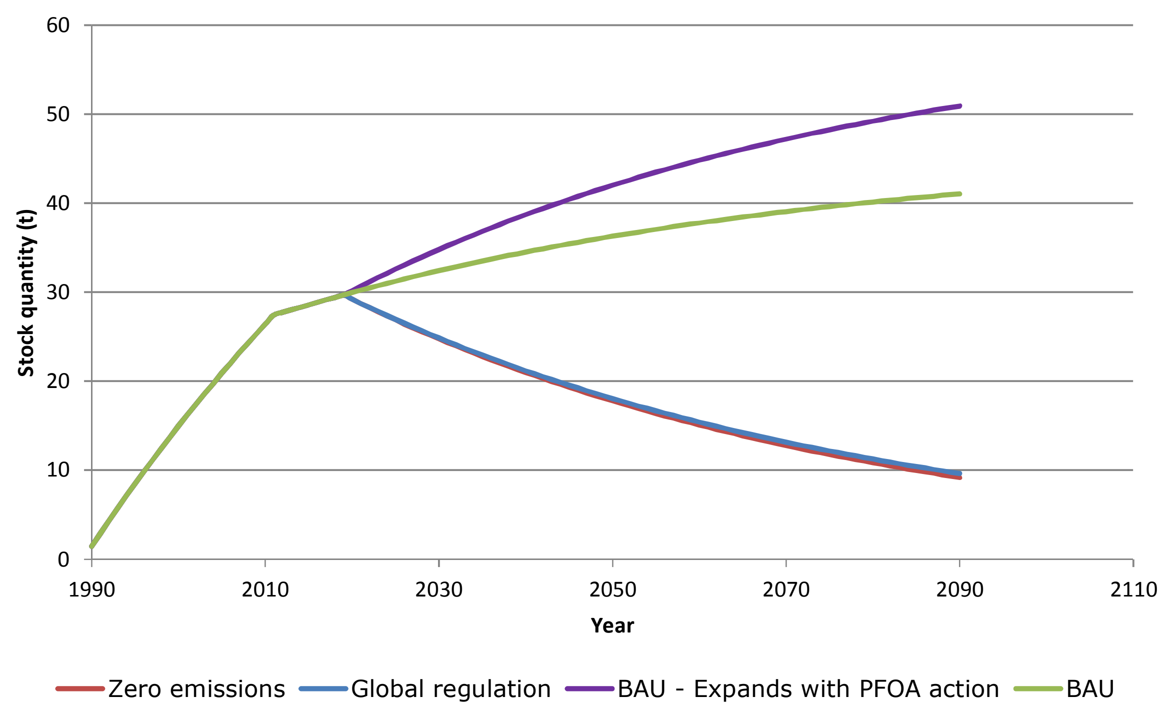

Figure 3-1: Environmental stock profile under the Baseline (BAU), expanded BAU and global regulation scenario

In the case of emissions of PFHxS provided in Figure 3-1, the data and assumptions suggest that annual emissions from 1990-present have produced a total environmental stock quantity of around 29.6t at present (2019).

Under the BAU case based on continued use at current rates, stock quantities will continue to increase to 32t in 2030 and 34t in 2040. Under the expanded BAU case where there is expansion in the use of PFHxS as global regulation of PFOA comes into effect (assumed 2020), stock increases more rapidly, reaching 34.5t in 2030 and 38.4t in 2040.

In contrast, by restricting use and by setting thresholds to reduce the quantity of PFHxS in articles (and mixtures) while also preventing a switch from PFOA to PFHxS, the global regulation scenario produces a downward trajectory. Here it is estimated that from an environmental stock of 29.6t at present stocks are reduced to 25t by 2030 and 21t in 2040.

Owing to the extremely persistent nature of PFHxS, the metric of annual reduction in emissions is not a suitable one for expressing reduced risks in the form of reduced environmental stocks. The peculiarities associated with extremely persistent substances means that the annual reduction in environmental stock is larger than the annual reduction in emissions. This is illustrated by the data in Table 3-2 and Table 3-3 which provide the annual emissions reductions relative to the BAU and the expanded BAU respectively that would normally be considered in the case equate of a ‘normal’ non-persistent substance. In the case of PFHxS, the reduction in annual emissions of 0.76tpa (or 1.00tpa for the expanded BAU) results in a steadily increasing reduction in environmental stock in each year. The cumulative stock reduction from the baseline over time (the sum of the annual reduction in stock in each year) provides the total stock reduction achieved over the time period. This suggests a total stock reduction of 46t by 2030 and 154t by 2040 for the BAU (60t and 202t respectively for the expanded BAU). This can be converted to a simple annual average equivalent stock ‘emissions’ reduction over the periods. Thus, considered over the 10 years between 2021 and 2030 (inclusive) and the 20 years between 2021 and 2040, annual average equivalent stock ‘emissions’ reduction is 3.1tpa and 4.7tpa respectively for the 2021-2030 and 2021-2040 periods under the BAU (4.0tpa and 6.2tpa under the expanded BAU).

Table 3-2: Annual emission reduction versus reduction in environmental stock under the global regulation scenario compared with BAU

Year	Annual emission reduction BAU minus (tpa)	Annual reduction in environmental stock (tpa)	Cumulative reduction in stock quantity over time (tonnes)
2021	0.76	1.5	1.5
2022	0.76	1.8	3.7
2023	0.76	2.2	6.6
2024	0.76	2.5	10.2
2025	0.76	2.9	14.5
2026	0.76	3.2	19.4
2027	0.76	3.6	25.1
2028	0.76	3.9	31.3
2029	0.76	4.3	38.3
2030	0.76	4.6	45.8
2031	0.76	4.9	54.0
2032	0.76	5.2	62.8
2033	0.76	5.5	72.1
2034	0.76	5.9	82.1
2035	0.76	6.2	92.7
2036	0.76	6.5	103.8
2037	0.76	6.8	115.5
2038	0.76	7.1	127.7
2039	0.76	7.4	140.5
2040	0.76	7.7	153.9

Table 3-3: Annual emission reduction versus reduction in environmental stock under the global regulation scenario compared with expanded BAU

Year	Annual emission reduction BAU minus (tpa)	Annual reduction in environmental stock (tpa)	Cumulative reduction in stock quantity over time (tonnes)
2021	1.00	1.9	1.9
2022	1.00	2.4	4.8
2023	1.00	2.9	8.6
2024	1.00	3.3	13.4
2025	1.00	3.8	19.0
2026	1.00	4.3	25.5
2027	1.00	4.7	32.9
2028	1.00	5.1	41.2
2029	1.00	5.6	50.3
2030	1.00	6.0	60.2
2031	1.00	6.5	71.0
2032	1.00	6.9	82.5
2033	1.00	7.3	94.8
2034	1.00	7.7	108.0
2035	1.00	8.1	121.8
2036	1.00	8.5	136.5
2037	1.00	8.9	151.8
2038	1.00	9.3	167.9
2039	1.00	9.7	184.7
2040	1.00	10.1	202.2

4 Information on socioeconomic costs and benefits of global regulation of PFHxS

4.1 Costs of actions

Regarding the costs of global regulation on PFHxS, in theory these will be associated with:

- **Fire-fighting foams:** identification and disposal of older ECF produced foams containing PFHxS, its salts and related substances;
- **Fire-fighting foams:** disposal of foams containing PFHxS as a the main fluoro active ingredient;
- **Textiles:** the cost of switching to alternative substances for the provision of waterproofing and fabric protection on DWR fabrics; and
- **Other uses:** the cost of switching to alternatives.

In relation to the identification and disposal of older ECF produced fire-fighting foams containing PFHxS, costs have been considered in the relevant section above. As noted there, there are no data on the total quantity of foam that may contain PFHxS as an impurity. However, total cost of the action in relation to a nominal 100,000t stockpile of 'general foam' (PFHxS-containing and non-PFHxS containing) has been estimated. This suggests costs of the order of €35.6million per 100,000t of 'general foam' resulting in the removal of 2.95kg PFHxS, equating to a cost of around €12million per kg PFHxS removed from the stockpile. Applied to estimates of total fire-fighting foam stock estimated in the EU (35,491t) and the US (37,661t) this equates to costs of €12.6million and €13.4million for the EU and US respectively and combined removal of 2.15kg of PFHxS.

As is identified in the relevant section above, work for ECHA's SEAC pn PBTs/vPvBs identified a 'grey zone' of €1000 - €50,000 per kg where costs may be proportionate/disproportionate. With costs of €12million per kg PFHxS calculated action to identify and dispose of AFFF containing PFHxS as an impurity are likely to be disproportionate. That said, it is noteworthy that all of the data on measured quantities of PFHxS in older foams provided by the German Mineralölwirtschaftsverband also reveal the presence of other substances including PFOA in the foams. As such, the action described would also lead to the elimination of PFOA as well as other fluorinated chemicals for which there is increased concern. This is out of the scope of the current report and has not been assessed in detail but is, nonetheless a factor that increases the benefits side of the equation.

In contrast to fire-fighting foams for which PFHxS is present only as an impurity, the cost of disposing of foams containing PFHxS as a the main fluoro active ingredient is likely to be much more cost-effective. As is discussed in the relevant section above, it is estimated that the global stockpile of such foams is around 6,160t and that the total costs of early disposal of these foams is of the order of €8.6million. The total quantity of PFHxS that would be eliminated from the global stockpile is 6,468kg. Accordingly the measure would cost of the order of €1,320/kg PFHxS destroyed. Comparing this with the 'grey zone' of €1000 - €50,000 per kg where costs may be proportionate/disproportionate suggests that the costs of the action are more likely to be proportionate than disproportionate.

In relation to the costs of switching to alternatives to PFHxS in textile applications, as identified in the relevant sections above, use has already decreased over time such that, at present, use is limited. In 2014 a study from NORAP (Nordic Risk Assessment Group, 2014) analysed 29 different consumer products including impregnated textiles (and also articles such as kitchenware and dental floss), but did not detect any PFHxS. In 2016 a study on per- and poly-fluorinated chemicals in outdoor gear (including waterproof clothing) showed that across the multiple articles and samples tested found PFHxS in only one item (a jacket manufactured in Vietnam) at very low levels (0.9 µg/kg) (Greenpeace, 2016).

Repeated and exhaustive stakeholder consultation as part of the preparation of the EU REACH Restriction (and also the previous BiPRO - 2018 study) did not identify any use by manufacturers in the EU with three industry associations stating that their members do not use these substances in the EU.

Other studies also report a consumer demand for more environmental friendly products, in for example the outdoor industry, which is driving a phasing out of PFAS in general (ECHA, 2017). A manufacturer of outdoor clothes reported that DWR-textiles will be PFASs free by 2020 (ECHA, 2017). Already now, PFASs-free DWR-textiles are available. A retailer stated that currently 80% of own brands are PFASs free in the spring/summer collection 2017 and more than 90% in the autumn/winter collection. The stakeholder is aiming for 100% PFASs-free of own brands by 2018 (ECHA, 2017).

This evidence tends to suggest that there is already a substantial shift away from the use of PFHxS as a waterproofing and protective agent in articles. As such any proposed global regulation of PFHxS would simply be reinforcing this shift while, importantly, ensuring that use of PFHxS does not increase (again) as a result of the changes brought about by any restrictions on PFOA. There are no data on which to base actual estimates of the costs. However, given the trends identified above, it has been assumed that the costs of the action are likely to be near-zero or limited/minimal.

In relation to other uses and potential uses such as mist suppressants in metal plating, polishing agents and cleaning/washing agents, coating and impregnation/proofing and manufacturing of semiconductors there are no specific data on either the uses or the costs. No such uses have been identified in the EU during preparation of the REACH Restriction Dossier on PFHxS, its salts and related substances. Although, manufacture and sale of car coating sprays containing PFHxS most likely unintentionally, have been identified in an EU member state during the call for information in the Stockholm Convention process. This suggests that if PFHxS is indeed used in any of these 'other uses' then alternatives are readily available and already generally applied at an at least economically equivalent cost to any supposed uses of PFHxS. For these uses too, then, the costs of the action are assumed to be near-zero or limited/minimal.

4.2 Competition

It is not anticipated that global regulation of PFHxS will have any negative competition effects as the regulation would apply to all actors.

4.3 Comparison with other similar PBT & vPvB, PFAS cases

PFHxS and related substances are substances of very high concern owing to their PBT/vPvB properties. The Risk Profile report (UNEP/POPS/POPRC.14/6/Add.1) concludes that:

- *"PFHxS is released into the environment, including from degradation of PFHxS related substances, and human activities e.g. from manufacturing processes, product use and disposal and management of waste. PFHxS is persistent, bioaccumulative and has the potential to undergo long-range environmental transport, making emissions of this* *substance a transboundary pollution problem including in remote areas. Globally, the occurrence and distribution of PFHxS is shown for humans, wildlife and the environment. Detections include measurements in the Arctic and Antarctic.*

- *PFHxS is one of the most frequently detected PFAS in human blood in the general population and has a very long half-life in humans of 8.5 years (range 2.2-27 years). Furthermore, PFHxS has been detected in human umbilical blood, serum and breast milk. High concentrations of PFHxS have been detected in soil, ground and drinking water near airports or fire-fighting training sites, sludge and wastewater from waste water treatment plants, as well as in the vicinity of PFAS/PFHxS production/usage plants and in leachate from landfills.*
- *Available scientific literature suggests that there is a risk for adverse effects on the general population, in particular for children and population groups that are exposed to elevated levels of PFHxS and other PFASs through drinking water.*
- *The concern for adverse effects relates to observed effects on the liver, thyroid hormone system, reproduction, and immune modulating effects, as well as indications of neurotoxic and neurodevelopmental effects have been shown. Furthermore, effects on lipid and lipoprotein metabolism add to the concern both for humans and Arctic animals.*
- *Recent data from polar bear studies at Svalbard (Norway) revealed increasing levels of PFHxS in plasma. PFASs, including PFHxS, contribute to the multiple-stressor effects observed in polar bears from Svalbard indicating a risk for adverse effects in wildlife.*
- *Based on the persistence, bioaccumulation, toxicity in mammals including humans and the widespread occurrence in environmental compartments including at remote regions, it is concluded that PFHxS, its salts and PFHxS related compounds are likely, as a result of their long-range environmental transport, to lead to significant adverse human health and environmental effects such that global action is warranted".*

Due to the extreme persistency of the substances, every emission contributes to the environmental stock of the substances. Stock quantities have been discussed above and the analysis concludes that annual emissions from 1990-present have produced a total environmental stock quantity of around (at least) 29.6t at present (2019).

Under the BAU case based on continued use at current rates, stock quantities will continue to increase to 32t in 2030 and 34t in 2040. Under the expanded BAU case where there is expansion in the use of PFHxS as global regulation of PFOA comes into effect (assumed 2020), stock increases more rapidly, reaching 34.5t in 2030 and 38.4t in 2040. In contrast, the global regulation scenario produces a downward trajectory reduced to 25t by 2030 and 21t in 2040.

In cases with other similar PBT and vPvB substances, where concentrations have reached the recommended guidance level, for example PFAS in drinking water in Sweden (from firefighting foam), it has been proven (Swedish Chemicals Agency, 2016), to be a cost effective measure to regulate these substances in beforehand rather than paying for the abatement and substitution cost afterwards.

Avoidance of future emissions of PFHxS into the environment is important to reducing impacts on the environment and human health. There are numerous examples in the literature of the costs of remediating sites where contamination of groundwater and soil has occurred due to the past use of PFASs at industrial sites, at airports, as part of training activities in the use of fire-fighting foams, and due to the need to put out fires. Although these examples are not specific to PFHxS, they provide an indication of the potential for significant costs should there be a need to undertake such remediation activities specific to PFHxS and related substances in the future due to the high levels of contamination that have been identified.

Weber[7] (2016) provides information on the costs of addressing unacceptably high levels of PFAS in drinking water due to PFAS pollution in the Ruhr and its tributaries. The costs of upgrading wastewater treatment works with, for example activated carbon filters, to reduce exposures cost are estimated to have cost around €100 million with the works taking several years. In addition, the mismanagement of industrial sludges from the Netherlands and Belgium was found to have resulted in a series of contaminated sites with the region. More specifically PFOS/PFAS contamination was identified as an issue for Dusseldorf, with sources including major fires where AFFFs were used, the airport, fire-fighting practice areas and at chromium plating facilities. The total remediation estimate for contamination at the airport was indicated as potentially reaching costs of €100 million, the remediation costs associated with foams used to put out a fire were greater than €10 million, and the costs of soil exchange for a site in Baden-Wurttemberg were estimated at between €1-3 billion.

Alling et al (2017) presented two case studies for remediation of PFAS contaminated fire-fighting sites in Norway. These report costs of up to 50 million NOK (€5.1 million) at Evenes airport and over 30 mill NOK (€3.1 million) at Oslo Gardermoen Airport.

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[7] Weber R (2016): Some lessons learned from PFOS/PFAS management in Germany, Science and Policy of Organohalogens pre-Dioxin Symposium, 28 August 2016, Firenze, Italy.

5 Information on cost and technical feasibilities for waste handling and clean-up of contaminated sites

Regarding clean-up of contaminated sites, the costs of cleaning up sites contaminated by fire-fighting foams (whether training sites or the site of actual fires) is well documented and some examples have been provided in the discussion above. Contamination specifically with PFHxS, its salts or related substances is not identified in these cases but, rather, PFASs in general and/or PFAS substances such as PFOS for which action is already being taken.

As noted earlier, all of the data on measured quantities of PFHxS in older foams provided by the German Mineralölwirtschaftsverband and used in this analysis also reveal the presence of other PFAS substances including PFOA in the foams. Accordingly, a site contaminated with PFHxS is likely to also be contaminated with other PFAS for which there is increased concern or for which action is being considered (for example, PFOA) or has already been taken (for example, PFOS). It is difficult, then, to isolate the costs of cleaning up PFHxS contaminated from other contaminants also likely to be present.

The same is also true for other locations contaminated with PFHxS from non-fire-fighting foam sources. For example, while PFHxS (133-330 ng/L) was identified as a contaminant at a semiconductor fabrication plant waste water effluent site in Taiwan, PFOS (128-670 ng/L) as well as other perfluorinated chemicals were also found (Lin et al, 2010). Lin et al (2009) found that PFOS was the major constituent in semiconductor wastewaters (up to 0.13 mg/L) and the amount of final waste effluents of PFHxS from semiconductor manufacturing process was estimated to be >0.68kg. In more recent article (Cui et al, 2018) the riverine flux of PFHxS to lake Baiyangdian was estimated at 37.35 kg/y. However, PFOA as well as PFHxS were the predominant PFASs (of several) detected in the surface water, reaching concentrations of 8,397 ng/L and 1,478 ng/L respectively.

Accordingly, the technical feasibility and cost of clean-up of sites contaminated with PFHxS as well as waste handling cannot be viewed in isolation. Rather, the costs (and benefits) need to be viewed under the wider lens of PFASs as a whole. The same is also true of some of the other actions under the proposed global regulation, where the interplay between identifying and disposing of older ECF produced fire-fighting foams has already been identified in the text above.

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